Study on Consistent Agricultural Compensation Standards for Ecosystem and Ecological Value

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Abstract: *Chinese and international studies on agricultural ecological compensation standards fall into two categories: While some focus on the cost of ecological protection, others proceed from the value of ecological services. Cost and value are two aspects of an integrated input-output system, but most existing studies on both types of compensation standards are independent of each other. Drawing upon the reasonable elements from both types of studies to overcome each other's one-sidedness, this paper has created a "model of consistent compensation standards for the ecosystem and ecological value," integrating the research approaches for both types of compensation standards under the same analytical framework. Through the application and analysis of this model, this paper has verified the model's theoretical and practical significance in correcting the one-sidedness of each type of research. The principles and methodologies for creating the model may be further extended to research on agricultural ecological compensation standards under different conditions. In some circumstances, the ability of relatively redundant resources to create ecological value is overlooked. To address this problem, this paper employs a linear programming (LP) sensitivity analysis instrument to correct the model's initial optimal solutions and arrive at consistent compensation standards that satisfy the consistency between ecosystem and ecological value, thus perfecting the theoretical and methodological system created by this paper for research on agricultural ecological compensation standards.*

Keywords: *agricultural ecological compensation standards, ecosystem, ecological value, consistency*

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1. Literature Review

There are two definitions of agricultural ecological compensation: First, "compensation for agricultural ecology", i.e., compensation for the repair of the agricultural ecosystem; second, "ecological compensation for agriculture", i.e., compensation for the ecological value of agriculture in improving human habitat that is not reflected in agriculture's actual economic value. With deepening research on ecological compensation, Chinese and international academics have developed increasingly clear-cut methodologies for determining ecological compensation standards as the linchpin of agricultural ecological compensation mechanisms. Corresponding to the two definitions of agricultural ecological compensation, those methodologies may also fall into two categories.

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1.1 Existing Studies on Both Types of Compensation Standards

(i) Estimation of ecological compensation standards based on the cost of ecological protection, also known as behavior-based ecological compensation standards, determines ecological compensation standards primarily based on the cost paid by agriculture for protecting the ecosystem. The basic idea behind this method is that the cost of environmental protection will improve the ecological environment and provide positive externalities of the ecological environment so that the accounting of such cost is an indirect estimation of such positive externalities. Many scholars have employed this methodology to estimate the compensation standards in various fields (Pham, 2009; Newton, 2012; Kosoy, 2007; Liu, 2006; Cai, 2008; Zhong, 2008; Zhang, 2011; Li, 2017; Dai, 2013; Gao, 2014; Liu, 2015; *et al.*). They have employed such methodologies as the direct cost method, opportunity cost method, among others.

(ii) Estimation of ecological compensation standards from the perspective of ecological service functions, also known as output-based ecological compensation standards. In relation to "ecological compensation for agriculture", i.e., compensation for agriculture's ecological value, this approach determines ecological compensation standards mainly based on the ecological functions and value offered by agriculture. Specific methods in this category include the ecosystem service value method (Landell Mills, 2002; Cesar, 2004; Pagiola, 2008; Zhang, 2015; Cao, 2016; Geng *et al.*, 2009; Shao, 2013), conditional value evaluation method (Loomis, 2004; Gong, 2011; Xu, 2012), selective test method (Li, 2018), carbon trading and carbon balance estimation method (Xu *et al.*, 2019; Peng, 2016; *et al.*).

1.2 Comments on the Two Types of Existing Studies

(i) The two types of estimation methods reflect the basic requirements and consensus on the determination of agricultural ecological compensation standards: First, those standards must reflect the cost for agricultural resources to create ecological value; second, they must also reflect the ecological value created by agricultural resources *per se*; from another perspective, they should reflect (1) "compensation for agricultural ecology" (i.e., compensation for the agricultural ecosystem) and (2) "ecological compensation for agriculture" (i.e., compensation for agriculture's ecological value).

(ii) The first type of method (i.e., based on the cost of ecological protection) is deeply flawed and extensively criticized by relevant studies. It is generally considered inappropriate to use the cost of environmental protection as an indirect account of the positive externalities from protecting the environment. On one hand, various inputs of ecological protection will neither equal to nor necessarily translate into the factors of the ecological environment; on the other, even if all the inputs of ecological protection are directly converted into ecological factors, the value of those inputs may not be consistent with the ecological value provided by the factors of ecological environment. Regarding the causes of such inconsistency, this paper believes that the theoretical basis for the agricultural ecosystem compensation underpinning this type of estimation methods is insufficient, and that the balanced compatibility of the agricultural ecosystem (or the degree of the scarcity or redundancy of each agricultural resource) under those methods is scantily related to the ability of each agricultural resource to create ecological value. As a result, the TFP-estimated compensation standards cannot reflect the marginal cost of ecological services provided by ecological resources.

(iii) The second type of method for estimating compensation standards (i.e., based on ecological value) - not least the ecosystem service value method - have gained currency over recent years. Despite the highly complex econometric estimation of the ecological functions of ecological resources and converting those functions into ecological value, relevant studies have accumulated extensive experience and developed sophisticated methodologies, which lay a solid foundation for subsequent research, including this paper. Furthermore, the core principle underpinning the conditional value estimation method and the selective test method is that "compensation standards should take into account the willingness of compensators to pay and the willingness of recipients to accept compensation", reflecting the non-market factors of compensation standards for adjusting compensation standards; the carbon trading and carbon balance method encompasses both positive and negative externalities of agricultural resources for the ecological environment and not just positive externalities alone. This approach may perfect the method for measuring the value of ecosystem services.

