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A study of provincial differences in China's eco-compensation framework

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Abstract: In this study, we developed a theoretical framework to analyze the provincial differences in eco-compensation and selected appropriate measurement methods to investigate these differences in the operation of the eco-compensation framework. Via the use of the coefficient of variation, Atkinson index, and Gini coefficient, we investigated the overall differences in Chinese provincial eco-compensation time series data from 2004 to 2014 and studied the driving mechanism underlying these differences. The results showed that: (1) The provincial eco-compensation standard has geographical features. For example, the provinces crossed by the "HU Huanyong Line", or located to its northwestern side, have obtained extensive eco-compensation. (2) There was a trend for differences in eco-compensation to increase over time, but with some fluctuations in 2006, 2009, and 2014 as shown by the coefficient of variation, in 2005, 2007, 2011, 2013, and 2014 as shown by the Gini coefficient, and in 2007, 2008, 2011, and 2012 as shown by the Atkinson index. (3) Time series curves indicated that while the signals from the three metrics (coefficient of variation, Atkinson index, and Gini coefficient) differ in a short-term analysis, they show the same tendency in the longer term. The results indicate that it is necessary to evaluate the differences in eco-compensation at the provincial level over a long period of time. (4) Via the calculation of the virtual Gini coefficient, we found that among the factors that influence provincial differences in eco-compensation, the economic value of eco-resources played the decisive role, explaining more than 73% of the difference. The cost of environmental pollution abatement was the second most important factor, accounting for more than 19% of the difference. The input to environmental pollution abatement had the least influence, accounting for less than 8% of the difference. The results agreed with those obtained from other studies, and could be used as a reference by policy makers.

Keywords: provincial eco-compensation; difference; measure; China

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1 Introduction

Eco-compensation is an important issue for ecologists, resource scholars, geographers, and government managers in China and overseas (SDSRG, ACCA, 2007; ACCA, 2012; Xie *et al*., 2015; Liu *et al*., 2016). There have been many studies of eco-compensation schemes and their differences (Salzman *et al*., 2000; Boyd *et al*., 2007; Wünscher *et al*., 2008; Yang *et al*., 2007; Qin *et al*., 2007; Yuan *et al*., 2014; Liu *et al*., 2015). Outside of China, eco-compensation is referred to as payment for ecosystem services (PES) or payment for ecological benefits (PEB). International studies of differences in eco-compensation have focused on the aspects of natural environment eco-compensation, the spatio-temporal distribution of eco-compensation, and human and economic eco- compensation. Studies of differences in natural environment eco-compensation frameworks are at an early stage overseas, and have mostly focused on plant tolerance to herbivory and its eco-compensation. For example, the differences in the eco-compensation provided for plants damaged from herbivores have been considered (Strauss *et al*., 1999), as has the impact of herbivory on different plants used as natural resources, and a comparison of the problems inherent in eco-compensation has been attempted (Hawkes *et al*., 2001). The spatial and temporal distribution of eco-compensation is an important research focus. For example, modeling procedures have been used to design compensation payments for the efficient spatio-temporal allocation of species protection measures (Johst *et al*., 2002), and spatially uniform versus spatially heterogeneous compensation payments have been considered for biodiversity-enhancing land-use measures (Wätzold *et al*., 2005). Human and economic eco-compensation and the differences between each framework have been an important focus of international studies in recent years. Such studies have considered the institutional dimensions of payments for ecosystem services (Corbera *et al*., 2009), eco-compensation scope and equity implications (Börner *et al*., 2010; Wunder *et al*., 2008), and payments for ecosystem services as commodity fetishism and the differences in such payments (Kosoy *et al*., 2010).

In China, studies of the differences in eco-compensation schemes have mainly focused on differences in the eco-compensation standard, stakeholders, and the type and mechanism of compensation. Some studies of the differences in eco-compensation standards have been based on questionnaire surveys of the willingness to pay for eco-compensation (Li *et al*., 2011; Yang *et al*., 2012), method modeling (Zhang *et al*., 2010; Ma *et al*., 2012), and related comparative studies (Xiong *et al*., 2004; Chen, 2011). There are large differences in the various eco-compensation standards in use worldwide. For the same objective, if different measures are adopted, there are different standards in use. Studies of the differences in types of eco-compensation have mostly focused on river basin eco-compensation (Ruan *et al*., 2008), forest eco-compensation (Li *et al*., 2007), and regional eco-compensation (Li *et al*., 2009; Xu *et al*., 2015). Studies of the differences in eco-compensation mechanisms have referred to the type of eco-compensation mechanism (Jiang, 2010), and have subdivided the type of eco-compensation, as well as designing plans to implement the various schemes (Huang *et al*., 2010). Studies of the differences in the subjects of interest in specific eco-compensation schemes have involved detailed comparisons of these subjects (Li *et al*., 2011), and the spatial selection of eco-compensation objectives (Dai, 2010). Moreover, many researchers have undertaken comprehensive analyses of these problems, and compared the differences between schemes.

Provincial differences in eco-compensation are an important aspect of eco-compensation, and are closely related to regional development and ecological construction (Zhao *et al*., 2010; Ding *et al*., 2012; Wu *et al*., 2003). In China, it is necessary and feasible to conduct investigations of provincial eco-compensation. Provincial eco-compensation (inter-regional eco-compensation) can not only advance the coordinated development of regional economies (Hu *et al*., 2007; Wang *et al*., 2010), but also promote eco-environmental protection during regional development (Ding *et al*., 2008). At the same time, to solve the development issues in various types of restricted and forbidden development zones in the main functional areas of China, we need to promote regional eco-compensation at different scales (Ding *et al*., 2012). Regional eco-compensation is critical at state level. There have been quantitative studies of provincial eco-compensation based on economics, ecological value equivalents, and other related factors (Song *et al*., 2010; Jin, 2009; Cai *et al*., 2005; Liu *et al*., 2014; Wang *et al*., 2011; Wu *et al*., 2013). In practice, it is feasible to conduct provincial eco-compensation in China. The government action pattern (An *et al*., 2012), market model, and non-governmental organization (NGO) model, have been used in some locations, and will be used in Chinese provincial eco-compensation in the future (TFEMP, CCICED, 2007; Gong, 2011; Liu G *et al*., 2013). For example, in upstream areas of the Zhanghe River, Shanxi, Hebei, and Henan had conducted trans-provincial water rights transfer compensation. Another example is located in the Dongjiang riverhead area, where Jiangxi and Guangdong have also conducted water rights transfer compensation. Beijing and Hebei have also conducted trans-provincial eco-compensation projects (Gong, 2011; Liu G *et al*., 2013; Huang, 2012).

