Scientific Research Publishing

Modern Economy, 2022, 13, 1025-1044
https://www.scirp.org/journal/me
ISSN Online: 2152-7261
ISSN Print: 2152-7245

Research of the Government Optimal Decision-Making of Energy Consumption

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How to cite this paper: Li, Y. (2022). Research of the Government Optimal Decision-Making of Energy Consumption. *Modern Economy, 13,* 1025-1044.
https://doi.org/10.4236/me.2022.138054

Received: May 13, 2022
Accepted: August 13, 2022
Published: August 16, 2022

Abstract

A dynamic optimization model and association analysis of data mining are used to analyze the main factors affecting the energy consumption decision of local government and the relations among those factors from the theoretical and empirical perspectives. The findings show that the energy consumption decisions of local government will vary in cycles along with local government political shuffle for gaining a better performance evaluation, and there is a deviation between the energy consumption decisions made by local government and the long-range energy consumption control policies of central government. To solve this principal-agent problem between central government and local government, a more scientific constraint encouraging mechanism and overall consideration of regional economic development mechanism should be designed to eliminate the difference between the short-run optimal energy consumption control decision of local government and the long-run energy policy of central government.

Keywords

Economic Growth, Energy Consumption, Dynamic Optimization, Association Analysis, Government Control

1. Introduction

As an important natural resource, energy has been supporting the development of human economy and society since ancient times. Since the reform and opening, China's economic development has made great achievements, and the extensive development with energy consumption as the traction has undoubtedly become the mainstream mode at this stage. Although this development mode

has promoted the rapid development of China's economy, it has also brought a series of negative effects, such as excessive energy consumption and deterioration of the natural environment. Since the beginning of the 21st century, the Chinese government has paid more and more attention to the construction of a sustainable scientific development model, and gradually shifted the focus of economic work to the optimization of industrial structure, energy conservation and consumption reduction, and environmental pollution control. In the context of the new economic normal and carbon peak, how to plan energy consumption in an overall way in the process of economic growth, prevent excessive energy consumption from causing resource depletion, environmental damage and reducing development potential has become an important issue for the government to consider when formulating economic and social development plans.

In this study, the government's control of energy consumption is introduced into the total social utility function, and the optimal energy consumption control decision is derived from the theory. Through empirical evidence, it is revealed that the local government's control of energy consumption tends to change periodically.

Due to data availability, we have not further verified the causal relationship between government control and regional energy consumption changes. There is no further research on specific environmental variables, such as the stability of environmental variables, the two-way impact effect of environmental variables and government-controlled variables, etc. Therefore, the exact role of government control in regional energy consumption cannot be effectively measured, which is a limitation of the research.

The rest of the paper is organized as follows: II. Literature review; III. Theoretical Framework: Establishing an optimal model of government energy consumption control based on the maximization of social utility; IV. Empirical Test: Correlation analysis of model variables using provincial statistics; V. Conclusions and policy recommendations.

2. Literature Review

In the 1970s, the world energy crisis broke out, and the energy problem began to become the focus of economists. Because the excessive consumption of energy has led to the rapid depletion of natural resources, serious environmental pollution and other practical problems, scholars have conducted extensive and in-depth research on energy consumption control and environmental governance.

Wang Haijian (2000) brought exhaustible resources into the endogenous economic growth model and discussed the policy implications under the condition that exhaustible resources can be used continuously. Yu Bo, Li Yongliang and Chi Chunjie (2006) added elements such as energy resource depletion, environmental threshold limit and environmental governance cost to the endogenous economic growth model, established a sustainable growth model conforming to the actual situation of China's economic development, and discussed

the dynamic relationship between the rate of energy resource depletion.

The impact of local government competition on government eco-environmental governance has always been a hot issue of academic concern, but the existing research has not reached a consistent conclusion. Many existing studies based on the theory of environmental federalism believe that: in the context of decentralization of environmental regulation, local governments will compete to reduce the level of environmental regulation in ecological environment governance in order to promote economic growth, and exchange short-term economic benefits by sacrificing the environment. This vicious competition behavior will have an adverse impact on the ecological environment (Ulph, 2000; Woods, 2006). Some studies also believe that under the action of the "voting with feet" mechanism, local governments will improve the supply level of ecological products and services through bottom-up "yardstick competition", thus forming a good situation of "competing upward" (Vogel, 1997; Fredriksson & Millimet, 2002).

With the concept of energy conservation and emission reduction, green economy and sustainable development deeply rooted in the hearts of the people. China's central government has begun to formulate scientific and long-term energy consumption strategies to support the sustainable development of economy and society. However, based on China's local government assessment system, the deviation between the behavior and decision-making of local governments and the central government is becoming more and more obvious.

