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Quantitative Analysis of Human Behavior in Environmental Protection

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Abstract
Ecological and environmental pollution is a common important problem, and it is impossible to talk about the relationship between humans and nature without involving human behavior. The analysis of human behavior not only sheds light on understanding man but also represents the importance of ecological development and growth. This paper builds a framework of external and internal factors to analyze human behavior, and game theory is used to simulate the conflicting interests of human behavior. Then the GMM method is used to empirically analyze the deduction function of the benefit and payment function from the game analysis, besides the MS-VAR model is also used to capture the dynamic change of human behavior in environmental protection. Games analysis integrating the use of GMM and MS-VAR links the theory analysis with the practice and uses real data to analyze human behavior instead of virtual assumptions. Although this paper takes the situation in China as an example, the framework of empirical analysis suggests a framework of quantitative analysis of human behavior in environmental protection for other countries and regions.

Keywords Human behavior · Game theory · IPAT · GMM · MS-VAR

Introduction

With the increasing impact of ecology on human beings, we have entered the "ecological era", and it is impossible to talk about the relationship between humans and nature without human behavior.

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On the one hand, there is widespread evidence that the global environmental problem is caused by human behavior. It is estimated that urban waste disposal is a major concern worldwide for its environmental costs in terms of emissions to soil, water, and air (Alessandra & Spagnolli, 2017), and human activity is one of the major driving factors to more carbon emissions which leads to higher temperatures (Greenstone & Hanna, 2014), then the rise in temperatures makes time frames for the transition to a low-carbon society longer. Due to the current environmental problems such as global warming and air pollution, sustainability is greatly threatened, and human is made vulnerable to disasters and tragedies (Lange & Dewitte, 2019; Maleksaeidi & Keshavarz, 2019; Raeisi et al., 2018).

On the other hand, human is also the practical executor for the protection of the ecological environment. Conservation is contingent upon human behavior, and at times, changing behavior (Reddy et al., 2016; Schultz, 2011; St. John et al., 2010). Scientific research increasingly emphasizes the contribution of human practices and efforts to environmental problems (Susie et al., 2010). In sectors of health, finance, transportation, and public utilities, etc., change of human behavior has become central to practice and policy, recycling (Alessandra & Spagnolli, 2017), social influence studies (Wokje & Linda, 2013), and sustainability in the workplace (Young et al., 2015) are applicated in the domain environmental sustainability field.

A human can destroy or protect the environment. The condition of the environment lies greatly on man's ecological view and his ecological environmental consciousness (St. John et al., 2010; Lange & Dewitte, 2019). If human behavior is the problem, behavior analysis can offer technological solutions for environmental protection. A better understanding of human behavior in the environmental protection is fundamental for the survival and development of environment (Schultz, 2011; Lange & Dewitte, 2019). This study is approximate to broad literature on the human behavior analysis by three following points:

Firstly, estimation of human behavior is challenging. Human behavior is an intangible element. How can the intangible element be quantified and measured? And what mathematical models can be used to depict human behavior in environmental protection?

Secondly, within the psychological literature, it is generally acknowledged that human behavior is influenced by internal and external factors (Wallen Kenneth & Elizabeth, 2018). Internal and external factors can depict why individuals behave in a certain way and how behavior can be effectively changed. Internal factors include human' s beliefs, values, attitudes, and emotions. External factors are related to the context in which humans will behave and make choices (Wallen Kenneth & Elizabeth, 2018). Therefore, what are the internal and external factors for human behavior? And how can we measure and quantify these internal and external factors?

Thirdly, human behavior is dynamic and can be changed under certain random circumstances affected by certain factors. Human makes rational behavioral decisions that link their behavioral intentions to execute their environmental activities (Hill & Lynchehaun, 2002). His behavior is determined by behavioral intentions (Zhang et al., 2019), and these intentions rely on attitude, subjective norms, and perceived behavioral control (Si et al., 2019). Human beliefs, values, attitudes, and emotions may have an effect on humans to protect the environment in a certain period and not to protect the environment in another period. Therefore, how can we depict the stochastic change of the behavioral intentions and thus the randomness of human behavior? And what mathematical models can provide effective simulation to this behavioral change?

This paper is approximate to work these three points out and explores the analysis method of quantifying human behavior by game theory. Econometrical methods are also developed to combine to use with game theory to analyze the conflicting interests of human behavior. Furthermore, internal and external factors for human behavior are also categorized and identified. Quantitative analysis of environmental protection behavior is not aimed to create something new and original, but for the requirement of sustainable development for human beings. Suggestions are then discussed, and best practices for a successful lead to encourage human environmental protection are proposed.

Review of Literature

Review of Human Behavior

Theories and models for human behavior have a long-standing tradition. In 1776, Adam Smith served as an activator for behavior analysts to embark on a new challenge, he took the motivation and behavior of individual's seeking their own interests as an important basis for economic analysis and discussed the correlation between the behavior of economic man and the affluence of the whole society. Human behavior not only affects the economic system but also the ecosystem. Human is the essential reason accounting for the destruction and protection of the ecological environment. Learning about human behavior becomes necessary.

Human behavior has two branches in its literary history. Some scholars believe that approaches to understanding human behavior are grounded on the idea that most actions in human's daily lives either provoke an unjustified waste of resources or correct behaviors allow higher environmental sustainability (Ertz et al., 2016). Humans must adjust their behavior to maintain environmental values (Soleimanpour Omran, 2014) and change their performance in environmental protection according to the environmental situation. This awareness around ecological and environmental problems highlights the importance of the role of each individual in the current environmental protection. As a result, the issue of pro-environmental behaviors as a priority in public debates has been raised (Li et al., 2019). Other scholars highlight the public environmental consciousness' importance in environmental protection (Powdthavee, 2021), and inducing human consciousness is the major provocation to protect the environment. They focus on the subject who conducts the human behavior. Thus, the concept of eco economic man has been raised (Li & Sun, 2014; Liu & Wang, 2007).

Review of Pro-environmental Behavior

Pro-environmental behaviors can be defined as an act causing minimal destruction or even beneficial to the environment (Steg & Vlek, 2009). Many environmental challenges are rooted in human behavior (Thondhlana & Hlatshwayo, 2018), and these problems will be reduced by pro-environmental behaviors (Dornhoff et al., 2019; Thondhlana & Hlatshwayo, 2018). Rogers (1975) explained human behavior by raising protection motivation theory (PMT) (Rogers, 1975). The PMT focuses not only on the costs of human behaviors but also examines the benefits of current environmentally unfriendly behaviors (Wang et al., 2019; Janmaimool, 2017; Bockarjova & Steg, 2014) and provides a more inclusive foundation for the existing knowledge about the motivations of pro-environmental behaviors (Keshavarz & Karami, 2016; Bockarjova & Steg, 2014).

The PMT helps humans to consider pro-environmental behaviors, and pro-environmental behaviors are influenced by internal and external factors (Blok et al., 2015; Juvan & Dolnicar, 2017; Mainieri et al., 1997; Vicente-Molina et al., 2013). The result of being pro-environmental is not only relevant to external factors but also the internal factors that cannot be neglected. External factors are related to the context, such as regulation or social norms in which humans will behave, internal factors comprise people's beliefs, values, attitudes, emotions, and knowledge (Wallen Kenneth & Elizabeth, 2018; Turaga et al., 2010). The heterogeneous nature of internal and external factors makes pro-environmental behavior a very complex issue, therefore, studies aiming to analyze human behavior should consider both internal and external factors and provide effective prompts to behavioral change.