(iv) However, the second type of method (i.e., based on ecological value) also has drawbacks that are hard to overcome. Setting compensation standards solely based on the ecological value created by agricultural resources, this type of method overlooks the scarcity (or redundancy) of resources within a region, nor does it consider the heterogeneity of costs for various agricultural resources with the same ecological functions to create ecological value. Compensation following those methods, therefore, may create or intensify imbalances of regional agricultural resources, which runs counter to the requirement of compensating for the agricultural ecosystems. The problems of the second type of estimation method have seldom been discussed in relevant literature by Chinese and international academics and will be analyzed in a subsequent section of this paper through case studies.

(v) Cost and value are two aspects of the integrated input and output system for agricultural resources to create ecological value: "Compensation for agricultural ecology" and "ecological compensation for agriculture" are two basic aspects of "agricultural ecological compensation." The existing two types of studies are flawed because each only considers one aspect while overlooking the other.

In a nutshell, this paper will draw upon the rational elements and extensive experiences of both types of research to overcome their respective one-sidedness and create a "model of consistent compensation standards for the ecosystem and ecological value". This brand-new approach to the research on agricultural compensation standards will further perfect the system of theories and methodologies for agricultural ecological compensation.

2. Theoretical Basis for Creating a Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

Definition of agricultural ecological compensation is the premise for specifying the analytical model. The existing two types of research on compensation standards are flawed because of nebulous definitions of agricultural ecological compensation and the nature of compensation standards. Figure 1

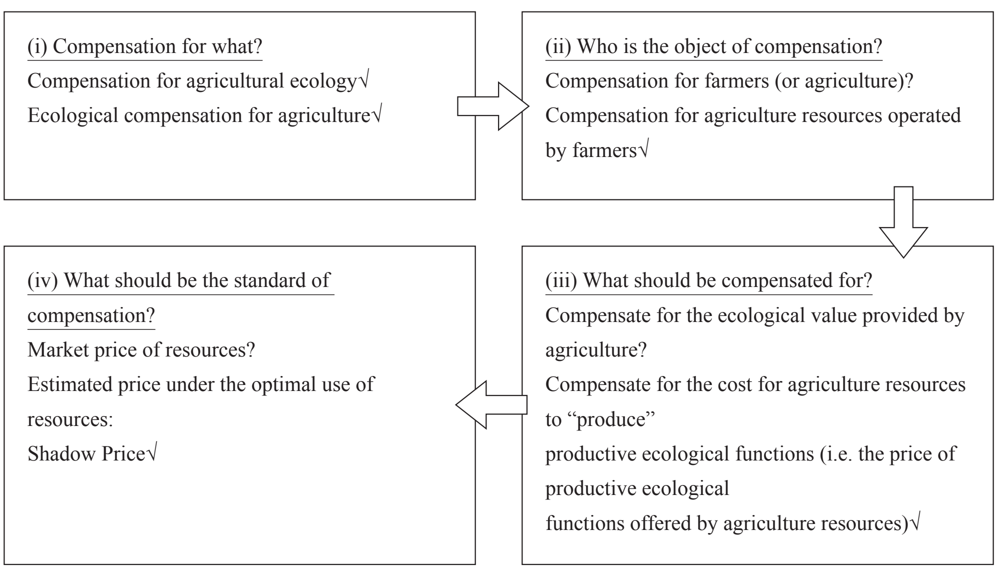

Figure 1: Reasoning behind the Definition of Agricultural Ecological Compensation

shows the reasoning behind our definition of agricultural ecological compensation and compensation standards.

2.1 Compensation for What?

There are two connotations of agricultural ecological compensation: One is “compensation for agricultural ecology”; the other is “ecological compensation for agriculture”. The existing two kinds of compensation standard research take one of each, considering one and losing the other. Combining both connotations and using “ecological compensation for agriculture” as the entry point, this paper creates the input-output linear programming (LP) duality problem model that essentially examines the scarcity of resources and is based on the balanced compatibility of regional resources, thus also taking into account “compensation for agricultural ecology”.

2.2 What Should Be the Object of Compensation?

Most of the existing two types of studies on compensation standards believed that farmers (or agriculture) should be the object of agricultural ecological compensation since farmers (or agriculture) have provided ecological value or paid a cost for protecting the ecosystem, which is not reflected in their actual economic interests. Notably, however, farmers (or agriculture) provide ecological functions or pay the cost by operating forest land, farmland, grassland and wetland resources and should be entitled to compensation based on each specific resource. In practice, agricultural ecological compensation is provided based on the hectares of forest land under management (or cultivation) rather than the number of farmers at the locality.

2.3 What to Compensate?

The second type of research on compensation standards (method for estimating the ecological value) follows a basic approach that the ecological value provided by farmers (or agriculture) should be compensated for because such value is not reflected in their actual economic value. However, the ecological value of agriculture comprises the value of myriad ecological functions, and the same ecological function could be provided by a multitude of agricultural resources at heterogeneous costs. This paper considers that agricultural ecological compensation should compensate for the cost or price of ecological functions *produced* by agricultural resources. While seemingly similar to the first type of research on compensation standards (based on the cost of ecological protection), our view is unlike most similar studies in the sense that “cost” here is closely linked to the ecological value created by agricultural resources via the *production* of ecological functions, representing two sides of the same coin.