Zhou Li'an (2007) studied the nature and characteristics of the governance model of Chinese local officials, namely the "Promotion Tournament governance model", and believed that the Promotion Tournament, as the incentive model of Chinese government officials, was an important source of China's economic miracle, but there was a serious conflict between the goal of encouraging officials and the reasonable design of government functions. Based on the deviation between local government behavior and central policies, Shen Liang (2011) built a theoretical model and studied the economic behavior of local governments in the implementation of energy conservation and emission reduction by using cluster and factor analysis. Findings show that the power and ability of local governments in energy conservation and emission reduction are insufficient. The current asymmetric financial system and performance evaluation mechanism are the main institutional obstacles for local governments to implement energy conservation and emission reduction. Zhang Hua (2014) used China's provincial panel data from 2000 to 2011 to construct a dynamic spatial panel model to test the impact of environmental regulation on carbon emissions. Its research showed that under the influence of local government competition, environmental regulation in this region and adjacent regions significantly promoted carbon emissions, leading to the "bottom effect" and "green paradox" phenomenon of environmental regulation competition. Bo Wenguang, Xu Wei and Wang Junfeng (2018) discussed that local governments adopt differentiated competition strategies for different types of environmental regulations under different competitive motives, and believed that the current competition in en-

vironmental regulations between local governments is brought about by the trade-off between "economic benefits" and "environmental benefits". Lu Fengzhi and Yang haochang (2019) empirically tested the impact of environmental decentralization and local government competition on Eco-environmental pollution using provincial data from 2000 to 2016, and found that there are regional differences in the spatial spillover effects of local government competition on ecological environment pollution. Zhang Jun, Fan Haichao, Xu Zhiwei, Zhou Longfei (2020) constructed a dynamic general equilibrium model with local government competitive behavior, found that local government competition tended to enlarge the welfare of spillover effect between regions, and the relationship between social welfare and environmental protection strength is inverted U-shaped. Hu Jiukai and Wang Yiming (2022) made an empirical evaluation of China's carbon emission reduction performance of the transformation of local government competition mode, showed that the transformation of local government competition mode reduced the intensity of carbon emissions and promoted the improvement of carbon emission performance.

Through the research of Chinese academic circles in recent years, it is obvious to see that China's existing decentralization mechanism and local assessment system make local governments deviate from the long-term policies of the central government in energy conservation, emission reduction, environmental governance and other behavioral decisions, and there is "competitions" between local governments.

Based on the research of Forster (1980) and Krautkraemer (1985), and research results of domestic and foreign scholars and the actual situation of China, this paper introduces elements such as the government's control over energy consumption into the utility function, deduces the optimal energy consumption control decisions of the central government and local governments in the long term and short term respectively through theoretical model research, and collects the data of 31 provinces and autonomous regions in China. The correlation analysis method in data mining is used to study the correlation degree and direction between the factors involved in the utility function. The empirical results show that the local government's control over energy consumption varies in different periods of the government's tenure, and changes periodically with the assessment and transition of local governments, which deviates from the central government's long-term energy consumption policy. The empirical results verify the inference obtained from the optimal decision-making model of government energy consumption control.

3. Theoretical Framework: An Optimal Model of Government Energy Consumption Control Based on Maximizing Social Utility

3.1. Model Description and Assumptions

The primary goal of the government is to improve the overall level of social and

economic development to improve people's living standards and the total social utility function (U) is used to express people's overall evaluation of social and economic development. The larger U is the more satisfied people are with the overall status of social and economic development. In this way, the goal of the government is to maximize U. To better express the energy consumption control decisions adopted by the government in the process of economic development and for the sake of simplification, here U is considered as a function of national income Y (economic growth), total energy consumption S[1] and the energy consumption control intensity u adopted by the government to avoid excessive consumption of resources, while other factors are not considered temporarily. With the improvement of social and economic level, people's satisfaction with society will increase. Excessive energy consumption and environmental damage will reduce people's satisfaction with social life. In addition, as the government increases its control over energy consumption, people will think that the energy control policy is conducive to the sustainable development of the economy, can prevent the depletion of natural resources and environmental pollution, and people will improve their satisfaction with economic life. Therefore, it is reasonable to think that the efficiency function is the increasing function of government intervention, hence the social utility function is the increasing function of national income and the efforts made by the government in energy consumption control, and the decreasing function of energy consumption, hence,

$\frac{\partial U}{\partial Y} > 0$, $\frac{\partial U}{\partial S} < 0$, $\frac{\partial U}{\partial u} > 0$.

Based on the above analysis, this paper sets the total social utility function as Equation (1):

$$U(Y,S,u) = a_1 Y - b_1 S + c_1 u^{\frac{1}{2}} \tag{1}$$

Among them, a_1 represents the degree of preference for income. The larger a_1 is, the stronger the desire of people to increase economic income, and the greater the utility of the improvement of life quality brought by economic growth to people which is related to the stage of the overall economy. b_1 indicates people's disgust with energy consumption. The higher the disgust level, the greater value of b_1, which is related to people's awareness of environmental protection and the current level of environmental conditions. The higher the awareness of environmental protection, the worse the current environmental quality, the higher people's disgust with energy consumption. C_1 indicates people's satisfaction with the government's energy consumption policies. The greater value of C_1 indicates that people are more satisfied with the government's relevant policies and regulations in energy consumption control and environmental protection. The reason why the social utility function is set to be in direct proportion to the 1/2 power of the government's control over energy consumption is that, on the one

[1]Here S is used to measure the energy consumption of economic activities and indirectly reflect the degree of pollution and damage to the environment.

hand, if the government makes too many regulations on energy consumption, it may affect the overall development of the economy, thus affecting the overall social utility. On the other hand, with the enhancement of government intervention, the social utility brought by the government is also gradually decreasing, that is, the marginal utility of government control is decreasing.