In recent years, China has made huge achievements in provincial eco-compensation, both in theory and in practice (Task Force on Eco-compensation Mechanisms and Policies, CCICED, 2007; Gong, 2011; Liu G *et al*., 2013). However, at the same time, differences in provincial eco-compensation frameworks have become apparent (Gong, 2011; Liu G *et al*., 2013; Kong, 2010; Li *et al*., 2010; Ding *et al*., 2010). Differences in eco-compensation frameworks are apparent not only at the national level, but also at the provincial or inter-regional levels, and these differences have become important issues for researchers and the public. When we study the issue of differences in Chinese provincial eco-compensation framework, we must first establish how to measure such differences and their changes. There have been few systematic studies that have measured provincial differences in eco-compensation, with most undertaking theoretical research of the theoretical framework, and compensation standards, mechanisms and types, using case studies. Studies of provincial differences in eco-compensation at the macro-scale are limited.

In this study, we investigated the theoretical framework and used various measurement methods to determine provincial differences in eco-compensation in China. We also analyzed the spatial differences in provincial eco-compensation, and considered differences in provincial eco-compensation over long time periods, including the differences in the detail and driving mechanisms of provincial eco-compensation. The conclusions can be used to improve theoretical studies of eco-compensation. At the same time, from a practical perspective, because of regional differences in China, one type of compensation may be unreasonable for application in other regions or by different bodies. The conclusions can be used to enable government to formulate a regionally related eco-compensation policy, enabling different zones to understand their own status in the national eco-compensation framework, and for establishing a national control on eco-compensation schemes.

2 Principles and methods

2.1 Theoretical framework

In China and overseas, studies have been undertaken to measure the quantity of eco-compensation. In this study, from the geographical perspective of scale relevance and scale transition, and with reference to existing methods of measuring regional differences, we propose a theoretical framework and measurement method to investigate provincial differences in eco-compensation.

2.1.1 Mechanism used to analyze provincial eco-compensation

In consideration of existing eco-compensation research (Pagiola *et al*., 2005, 2007), and from a geographical perspective of scale relevance and scale transition, we described the logical framework of provincial eco-compensation in China (Figure 1a). When a region's "quantity of pollutants discharged (converted to the corresponding cost of pollution abatement)" is subtracted from the "eco-resources value", and then added to the "economic input of pollution abatement", a positive value [i.e., eco-resources value – quantity of pollutant discharged (converted to the corresponding cost of pollution abatement) + the economic input of pollution abatement) >0] means the region makes a positive contribution to the ecological construction of the whole nation (Liu *et al*., 2014; Zhang *et al*., 2015).

2.1.2 Mechanism used to analyze differences in provincial eco-compensation

In general, there are large differences in eco-compensation standards and the spatial and temporal distribution of eco-compensation between different regions. This is due to differences in the value of regional ecological resources, regional pollution control inputs, and regional pollution emissions, in combination with differences in national regulations and regional self-development (Figure 1b). Studies of these regional differences have been a key focus of geographers. Attempts have been made to determine the actual differences, how large they are, what factors cause them, and what the trends are in the development of regional differences (Liu W *et al*., 2013b). To measure provincial differences in eco-compensation, we used related research findings regarding regional differences as a reference (Liu W *et al*., 2013; Long, 1999; Kim *et al*., 2001; Guang, 2001; Jonathan *et al*., 2002; Liu, 2006; Liu W *et al*., 2013b). We focused on the key issues of the formation mechanisms of provincial differences in eco-compensation, regional differences at different spatial scales, changes in regional differences over a time series, and an analysis and comparison of the detailed differences (Figure 1c).

2.2 Calculation methods

2.2.1 Calculation of a provincial eco-compensation standard

The calculation of an eco-compensation standard is the basis of a provincial eco-compensation standard scheme. According to the mechanism of analysis of provincial eco-compensation presented in Figure 1, to calculate a provincial eco-compensation standard, we used the following frameworks: (1) measure an ecological value equivalent, (2) account for