2.4 What Should Be the Compensation Standards?

The ecological compensation standards of agricultural resources (i.e., the price of *producing* ecological functions) should equal the estimated price of resources in optimal use, which is not the market price of resources but the estimated value of resources based on their contribution to the *production* process. Hence, the “shadow price” should be adopted to reflect the marginal price of use under the conditions of optimal resource allocation and optimal resource structure.

Hence, this paper defines agricultural ecological compensation as “compensation for the cost paid by agricultural resources in *producing* ecological functions according to the marginal price of use of those resources under the condition of optimal resource allocation, i.e., the shadow price of ecological functions ‘produced’ by agricultural resources”.

On such a basis, the LP method as a mature method for solving shadow prices can be employed as the main approach for creating this paper’s analytical model. By creating an input-output matrix comprising the four agricultural resources and the ecological functions *produced* by them and

Table 1: Four Major Agricultural Resources and the Input-Output Matrix of Ecological Functions Produced by Them

	Ecological function x_1 (amount of oxygen released)	Ecological function x_2 (amount of carbon sequestration)	……	Ecological function x_n (absorption of precipitation water)	Resource inventory
Agricultural resource 1 (forest) y_1	a_{11}	a_{12}	……	a_{1n}	b_1
Agricultural resource 2 (farmland) y_2	a_{21}	a_{22}	……	a_{2n}	b_2
Agricultural resource 3 (grassland) y_3	a_{31}	a_{32}	……	a_{3n}	b_3
Agricultural resource 4 (wetland) y_4	a_{41}	a_{42}	……	a_{4n}	b_4
Price of ecological functions (ecological value)	p_1 (Cost of industrial oxygenation)	p_2 (Cost of afforestation for carbon sequestration)	……	P_n (Cost of each unit capacity of reservoir)	

introducing the column vector of resource inventory and the row vector of the prices of ecological functions, i.e., the value of various ecological functions (as shown in Table 1), we have constituted a standard LP problem, and the solution to the duality problem is the shadow prices of ecological functions *produced* by the four major agricultural resources, as shown in Figure 2.

The analytical model created based on the above theory is the "model of consistent compensation standards for the ecosystem and ecological value" referred to in this paper. This model helps unify two otherwise independent sets of compensation standards into one analytical framework.

(i) The shadow price of ecological functions *produced* by agricultural resources (ecological compensation standards for agricultural resources) estimated using this model and the estimation of ecological value created by agricultural resources have become two sides of the same coin, both of which are closely linked with each other, reflecting not only the "cost for agriculture to create ecological value", but the "ecological value created by agriculture" as well.

(ii) Based on the basic principle of solving shadow price through the LP duality problem, the shadow price of ecological functions *produced* by agricultural resources estimated using this model (i.e., ecological compensation standards for agricultural resources) is the marginal price of resource use under the condition of optimal resource allocation. Not only does it meet the requirement that "compensation standards must take into account the willingness of compensators to pay and the willingness of recipients to accept the compensation", but it also reflects more non-market factors that influence compensation standards.

(iii) The LP duality problem essentially examines the scarcity of resources, so this model is essentially a study based on the balanced compatibility of regional ecosystems, which unifies the "compensation for the agricultural ecosystem" and "compensation for agricultural ecological value".

3. Application and Verification of the Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

After estimating the ecological compensation standards for the four major agricultural resources (forest land, farmland, grassland, and wetland) in Beijing in 2011 and 2016 using the model of consistent compensation standards for the ecosystem and ecological value, we carry out an in-depth study in the

$$\max Z = \sum_{j=1}^{n} p_j x_j \quad s.t.\sum_{j=1}^{n} a_{ij} x_j \le b_i \quad x_j \ge 0$$

$$\Rightarrow$$

$$\min W = \sum_{i=1}^{4} b_i y_i \quad s.t.\sum_{i=1}^{4} a_{ij} y_i \ge p_j \quad y_i \ge 0$$

$$\Rightarrow$$

$$\begin{cases} y_1 = y_1^* \\ y_2 = y_2^* \\ y_3 = y_3^* \\ y_4 = y_4^* \end{cases}$$

Linear programming problem | Duality problem | Solution of duality problem: Shadow price

Figure 2: Relationship between Linear Programming Problem, Duality Problem and Shadow Price

Note: y_i in Table 1 and Figure 2 denotes the four major agricultural resources; x_j denotes ecological functions; a_{ij} denotes the amount of type i agricultural resources required for *producing* each unit of type j ecological function; p_j is the price of type j ecological function; b_i denotes the inventory of the four major agricultural resources in each region.

following aspects: First, examine the flaws of Beijing Municipality's original compensation policies, reveal the disequilibrium of Beijing Municipality's agricultural ecosystem, and demonstrate our model's contribution to the equilibrium of the agricultural ecosystem in Beijing Municipality. Second, the results of our estimation are employed to compare with the second type of research on compensation standards to reveal its drawbacks and validate the rationality of our model for correcting the one-sidedness of the second type of research on compensation standards. Lastly, the estimated results are employed to further analyze the connotation of "balanced compatibility of the agricultural ecosystems", reveal the drawbacks of the first type of research, and validate the rationality of our model for correcting the one-sidedness of the first type of research on compensation standards.