Energy consumption is gradually increasing with the acceleration of economic growth. The growth of national income and economic development means the increase of energy input, and the improvement of people's living standards, which will correspondingly increase energy consumption, such as water, electricity, coal, etc.; in addition, the government's efforts in energy consumption control will force enterprises and residents to reduce energy consumption. With the promotion of control level, energy consumption will decrease. Therefore, Equation (2) is obtained:

$$\dot{S} = a_2 Y - c_2 u \tag{2}$$

In formula (2), a_2 is used to measure the energy utilization efficiency of the whole society. The higher the energy utilization efficiency is, the less energy will be consumed per unit of national income, and the smaller the a_2 will be, vice versa. C_2 refers to the efficiency of the government in controlling energy consumption. The higher its efficiency, the greater C_2 will be, vice versa. Since the government can only control energy consumption within a certain range, therefore, the maximum energy consumption control that the government can take is assumed to be U_M, $u \in (0, u_M)$.

Similarly, the increase of national income is also inseparable from the increase of energy input. Energy consumption is directly proportional to output. For simplicity, suppose that there is a linear relationship between energy consumption and economic output, as shown in Equation (3):

$$Y = b_2 S \tag{3}$$

In formula (3), b_2 is used to measure the overall technical level of social production. The larger b_2 is, the higher the technical level is, and the more output will be produced for the same energy consumption. At the same time, it is assumed that the social economic income starts from the initial zero moment, and the national income at this time is Y_0.

To sum up, socio-economic development and energy consumption can be expressed by the following optimization model:

$$\text{s.t.} \begin{cases} U(Y,S,u) = a_1 Y - b_1 S + c_1 u^{\frac{1}{2}} \\ \dot{S} = a_2 Y - c_2 u \\ Y = b_2 S \\ Y(0) = Y_0 \\ u \in (0, u_M) \\ a_1, a_2, b_1, b_2, c_1, c_2 > 0 \end{cases}$$

Among them, Y and S are state variables, u is a control variable, and they are

all functions of time t. For the convenience of writing, here the subscript t representing time is omitted in the model. ρ is the discount rate of intertemporal utility, and $\rho > a_2 b_2$. In order to better obtain the equilibrium solution of the above optimization problem, it is necessary to replace a variable in Y, S, and u. Since this paper discusses how the government takes the most appropriate energy consumption control decision in the process of economic growth, the model retains Y and u to eliminate S. Substituting Equation (3) into Equation (1), and after differentiating Equation (3) into Equation (2), the original problem is further transformed into the following optimization model:

$$\max \int_0^T U(Y,S,u)\mathrm{e}^{-\rho t}\mathrm{d}t = \int_0^T \left[\left(a_1 - \frac{b_1}{b_2}\right)Y + c_1 u^{\frac{1}{2}}\right]\mathrm{e}^{-\rho t}\mathrm{d}t$$

$$\text{s.t.}\begin{cases} \dot{Y} = a_2 b_2 Y - c_2 b_2 u \\ Y(0) = Y_0 \\ u \in (0, u_M) \end{cases}.$$

3.2. Model Solution and Economic Significance Analysis

After the above substitution, $a_1 - \frac{b_1}{b_2}$ represents people's preference for economic growth relative to energy consumption, which changes with economic development and people's awareness of environmental protection. In the early stage of economic development, people's living standards were relatively low, the environmental quality was generally better, the resources were relatively abundant, and people's Environmental awareness is also relatively low, and the social development is mainly focused on improving living standards. Therefore, in the early stage of economic development, people prefer income growth, therefore, $a_1 - \frac{b_1}{b_2} > 0$ when the economy growth is at a high level, people's living standards are improved, energy consumption continues to increase, and environmental quality continues to deteriorate. People's awareness of environmental protection is gradually increasing, so that people will prefer energy consumption control and environmental protection, hence $a_1 - \frac{b_1}{b_2} < 0$. Combined with the actual situation of China's social and economic development, the economy is assumed to be in the rising in the stage. In the subsequent analysis, it is assumed that $a_1 - \frac{b_1}{b_2} > 0$ to sole the optimal decision-making issue of government energy consumption control. First, the present value Hamiltonian function is established: $H = \left(a_1 - \frac{b_1}{b_2}\right)Y + c_1 u^{\frac{1}{2}} + \lambda(a_2 Y - c_2 u)$.

The solutions to the above problems satisfy the following Equations (4)-(7):

$$\frac{\partial H}{\partial u} = \frac{1}{2} c_1 u^{-\frac{1}{2}} - \lambda c_2 b_2 = 0 \tag{4}$$

Simplifies to:

$$u = \left[\frac{c_1}{2c_2 b_2}\right]^2 \lambda^{-2} \tag{5}$$

$$\dot{\lambda} = -\frac{\partial H}{\partial Y} + \lambda\rho = -\left(a_1 - \frac{b_1}{b_2}\right) - a_2 b_2 \lambda + \lambda\rho \tag{6}$$

$$\mathrm{e}^{-\rho T}\lambda(T) = 0 \tag{7}$$

From formula (6), Equation (8) can be obtained:

$$\lambda(t) = \frac{a_1 - \dfrac{b_1}{b_2}}{\rho - a_2 b_2} + C\mathrm{e}^{(\rho - a_2 b_2)t} \tag{8}$$

where C is an undetermined constant, which can be obtained from Equations (7) and (8), $C = -\dfrac{a_1 - \dfrac{b_1}{b_2}}{\rho - a_2 b_2}\mathrm{e}^{-(\rho - a_2 b_2)T}$, and get Equation (9):

$$\lambda(t) = \frac{a_1 - \dfrac{b_1}{b_2}}{\rho - a_2 b_2}\left[1 - \mathrm{e}^{-(\rho - a_2 b_2)(T-t)}\right] \tag{9}$$