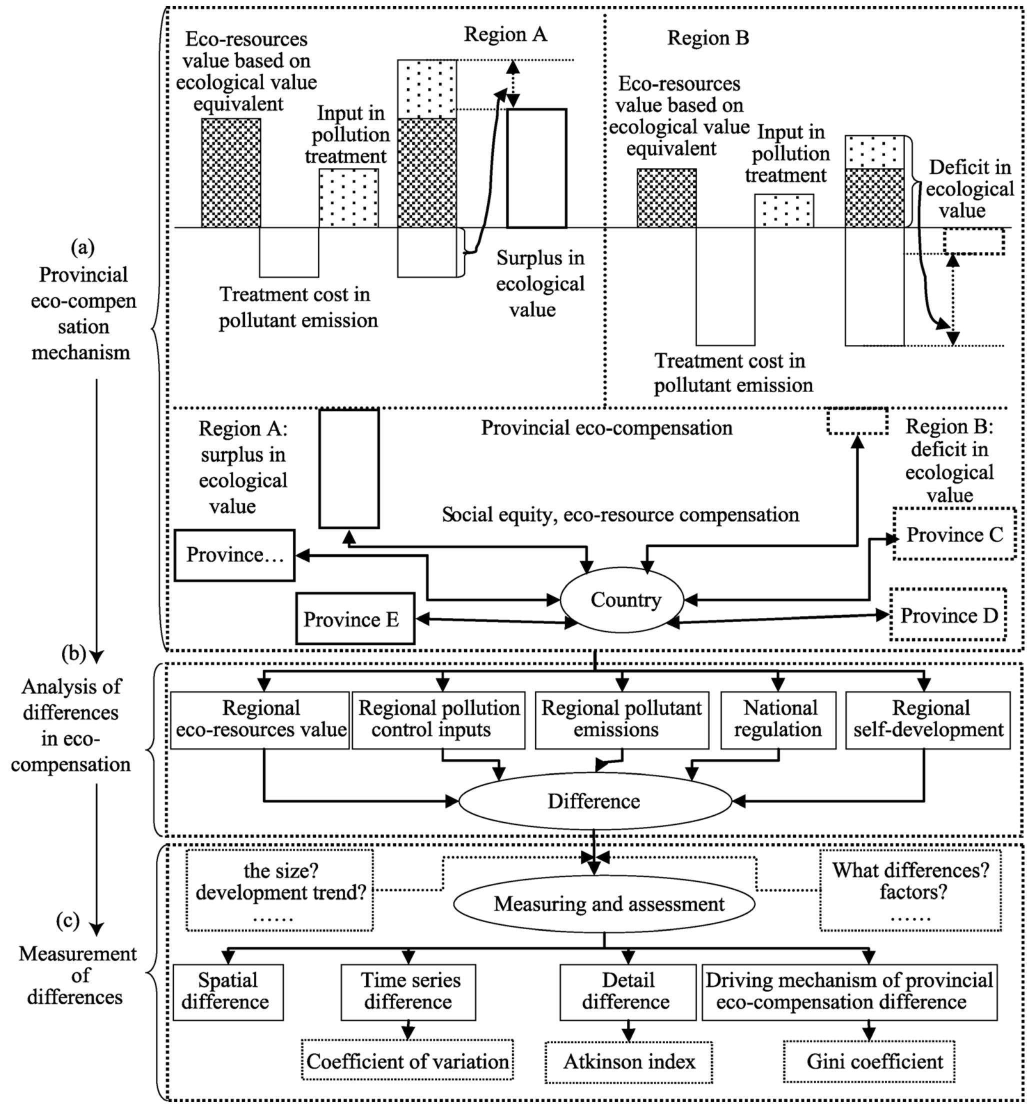

Figure 1 Logical framework of provincial eco-compensation and an analysis of its differences

ecological value based on the ecological value equivalent, and (3) calculate the ecological economic surplus value (provincial eco-compensation standard) (Liu *et al*., 2014).

(1) Measuring an ecological value equivalent

Based on the concept of normalization, we considered the ecological value of a forest ecosystem as a reference, and consulted related published research (Xie *et al*., 2008), to obtain an ecological value equivalent scale for different ecosystems. The ecological value equivalent of forest was set to 1, and then grassland was 0.42, farmland was 0.28, wetland was 1.95, rivers and lakes were 1.61, and desert was 0.05.

(2) Accounting for ecological value based on the ecological value equivalent

The provincial ecological value equivalent was calculated using Eq.1:

$$Q=S_F\times F_E+S_G\times G_E+S_C\times C_E+S_W\times W_E+S_D\times D_E+S_R\times R_E \quad (1)$$

where Q is the total ecological value equivalent, S is ecosystem area, E is the ecological value equivalent of the ecosystem, F is the ecological value equivalent of forest, G is the ecological value equivalent of grassland, C is the ecological value equivalent of farmland, W is the ecological value equivalent of wetland, D is the ecological value equivalent of desert, and R is the ecological value equivalent of rivers and lakes. For example, S_F represents forest ecosystem area and F_E represents the ecological value equivalent of a forest ecosystem.

Provincial ecological value was calculated using Eq.2:

$$H=Q\times U\times \lambda \tag{2}$$

where H is the economic value (yuan) of ecological resource of a region, Q is the total ecological value equivalent, U is the economic value of a unit of ecological value equivalent, and λ is a coefficient (the coefficient is a positive number, which is a scenario adjustment and amends the economic value of a unit ecological value equivalent; in this study, $\lambda = 1$). According to Xie Gaodi *et al*. (2008), in 2007 in China, the economic value of a unit ecological value equivalent was 449.1 yuan/ha. Based on changes in the Chinese agricultural production price index, we calculated the economic value of a unit ecological value equivalent over the subsequent years in China. We assumed that there was little difference in the average price of agricultural production among provinces, which, due to the large amount of subsidy in agricultural production and agricultural machinery in China, was considered reasonable. For each province it was possible to obtain the mean economic value of a unit ecological value equivalent, and then obtain an overall mean value. For example, in 2011, the mean economic value of the unit ecological value equivalent for each province in China was 603.3 yuan/hm^2.

(3) Calculating the ecological economic surplus value (provincial eco-compensation standard)

The ecological economic surplus value was calculated using Eq. 3:

$$Y = H + I - \sum(T_K\times V_K) \tag{3}$$

where H is the economic value of regional ecological resources, I is the input in pollution treatment, T is the total amount of pollution discharged, V is the economic input for treating a unit of pollution discharged, and K = 1, 2, 3 is the treatment of waste water, flue gas, and solid waste, respectively

2.2.2 Different methods for analyzing provincial eco-compensation

By referring to the existing methods of measuring regional differences (Liu, 2006; Liu W *et al*., 2013; Zhang *et al*., 2011; Chen, 2009; Athar *et al*., 1994), we applied the three metrics of the coefficient of variation, Atkinson index, and Gini coefficient to analyze the time series, details, and driving mechanisms of provincial differences in eco-compensation in China.