3.1 Estimation and Results of Ecological Compensation Standards for the Four Agricultural Resources in Beijing Using the Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

Table 2 displays the estimation and results of ecological compensation standards for the four agricultural resources in Beijing in 2011 and 2016, respectively, based on the model.

Table 2 shows the inventory b_i of the four major agricultural resources Y_i in Beijing Municipality in 2011 and 2016; the last column of Table 2 shows the price P_j of ecological function X_j; a_{ij} denotes the amount of type j agricultural resource required for *producing* type i ecological function with various values located at the intersection between the vertical coordinate X_j and the horizontal coordinate Y_i.

The linear planning problem can be solved with Excel:

$$\min W = \sum_{i=1}^{4} b_i y_i$$
$$s.t.\sum\nolimits_{i=1}^{4} a_{ij} y_i \ge p_j \ , \ y_i \ge 0$$

Results suggest that in 2011, the compensation standards for the four major agricultural resources in Beijing Municipality should be 8 yuan/hectare for forest land Y_1, 2,088 yuan/hectare for farmland Y_2, 1,150 yuan/hectare for grassland Y_3, and 39,548 yuan/hectare for wetland Y_4, and the total amount of compensation $\Sigma b_i Y_i$ should be 594,032,252 yuan; in 2016, the compensation standards for the four major agricultural resources in Beijing Municipality should be 1,668 yuan/hectare for forest land Y_1, 1,727 yuan/hectare for farmland Y_2, 994 yuan/hectare for grassland Y_3 and 39,548 yuan/hectare for wetland Y_4, and the total amount of compensation $\Sigma b_i Y_i$ should be 4,316,506,348 yuan.

Table 2: Estimation and Results of Ecological Compensation Standards for the Four Agricultural Resources in Beijing (2011, 2016)

		Forest land Y_1	Farmland Y_2	Grassland Y_3	Wetland Y_4	$\Sigma a_{ij} Y_i$ (yuan)		Price of ecological function P_j (yuan)
Ecological function / inventory b_i of resource (ha.)	2011 2016	**1,054,466** **1,089,534**	**223,700** **221,157**	**86,280** **85,139**	**496** **51,400**			
X_1 Amount of oxygen release (t)		0.12	0.06	0.22	0.47	19,076	≥	400
X_2 Amount of carbon sequestration (t)		0.31	0.15	0.59	1.26	51,035	≥	759.15
X_3 Amount of water retention (t)		0.0003	0.0010	0.0013		4	≥	1.63
X_4 Amount of water purification (t)		0.0004	0.0011			2.6	≥	2.6
X_5 Amount of nitrogen (N) removal from wetlands (t)					0.25126	9,937	≥	1,500
X_6 Amount of phosphorus (P) removal from wetlands (t)					0.53763	21,262	≥	2,500
X_7 Amount of flood storage by wetlands (t)					0.00004	1.63	≥	1.63
X_8 Amount of SO_2 absorption (t)		12.51	22.22	33.30		92,335	≥	600
X_9 Amount of NO_2 absorption (t)		17.00	30.20	45.26		125,496	≥	600
X_{10} Amount of HF absorption (t)		1,065.03	1,892.11	2,835.51		7,861,897	≥	900
X_{11} Amount of dust absorption (t)		0.07	1,079.27		6,267.55	249,732,433	≥	170
X_{12} Amount of solid wastes dissolved by grassland (t)				4.71		4,684	≥	4,684
X_{13} Retention of organic mass (t)		1.11	8.75			16,963	≥	320
X_{14} Retention of nitrogen (N) (t)		296.74	17.50	6.76		531,865	≥	17,143
X_{15} Retention of phosphorus (P) (t)		107.87	24.51	82.51		304,251	≥	15,989
X_{16} Retention of potassium (K) (t)		544.07	12.76	82.51		10,11,490	≥	4,400
X_{17} Avoidance of wasteland by forest land (ha.)		34.19				57,022	≥	264
X_{18} Avoidance of wasteland by farmland (ha.)			73.63			127,156	≥	1,343
X_{19} Avoidance of wasteland by grassland (ha.)				33.72		33,514	≥	246
X_{20} Retention of wetland soil (ha)					0.21	8,238	≥	5,198
X_{21} Reduction of sediment accumulation (m^3)		0.022	0.016	0.022		87	≥	1.63
X_{22} Protection of forest land biodiversity		1.79				2,978	≥	2,978
X_{23} Protection of grassland biodiversity				1		994	≥	314
X_{24} Protection of wetland biodiversity					1	39,548	≥	2,998
		≥0	≥0	≥0	≥0			
		Y_1	Y_2	Y_3	Y_4	$\Sigma b_i Y_i$		
Y_i compensation standards (yuan/ha.)	2011 2016	**8** **1,668**	**2,088** **1,727**	**1,150** **994**	**39,548** **39,548**	**594,032,252** **4,316,506,348**		

Source: Estimated based on the Statistical Yearbooks of Beijing Municipality.