Bring Equation (9) into (5) to get Equation (10):

$$u(t) = \left[\frac{c_1(\rho - a_2 b_2)}{2c_2(b_1 - a_1 b_2)}\right]^2 \left[1 - \mathrm{e}^{-(\rho - a_2 b_2)(T-t)}\right]^{-2} \tag{10}$$

By derivation of Equations (9) and (10), the results shown in Equations (11) and (12) can be obtained:

$$\frac{\mathrm{d}\lambda}{\mathrm{d}t} = -A(\rho - a_2 b_2)\mathrm{e}^{-(\rho - a_2 b_2)(T-t)} \tag{11}$$

$$\frac{\mathrm{d}u}{\mathrm{d}t} = 2\left(\frac{c_1}{2b_2 c_2 A}\right)^2 A(\rho - a_2 b_2)\left[1 - \mathrm{e}^{-(\rho - a_2 b_2)(T-t)}\right]^{-3} \tag{12}$$

$\left(A = \dfrac{a_1 - \dfrac{b_1}{b_2}}{\rho - a_2 b_2}\right)$

From the above assumptions: $\rho > a_2 b_2$, and $a_1 - \dfrac{b_1}{b_2} > 0$, we can get $\dfrac{\mathrm{d}\lambda}{\mathrm{d}t} < 0$, $\dfrac{\mathrm{d}u}{\mathrm{d}t} > 0$.

It can be judged by $\dfrac{\mathrm{d}u}{\mathrm{d}t} > 0$, that the government's control of energy consumption is constantly increasing. With the passage of time, the total socio-economic volume continues to increase, and the energy consumption will also gradually increase. It is necessary to strengthen the control of energy consumption to make the economy develop to gain steady-state equilibrium, however, the maximum value of energy consumption control u cannot exceed u_M.

When time $t=\tau$, u reaches its maximum value u_M, and then the government's energy consumption control strength will always be maintained at u_M.

The economic meaning of λ here is the value of national income expressed by social utility, that is, the added value of social utility caused by the increase of national income. Since $\lambda(t)$ is gradually decreasing, the value of national income expressed by social utility is also decreasing, which shows that with the development of social economy, people become richer, and the pursuit of income is not as strong as at the initial moment, which is the diminishing marginal utility of income. On the other hand, the increase in income also causes excessive consumption of energy and damage to the natural environment, which will affect the improvement of the overall social utility; when the time T is reached, the social utility of the national economic income becomes zero, that is to say, only to make full use of the utility value of the income increase in a limited period of time can maximize the social utility during this period.

After analyzing the optimal control of government energy consumption, he trajectory of national income Y is discussed.

From $\dot{Y}=a_2b_2Y-c_2b_2u$, Y can be solved directly, as shown in Equations (13) and (14):

when

$$t\in(0,\tau),\quad Y(t)=\mathrm{e}^{a_2b_2t}\left[\int -b_2c_2u(t)\mathrm{e}^{-a_2b_2t}\mathrm{d}t+C'\right] \tag{13}$$

when

$$t\in(\tau,T),\quad Y(t)=\frac{b_2c_2u_M}{a_ab_2}+C''\mathrm{e}^{a_2b_2t} \tag{14}$$

Both C' and C'' here are undetermined constants, which can be obtained from the continuity of $Y(0)=Y_0$ and $Y(t)$. Because the expression is too complicated, their specific values are not listed here.

From formula (3), $S(t)=\dfrac{Y(t)}{b_2}$ can be obtained, and the energy consumption in different periods can be obtained.

Now we further analyze the influence of the changes of various exogenous variables on government behavior.

Firstly, when $a_1-\dfrac{b_1}{b_2}$ increases, it can be seen from Equation (10) that u becomes smaller which means that when people have a higher preference for economic growth relative to energy consumption, the tolerance for energy consumption and environmental damage will be stronger. The desire of taking measures to control energy consumption will be lower, so there is no need for the government to take too strong energy consumption control decisions.

Secondly, when c_1 increases, u also increases accordingly, indicating that people are not willing to take measures by the government to control energy consumption. The higher the preference, the more the government tends to take stricter energy consumption control decisions. When c_2 increases, u becomes smaller, which means that the higher efficiency of governments' control of

energy consumption, the less control policies it will take.

Thirdly, when b_2 increases, u will also become smaller, which indicates that the higher the energy utilization efficiency of enterprises, the less the government can control energy consumption. In this way, under other conditions unchanged, if the government wants to reduce the control of energy consumption, it has to improve the technological level of the whole society, the energy utilization efficiency of enterprises and the efficiency of the control policies adopted by the government; that is, when the overall economic efficiency is improved, the government's efforts to control energy consumption will decline.