Review of Eco Economic Man

The idea that "everybody can make a difference" for the environment has led other researchers to strip the "rational economic man" from the pure economic environment and put it into the ecological environment, giving the economic man the identity of "eco economic man". Here, eco economic man is one whose actions are restricted to the comprehensive benefits of society, economy and ecology. With the development of society and economy, the contradiction between the deterioration of environmental conditions, the limitation of resources, and economic development have become increasingly prominent. Eco economic man is the practical executor for the protection of the economic and ecological environment (Li & Sun, 2014; Liu & Wang, 2007). Environmental protection lies greatly on Eco economic man's ecological view and his ecological environmental consciousness (Oliver et al., 2020; Papadavid et al., 2017), whereas, environmental consciousness refers to the concerns and comprehension of environmental problems (Chen et al., 2019).

If the eco economic man pursues the maximization of his own economic interests and neglects the enormous negative externalities of his own behavior to the environment, it will easily lead to over-exploitation and waste of resources, and thus destroy the living environment and development space of future generations. The proposal of Eco economic man is not aimed to create something new and original (Liu & Wang, 2007), but for the requirement of sustainable development of human beings.

It aims to overcome the inherent limitation of the hypothesis of "economic man". Differing from the hypothesis of "economic man", it clearly points out that human beings not only benefit from the economic system but also the ecosystem at the same time. The proposal of Eco economic man can reasonably explain the preferences of Eco economic individuals and their different behaviors in environmental protection. The establishment of the identity of eco economic man makes his behavior limit in environmental constraints.

Both studies of pro-environmental behavior and eco economic man are developed with the objective of encouraging the wider audience to adopt environmentally conscious behaviors and take more sustainable lifestyles. Despite the increasingly emphasizing the contribution of human's environmental attitude to environmental protection, how to measure human behavior and provide theoretical and empirical evidence to further policy is also necessary. However, difficulties arise with the quantification of human behavior, the absence of data makes it hard to measure human behavior. The lack of effective data sources for human behavior is one of the greatest limitations of analyzing human behavior. Therefore, we try to quantify human behavior based on a framework of external and internal factors and find out what are the external and internal factors.

Review of Methods

Review of Game Theory

Game theory, which was first developed as a mathematical tool in economic analysis, was widely applied to study human behavior in environmental protection. In general, the principle of game theory can be summarized as a method to deal with conflicts of maximizing decision-makers' respective payoffs to achieve better outcomes under certain strategies of opponents. Early studies simulated the process of human natural competitive and cooperative behaviors based on natural resources. In this theory, using natural resources involves conflicts of maximizing economic benefits versus minimizing environmental damage (Raquel et al., 2007). The advantage of game theory over other methods is that game theory can simulate different aspects of conflicts and estimate possible solutions in the absence of quantitative information about payoffs (Hui & Bao, 2013; Nazari et al., 2020).

Games typically belong to one of two broad categories: static or dynamic. In essence, game theory analyzes the decision-makers benefit and payment while other players may affect the actual outcome (Madani, 2010) under static or dynamic conditions. In a static game, each decision-maker thinks about what the opponent is going to do right now, while in a dynamic game, each decision-maker contemplates that what the opponent will do after his own decision (Nazari et al., 2020). In a static game, decision-makers make their choices at the same time (Alizadeh et al., 2017; Madani & Dinar, 2012; Nazari & Ahmadi, 2019), while in a dynamic game, decision-makers make their choices as the determination of an optimal sequence of targets (Damon, 2010; Zheng et al., 2019; Mandel & Venel, 2020). Dynamic games take advantage of static games in considering the next choices and sequences in the decision-making procedure, yet most of existing literature examines human behavior with the static approach (Alizadeh et al., 2017; Madani & Dinar, 2012), and even within the literature using the approach of dynamic analysis (Damon, 2010; Zheng et al., 2019 ; Mandel & Venel, 2020), they seldom identify the stochastic change and random change.

Furthermore, a dynamic game can likely provide an analytical frame for the process of human behavior, but it is likely impossible to figure out how much trade-off in detail that a man can obtain in this process. Actually, most existing literature uses artificial intelligence to simulate the process (Zheng et al., 2020; Kraus, 2016), and the trade-off in detail cannot be shown in an empirical way based on facts instead of virtual assumptions. In this paper, we try to integrate methods of econometrics and game theory and provide empirical evidence for game analysis.

Review of GMM and MS-VAR

The dynamic generalized method of moments model (GMM) is used to address panel data dealing with endogeneity bias. It was developed by Arellano and Bond (1991) and Blundell and Bond (1998), it can be used for dynamic panel data. In dynamic panel data, the causal relationship for underlying phenomena generally changes over time. To capture this, GMM uses lags of the dependent variables as instruments to control this endogenous relationship (Ketokivi & McIntosh, 2017). GMM model provides consistent results in the presence of different sources of endogeneity, namely "unobserved heterogeneity, simultaneity, and dynamic endogeneity" (Wintoki et al., 2012).

Hamilton (1989) once proposed a widely used time-varying method, namely the Markov switching model. This model can describe the change and transformation of variables in different regimes and capture the more complex dynamic evolution process of variables. He also introduced the Markov chain into the general vector autoregressive model (MS-VAR), so that the VAR model can be used to describe the different characteristics of research objects in different regimes too. Then the model is further developed by Krolzig (1997, 1998) and Kim and Nelson (1999). Now MS-VAR model is extended to be used in many fields (Ismail & Rahman, 2009; Guo & Stepanyan, 2011; Falahi, 2011; Bildirici, 2013).

The basic idea of this MS-VAR model is that the parameters of a VAR process may not be time-invariant, it may change as the regime changes. Linear models always assume that the parameters of a VAR process are time-invariant, and they cannot capture the change and transformation of the process. Instead, the dynamic evolution process can be described by the MS-VAR model more precisely. In order to capture the dynamic evolution process of human behavior, the MS-VAR model is adopted.

This paper quantifies human behavior through constructing an index system and combines the methods of game theory, GMM, and MS-VAR to describe the situation of human behavior from the perspective of environmental sociology and behavioral psychology, and explores environmental protection behavior by linking the theory with practice and taking the situation in China as an example. In this paper, we are concerned with two main issues: Firstly, this paper aims to identify the internal and external factors which drive individual behavior and establish the relationships between individual's benefit and payment to explore human behavior in environmental protection. Secondly, this study depicts the human behavior linking theory with the practice by game theory integrated with GMM method, and in order to overcome the problems of randomness and stochastic change of human behavior, this study uses the MS-VAR model to simulate the dynamic change of human behavior.

Compared with previous studies, the research contributions in this study can be summarized as follows:

1. This study further develops a new method to quantify human behavior, which has great significant theoretical importance and practical meaning. The lack of individual research data makes the research of human behavior encounter bottlenecks. This study is approximate to work it out by constructing a theoretical framework of external and internal factors and identifying what are the factors and how they influence human behavior. Although it mainly focuses on the situation of men in China, the framework this study proposes can be applied to other countries and regions.
2. This study firstly uses game theory to deduce the estimation equation, then the GMM method is combined to use to estimate the benefit and payment of human behavior, and how human behaves under stochastic conditions is also estimated by the MS-VAR method. Many factors can alter human behavior to obtain the benefit as circumstances vary. The relationship between human behavior and these factors may change, and the relationship between them may also be time dependent, or they may depend on the states of the factors. In addition, the relationship is very flexible, the changes in the relationship could happen once or frequently, be permanent or temporary. In order to depict the complexity shown in this process of change, we introduce stochastic change into the analysis of dynamic games and highlight the relationship between the factors and human behavior. The combining use of game theory and econometrical methods brings some new to the research of human behavior.