3.2 In-Depth Research on the Estimated Results of the Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

3.2.1 Flaws of Beijing Municipality's original compensation policies

In August 2004, Beijing Municipality started to explore agricultural ecological compensation. Back then, Beijing Municipality's agricultural ecological compensation was limited to forest land while farmland, grassland and wetland were not entitled to any ecological compensation. Guided by such a compensation policy, Beijing Municipality saw a continuous increase in forest land resources while the other three types of agricultural resources were shrinking. As shown in Table 2, by 2011, the ratio between the four major agricultural resources in Beijing Municipality (forest land area : farmland area : grassland area : wetland area) was 2126:451:174:1, suggesting a severe imbalance of the agricultural ecosystem.

According to the estimated results of our model of consistent compensation standards for the ecosystem and ecological value (data in the bottom second row of Table 2), the scarcity of agricultural ecological resources in Beijing Municipality in 2011 can be ranked as follows: Wetland > grassland > farmland > forest land, so the compensation standards for wetland, grassland and farmland should be much higher than for forest land. Compensation standard for the scarcest wetland resources, in particular, should be 5,142.8 times higher than for forest land.

Over recent years, Beijing Municipality has taken an array of measures to restore and maintain the equilibrium of the agricultural ecosystem. In 2011, the total land area of wetlands in Beijing Municipality decreased sharply to 496 hectares. By 2016, the city's total wetland area reached 51,400 hectares, up 104 times over 2011. Based on the estimated results of Table 2, the scarcity of agricultural ecological resources in Beijing Municipality in 2016 can be ranked as follows: Wetland > farmland > forest land > grassland, and wetland remained the scarcest resource in Beijing Municipality and should be entitled to compensation 23.7 times higher than for forest land. Compared with 2011, Beijing Municipality saw an improvement in its ecosystem imbalance.

3.2.2 Comparison between the model-estimated results and the second type of compensation standards

Table 3 shows the ecological value created by each unit area of the four ecological resources in Beijing Municipality in 2011 and 2016 (item 4 in the table) and the total ecological value created by all those resources. Following the second type of research on compensation standards (estimation approach from an ecological value perspective), the numerical values corresponding to item (4) are the compensation standards for each resource; the numerical values corresponding to item (5) are the total compensation for all those resources.

Table 3 also reveals the model-estimated compensation standards for the four major agricultural resources and the total compensation for all those resources in Beijing Municipality in 2011 and 2016, respectively.

By comparing "the compensation standard measured by the model" with "the ecological value created per unit area", the results calculated by the model are far from the results calculated by the second type of compensation standard. The model-estimated wetland compensation standard for 2011 is 5,142.8 times that for forest land, but estimated with the ecological value created by each unit area of agricultural resources, the compensation standard for wetlands is 3.6 times that for forest land. Such difference stems from the fact that the model-estimated compensation standards take into account both the resource-created ecological value and resource scarcity in the ecosystem. The second type of research on compensation standards estimates compensation standards based on the ecological value created by resources without taking into account their scarcity in the ecosystem. As revealed by a comparison between the "model-estimated total amount of compensation for various resources" and "total ecological value created by various resources", the total model-estimated amount of wetland

Table 3: Comparison of Estimated Ecological Compensation Standards for the Four Agricultural Resources in Beijing Municipality

		Forest land	Farmland	Grassland	Wetland	Ratio between forest land and wetland
2011	(1) Total resource area (hectare)	1,054,466	223,700	86,280	496	2,125.9 (forest land/wetland)
	(2) Model-estimated compensation standard (yuan/hectare)	8	2,088	1,150	39,548	5,142.8 (wetland/forest land)
	(3) Model-estimated total compensation for all resources (yuan)	8,108,844	4.67E+08	9.92E+07	1.96E+07	2.4 (wetland/forest land)
	(4) Ecological value created by unit area of resources (yuan/hectare)	22,386	17,244	8,033	79,576	3.6 (wetland/forest land)
	(5) Total ecological value created by all resources (yuan)	2.36E+10	3.86E+09	6.93E+08	3.95E+07	598.1 (forest land/wetland)
2016	(1) Total resource area (hectare)	1,089,534	221,157	85,139	51,400	21.2 (forest land/wetland)
	(2) Model-estimated compensation standard (yuan/hectare)	1,668	1,727	994	39,548	23.7 (wetland/forest land)
	(3) Model-estimated total compensation for all resources (yuan)	1.817E+09	3.82E+08	8.46E+07	2.03E+09	1.1 (wetland/forest land)
	(4) Ecological value created by unit area of resources (yuan/hectare)	22,386	17,244	8,033	79,576	3.6 (wetland/forest land)
	(5) Total ecological value created by all resources (yuan)	2.44E+10	3.81E+09	6.84E+08	4.09E+09	6.0 (wetland/forest land)

Note: "Ecological value created by unit area of resources (yuan/hectare)" is unrelated to the area of each resource, hence the identical values for item (4) in 2011 and 2016.

Source: Estimated based on the *Statistical Yearbook of Beijing Municipality*.

compensation for 2011 is 2.4 times the level of forest land compensation; however, the total amount of forest land compensation estimated based on the second type of compensation standards is 598.1 times the level of wetland compensation. By the relatively popular second type of compensation standards, forest land area in Beijing Municipality is much greater than those of the other three resources, provides the highest ecological value, and deserves the most ecological compensation. If such a compensation policy is followed, Beijing Municipality would only see its agricultural ecosystem deteriorate in terms of balanced compatibility.