3.3. Conclusions of the Model Analysis

1) Long-term government optimal energy control

The above model analysis process explains the optimal energy consumption control decision taken by the government in time (0, T). If t tends to be infinity, the overall welfare of the society tends to be considered as welfare in the long-term. The optimal energy control decision taken to maximize the long-term utility of u and Y can be used to illustrate the national income and the government's optimal energy consumption control when the economy is in long-term equilibrium by plotting the phase diagrams of u and Y motions and finding their saddle paths strength.

λ can be eliminated by formula (5) and formula (8), and the equations of motion of u and Y can be obtained: $\dot{u} = 4\left(a_1 - \frac{b_1}{b_2}\right)\frac{b_2c_2}{c_1}u^{\frac{3}{2}} - 2\left(\rho - a_2b_2\right)u$, then combining formula (2), $\dot{Y} = a_2b_2Y - c_2b_2u$, let $\dot{u} = 0$ and $\dot{Y} = 0$ to obtain a balanced national income Y^* and government energy consumption control u^*, i.e. $Y^* = \left[\frac{Ac_1}{2b_2c_2}\right]^2$ and $u^* = \frac{1}{a_2c_2}\left[\frac{Ac_1}{2b_2}\right]^2$.

The phase diagram of long-term economic growth and changes in government energy consumption control efforts is shown in Figure 1.

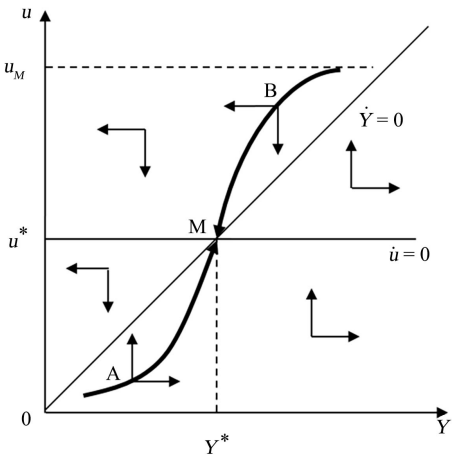

Figure 1. Phase diagram of long-term economic growth and changes in government energy consumption control efforts.

As shown in phase diagram of u and Y movements, national income and government control over energy consumption can only move towards the final equilibrium point m along one route, that is, along the path shown by the thick line (AMB) in the figure, the economy can move towards stability; while along other paths, the economy cannot move towards stability. This shows that when the national income is at a low point, the government's energy consumption control must be at a low point correspondingly. The government should implement a relatively loose energy consumption control decision, as shown in point A in the figure, so that the economy can move towards the equilibrium point along the optimal path; When the national income is at a high point, the government's control over energy consumption must also be at a high position. The government should implement stricter energy consumption control policies, as shown in point B in the figure, so that the economy can converge to the equilibrium point M.

2) Short-term government optimal energy control

If u is regarded as a local social utility function, y as the local national income and local economic output value, and s as the local overall energy consumption, then u can be expressed as the energy consumption control decision taken by the local government during its tenure. The time period from 0 to t is regarded as the term of office of each government leader, that is, the government leader takes office at time 0, and the local government leaves office after the end of the term of office at time t; If the re-election or promotion of government leaders is only related to the local political achievements during their tenure, the local government will strive to create political achievements in order to re-election or seek further promotion. This political achievement can be considered as the overall evaluation of the local people, that is, whether they are satisfied with their ruling ability. Therefore, each local government and leader will take efforts to maximize the total social utility of the place during their tenure, so that the model can be used to analyze the optimal resource consumption control decision of the local government.

From the above analysis, we can see that u is increasing. At the initial moment, u is at a low level, indicating that the government generally tends to have less intervention in energy consumption at the beginning, which is conducive to economic development, to improve the overall living standards of local people. However, when it is close to time t, although the economy has been greatly developed, energy consumption and environmental pollution are also becoming more and more serious. At this time, the local government will improve its intervention control on energy consumption, and government's control over energy consumption will be maximized in order to enhance people's recognition of government work through energy conservation and emission reduction. In this way, the government mainly implements less regulation on energy consumption and environmental pollution in the early stage of taking office, and more regulations in the later stage. In the short term, the stage of the economy remains unchanged, and the overall preference of residents is relatively stable, so

all parameters remain unchanged. It can be seen from the model that if all parameters remain basically unchanged, the government's control over energy consumption will gradually increase. In this way, with the change of the local government, the control over energy consumption when the next government leader arrives will also be at a low level at the beginning of his tenure. As time goes by, the control over energy consumption will gradually increase, so that the control over energy consumption by the local government will change periodically with the change of the local government and leaders, as shown in Figure 2. The horizontal axis I in Figure 2 is the time axis T, and the vertical axis is the local government's control over local energy consumption. This control will change periodically based on the assessment of the local government. The current government's control over energy consumption will gradually increase from the initial low level until it reaches the highest level at the time of the examination, and will show the same trend in the next term.

3) Comparative analysis of optimal energy consumption control decision-making between local and central governments

From the above analysis, it can be seen that in the long run, the central government's control of energy consumption should be gradually strengthened, but in the short term, the local government's energy control intensity changes periodically with the evaluation of the local government. The energy consumption control strength of China is not completely in line with the long-term energy control policy of the central government, which explains the gap between the central government's great efforts in energy consumption control, and the unsatisfied results of local governments control on energy consumption, energy conservation and emission reduction.