Variables and Data Sources

The PMT helps humans to understand that human behavior is influenced by internal and external factors (Blok et al., 2015; Juvan & Dolnicar, 2017). As discussed before, external factors are related to the context, such as regulation or social norms in which humans will behave, in this paper, we construct the external variables based on the theory of the IPAT model. At present, the IPAT model (Ehrlich & Holden, 1971) is one series model which is used to analyze the influence factors of environmental pollution in the academic fields. In the IPAT model, the factors affecting the environmental pressure are divided into three categories of population, affluence, and technology. This study also constructs factors based on the series model of IPAT and divides the influencing factors of human behavior mainly into three categories: population, affluence, and technology. The affluence category is including GDP growth rate (GDP) and recessive economy (EOR). The technology category is including R&D expenditure (RAD). Population category is including population density (POP).

Internal factors are related to people's beliefs, values, attitudes, emotions, and knowledge (Wallen Kenneth & Elizabeth, 2018; Turaga et al., 2010), and specific beliefs, values, attitudes, emotions, and knowledge affect people's efforts in environmental protection. Human efforts are the results of their consciousness. In this paper, efforts are viewed as the internal factor, which influences human behavior's benefit and payment. Different from the external factors such as the affluence factor which is exogenous to individuals, efforts are made by humans themselves. It is difficult to calculate the efforts of humans in environmental protection. One of the fundamental insights in human efforts is the way to observe the performance of humans in protecting the environment. In order to understand the efforts in environmental protection, we construct an index system to measure the efforts.

Variables and data sources for human behavior are listed in Table 1 as follows, and data are coming from statistical yearbooks from various provinces and cities, China Population Statistics Yearbook, China Population and Employment Statistics Yearbook, and China Energy Statistics Yearbook.

China National Development and Reform Commission published the "green development index system" in 2016 as the basis for evaluation and assessment of ecological civilization construction in China (China National Development and Reform Commission, 2016). Since this paper mainly focuses on China, the benefit and payment of human behavior in this paper are calculated according to the "green development index system" (Appendix 1).

External factor GDP growth rate uses GDP growth rate to express the level of local economic development. R&D expenditure uses the ratio of R&D expenditure to GDP to express the level of technological progress. And the ratio of the total population to

Table 1 Variables and data sources

Variable	Sub variable	Expression
Benefit of human behavior (Explained variable)	Benefit of human behavior (*I*)	Amount of benefit of human behavior
Payment of human behavior (Explained variable)	Payment of human behavior (*C*)	Amount of payment of human behavior
Population (External factor)	Population density (pop)	Ratio of the total population to the administrative area
Affluence (External factor)	The level of economic development (gdp)	Growth rate of per capita GDP
	Recessive economy (eor)	Ratio of recessive economy to GDP
Technology (External factors)	R&D expenditure (rad)	Ratio of expenditure of R&D to GDP
Efforts (Internal factors)	Efforts (*a*)	Index system for efforts

the administrative area is used to denote the density of the local population. It is worthy to point out that, the recessive economy is estimated by MIMIC (Frey & Weck, 1984; Loayza, 1996; Alan, 2001; Giles et al., 2002). The results of the calculation reveal that the average annual recessive economy scale in some years is even more than 20% in some provinces. The recessive economy has a relatively large scale in China, and its influence cannot be ignored.

It is difficult to calculate the efforts of humans in environmental protection. In order to understand the efforts, we construct an index system to measure the efforts. One of the fundamental insights in human efforts is the way to observe the performance of humans in protecting the environment. The index system is divided into five categories (level 1 in Table 2), including resource utilization, environmental governance, environmental quality, ecological protection, and green life. The efforts are reflected in the ecological indicators. For example, if one man pays more attention to environmental protection, the total energy consumption will be lower, the energy consumption per unit GDP will decrease, and the construction land area per unit GDP will decrease too. The weight for the indicators is calculated according to the weight listed in the green development index system published by China National Development and Reform Commission.

In order to further calculate man's efforts, indicators for the index system (level 2 in Table 2) are also categorized into the positive part, which increases the whole efforts, and the negative part, which decreases the whole efforts. "+" means the indicator can be calculated as positive, and "−" stands for the indicator can be calculated as negative. The calculation results are shown in Appendix 2.

Game Analysis of Human Behavior

Existing literature proposes that no matter what external factors or internal factors people experience, only when people perceive the need for action and generate behavioral intention (awareness) will they make corresponding behavioral decisions. That is, people perceive risks and make corresponding behavioral decisions after comprehensively weighing the pros and cons (Fans et al., 2016). This paper follows the theory and uses benefits and payment to describe the individual's pros and cons.

Supposing each man is rational, his human behavior in environmental protection is according to his benefit and payment. If one man chooses to be environmentally friendly, he will obtain benefit I, at the same time he pays effort C as his cost. Referring to the paper of Hong and Lim (2016), Hong et al. (2018), it is assumed that I is a linear form and the payment function C is a quadratic form. Supposing that the benefit function is $I(a_i) = \lambda a_i + \xi$, and the payment function is $C(a_i) = \theta a_i^2 + \zeta$.

Here, ξ 、 ζ are exogenous random variables. a is the effort of an individual in environmental protection (a is a nonnegative number) and i represents an individual.

Table 2 Index system for human's efforts in protecting environment

Level 1	Level 2	Measurement unit	Weight	+/−
Resource utilization (weight 29.3%)	Total energy consumption	10,000 ton standard coal	2.48	−
	Reduction of energy consumption per unit of GDP	%	3.73	+
	Reduction of co_2 emission per unit of GDP	%	3.73	+
	Total amount of water	100 million m^3	2.48	−
	Reduction of water consumption per ten thousand unit of GDP	%	3.73	+
	Reduction of water consumption per unit of industrial added value	%	2.48	+
	Cultivated land	100 million mu	3.73	+
	New construction land scale	10,000 mu	3.73	−
	Reduction of land use per unit of GDP	%	2.48	+
	Output for energy consumption	10,000 yuan/ton	2.48	+
	Industrial solid waste comprehensive utilization	%	1.22	+
Environmental governance (weight 16.5%)	Reduction of chemical oxygen demand	%	4.96	+
	Reduction of ammonia nitrogen emission	%	4.96	+
	Reduction of SO_2 emission	%	4.96	+
	Hazard-free treatment rate of household waste	%	3.29	+
Environmental quality (weight 19.3%)	Rate of high air quality days	%	4.88	+
	Reduction of pm10 in capital city	%	4.88	+
	Proportion of surface water reaches or is better than class III water	%	4.88	+
	Proportion of class one and two of coastal water	%	3.24	+
	Fertilizer use per unit land	kg/ha	1.69	−
	Pesticide use per unit land	kg/ha	1.69	−
Ecological protection (weight 16.5%)	Forest coverage rate	%	6.81	+
	Forest growing stock	100 million m^3	6.81	+
	Proportion of nature reserves	%	2.27	+
	Proportion of new governance area of soil and water loss	10,000 ha	2.27	+

Table 2 (continued)

Level 1	Level 2	Measurement unit	Weight	+/−
Green life (weight 9.2%)	Public transport volume per 10,000 population	10,000/10,000	2.54	+
	Rate of tap water in countryside	%	5.05	+
	Rate of sanitary toilet in countryside	%	2.54	+

Mu = 6.07 acres; There is soil erosion every year, and there is also soil and water loss every year. New governance area of soil and water loss means the new area of soil and water loss is under control in a certain year. The data for Shanghai is missing; Indicators of the proportion of surface water reach or are better than class III water and proportion of class one and two of coastal water are used to measure the water environment. Surface water reaches or is better than class III water means the quality of surface water is good to be used. The proportion of class one and two of coastal water means the proportion of good water quality in the nearshore; An indicator of rate of the tap water in the countryside is to measure the popularity of rural tap water. It means the proportion of using tap water in the countryside. Usually, the data are measured by the Ministry of water resources in China

$$\begin{aligned}
&I = \alpha^T \mu(a_2) + g + \alpha_1 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \\
&\beta_1 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \gamma_1 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
&+ \varphi_1 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \mu
\end{aligned} \tag{1}$$

$$\begin{aligned}
&C = \beta^T \mu(a_2^2) + f + \alpha_2 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \\
&\beta_2 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \gamma_2 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
&+ \varphi_2 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \nu
\end{aligned} \tag{2}$$

a_1 is the current value of human's effort, and a_2 is the value of human's effort in the next stage, g is a constant, T is transit, I_0 is the initial benefit, μ,ν are exogenous random variables.