3.2.3 Further analysis of "the agricultural ecosystem's balanced compatibility" based on the estimated results

Item (1) of Table 3 displays the area of the four major ecological resources of Beijing Municipality in 2011 and 2016, and item (2) shows the model-estimated ecological compensation standards for such resources in both years. Both types of data reflect the balanced compatibility status of the agricultural ecosystem in Beijing Municipality. The difference is that "total resource area" reflects the degree of resource scarcity (or redundancy) by only one indicator of resource inventory while "model-estimated compensation standard" is the shadow price of ecological function *produced* by each agriculture resource, which evaluates the degree of scarcity (or redundancy) of each resource in the ecosystem by both the ability of each resource to create ecological value and resource inventory. Obviously, the latter is more consistent with the connotations of "the agricultural ecosystem's balanced compatibility".

As shown in Table 3, forest land area in Beijing Municipality was 2,125.9 times greater than wetland area. Judging by the amount of resources alone, wetlands were 2,125.9 times more scarce than forest land; however, the model-estimated compensation standard for wetlands is 5,142.8 times higher than that for forest land. That is to say, the scarcity of wetlands reflected by resource inventory is magnified by many times if their ability to create huge ecological value is also taken into account (see "ecological value created by unit area of resources", which shows that wetlands create 3.6 times more ecological value than forest land does). Considering the soaring wetland area in Beijing Municipality by 2016, there has been a sharp reduction in the gap between the scarcity reflected by resource inventory (wetland area was 21.2 times greater than forest land area) and the scarcity measured by the model-estimated compensation standard (estimated compensation standard for wetlands is 23.7 times higher than for forest land).

As mentioned before, the first type of research on the compensation standards (i.e., based on ecosystem protection) is flawed primarily because the ecosystem's balanced compatibility is less correlated with the ability of each agricultural resource to create ecological value, so that the estimated compensation standard cannot reflect the marginal cost of ecological services provided by ecological resources. As demonstrated in the above analysis, this flaw is fundamentally addressed by our model of consistent compensation standards for the ecosystem and ecological value based on the "marginal price of resource use under the condition of optimal resource allocation".

4. Extension and Improvement of the Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

4.1 Extension of the Model of Consistent Compensation Standards for the Ecosystem and Ecological Value

The model of consistent compensation standards for the ecosystem and ecological value may be further extended for research on agricultural ecological compensation standards and relevant matters. In this paper, we list three types of extended research (see Table 4)

4.1.1 Research on the compensation standards for the four major agricultural resources in different regions

The basic analytical model created above is employed directly to estimate compensation standards for the four major agricultural resources in different regions. In estimating the compensation standards

Table 4: Descriptions of Research on Agricultural Ecological Compensation Standards under Different Conditions

Different conditions	Scope of agricultural resources	Classification of different conditions	Key variables	Research objective
Different regional scopes	Four agricultural resources: forest land, farmland, grassland and wetland, i.e. the same as the basic model	Different regional scopes	b_i, p_j	Compensation standards based on the balanced compatibility of the four resources in various regions
Structural differences of agricultural resources	Within each of the four resources in a region	Sub-types of the same resource in a region	y_i, a_{ij}, b_i	Compensation standards based on the balanced compatibility of the same resource in a region with structural differences of sub-types
Positive and negative externalities of each agricultural resource	Within each of the four resources in a region	Different positive and negative externalities of the same resource in a region	y_i, a_{ij}, b_i	Compensation standards for the same resources with different positive and negative externalities in a region

for different regions, change in variables b_i and p_j should be followed closely. Change in b_i is evident since the inventory of the four resources varies across regions. Change in p_j stems from the different value manifestations of the same unit of ecological functions across regions.

4.1.2 Research on compensation standards for each agricultural resource in a region with structural differences

Following the approach of the basic model, an analytical model is created to estimate the compensation standards for each agricultural resource in a region with structural differences (e.g. for different types of forest land such as nature reserve forest, regenerated forest, and economic forests). Compensation standards for each agricultural resource in a region with structural differences should be estimated based on the values of model variables y_i、a_{ij} and b_i.

4.1.3 Research on compensation standards for each agricultural resource in a region with different positive and negative externalities

Drawing upon the strengths of carbon trading and carbon balance analysis methods, an analytical model is created to estimate the compensation standards for different positive and negative externalities of each agricultural resource in a region, taking into account differences between organic and non-organic sorts of the same resource in *producing* ecological functions, differences between various methods of production (such as methods for the disposal of farm and forest wastes) in *producing* ecological functions, among others. The values of model variables y_i、a_{ij} and b_i should be determined for estimating compensation standards for each agricultural resource in a region with different positive and negative externalities.

4.2 Improvement of the Model of Consistent Ecosystem and Ecological Value Compensation Standards

Reflecting the ecological value created by agricultural resources and the scarcity of those resources, the model of consistent compensation standards for the ecosystem and ecological value created in this paper overcomes the one-sidedness of each of the existing two types of research. When estimating agricultural ecological compensation standards under different conditions using this model, however, we found that the LP's initial optimal solution must be rectified under some circumstances to obtain compensation standards that satisfy the consistency between ecosystem and ecological value. The need for such rectification is explained with our estimation of compensation standards for 15 types of forest land in Liaoning Province in 2016.