On the one hand, this is because economic development cannot be separated from energy consumption. Without energy input, the economy cannot continue to develop for a long time, and the slow economic development will lead to the poor evaluation of residents on the work of the government; On the other hand, under the existing evaluation and promotion mechanism of local governments, local governments mainly focus on the economic development of the region

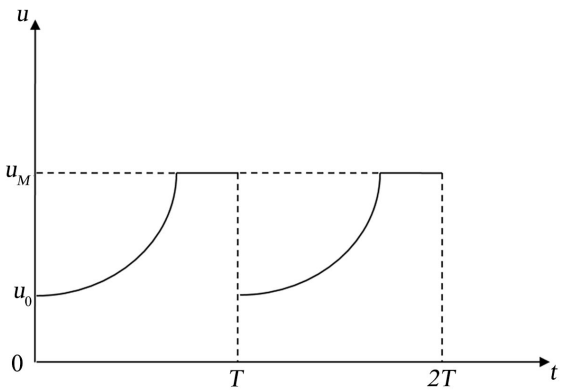

Figure 2. Changes in short-term government energy consumption control efforts.

during their tenure. To win enough political achievements within a limited term, local governments usually to some extents do not consider from the perspective of long-term and overall development, which discounts the full implementation of the central government's energy consumption control policy, and affects the final effect of reducing the total energy consumption. Local governments tend to put economic growth in the first place and lack the power to strictly control the total energy consumption, which will lead to short-term excessive economic growth, accompanied by overcapacity, excessive energy consumption and environmental pollution, which inevitably affects the sustainable development of China's overall economy and society.

4. Empirical Test: Association Analysis of Model Variables Based on Provincial Statistics

Through the construction and solution of the above theoretical model, the factors that affect the final total social utility can be attributed to economic growth, energy consumption control and environmental pollution control. And we will use the available provincial statistical data to verify and empirical study the conclusions of the above model.

4.1. Selection of Study Period and Statistical Data

China officially joined the WTO in 2001, which has promoted the further optimization of the economic growth model, and economic development policy environment largely remains consistent during these years. Considering the availability of data, this paper selects 2001-2017 as the research interval, and takes the statistical data of 31 provinces, cities and autonomous regions published by the National Bureau of statistics of China as the sample observation value to analyze the theoretical model empirically.

For regional economic growth factors, this paper selects the statistical indicator of regional GDP (unit: 100 million yuan), which is deflated, and the actual value of the annual GDP of each province and city is calculated; the growth rate of the actual regional GDP is used to measure the regional economic growth capacity.

For the control of regional energy consumption, this paper selects the growth rate of regional total energy consumption as the measurement index. When the growth rate decreases, it means that the energy consumption in the region has been restrained to some extent. On the contrary, if the growth rate increases, it means that the control of energy consumption in the region has decreased.

The energy consumption brought about by economic growth will largely have a negative impact on the environment, which is mainly reflected in the discharge and treatment of wastewater, waste gas and wastes. In order to reflect the strength of regional environmental protection and consider the availability of data, this paper selects the total amount of regional (industrial) wastewater discharge (unit: 10,000 tons), the total amount of sulfur dioxide emission in region-

al (industrial) waste gas (10,000 tons) and regional (general) industrial solid waste production (10,000 tons) as indicators to measure the discharge of regional "three wastes" respectively, and calculate the growth rate to measure the regional government's efforts to control environmental pollution. An increase in the growth rate of total emissions means that the regional control of environmental pollution has been reduced, and vice versa.

In addition, due to the increasingly obvious role of foreign direct investment (FDI) in promoting local economic growth, there is a competitive relationship between regions at this level. The performance evaluation and promotion of local governments are also mainly determined by regional economic development, therefore, these competitive relationship among regions are more significant. This paper selects FDI in various regions (unit: 10,000 US dollars) and calculates the growth rate of FDI to calculate the development competitiveness between regions. The increase of FDI growth rate indicates that when the attraction of the region to foreign investment is increased, the regional competitiveness is correspondingly increased, and vice versa.

Since year 2001, the term of office of successive leaders at the provincial and municipal levels in China has been 4 - 5 years, and the last three terms of office have been concentrated in 2002, 2008, 2012 and 2017. Considering the impact of the concept of energy conservation and emission reduction and green sustainable development on the energy consumption pattern of regional economic development within the research range, and in combination with the caliber and availability of statistical data, especially considering the links between regional economic development and changes in energy consumption control and environmental protection during 2003, 2007-2009, 2012-2013 and 2016-2017. This paper uses the Apriori algorithm of association analysis in data mining to mine the strong association rules between variables involved in the theoretical model, and practices it on the modeler data mining platform.

4.2. Association Analysis Based on IBM SPSS Modeler Data Mining Platform

Association rules in data mining can be understood as implied expressions in the form of "$x \Rightarrow y$, *sup*, *conf*". X and Y in this paper represent different variables or variable combinations; *Sup* is the degree of support, indicating the probability that variables X and Y appear at the same time, that is, they are related; *Conf* is the confidence, which indicates the probability that the change of variable x causes the change of variable y, that is, the causal direction of the correlation between variables. If the support and confidence are high, this association rule is called strong association rule, which is a law with research value hidden in the data. Before using modeler to mine strong association rules, we must first preprocess the data to form a data source that can be used by modeler. The mining data source is obtained by converting the data collected and sorted in the text. The variables and data descriptions are shown in Table 1.