(1) Analysis of a time series of provincial differences in eco-compensation

To analyze a time series of provincial differences in eco-compensation, we used the coefficient of variation to compare the differences between years. In view of the population size, we used a weighting function to calculate each year's coefficient of variation. The computation was made using Eq. 4 (Liu, 2006):

$$CV = \sqrt{\sum_{i=1}^{n}(y_i - EC_u)^2 / q_i / EC_u} \tag{4}$$

where y_i (i = 1, 2, 3, …, n) is the per capita eco-compensation standard, EC_u is the average per capita eco-compensation standard throughout the country, n is the number of regions, and q_i is the proportional population of area *i* to the country as a whole.

(2) Analysis of the details of provincial differences in eco-compensation

The Atkinson index can identify the external visibility of regional differences in eco-compensation by establishing different parameters. If the regional differences within an area are small, and these changes cannot be observed by other methods, but we need to analyze them, we can use the Atkinson index method (Liu, 2006). To analyze and compare the details of provincial differences in eco-compensation, we used the Atkinson index method as given in Eq. 5 (Liu, 2006; Yuen, 1991):

$$I = 1 - [\sum_i (y_i/EC_u)^{1-\varepsilon} q_i]^{1/(1-\varepsilon)} \tag{5}$$

where y_i (i = 1, 2, 3, ⋯, n) is the per capita eco-compensation standard, EC_u is the average per capita eco-compensation standard throughout the country, q_i is the proportional population of area *i* to the country as a whole, and ε is a parameter related to imbalances in the external visibility of regional eco-compensation. If ε = 2, the imbalance in external visibility is moderate (Liu, 2006; Yuen, 1991). In this study, ε = 2.

(3) Analysis of the driving mechanism of provincial differences in eco-compensation

For the driving mechanism of provincial differences in eco-compensation we determined the factors influencing the extent of the differences. The Gini coefficient can be used to measure this. It was calculated using Eq. 6:

$$G = \left[\sum_{i=1}^{n} \sum_{j=1}^{n} | y_j - y_i | q_i q_j \right] / 2EC_u \tag{6}$$

where y_i (or y_j) (i, j = 1, 2, 3, ⋯, n) is the per capita eco-compensation standard in area *i* (or area *j*), EC_u is the average value of the total compensation standard, *n* is the number of regions, and q_i (or q_j) is the proportional population of area *i* (or area *j*) to the country as a whole.

The biggest advantage of using the Gini coefficient is that it can resolve the total difference into factorial differences, and then analyze the influence of the different factors on the total difference:

$$G = (EC_{u1}/EC_u)G^*_1 + \cdots + (EC_{uk}/EC_u)\, G^*_k \tag{7}$$

where EC_u is the average value of the total compensation standard, EC_{uk} is the average value of factor *k*, and G^*_k is the virtual Gini coefficient of factor *k*.

The virtual Gini coefficient is not the general Gini coefficient, but is calculated from Eq. 8. The virtual Gini coefficient can be a positive or negative number (Chen, 2009):

$$G^*_k = [\mathrm{cov}(y_k, F(y))] / [\mathrm{cov}(y_k, F(y_k))] \times [2\mathrm{cov}(y_k, F(y_k)) / EC_u] \tag{8}$$

To calculate the virtual Gini coefficient (Jonathan *et al*., 2002), we first ranked each province's eco-compensation standard and the data for each factor, $y_1 \leqslant y_2 \leqslant \cdots \leqslant y_n$. In Eq. 8, $\mathrm{cov}(y_k, F(y))$ is the index of correlation of factor *k* with the total eco-compensation's rank data, $\mathrm{cov}(y_k, F(y_k))$ is the index of correlation of factor *k* with factor *k*'s rank data, and EC_u is the average value of the total compensation standard.

S_k, the contribution of factor *k* to the total difference, was calculated using Eq. 9:

$$S_k = (EC_{uk} / EC_u) \times (G^*_k / G) \tag{9}$$

The contribution of factor *k* to the total difference in eco-compensation not only depends on the value of factor *k*, but also depends on the value of the factor *k* Gini coefficient as a proportion of the total Gini coefficient (Liu, 2006).

3 An empirical study of the provincial differences in eco-compensation in China

3.1 Data sources

For each province, we obtained the area of forest, grassland, farmland, wetland, rivers and lakes, and deserts, and related socio-economic data information. The main data sources we consulted were the *China Statistical Yearbook* (2005–2015) and *China Environment Statistical Yearbook* (2005–2015).

3.2 Calculation of the provincial eco-compensation standard

From 2004 to 2014, the overall condition of China's provincial eco-compensation standard did not change (Figure 2). The eco-compensation standards of developed provinces, such as Beijing, Shanghai, Guangdong, Tianjin, and Jiangsu, were negative, which means the development of these provinces had consumed the eco-resources of other regions. Therefore, the developed provinces should pay eco-compensation. The eco-compensation standards of developing provinces, such as Tibet, Qinghai, Xinjiang, Ningxia, Gansu, Yunnan, Guangxi, Inner Mongolia, and Heilongjiang, were positive, which means they should receive eco-compensation. In general, Inner Mongolia, Tibet, and Xinjiang were always the type of provinces that should receive eco-compensation, while Shanghai, Beijing, and other developed provinces were always the type of provinces that should pay eco-compensation.