According to the results of compensation standards estimated with the linear planning model for the 15 types of forest land in Liaoning Province, except that the optimal solution is 30,000 yuan/hectare for spruce, the results are zero for all the remaining 14 types of forest land (see Table 5). This phenomenon has also occurred in the other estimations of the latter two cases of Table 4 (sub-type resources). The reason is that given the high correlation between the input-output matrix's column vectors for sub-type resources, the input-output matrix may not be a tall matrix (column vector linear correlation matrix). At this moment, a few optimal solutions (final values) could be zero. This phenomenon reflects the LP method's emphasis on resource scarcity. When the input-output matrix is not a tall matrix, the ability of relatively redundant resources to create ecological value could be overlooked, thus failing to achieve the basic requirement of consistency between ecosystem and ecological value followed by this paper.

Our approach for solving this problem is to use the LP sensitivity analysis tool to estimate the scarcity of each resource and its ability to create ecological value and combine the two to arrive at its ecological compensation standard. Specifically, three variables are specified in the LP sensitivity analysis, including "improvement by reduced cost", "improvement ratio" and "final value after improvement by reduced cost", and estimated values are employed to adjust the initially estimated ecological compensation standards. Take the estimation of compensation standards for the 15 types of forest land in Liaoning Province, for instance, we took the following steps (see Table 5).

(i) Specify the "improvement by reduced cost" variable, i.e., "objective coefficient-reduced cost", which displays the remaining necessary area after improving for the redundant forest land.

(ii) Specify the "improvement ratio" variable, i.e., "improvement by reduced cost/objective coefficient*100%", which displays the ratio of various required forest land resources to the original resource inventory, and the size of this ratio reflects the scarcity of each resource from an ecological value perspective.

Table 5: Adjustment of Ecological Compensation Standards for and Scarcity of Various Types of Forest Land in Liaoning Province

Name	Final values Y_i (yuan/ hectare)	Reduced cost (hectare)	Objective function b_i	Improvement by reduced cost (hectare)	Improvement ratio (amount of required resources as a share of the original resource inventory)	Final value after improvement by reduced cost (yuan/ hectare)	Improvement ratio × final value after improved by reduced cost (yuan/ hectare)	Ranking of resource scarcity
Larch forest	0	402,900	407,700	4,800	1.18	20,000	236	9
Korean pine	0	47,400	50,600	3,200	6.32	30,000	1,896	6
Pinus sylvestris	0	31,700	34,900	3,200	9.17	30,000	2,751	5
Pinus tabulaeformis	0	475,400	480,200	4,800	1.00	20,000	200	11
Spruce	30,000	0	3,200	3,200	100.00	30,000	30,000	1
Other conifers	0	17,300	22,100	4,800	21.72	20,000	4,344	3
Quercus	0	818,600	821,800	3,200	0.39	30,000	117	12
Birch	0	1,600	6,400	4,800	75.00	20,000	15,000	2
Poplar	0	383,900	388,700	4,800	1.23	20,000	246	8
Other broadleaf	0	461,900	465,100	3,200	0.69	30,000	207	10
Coniferous mixed forest	0	28,200	31,400	3,200	10.19	30,000	3,057	4
Broadleaf mixed Forest	0	1,036,800	1,041,600	4,800	0.46	20,000	92	13
Coniferous and broad-leaved mixed forest	0	139,300	142,500	3,200	2.25	30,000	675	7
Economic forest	0	1,256,700	1,275,900	19,200	1.50	3,472	52	15
Sparse forest and leaf forest	0	757,800	789,800	32,000	4.05	1,903	77	14

Notes: "Final values" are the final values of decision-making variable Y_i, i.e. the values of LP optimal solutions. Compensation standards for various types of forest land resources in Liaoning Province are initially estimated to be 30,000 yuan/hectare for spruce and 0 yuan/hectare for all other types of forest land. The absolute value of "reduced cost" means how much the coefficient of decision-making variable of the objective function should be improved to arrive at a positive solution (non-zero solution) of the decision-making variable. As shown in Table 5, the reduced cost of spruce among various types of forest land in Liaoning Province is 0, and none of the other types of forest land has a reduced cost of 0. "Coefficient of objective function" is the current area of various types of forest land in Liaoning Province, i.e. value of b_i in the LP model.

Source: Estimated based on open data (Liu, 2016).

(iii) Specify the "final value after improvement by reduced cost" variable, which is the value of compensation standard estimated by adjusting the area of each resource to be smaller than the area "improved by reduced cost" while the areas of other resources remain constant to reflect the ability of each resource to create ecological value.

(iv) "Improvement ratio" is multiplied by "final value after improvement by reduced cost" to arrive at the adjusted ecological compensation standards for various resources. This result takes into account both resource scarcity and the ability to create ecological value.

(v) The scarcity of agricultural and resource is ranked by the descending order according to the adjusted ecological compensation standards.