Using Modeler to conduct association analysis with provincial and municipal data as observations in 2003, 2007-2009, 2012-2013, 2016-2017, the obtained strong association rules are shown in Table 2.

Table 1. Variable name, meaning and value description of Modeler data source.

Variable name	Variable meaning	Variable value meaning	Data Sources
GDP	Gross domestic product	T indicates that the regional GDP growth rate is quite high and the economy is improving.	The nominal value of the gross regional product comes from the Gross Regional Product in Chapter 3 National Accounts of the China Statistical Yearbook 2002-2021. Taking 2001 as the base period, the actual and actual growth rates of the annual GDP of each province and city are calculated by using the GDP index.
EC	Energy consumption control	T indicates that the growth rate of energy consumption has declined and the control of energy consumption has been improved.	The regional energy consumption data comes from the energy consumption by region and variety in Chapter 4 Energy Consumption of China Energy Statistical Yearbook 2002-2020. By calculating the annual data change rate to indicate the energy consumption control strength.
EC2	Energy consumption growth	T indicates that the growth rate of energy consumption has increased, and the control of energy consumption has decreased.	The regional energy consumption data comes from Energy Consumption by Region in Chapter 4 Energy Consumption of China Energy Statistical Yearbook 2002-2020. The energy consumption growth is represented by calculating the annual rate of change in data.
FDI	Foreign direct investment growth	T means that the growth rate of FDI has increased, and the local government has strengthened the introduction of FDI.	The data on the total amount of foreign direct investment in each province is taken from Wind Information. The growth rate of trauma investment is represented by calculating the annual data change rate.
Water	Regional (industrial) wastewater discharge control efforts	T indicates that the growth rate of (industrial) wastewater discharge has decreased, and the control of water environmental protection has increased.	The regional (industrial) wastewater discharge data comes from the discharge of main pollutants in wastewater by region in Chapter 8 Resources and Environment of China Statistical Yearbook 2002-2021. Region). Changes in wastewater discharge are represented by calculating the annual rate of data change.
SO2	(Industrial) Sulfur Dioxide Emission Control in Exhaust Gas	T means that the growth rate of (industrial) sulfur dioxide emissions has decreased, and air protection control has improved.	The emission data of sulfur dioxide in regional (industrial) exhaust gas is taken from the emission of main pollutants in main urban exhaust gas in Chapter 8 Resources and Environment of "China Statistical Yearbook 2002-2021" (8 - 13 Main Pollutant Emission in Waste Gas in Main Cities). Changes in sulfur dioxide emissions are represented by calculating the annual rate of change in data.
Solid	(General) Control of Industrial Solid Waste Generation	T means that the growth rate of (industrial) solid waste emissions has decreased, and environmental protection control has increased.	The data on regional (general) industrial solid waste generation are taken from Chapter 8 Resources and Environment of the China Statistical Yearbook 2002-2021, in which chapter the treatment and utilization of solid waste by region (8 - 15 Disposal and Utilization of Industrial Solid Wastes in Main Cities. Changes in solid waste emissions are represented by calculating the annual rate of change in data.

Note: The data of GDP, regional (industrial) wastewater discharge, sulfur dioxide emissions in (industrial) waste gas, and (general) industrial solid waste production of each province and city are taken from the "China Statistical Yearbook 2002-2021"; The total energy consumption data of control strength and consumption are taken from the "China Energy Statistical Yearbook 2002-2020"; the total foreign direct investment data is taken from Wind Information.

Table 2. Mining results of Modeler association rule.

Year	Antecedent set	⇒	Back item set	Support	Confidence
2003	FDI	⇒	GDP	0.57	0.88
	EC2	⇒	GDP	0.60	0.83
	Solid	⇒	GDP	0.60	0.83
2007	EC	⇒	SO2	0.60	1.00
	Solid	⇒	SO2	0.57	1.00
	Water	⇒	SO2	0.50	1.00
2008	SO2	⇒	EC	0.70	1.00
	Solid	⇒	EC	0.67	1.00
	Water	⇒	EC	0.57	1.00
2009	Solid	⇒	EC	0.53	0.63
	EC2	⇒	GDP	0.43	0.62
2012	SO2	⇒	EC2	0.73	1.00
	SO2	⇒	Solid	0.73	0.86
	Solid	⇒	EC2	0.87	0.92
2013	Water	⇒	EC	0.73	0.91
	EC	⇒	Water	0.93	0.71
2016	FDI	⇒	Water	0.23	1.00
	{GDP, Solid}	⇒	Water	0.10	1.00
	{GDP, Water}	⇒	Solid	0.10	1.00
2017	{Solid, FDI}	⇒	EC	0.10	1.00
	{GDP, Water}	⇒	FDI	0.10	1.00
	GDP	⇒	EC2	0.33	0.80

Note: Only the top 3 association rules with the highest confidence in each year are analyzed here.