The expected return of human being is

$$\begin{aligned}
I - C = {} & \alpha^T \mu(a_2) + g + \alpha_1 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& + \beta_1 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \gamma_1 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& + \varphi_1 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \mu \\
& - \beta^T \mu(a_2^2) + f + \alpha_2 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \\
& \beta_2 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \gamma_2 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& + \varphi_2 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \nu
\end{aligned} \tag{3}$$

And the participation constraints are

$$I - C \geq U_0 \tag{4}$$

That is

$$\begin{aligned}
& \alpha^T \mu(a_2) + g + \alpha_1 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& + \beta_1 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \gamma_1 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& + \varphi_1 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] + \mu \\
& - \beta^T \mu(a_2^2) - f - \alpha_2 pop_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] - \\
& \beta_2 gdp_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] - \gamma_2 eor_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] \\
& - \varphi_2 rad_{it} \max\left[(\alpha^T \mu(a_1, a_2) + g - I_0), 0\right] - \nu \\
& \geq \mathrm{U}_0
\end{aligned} \tag{5}$$

U_0 is the initial expected return of man. Only when $I - C \geq U_0$, human will choose to be environmentally friendly. To simplify the calculation, we are supposing $\mu\left(a_1,\ a_2\right) = \left(a_1,\ a_2\right)$, and the best choice for the man will be the first order condition is 0, and we can get the equation as follows:

$$\lambda a_{it} + \alpha pop_{it} + \beta gdp_{it} + \gamma eor_{it} + \varphi rad_{it} + \rho I_{it}(-1) + \mu = \theta a_{it}^2 + \alpha' pop_{it} + \beta' gdp_{it} + \gamma' eor_{it} + \varphi' rad_{it} + \rho' C_{it}(-1) + \upsilon \tag{6}$$

Thus, we suppose the benefit and payment function for a man will be:

$$I_{it} = \lambda a_{it} + \alpha pop_{it} + \beta gdp_{it} + \gamma eor_{it} + \varphi rad_{it} + \rho I_{it}(-1) + \mu \tag{7}$$

$$C_{it} = \theta a_{it}^2 + \alpha' pop_{it} + \beta' gdp_{it} + \gamma' eor_{it} + \varphi' rad_{it} + \rho' C_{it}(-1) + \upsilon \tag{8}$$

Quantitative Analysis of GMM

GMM method is used for estimating Eqs. (7) and (8). GMM method does not need to know the distribution of variables when estimating the panel model. It only needs to find the moment condition instead of the whole density function, which allows the model with heteroscedasticity and correlation.

The result of the unit root test is shown in Appendix 3, and the result of estimation is revealed in Table 3.

Table 3 shows the results of GMM estimation. *J*-statistic and Sargent tests show that the model is robust. The internal factor of human efforts in environmental protection not only increases the benefits of humans, but also decreases the payment of humans (increasing the effort of humans can increase the benefit of man's environmental protection by more than 3.3, and reduce the payment by more than 3.87), this conclusion goes along with that of Moloney Susie and Horne Ralph E (Susie et al., 2010), which also verifies that environmntal protection is contingent upon human behavior (Reddy et al., 2016; Schultz, 2011; St. John et al., 2010).

External factors also mean a lot to the benefit and payment of human behavior. The increase of GDP growth rate reduces the benefit and payment of human. On the one hand, economic development is at the cost of deterioration of environment surrounded and thus reduces the human's benefit from the environment, and on the other hand, economic development increases the affluence of humans and thus ensures humans have enough economic capacity to behave environmentally friendly. The situation is similar to the scale of recessive economy, it reduces the payment of humans too. Yet due

Table 3 Benefit and payment of human behavior

Variable	ln*a*/lna^2	$I(-1)/C(-1)$	lngdp	lneor	lnrad	lnpop
I	3.301115*** (0.0001)	−2.065526*** (0.0091)	−0.013541 (0.6120)	0.025755 (0.2466)	0.048364** (0.0265)	0.047035 (0.0012)
C	−3.872805* (0.0613)	1.035060*** (0.000)	−0.507396* (0.1163)	−0.229617 (0.1349)	0.086086 (0.3281)	−0.087179 (0.1334)

The brackets are standard deviations

***; **; * indicate the significance test at 1%, 5%, 10% level, respectively to its characteristic of avoidance of environmental regulation, the recessive economy improves man's benefits instead.

Factor "rad" represents the proportion of R&D technology investment in GDP. On the one hand, the increase of R&D investment has brought about technological progress, which has increased man's benefits; on the other hand, the investment of funds has increased man's payment.

It is interesting that the increase of population density can both reduce the benefit and payment of humans. The increase in population means that more people use resources. But as man pays more attention to the environment, and more and more humans choose environmental protection behavior, therefore more population brings benefit to the environment.

It is worthy to point out that, human's benefit and payment values with first-order lag have a negative impact on the benefit and positive impact on payment in the next period, that means whether a human chooses environmental protection behavior or not in this period has significant meaning for the next period, and this significance is obvious (see Table 3). Furthermore, the results also reveal that human tend to behave environmentally friendly, although human environmentally friendly behavior increase the payment and decrease the benefit for the next period, yet human still tends to choose environmentally friendly behavior in the next period despite of the decreasing benefit and increasing payment. Since human tends to be environmentally friendly, then questions arise that whether human behaves environmentally friendly is a stable state, and is this state dynamic and time dependent? In order to further depict the state of human behavior, MS-VAR is introduced in the next part of this paper.

Quantitative Analysis of MS-VAR

Two discrete regimes including environmentally friendly and environmentally unfriendly behavior are considered. And expected return can be expressed as $(I_1 - C_1, I_2 - C_2)$ (both I and C are nonnegative). Supposing that at period t, the expected return for the two regimes can be expressed as $\begin{bmatrix} I_{1,t} - C_{1,t} \\ I_{2,t} - C_{2,t} \end{bmatrix}$, then at period $t + 1$, their expected return are

$$\begin{bmatrix} I_{1,t+1} - C_{1,t+1} \\ I_{2,t+1} - C_{2,t+1} \end{bmatrix} = \begin{bmatrix} Q_{1,s_{t+1}} & 0 \\ 0 & Q_{2,s_{t+1}} \end{bmatrix} \times \begin{bmatrix} I_{1,t} - C_{1,t} \\ I_{2,t} - C_{2,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} \tag{9}$$

where $\begin{bmatrix} Q_{1,s_{t+1}} & 0 \\ 0 & Q_{2,s_{t+1}} \end{bmatrix}$ represent correlation matrix which shows the relation between the values at period t and period $t + 1$, and this relationship is affected by the Markov mechanism. $\begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$ represent residual matrix. Actually, according to Eqs. (7) and (8), it is the difference of external and internal factors between this period and next period. We suppose that $\begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} \sim NID \left[0, \begin{pmatrix} \sigma^2_{1s_t} & \sigma_{12,s_t} \\ \sigma_{12,s_t} & \sigma^2_{2,s_t} \end{pmatrix} \right]$.