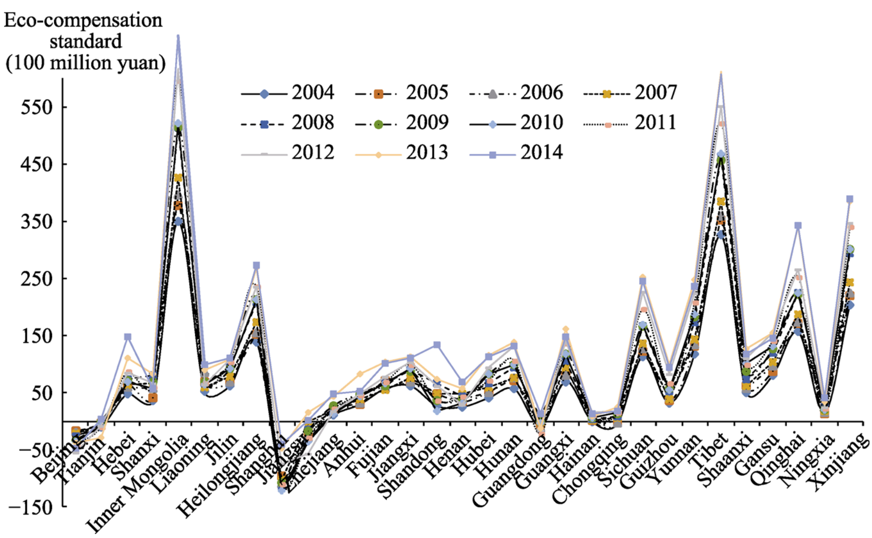

Figure 2 The value of the eco-compensation standard of each province in China from 2004 to 2014
Note: This study did not calculate the eco-compensation standard of Hong Kong, Macao, and Taiwan

To verify the authenticity of the calculated provincial eco-compensation standard we calculated the eco-compensation standard as a proportion of GDP to obtain a per capita eco-compensation standard (Tables 1 and 2).

The results indicated that the eco-compensation standard as a proportion of GDP and the per capita eco-compensation standard were realistic values. Tibet had the largest eco-compensation standard as a proportion of GDP, followed by Qinghai, Xinjiang, Inner Mongolia, Gansu, Yunnan, Heilongjiang, Guangxi, Guizhou, and Ningxia. The eco-compensation standard as a proportion of GDP was the smallest for Guangdong, followed by Jiangsu, Zhejiang, Shandong, Tianjin, Chongqing, Henan, Anhui, Beijing and Liaoning. From the perspective of a per capita eco-compensation standard, of the provinces that should receive compensation, Tibet had the largest eco-compensation standard and Shandong had the smallest. Of the provinces that should pay eco-compensation, Shanghai had the largest standard, followed by Beijing, Tianjin, Jiangsu, and Guangdong. These results are comparable with those of other studies (Song *et al*., 2010; Jin, 2009).

Table 1 The eco-compensation standard as a proportion (%) of GDP for each province in China from 2004 to 2014

Province	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Beijing	0.39	0.24	0.23	0.23	0.23	0.27	0.25	0.25	0.31	0.19	0.22
Tianjin	0.31	0.06	0.12	0.10	0.08	0.02	0.09	0.08	0.07	0.20	0.02
Hebei	0.57	0.64	0.51	0.48	0.46	0.41	0.33	0.36	0.32	0.39	0.50
Shanxi	0.99	0.96	1.17	1.12	1.11	0.94	0.61	0.54	0.55	0.65	0.45
Inner Mongolia	11.49	9.64	8.03	6.62	6.04	5.28	4.46	4.15	3.88	4.00	3.80
Liaoning	0.78	0.86	0.92	0.54	0.49	0.45	0.35	0.30	0.26	0.33	0.35
Jilin	2.02	1.90	1.61	1.48	1.47	1.27	1.06	0.97	0.91	0.83	0.81
Heilongjiang	2.91	2.74	2.49	2.44	2.52	2.49	2.04	1.87	1.72	1.87	1.82
Shanghai	1.34	1.02	1.04	0.83	0.81	0.71	0.71	0.57	0.37	0.21	0.17
Jiangsu	0.21	0.10	0.13	0.00	0.04	0.05	0.09	0.06	0.10	0.03	0.00
Zhejiang	0.09	0.15	0.14	0.11	0.09	0.12	0.05	0.07	0.05	0.11	0.12
Anhui	0.60	0.56	0.50	0.53	0.53	0.47	0.34	0.30	0.28	0.43	0.26
Fujian	0.94	1.10	0.76	0.59	0.61	0.51	0.45	0.39	0.40	0.48	0.43
Jiangxi	1.79	1.72	1.44	1.31	1.27	1.15	0.96	0.84	0.81	0.79	0.70
Shandong	0.17	0.26	0.20	0.19	0.21	0.11	0.05	0.08	0.12	0.14	0.22
Henan	0.30	0.33	0.30	0.32	0.25	0.20	0.14	0.17	0.10	0.18	0.20
Hubei	0.72	0.77	0.67	0.63	0.59	0.64	0.52	0.36	0.43	0.47	0.41
Hunan	1.01	1.07	0.99	0.82	0.83	0.75	0.62	0.54	0.60	0.56	0.49
Guangdong	0.04	0.02	0.04	0.00	0.02	0.00	0.01	0.04	0.02	0.02	0.02
Guangxi	2.03	1.99	1.68	1.61	1.53	1.53	1.24	1.16	1.07	1.13	0.95
Hainan	0.05	0.14	0.31	0.19	0.30	0.34	0.28	0.40	0.51	0.30	0.38
Chongqing	0.13	0.06	0.07	0.15	0.14	0.19	0.20	0.15	0.15	0.20	0.13
Sichuan	1.78	1.64	1.45	1.29	1.31	1.18	0.98	0.93	0.95	0.96	0.86
Guizhou	1.87	1.84	1.76	1.34	1.49	1.47	1.20	1.16	1.20	1.24	1.03
Yunnan	3.83	3.77	3.37	3.01	3.06	2.96	2.61	2.33	2.18	2.11	1.84
Tibet	147.62	140.27	122.96	112.86	117.39	103.26	92.37	86.18	78.54	75.70	65.81
Shaanxi	1.74	1.67	1.25	1.06	1.02	1.08	1.01	0.80	0.76	0.80	0.67
Gansu	4.77	4.56	4.23	3.87	3.79	3.75	3.21	2.81	2.74	2.46	2.13
Qinghai	33.65	31.28	26.66	23.34	22.01	20.45	16.68	15.10	14.02	16.20	14.89
Ningxia	3.09	2.09	2.17	1.83	2.03	1.47	1.18	1.05	1.08	1.32	1.46
Xinjiang	9.02	8.36	7.35	6.90	7.02	7.05	5.54	5.13	4.62	4.60	4.19