As shown in Table 2, the strong association rule in 2003: FDI ⇒ GDP supp: (0.57) conf: (0.88), which means that the probability of simultaneous FDI and GDP is 0.88, when FDI increases, the probability of GDP increase is 0.57, which reflects that the increase of local foreign direct investment FDI has a strong role in promoting GDP growth. The improvement of energy consumption (the reduction of energy consumption control) has a strong role in promoting regional GDP growth; The improvement of (general) industrial solid waste generation control has led to the increase of regional GDP growth. It can be inferred that in 2003, the increase of energy consumption significantly promoted the growth of regional economy. In addition, the rapid growth of foreign direct investment will also drive the growth of local economy; the control of solid industrial waste has increased the regional economic growth rate, which means that local governments have attached importance to environmental governance, and taken

environmental governance, especially solid industrial waste governance, as an industry to promote local economic development. The strong association rules from 2007 to 2009 generally reflect the improvement of energy consumption control and the improvement of three wastes control, showing a strong degree of correlation, which indicating that during this period, local governments pay more and more attention to energy consumption control and environmental governance. The association rules in 2012 and 2013 mainly reflect the strong correlation between energy consumption control and environmental protection. The association rules in 2016 mainly reflect the positive change of social and economic development and environmental protection; The association rules in 2017 mainly reflect that regional economic and social development and environmental optimization are significantly attractive to foreign investment, and regional economic development needs the support of energy consumption.

The correlation between energy consumption control and environmental governance on local economic development has shown a strong degree of correlation in recent years. This conclusion is basically consistent with the assumption that local economic growth and energy consumption show a strong correlation in the dynamic optimization model established above.

5. Conclusions and Policy Recommendations

5.1. Conclusion

This paper introduces the government's control of energy consumption into the total social utility function to illustrate the optimal energy consumption control decision taken by the government to maximize the total social utility, and reveals that the local government's control of energy consumption presents a cyclical tendency to the change. In the early stage of economic development, local governments mainly focused on developing the economy, improving people's living standards and quality, and less on energy consumption control. With the development of economy and the approaching of government performance evaluation and term change, the control of energy consumption is gradually increased, which directly reduces the level and growth rate of regional energy consumption and indirectly improves the strength of regional environmental governance. Findings also show that the energy consumption control decisions of local governments during their term of office will change periodically with the performance evaluation and the change of the government, which is not completely consistent with the long-term energy control policies formulated by the central government, which explains from a new perspective the reasons why energy and environmental problems cannot be effectively solved. The local government's energy consumption decision-making, which is the periodic evolution of energy consumption control, deviates from the central government's long-term policies of energy conservation, emission reduction and green sustainable development. In the long run, it will have a negative impact on the implementation effect of the central government's long-term energy policy, cause excessive consumption

of energy, and affect the sustainable development potential of China's economy and society. In order to solve this problem, we should design scientific incentive and restraint mechanisms, and promote coordinated development between regions.

5.2. Policy Recommendations

Based on the above research conclusions, the following countermeasures are proposed:

1) Incentive mechanism design: improve local government performance assessment objectives and assessment systems.

The relationship between the central government and the local government is actually a typical principal-agent relationship. The central government, as the principal, entrusts the task of local economic development to the local government which acts as the agent, but the goals of the two are different. The long-term goal of the central government is inevitably the sustainable development of the economy and society, and the energy conservation and emission reduction will be the basic energy policy implemented in the long term. While due to factors such as performance appraisal and promotion during the term of office, the short-term optimal behavior decision of the local government during the term of office must meet the local political achievements and assessment goal, therefore it is inevitable that local energy consumption decisions will show cyclical changes based on the year of the government's change of office. To solve this problem at the root, it is necessary to make the goals pursued by the principal and the agent as consistent as possible, that is, to make the short-term optimal behavior of the local government consistent with the long-term policy goal of the central government, which requires changing the assessment system based on the regional economic development indicator—GDP, aligning the performance assessment objectives of local governments during their tenure with the central government's policy objectives, and building a scientific incentive mechanism incorporating sustainable development indicators such as energy conservation, emission reduction, and environmental governance to influence local performance assessments. Non-quantitative indicators such as the implementation of central policies by local governments are set as references for government evaluation and promotion, and reasonable incentive mechanisms are used to tie the economic and social goals of local governments and the central government.

2) Restraint mechanism design—perfect and enforce energy consumption policies, laws and regulations.

Scientific incentive mechanism can indeed bind the goals and behavior decisions of local government and central government to a large extent, but only incentive mechanism is not enough to achieve a high degree of unity of the two goals. At this time, a strong restraint mechanism is needed to forcibly regulate the behavior of local government. The most effective and direct restraint mechanism is to formulate energy consumption laws and regulations that conform

to the characteristics of local development and consistent with the long-term energy consumption policies of the central government. It is necessary to standardize the energy consumption behavior decisions of local governments from the force and restraint of legal norms, take the energy consumption violations of local governments as the punitive indicators of the assessment system, combine the force and restraint of laws with the performance assessment of local governments, build a strong restraint mechanism and deepen the consistency between local government behavior and decision-making and the central long-term energy policy. Strong restraint mechanism and scientific incentive mechanism will be able to achieve a high degree of consistency between the local government and the central government in the decision-making of the optimal energy consumption behavior.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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