$\begin{pmatrix} \sigma^2_{1s_t} & \sigma_{12,s_t} \\ \sigma_{12,s_t} & \sigma^2_{2,s_t} \end{pmatrix}$ is a standard deviations matrix and the standard deviations are also affected by the Markov mechanism.S_t represents a Markov mechanism. Its constant transfer probability is $p_{u,v} = P_r(S(t+1) = u|S(t) = v)$. It represents the probability that transfers form t period to $t+1$ period. $p_{u,v}$ is the generic $[u, v]$ element of the transition matrix p:

$$P = \begin{bmatrix} p_{11} \, p_{12} \\ p_{21} \, p_{22} \end{bmatrix}, \sum_{v=1}^{2} p_{u,v} = 1, \forall u, v \in \{1, 2\} \tag{10}$$

MS-VAR model is based on the assumption that the error term is subjected to a normal distribution, and it is estimated by direct maximization of log-likelihood function.

$$p((I-C)_t|s_t = v, (I-C)_{t-1}) = \ln(2\pi)^{-1/2} \ln|\Sigma|^{-1/2} \exp\{((I-C)_t - \mu)' \Sigma_m^{-1}((I-C)_t - \mu)\} \tag{11}$$

Here, μ is the mean value of human's return in the regime of $s_t = v$, and all calculation is implemented by Matlab.

MS-VAR model is used based on the ADF unit root tests and the cointegration tests. The test results are shown in Appendix 3. And the estimation results are shown in Table 4, which reports regime shift probability, frequency, and duration in each region. Situations in eastern, middle, and western China and even the whole country are also presented (according to the results of ADF unit root tests, data in some regions are nonstationary, but the first difference are stationary. Then the results for the MS-VAR model in these regions are calculated by data after the first-order difference, which is marked with a star in Table 4).

The average duration period $D(R_i)$ can be calculated by the formula $D(R_i) = 1/(1 - p_{ii})$. R represents the different regions in China and p_{ii} represents the probability of regime shift. $i = 1, 2$, represent regime 1 and regime 2. In the situation of Beijing, p_{ii} for regime 1 is 0.58 and for regime 2 is 0.42. Then the average duration periods for environmentally friendly and environmentally unfriendly behavior can be calculated by the formula. The results are 2.37 and 1 separately. If the longer the environmentally friendly behavior's average duration period, the better the ecological environment for the certain region is.

From the view of specific regions, Table 4 shows that environmentally friendly behavior's average duration periods in Fujian (10.12), Jiangsu (10), Jiangxi (10.03), Henan (12), Guizhou (10.02) are relatively longer than other regions. It means that human in these regions tends to be environmentally friendly. Instead, environmentally friendly behavior's average duration periods in Hebei (2.4) and Sichuan (2.59) are relatively shorter. With less economic development and heavy industrial construction, human in Hebei and Sichuan tends to pay more attention to economic development rather than ecological protection. Humans behave less environmentally friendly in these regions.

It is worth pointing out that the results of regions marked star show the change of annual marginal increment of these regions. The annual marginal increment presents

Table 4 Human behavior's regime shift probability, frequency, and duration

Region	Friendly		Unfriendly		Frequency		Duration	
	Friendly	Unfriendly	Friendly	Unfriendly	Friendly	Unfriendly	Friendly	Unfriendly
Beijing	0.58	0.42	1	0	0.5	0.5	2.37	1
Tianjin	0.72	0.28	1	0	0.64	0.36	3.56	1
Hebei	0.58	0.42	0.47	0.53	0.57	0.43	2.4	2.15
Shanxi	0.8	0.2	0.67	0.33	0.43	0.57	5	1.5
Inner Mongolia*	0.5	0.5	0.1	0.9	0.38	0.62	2	10
Liaoning	0.8	0.2	1	0	0.36	0.64	5.05	1
Jilin*	0.74	0.26	0.25	0.75	0.46	0.54	3.89	3.96
Heilongjiang	0.90	0.10	0.38	0.62	0.43	0.57	10.07	2.63
Shanghai	0.80	0.20	0.67	0.33	0.36	0.64	5	1.5
Jiangsu	0.90	0.10	0.33	0.67	0.64	0.36	10	3
Zhejiang*	0.57	0.43	0.39	0.61	0.62	0.38	2.31	2.54
Anhui	0.52	0.48	0.5	0.5	0.43	0.57	2.09	2.00
Fujian	0.90	0.10	0.38	0.62	0.43	0.57	10.12	2.66
Jiangxi	0.90	0.10	0.34	0.66	0.43	0.57	10.03	2.94
Shandong	0.73	0.27	1.00	0.00	0.57	0.43	3.67	1
Henan	0.92	0.08	1.00	0.00	0.36	0.64	12	1
Hubei	0.80	0.20	0.72	0.28	0.36	0.64	5.11	1.39
Hunan*	0.62	0.38	0.27	0.73	0.57	0.43	2.61	3.75
Guangdong	0.79	0.21	0.72	0.28	0.57	0.43	4.73	1.38
Guangxi*	0.71	0.29	0.12	0.88	0.5	0.5	3.48	8.14
Hainan	0.63	0.37	0.6	0.4	0.5	0.5	2.68	1.67
Chongqing*	0.51	0.49	0.25	0.75	0.64	0.36	2.03	3.94
Sichuan	0.61	0.39	0.45	0.55	0.5	0.5	2.59	2.22
Guizhou	0.90	0.10	0.34	0.66	0.43	0.57	10.02	2.97
Yunnan	0.81	0.19	0.33	0.67	0.5	0.5	5.34	3.07
Shaanxi*	0.40	0.60	0.30	0.70	0.57	0.43	1.68	3.35
Gansu*	0.31	0.69	0.26	0.74	0.43	0.57	1.45	3.90
Qinghai*	0.79	0.21	1	0	0.43	0.57	4.87	1
Ningxia*	0.76	0.24	0.26	0.74	0.5	0.5	4.08	3.83
Xinjiang*	0.76	0.24	0.26	0.74	0.5	0.5	4.08	3.83
Eastern China*	0.31	0.69	0.8	0.2	0.57	0.43	1.46	1.25
Middle China*	0.69	0.31	0.40	0.60	0.43	0.57	3.19	2.49
Western China*	0.80	0.20	1.00	0.00	0.43	0.57	5.00	1.00
Whole country*	0.26	0.74	0.57	0.43	0.5	0.5	1.35	1.76

*Data used are after first order difference the trend of change. For example, in the area of in these regions, p_{ii} for regime 1 is 0.5 and for regime 2 is 0.9, average duration period for regime 1 is 2 and 10 for regime 2, these results reveal that in Inner Mongolia, human changes more from the environmentally friendly state to an unfriendly one rather than from an unfriendly one to a friendly one. Humans in Inner Mongolia pay less attention to environmental protection. Instead, in Qinghai, the average duration period for regime 1 is 4.87 and 1 for regime 2, the frequency changing from the environmentally unfriendly state to a friendly one is more often than changing from the environmentally friendly state to an unfriendly one. That means human here pays more attention to environmental protection.