Table 2 The per capita eco-compensation standard for each province in China from 2004 to 2014 (yuan)

Province	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Beijing	–158.20	–110.27	–117.86	–133.00	–142.24	–179.19	–182.87	–199.46	–265.78	–179.53	–213.76
Tianjin	–93.07	–19.94	–50.70	–45.56	–47.79	–10.42	–61.20	–65.39	–60.74	–191.86	20.69
Hebei	71.39	94.67	85.45	93.49	105.75	100.10	94.80	121.93	116.62	152.27	200.63
Shanxi	106.27	120.75	168.53	199.68	238.70	200.79	157.44	168.19	185.00	227.01	157.11
Inner Mongolia	1459.67	1566.38	1643.48	1750.93	2100.86	2090.76	2108.05	2402.22	2472.26	2695.39	2692.56
Liaoning	123.78	163.52	199.84	139.16	155.85	157.29	146.58	152.45	148.16	202.41	225.64
Jilin	232.41	253.17	252.59	286.41	344.77	336.46	335.78	374.57	393.13	391.56	405.06
Heilongjiang	361.75	396.07	405.47	453.92	546.90	557.97	552.70	614.50	614.48	702.84	712.29
Shanghai	–543.32	–500.63	–560.69	–502.81	–529.61	–484.25	–526.53	–462.42	–313.08	–191.09	–167.17
Jiangsu	–42.71	–24.88	–37.66	–1.49	–17.29	–22.93	–46.16	–36.32	–70.40	19.48	1.13
Zhejiang	20.89	39.05	44.85	39.50	37.26	52.58	26.47	39.78	32.44	77.65	85.50
Anhui	46.53	49.28	50.47	63.26	76.97	77.30	71.51	77.75	80.62	136.45	87.95
Fujian	161.07	202.61	160.64	151.25	182.14	171.63	180.07	183.98	209.71	274.42	269.20
Jiangxi	146.20	161.96	160.08	173.37	201.59	198.78	204.03	219.92	232.88	251.61	242.95
Shandong	29.35	53.04	47.70	51.02	70.05	38.93	19.24	38.55	64.30	76.00	135.63
Henan	26.04	37.00	40.24	50.64	47.10	40.52	34.56	47.46	31.74	53.51	64.48
Hubei	71.15	88.53	90.04	102.86	116.56	145.28	144.45	122.46	164.38	199.16	194.08
Hunan	85.37	111.08	119.77	121.13	149.50	153.22	150.96	160.51	199.77	205.66	196.89
Guangdong	–8.10	–4.51	–12.14	–0.37	5.61	–0.41	–2.80	–20.63	–13.25	–12.49	12.45
Guangxi	142.65	173.71	171.60	197.02	222.36	244.38	257.07	292.03	299.19	306.83	312.17
Hainan	4.40	15.70	39.00	28.52	52.81	64.70	65.36	115.85	165.13	106.52	147.27
Chongqing	–13.00	–6.86	–9.79	25.64	28.39	44.28	54.97	52.00	58.74	84.54	56.47
Sichuan	140.62	147.86	154.25	168.01	203.59	204.13	209.72	243.49	279.53	310.87	302.16
Guizhou	80.48	98.87	111.25	106.17	147.61	162.68	159.36	190.98	235.80	283.05	272.47
Yunnan	267.59	293.87	300.98	318.54	382.85	400.13	409.28	447.31	482.06	527.07	500.30
Tibet	11784.78	12584.29	12555.44	13333.22	15873.63	15396.28	15624.33	17231.68	17877.36	19594.46	19055.43
Shaanxi	136.10	166.42	152.85	165.26	199.70	236.71	272.64	267.81	292.16	340.13	313.91
Gansu	316.77	346.88	378.29	409.97	470.56	497.10	516.09	549.26	600.26	597.50	560.77
Qinghai	2910.02	3129.65	3154.38	3371.92	4047.11	3968.94	4000.71	4441.20	4633.86	5890.33	5877.77
Ningxia	281.97	214.93	261.26	275.41	394.66	317.60	315.17	346.48	389.62	515.76	608.41
Xinjiang	1033.77	1097.51	1092.24	1159.62	1377.57	1397.13	1377.89	1535.90	1553.15	1699.85	1689.18

3.3 Analysis of provincial differences in eco-compensation in China

3.3.1 Spatial differences

Seen from a geographic perspective (Figure 3), there is certain zonality in China's provincial eco-compensation. The "Hu Huanyong Line[1]" can be taken as a boundary. Most of the provinces that are pierced by the "Hu Huanyong Line" or are located to its northwest side

[1] The "Hu Huanyong Line" is indicated in Figure 3.