5. Conclusions and Outlook

5.1 Primary Explorative Activities and Conclusions

(i) The two types of methods for estimating agricultural ecological compensation standards by Chinese and international scholars reflect the basic principles and consensus on agricultural ecological compensation standards: First, such standards must reflect the cost for agricultural resources to create ecological value; second, they should also reflect the ecological value created by agricultural resources, taking into account both "compensation for agricultural ecology" and "ecological compensation for agriculture". Cost and value are two aspects of input and output for agricultural resources to create ecological value, and "compensation for agricultural ecology" and "ecological compensation for agriculture" are two basic pillars of "agricultural ecological compensation" that are equally important. The existing two types of estimation methods are flawed because they are focused on one aspect while overlooking the other.

(ii) Those estimation methods have also failed to clearly define agricultural ecological compensation and compensation standards. By raising and answering four basic questions as "Compensation for what?", "What is the object of compensation?", "What to compensate?" and "What should be the compensation standards?", this paper examines the defects of the theoretical basis for the two types of compensation standards, defines agricultural ecological compensation as "compensation for the cost for agricultural resources to 'produce' ecological functions by the standard of the marginal price of using resources under the condition of optimal resource allocation, i.e., the shadow price for agricultural resources to *produce* ecological functions". On such basis, we created a "model of consistent compensation standards for the ecosystem and ecological value", integrating the otherwise independent two types of research on compensation standards into one analytical framework.

(iii) Using the model of consistent compensation standards for the ecosystem and ecological value, we estimated and analyzed the ecological compensation standards for the four types of resources in Beijing Municipality to validate the model's theoretical and practical significance: First, based on the estimated results, we analyzed the drawbacks of the original compensation policies of Beijing Municipality, as well as the current disequilibrium of its the agricultural ecosystem, thus providing decision-making reference for Beijing Municipality to restore and maintain the agricultural ecosystem.

Second, we compared the estimated results with the second type of research on compensation standards, and revealed its drawbacks: Compensation standards determined based on only one aspect of ecological value created by agricultural resources would misinform policy-making, resulting in the disequilibrium, or worsening disequilibrium, of regional agricultural resources. This analysis also verifies the rationality of the model created in this paper for correcting the one-sidedness of the second type of research on compensation standards.

Third, based on the estimated results, we further dissected connotations of "balanced compatibility of the agricultural ecosystem", revealing the drawbacks of the first type of research: The balanced compatibility of the ecosystem that it focuses on has a small correlation with the ability of agricultural resources to create ecological value, so the estimated compensation standards cannot reflect the marginal cost for agricultural resources to provide ecological services. This conclusion has also verified the rationality of our model in correcting the first type of compensation standards.

(iv) The model of consistent compensation standards for the ecosystem and ecological value may also be extended to research on agricultural ecological compensation standards and relevant issues under different conditions. For instance, this model may also be applied in the research on compensation standards for the four agricultural resources in different regions, for each agricultural resource with structural differences in a region, and for the positive and negative externalities of each agricultural resource in a region. In estimating for different regions, attention needs to be paid to change in variables b_i and p_j in the model; the values of variables y_i、a_{ij} and b_i in the model need to be determined in estimating compensation standards for each agricultural resource with structural differences in a region and estimating compensation standards for the positive and negative externalities of each agricultural resource in a region.

(v) Our study found that zero solution would occur when estimating ecological compensation standards for the sub-types of each resource. The reason is that the strong correlation between the column vectors of the input-output matrix for the sub-types of each resource could lead to the non-tall input-output matrix with a few optimal solutions (final values) being zero. This result reflects the focus of the LP method on resource scarcity: When the input-output matrix is a non-tall matrix, it may overlook the ability of relatively redundant resources to create ecological value, thus failing to meet the required consistency between ecosystem and ecological value. To address this problem, this paper has attempted an explorative approach: Three variables including "improvement by reduced cost", "improvement ratio" and "final value after improvement by reduced cost" are specified in the LP sensitivity analysis to estimate the scarcity of each resource and its ability to create ecological value, respectively, and adjust the initial optimal solutions estimated with the model to obtain compensation standards that satisfy the consistency between ecosystem and ecological value.

5.2 Research Limitations and Outlook

(i) Fundamental data for the ecological functions and value of agricultural resources need to be further developed and improved. In the research process, this paper needed to rely on fundamental data of each agriculture resource's ecological functions and value estimated with the ecological value method, but the fundamental data was problematic: Existing studies offered different results of the estimated data on the ecological functions and prices of the same ecological resource; data on the types of ecological functions and each resource's ecological functions were incomplete: While some agricultural resources should have their ecological functions, relevant data could not be found; and so on. Subsequent research should engage experts specialized in the technical and economic analysis of the ecological functions and value of agricultural resources to further develop and improve various fundamental data.

(ii) Questions related to the LP solution method have yet to be further discussed. By solving the linear programming (LP) model and performing a sensitivity analysis, this paper has uncovered multiple principles and patterns, attempted to address difficult problems with new perspectives and methods, and initially created the procedures and steps to estimate the compensation standards for agricultural resources using a model of consistent compensation standards for the ecosystem and ecological value. However, some questions remain to be further explored, including how to reflect "a strong correlation between the ecological functions of two ecological resources?" There appear to be significant differences with mathematical linear correlation in terms of accuracy; which factors are correlated with the amount of agricultural resources whose ecological functions have linear correlation and whose final values of compensation standards are positive? And so on. While this paper has created an applicable model for agricultural compensation standards based on the consistency between ecosystem and ecological value, relevant research still needs to be further developed and improved.

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