In order to study the overall trend of human change in the whole country, the situations of eastern, middle, and western China are specially listed at the end of Table 4. In detail, environmentally friendly behavior's average duration for the whole country is 1.35, for the east of China is 1.46, 3.19 for the midland, and 5.00 for the west. Instead, environmentally unfriendly behavior's average duration for the whole country is 1.76, for the east of China is 1.25, 2.49 for the midland,

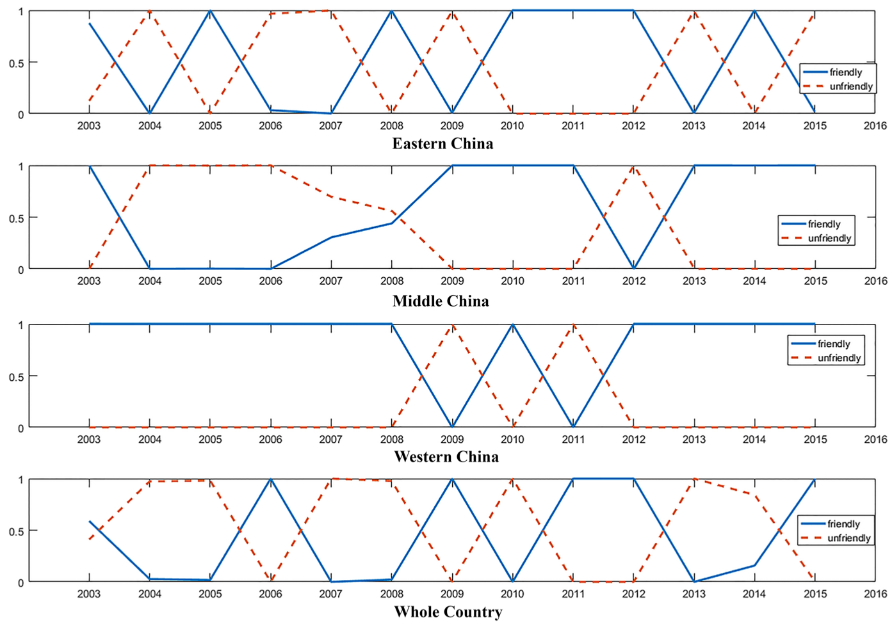

Fig. 1 Probabilities of regime. Note: Longitudinal axes represent probabilities of the regime; transverse axes represent the annual time dated from 2003 to 2016. State 1 means the regime of environmentally friendly behavior. State 2 means the regime of environmentally unfriendly behavior

and 1 for the west. These data mean that human behavior in eastern China has a higher shift probability than in the rest part of China. In addition, in eastern China, within the whole sample interval, the proportion of sample belongs to environmentally friendly behavior is 0.57 and 0.43, respectively, for western and middle China. This reveals that from 2003 to 2016, the proportion of environmentally friendly behavior in the east is more than in other areas, which goes along with the results of Chen et al. (2019). Eastern China is more eco-conscious (Liu & Wang, 2007; Li & Sun, 2014). Although eastern China has a large population and human behavior tends not to stay in a stable state, yet the higher shift probability ensures that humans in eastern China behave more environmentally friendly than those in other parts of China.

The shifting probability of each district can be shown in the figure of the probabilities of the regime (Fig. 1). Lines of probabilities for the two regimes are just alternating frequently, especially in eastern China and the whole country. Alternation of lines of probabilities means that the situation for human behavior is unstable. Men in China need further efforts to improve the environment, this finding confirmed the results of studies by Zhang et al. (2018). Due to the fragile ecological conditions, there is still a long way to go to improve the environmental situations, change of human behavior has become central to practice and policy.

Conclusion and Suggestion

Results of the quantitative analysis suggest ways to regulate human behavior in China. The internal factor of efforts is the internal drive to human behavior. In the process of human living, production, and consumption, a human emits pollution from household wastes, pollution from chemical fertilizers, pesticides, and even pollution from the production of feed in the process of livestock and poultry breeding. Findings highlight that by increasing perceived payments of behavior and perceived intrinsic and extrinsic benefits of current environmentally unfriendly behaviors will decrease the environmentally unfriendly behaviors. Comprehensive management to control household waste emission, ensure the sustainable utilization of cultivated land, and improve the resource utilization of agricultural waste has a potential great contribution to reducing pollution from a human being. Besides, special attention should be taken to the field of terrestrial and aquatic ecosystems, human should realize that terrestrial and marine ecosystems are the largest treasure on earth and make more efforts to promote afforestation and forest restoration. A flexible compensation mechanism will have great significance. Due to the complexity and mobility of pollution, the environment surrounding each individual is different; therefore, the work of compensation should be different, which requires different implementation of environmental control policies.

Findings of external factors reveal that for areas with an undeveloped economy and high recessive economy, we can fundamentally reduce the environmental deterioration caused by human behavior through policy guidance and restraint. For regions with developed economies and abundant endowments, we can encourage humans to consider further strengthening the application of new energy development technology through technological innovation policies, including renewable energy production, food system transformation, waste recycling, and other innovative technologies.

Among all the external factors, technology will be the basic and fundamental factor that can reduce pollution for now. To integrate geospatial technology and network distributed processing technology based on the temporal and spatial differentiation of pollution, and to build an early warning system for pollution intensity to realize the real-time query and update the pollution data is an efficient way to promote the technology in human's environmental protection action.

The main principle of this paper is to further propose how to quantify human behavior in environmental protection and study when and how humans choose to behave environmentally friendly. Can the method be designed to directly measure human behavior, is there any external or internal factors affecting human behavior? These questions are discussed in this paper. Influencing factors of human behavior are including internal factors of efforts made by humans themselves and external factors of wealth, population, and technology based on IPAT theory. Then the benefit and payment function are deduced by game analysis, and GMM and MS-VAR are integrated to use to analyze human behavior. Although this paper takes the situation in China as an example, the framework this paper suggests can be extended to other countries and regions in the world.

Appendix 1 Benefit and Payment for Different Regions in Different Years

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Beijing														
I	0.5569	0.5727	0.6546	0.6556	0.6831	0.7197	0.7301	0.7748	0.7647	0.6981	0.6830	0.7196	0.7490	0.6827
C	0.2299	0.2446	0.2441	0.2470	0.2446	0.2482	0.2580	0.2659	0.2720	0.2753	0.2766	0.2821	0.2776	0.2755
Tianjin														
I	0.3479	0.4102	0.5278	0.5664	0.5694	0.6252	0.6179	0.5639	0.5480	0.6054	0.5150	0.4576	0.4586	0.6245
C	0.0843	0.1005	0.1072	0.1136	0.1241	0.1367	0.1434	0.1533	0.1602	0.1651	0.1713	0.1777	0.1912	0.1981
Hebei														
I	0.3759	0.3516	0.3743	0.3919	0.4206	0.4740	0.4754	0.5364	0.4144	0.5654	0.5718	0.5500	0.5678	0.5905
C	0.3240	0.3449	0.3748	0.3949	0.4133	0.4229	0.4358	0.4494	0.4687	0.4717	0.4756	0.4882	0.5019	0.5048
Shanxi														
I	0.2470	0.2597	0.2110	0.2210	0.2893	0.2786	0.2821	0.3695	0.3599	0.3911	0.3505	0.4265	0.4279	0.5801
C	0.1315	0.1471	0.1544	0.1662	0.1787	0.1821	0.1892	0.2032	0.2188	0.2368	0.2469	0.2499	0.2515	0.2525
Inner Mongolia														
I	0.2951	0.3802	0.3861	0.4293	0.4831	0.5299	0.5435	0.4523	0.6355	0.6667	0.8012	0.8018	0.7080	0.7773
C	0.1570	0.1808	0.2106	0.2291	0.2509	0.2659	0.2861	0.3175	0.3756	0.3839	0.3487	0.3642	0.3595	0.3643
Liaoning														
I	0.5719	0.5335	0.5102	0.5359	0.5477	0.6045	0.5970	0.6059	0.6413	0.7210	0.7793	0.7706	0.7409	0.6639
C	0.3140	0.3370	0.3303	0.3567	0.3803	0.4086	0.4217	0.4531	0.4667	0.4885	0.4684	0.4631	0.4794	0.4734
Jilin														
I	0.3893	0.4088	0.3261	0.3527	0.4611	0.5010	0.4449	0.5403	0.5829	0.5928	0.7178	0.6576	0.6577	0.7484
C	0.1401	0.1464	0.1563	0.1739	0.1844	0.2023	0.2159	0.2321	0.2450	0.2553	0.2606	0.2672	0.2651	0.3179
Heilongjiang														