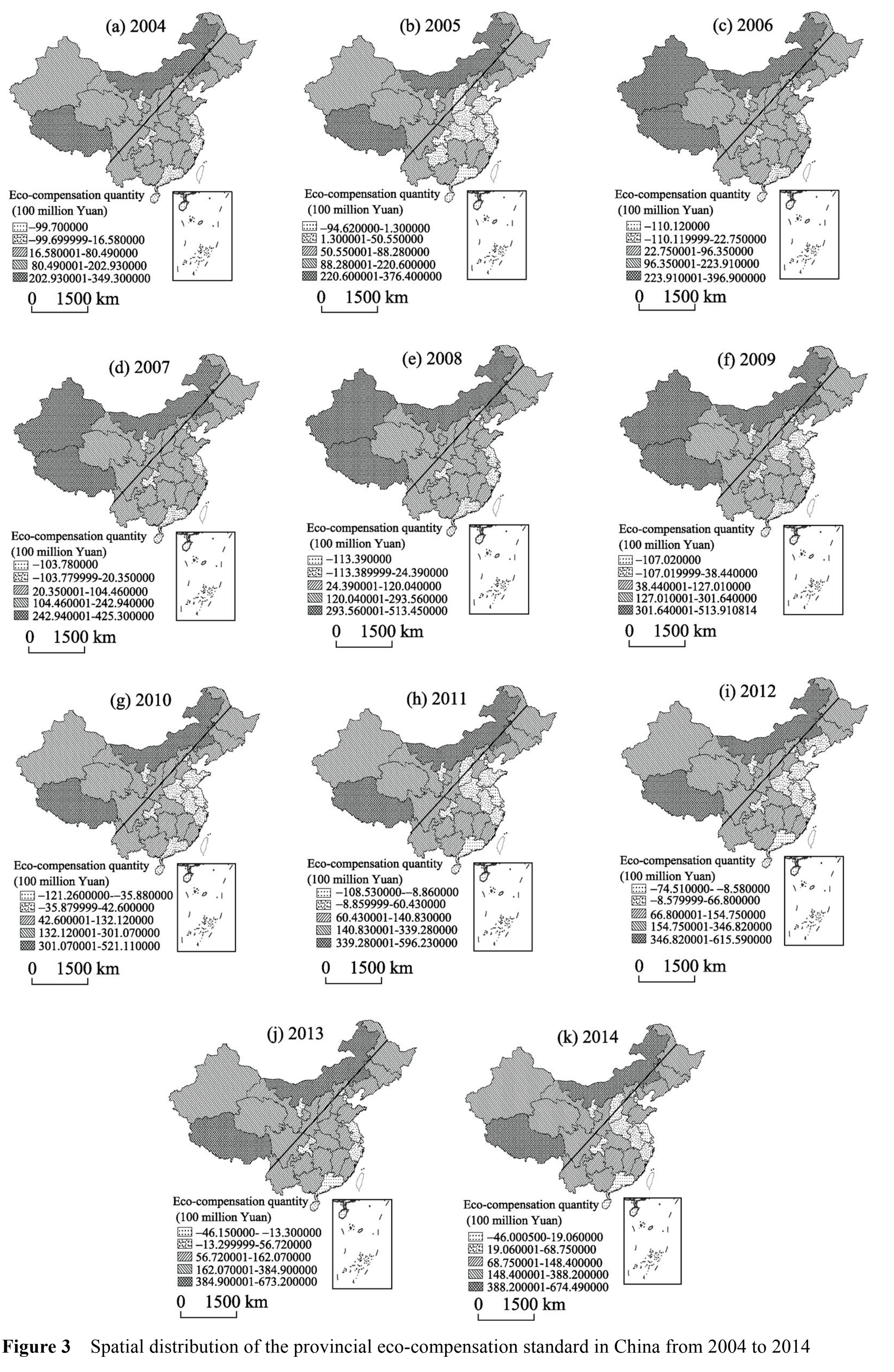

Figure 3 Spatial distribution of the provincial eco-compensation standard in China from 2004 to 2014

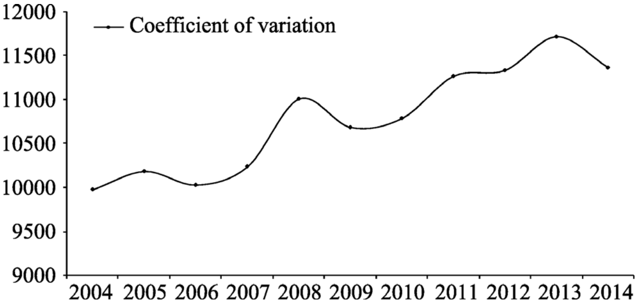

Figure 4 The coefficient of variation of provincial eco-compensation in China from 2004 to 2014

should receive eco-compensation (except Gansu and Ningxia[2]). The area southeast of the "Hu Huanyong Line" comprises about 43% of the country, and contains more than 90% of China's population and GDP. The southeast area functions as a high-density socio-economy. To the northwest of the "Hu Huanyong Line", there is a vast but sparsely populated territory, which functions as a developing economy and has a small population. The main priorities in this area are ecological restoration and protection.

3.3.2 Time series of provincial differences in eco-compensation

The coefficient of variation is a suitable parameter for analyzing variations in a time series (Liu W *et al.*, 2013b; Liu, 2006). By calculating the coefficient of variation for China's provincial eco-compensation from 2004 to 2014 (Figure 4), we found that in recent years the provincial differences in eco-compensation have tended to increase, with an annual average increase of 1.4%. However, there were fluctuations in 2006, 2009, and 2014 when the differences were not as large. The largest annual average value of the coefficient of variation was 7.5% in 2008, and the next largest values were 4.5% in 2011, 3.4% in 2013, and 2.1% in 2005 and 2007. In 2009 and 2014 the value was –3%, which was the largest reduction in the coefficient of variation, with the next largest being –1.5% in 2006.

3.3.3 Details of the provincial differences in eco-compensation

The Atkinson index is a suitable metric for analyzing the details (i.e., rate of increase or decrease) of the provincial differences in eco-compensation. It can be seen from Figure 5 that in recent years, the provincial differences in eco-compensation in China have increased, with an annual average rate of increase of 23.9%. In 2005, 2006, 2013, and 2014, the rate of increase was larger, at 284.8%, 105.3%, 254.4%, and 71.5%, respectively. In 2009 and 2010, the rate of increase was 7.7% and 5.7%, respectively. However, in 2007, 2008, 2011, and 2012 the rate of increase became negative at –56.2%, –7.1%, –48%, and –70.7%, respectively.

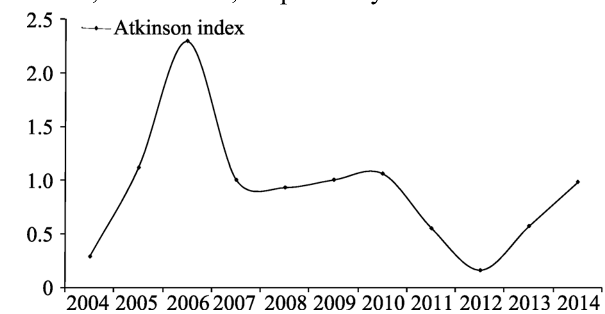

Figure 5 Atkinson index values of provincial differences in eco-compensation in China from 2004 to 2014

3.3.4 The driving mechanism of provincial differences in eco-compensation

In 2004–2014, the Gini coefficient of provincial differences in eco-compen-

[2] The eco-compensation standards of Gansu are increasing annually and are similar to those of Qinghai and Sichuan. The eco-compensation standard is small in Ningxia owing to its small area.

sation showed a tendency of increasing fluctuation (Figure 6). In most years, especially from 2004 to 2012, there was a tendency for fluctuations to increase, but in recent years this tendency has declined.

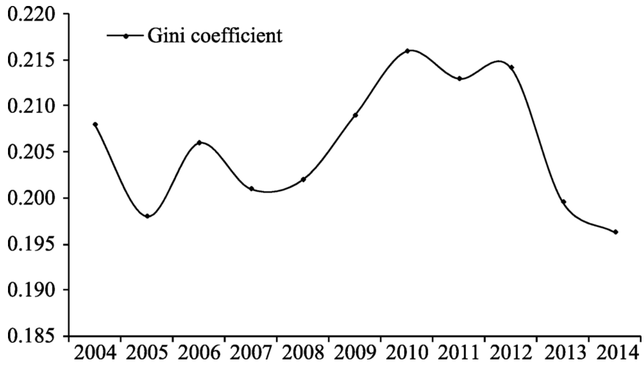

Figure 6 The Gini coefficient of provincial differences in eco-compensation in China from 2004 to 2014

By calculating the virtual Gini index, we can decompose the total provincial differences in eco-compensation into various factors that influence the difference. The contribution of the factors determined from the virtual Gini index of China's provincial eco-compensation in 2014 are shown in Table 3.

Table 3 Factors affecting the provincial differences in eco-compensation in China in 2014

Factor of influence	G* (virtual)	G (total)	S (factor contribution)
Eco-resources value	0.018	0.029	0.733
Economic input of pollution abatement	0.017		0.077
Cost of pollution abatement	0.018		0.190

It can be seen from Table 3 that the value of eco-resources played the decisive role in provincial differences in eco-compensation in China, with a proportional contribution of 73.3%. The next most important factor was the cost of pollution abatement, with a contribution of 19%. The economic input of pollution abatement had a minor role, with a contribution of less than 8%. Enhancing the value of provincial eco-resources and reducing pollution emissions are the main considerations when regulating provincial eco-compensation.

4 Conclusions and discussion

4.1 Research conclusions

(1) Inspired by the work of Pagiola and others with regard to eco-compensation, we described the logical framework of provincial eco-compensation in China, expounded the theoretical framework of measuring provincial differences in eco-compensation, and investigated the variation in a time series of these differences, the details of the differences, and the driving mechanism of provincial differences in eco-compensation in China.

(2) Using statistical data for the provinces of China from 2004 to 2014, we calculated a provincial eco-compensation standard, determined the eco-compensation standard as a proportion of GDP, and calculated a per capita eco-compensation standard. The results confirmed that the eco-compensation standard as a proportion of GDP and the per capita eco-compensation standard produced realistic values. Seen from a geographic perspective, most of the provinces that are pierced by the "Hu Huanyong Line" or are located to the northwest of the line should receive eco-compensation.

(3) We calculated the coefficient of variation, Atkinson index, and Gini coefficient of China's provincial eco-compensation. From 2004 to 2014, provincial differences in eco-compensation in China had a tendency to increase, but there were fluctuations in this trend in some years. The range of the Atkinson index was larger than that of the other two indices. The Atkinson index is suitable for analyzing the detailed differences in provincial eco-compensation.

(4) Among the curves produced to represent the whole time series there were differences in the peaks and troughs produced by the different methods. In the short-term, the analysis results indicated a lack of conformity in the degree of difference produced by each index. Over the long-term, the tendency for variation was similar among the three indices. When considering provincial differences in eco-compensation, we should obtain the long-term tendency for variation as a reference. The results obtained in this study were comparable with those obtained from other studies.

(5) By calculating the virtual Gini index it was found that the value of eco-resources played a decisive role in provincial differences in eco-compensation in China, accounting for 73.3% of the overall differences. The next most important factor was the cost of pollution abatement, which accounted for 19% of the differences. The economic input on pollution abatement had a minor role, accounting for just 7.7% of the differences. By enhancing the protection and establishment of forest, grassland, farmland, wetland, and river and lake eco-resources, and reducing waste water, atmospheric emissions, waste residues and other forms of pollution, provincial eco-compensation will be effectively regulated.

4.2 Limitations of this study

Due to data limitations this study just applied the methods of the coefficient of variation, Atkinson index, and Gini coefficient, and investigated the variation in a time series of these differences, the details of the differences, and the driving mechanism of provincial differences in eco-compensation in China. In practice, there are other methods that could have been applied, such as the Selma index and index system methods. Whether these methods are suitable to measure provincial differences in eco-compensation requires further investigation.

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