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
I	0.4768	0.4871	0.4553	0.4945	0.5239	0.5614	0.5346	0.6884	0.3629	0.6993	0.8198	0.8480	0.8211	0.9378
C	0.2647	0.2967	0.3141	0.3315	0.3495	0.3579	0.3861	0.4006	0.4127	0.4536	0.4359	0.4321	0.4336	0.4321
Shanghai														
I	0.4168	0.4057	0.4294	0.5047	0.5656	0.5759	0.5530	0.5824	0.6017	0.6124	0.5529	0.6714	0.6339	0.7174
C	0.3648	0.3610	0.4471	0.4502	0.4748	0.4853	0.4785	0.4797	0.4735	0.4658	0.4654	0.4693	0.4661	0.4605
Jiangsu														
I	0.3915	0.4509	0.5238	0.5329	0.6220	0.6098	0.6567	0.6924	0.6628	0.7394	0.7056	0.7254	0.7731	0.8001
C	0.5179	0.5975	0.6396	0.6727	0.7101	0.7374	0.7751	0.8112	0.8508	0.8830	0.9171	0.9442	0.9563	0.9768
Zhejiang														
I	0.4838	0.5043	0.5395	0.5567	0.5875	0.6497	0.7009	0.7107	0.6104	0.7179	0.6575	0.6786	0.7691	0.8335
C	0.3390	0.3589	0.3806	0.3833	0.4161	0.4359	0.4469	0.4730	0.4880	0.4858	0.5118	0.5164	0.4924	0.4876
Anhui														
I	0.0640	0.2301	0.1497	0.1904	0.2571	0.2174	0.2951	0.3355	0.3013	0.4336	0.4683	0.5111	0.4500	0.5573
C	0.2641	0.2800	0.2971	0.3225	0.3354	0.3782	0.4055	0.4219	0.4288	0.4436	0.4645	0.4595	0.4809	0.5106
Fujian														
I	0.4716	0.5527	0.5761	0.6005	0.6879	0.6747	0.7064	0.7702	0.6860	0.8256	0.8608	0.8734	0.8919	0.9999
C	0.2583	0.2630	0.2809	0.2894	0.3202	0.3293	0.3429	0.3658	0.3773	0.3896	0.4019	0.4106	0.4190	0.4137
Jiangxi														
I	0.2430	0.3147	0.3487	0.3702	0.4049	0.4611	0.4644	0.5509	0.4755	0.5963	0.6357	0.6478	0.6450	0.7021
C	0.1827	0.2179	0.2293	0.2353	0.2671	0.2778	0.2994	0.3171	0.3200	0.3282	0.3448	0.3419	0.3519	0.3494
Shandong														
I	0.5220	0.5315	0.4882	0.5118	0.6634	0.6669	0.6579	0.7144	0.6427	0.6333	0.8873	0.8649	0.8432	0.9365
C	0.4610	0.5024	0.5464	0.6003	0.5607	0.5908	0.6352	0.6614	0.7062	0.7501	0.7326	0.7956	0.8111	0.7846
Henan														
I	0.2306	0.2408	0.2720	0.2560	0.3698	0.3764	0.3364	0.4967	0.2981	0.4410	0.5051	0.5688	0.4992	0.7469
C	0.3132	0.3491	0.3726	0.4119	0.4331	0.4655	0.4723	0.4736	0.5008	0.5234	0.5336	0.5261	0.5547	0.5550

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Hubei														
I	0.6446	0.3147	0.3190	0.2560	0.3239	0.3683	0.4199	0.5043	0.4854	0.5365	0.6622	0.5985	0.5457	0.6254
C	0.3583	0.3757	0.3851	0.4285	0.3942	0.4119	0.4817	0.5474	0.5598	0.5774	0.5420	0.5833	0.5329	0.5459
Hunan														
I	0.2548	0.2773	0.2950	0.3432	0.4294	0.4885	0.5029	0.5612	0.5164	0.5914	0.6108	0.6205	0.6511	0.6983
C	0.3340	0.3623	0.3897	0.4063	0.4154	0.4317	0.4543	0.4793	0.4984	0.5125	0.4995	0.4883	0.4860	0.4884
Guangdong														
I	0.4898	0.4575	0.4529	0.4887	0.6290	0.7011	0.7187	0.7757	0.7458	0.8568	0.8371	0.8436	0.8311	0.8456
C	0.6948	0.6943	0.7326	0.7412	0.9199	0.8588	0.8225	0.8497	0.9548	0.9595	0.9311	0.9795	0.9884	1.0000
Guangxi														
I	0.4791	0.5782	0.6039	0.6473	0.5841	0.6370	0.6558	0.7256	0.7530	0.7508	0.7989	0.8254	0.8482	0.8735
C	0.2482	0.2612	0.3427	0.3475	0.3596	0.3808	0.3536	0.3512	0.3534	0.3607	0.3779	0.3803	0.3842	0.3820
Hainan														
I	0.3179	0.3995	0.4478	0.3432	0.4481	0.5272	0.4949	0.5701	0.4343	0.6384	0.6804	0.6497	0.6468	0.6763
C	0.1979	0.2100	0.2108	0.2526	0.2840	0.3216	0.3768	0.3895	0.3666	0.3720	0.3977	0.3887	0.4090	0.3726
Chongqing														
I	0.1661	0.1727	0.2915	0.3546	0.4425	0.5052	0.5087	0.5536	0.5327	0.6040	0.5371	0.5539	0.6208	0.6991
C	0.0899	0.0951	0.1148	0.1353	0.1481	0.1586	0.1649	0.1897	0.2059	0.1961	0.2070	0.2181	0.2312	0.2311
Sichuan														
I	0.4886	0.6071	0.5791	0.6586	0.6216	0.6812	0.6790	0.7517	0.7605	0.8229	0.8861	0.9149	0.8333	0.8838
C	0.2995	0.3157	0.3326	0.3474	0.3665	0.3785	0.4131	0.4368	0.4638	0.4920	0.5106	0.4828	0.5068	0.5182
Guizhou														
I	0.1832	0.2241	0.3054	0.2982	0.3439	0.4123	0.4306	0.4597	0.4327	0.5505	0.6332	0.5607	0.6073	0.6380
C	0.0848	0.1359	0.1367	0.1009	0.1115	0.1206	0.1254	0.1232	0.1381	0.1484	0.1188	0.1514	0.1349	0.1383
Yunnan														
I	0.5533	0.6388	0.6037	0.5677	0.6471	0.6695	0.6657	0.7430	0.5820	0.7628	0.8406	0.8203	0.8318	0.8422

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
C	0.1164	0.1276	0.1425	0.1458	0.1739	0.1855	0.1904	0.1986	0.2074	0.2235	0.2201	0.2282	0.2299	0.2296
Shaanxi														
I	0	0.2102	0.2306	0.2417	0.3140	0.4435	0.4821	0.5023	0.4176	0.5101	0.5659	0.4248	0.4545	0.6026
C	0.1210	0.1320	0.1368	0.1572	0.1703	0.2028	0.2137	0.2083	0.2149	0.2404	0.2556	0.2606	0.2675	0.2715
Gansu														
I	0.2156	0.3671	0.2115	0.2762	0.3180	0.3343	0.2862	0.3443	0.2970	0.4485	0.4446	0.4677	0.4725	0.6966
C	0.1220	0.1300	0.1348	0.1347	0.1449	0.1463	0.1574	0.1613	0.1887	0.2015	0.2071	0.2070	0.2115	0.2054
Qinghai														
I	0.2309	0.2049	0.2081	0.3235	0.3683	0.3510	0.3580	0.3691	0.4126	0.4938	0.4891	0.5351	0.4977	0.5568
C	0.0098	0	0.0170	0.0080	0.0096	0.0142	0.0095	0.0149	0.0172	0.0186	0.0279	0.0247	0.0420	0.0955
Ningxia														
I	0.0294	0.2018	0.0552	0.1717	0.2495	0.2960	0.2445	0.3414	0.3403	0.3934	0.4628	0.4735	0.4153	0.5553
C	0.0704	0.0844	0.0911	0.0982	0.1015	0.1073	0.1100	0.1213	0.1186	0.1161	0.1240	0.1234	0.1292	0.1312
Xinjiang														
I	0.2302	0.1537	0.2355	0.3277	0.3653	0.4206	0.4071	0.542	0.5005	0.5415	0.5845	0.6488	0.6040	0.7838
C	0.2861	0.2922	0.3052	0.3215	0.3325	0.3509	0.3618	0.3712	0.3924	0.4374	0.4543	0.4594	0.4632	0.2654

I stands for the benefit value and *C* stands for the payment value

Appendix 2 Efforts of Human for Different Regions in Different Years

Region	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Bj	39.48	39.72	41.42	41.26	41.85	42.53	42.56	43.45	42.92	41.03	40.57	41.19	41.60	42.02
Tj	36.97	38.63	40.83	41.95	41.91	42.98	42.60	41.09	40.51	41.86	37.33	37.97	37.76	41.74
Heb	36.63	35.95	36.02	36.31	36.85	38.07	37.90	39.20	35.70	39.47	39.31	38.39	38.67	39.16
Sx	35.45	35.72	34.48	34.66	36.13	35.73	35.71	37.60	37.04	37.49	36.25	37.44	36.99	40.45
IM	35.75	37.75	37.70	38.22	39.46	40.38	40.67	38.10	42.00	42.76	45.68	44.89	42.88	44.40
Ln	40.83	39.53	38.69	39.05	39.62	40.86	40.51	40.43	41.20	42.76	43.97	43.57	42.56	41.08
Jl	38.43	38.82	36.61	37.15	39.62	40.41	38.99	41.21	42.05	42.20	44.99	43.39	43.33	45.00
Hlj	39.44	39.47	38.58	39.38	39.72	40.52	39.42	42.98	34.67	42.62	45.28	45.72	44.80	47.52
Sh	35.99	35.60	35.29	37.07	37.84	38.04	37.45	38.05	38.25	38.28	36.63	39.03	37.80	39.48
Js	35.38	36.07	37.13	37.15	38.66	38.11	38.82	39.19	37.74	39.24	37.88	38.00	38.80	39.02
Zj	38.69	38.98	39.41	39.70	40.10	41.36	42.29	42.17	39.27	41.76	39.81	40.03	42.15	43.55
Ah	30.06	33.35	31.36	32.17	33.64	32.45	34.14	35.04	34.09	37.21	37.55	38.62	36.73	38.83
Fj	38.97	40.76	40.79	41.62	43.58	43.15	43.69	44.98	42.63	45.85	46.32	46.40	46.70	49.39
Jx	34.70	36.00	36.68	37.25	37.80	39.05	38.94	40.78	38.68	41.58	42.12	42.30	41.91	43.26
Sd	38.89	38.91	37.24	37.44	41.30	41.00	40.52	41.47	39.00	38.12	44.51	43.11	42.43	44.80
Hen	33.63	33.54	34.03	33.34	35.76	35.87	34.80	38.67	33.29	36.62	37.75	39.16	37.18	42.98
Hb	42.31	34.36	34.36	32.39	34.22	35.22	35.68	37.18	36.68	37.74	40.71	38.74	37.81	39.48
Hn	33.35	33.52	33.54	34.59	36.68	37.94	38.01	39.24	37.93	39.55	39.89	40.06	40.57	41.75
Gd	35.77	34.71	34.22	35.10	36.76	38.97	39.54	40.53	38.67	41.21	40.77	40.50	39.96	40.05
Gx	39.52	41.68	41.44	42.55	40.79	42.01	42.66	44.40	45.14	44.82	45.52	46.05	46.42	47.08
Han	36.54	38.23	39.37	36.30	38.69	40.30	38.76	40.28	36.82	41.74	42.48	41.47	41.32	42.26
Cq	33.38	33.35	35.88	37.15	39.08	40.53	40.76	41.61	40.80	42.45	40.53	40.61	41.92	43.80
Sc	39.10	41.58	41.18	40.44	41.80	43.14	42.64	44.16	43.94	45.21	46.38	47.06	44.89	45.82
Gz	33.86	34.29	36.04	35.86	37.08	38.34	38.71	39.52	38.27	41.17	43.22	41.36	42.65	43.41
Yn	42.51	44.30	43.25	42.19	43.97	44.33	44.12	45.83	41.35	45.72	47.44	46.83	46.94	47.21
Sax	28.78	34.23	34.14	34.19	35.85	38.76	39.08	39.98	37.89	40.01	40.97	37.66	37.54	41.22
Gs	34.35	37.42	33.59	34.80	35.82	36.40	35.08	36.48	34.97	38.31	38.17	38.52	38.58	43.84
Qh	35.62	35.16	34.98	38.04	39.13	38.65	38.39	38.90	39.85	41.79	41.44	41.97	40.46	41.00
Nx	30.34	32.86	30.35	32.82	34.67	35.35	34.45	36.75	36.66	37.73	38.74	38.31	37.74	40.39
Xj	33.48	31.37	33.39	35.45	36.10	37.29	36.55	40.11	38.64	39.22	39.70	40.76	39.63	45.22

For the sake of the lack of data, regions are including Beijing (Bj), Tianjin (Tj), Hebei (Heb), Shanxi (Sx), Inner Mongolia (IM), Liaoning (Ln), Jilin (Jl), Heilongjiang (Hlj), Shanghai (Sh), Jiangsu (Js), Zhejiang (Zj), Anhui (Ah), Fujian (Fj), Jiangxi (Jx), Shandong (Sd), Henan (Hen), Hubei (Hb), Hunan (Hn), Guangdong (Gd), Guangxi (Gx), Hainan (Han), Chongqing (Cq), Sichuan (Sc), Guizhou (Gz), Yunnan (Yn), Shaanxi (Sax), Gansu (Gs), Qinghai (Qh), Ningxia (Nx), and Xinjiang (Xj)

Appendix 3 Panel Unit Root Test Results

Variable	Levin, Lin and Chu t*	Breitung *t*-stat	Im, Pesaran, and Shin *W*-stat	ADF—Fisher chi-square	PP—Fisher chi-square	Conclusion
ln*a*	−3.61788*** (0.00)	0.34256 (0.63)	−2.18156** (0.01)	82.1583** (0.03)	191.778*** (0.00)	Stable
ln*a*2	−3.61788*** (0.00)	0.34256 (0.63)	−2.18156** (0.01)	82.1583** (0.03)	191.778*** (0.00)	Stable
lngdp	−5.04779*** (0.00)	– –	– –	75.8485* (0.08)	75.1175* (0.09)	Stable
lnRAD	−1.61901* (0.05)	−0.6509 (0.26)	−0.5352 (0.29)	74.9826* (0.09)	157.253*** (0.00)	Stable
lneor	−10.1386*** (0.00)	–	−1.80538** (0.03)	75.183* (0.08)	117.903*** (0.00)	Stable
lnpop	−3.08242*** (0.00)	–	1.73366 (0.95)	66.2399 (0.27)	83.733** (0.02)	Stable
lnbenefit	−3.89687*** (0.00)	1.00744 (0.84)	−2.25404** (0.01)	85.9208** (0.01)	217.812*** (0.00)	Stable
lnpayment	−9.94471*** (0.00)	– –	−4.92064*** (0.00)	127.380***(0.00)	251.624*** (0.00)	Stable

The brackets are the value for *p*

***; **; * indicate the significance test at 1%, 5%, 10% level, respectively

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