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# The Value of Ecosystem Service and Its Dynamic Model

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**Abstract:** The estimate of ecosystem service value is a hotspot of ecological research. To figure out the value of ecosystem service and its feature of changes, we refer to the 17 ecosystem services which were raised by Costanza in 1997. We decide to divide the ecosystem services into 9 categories. Using the market value method, afforestation cost approach, shadow engineering approach and replacement cost approach, we could build two kinds of models which are related to both ecology and economics. First of all, we build a static model using the methods above and set some environment parameters to help we understand how we estimate the abstract ecosystem service value. Then we decide to give all the environment parameters a dynamic perform. By calculating the dynamic degree of each parameter, we could speculate the parameter in the next years. After this, we should look at how would the price change with the parameter. However, lots of data shows that there isn't a clear relationship between them. That means we could hardly get a mathematical description of market price and these parameters. In this condition, we have to make some assumptions. The most significant one is all the price parameters obey the scale effect law. Using the same methods, we could get 9 dynamic models which are connected with time. Finally, we make the sensitivity analysis, due to the complexity of our model, it is hard to make the analysis quantitative. So we just make qualitative analysis. And we found our model is quite reliable.

**Keywords:** Ecosystem services; Static model; Dynamic mode; Market value method; Replacement cost approach

## 1. Introduction

### 1.1. Background

Economic theory often disregards the impact of its decisions on the biosphere or assumes unlimited resources or capacity for its needs. This viewpoint has a flaw, which means that the environment is now facing the consequences. Countless roads, sewers, bridges, houses, or factories were added to substantial large-scale projects. That makes these negligible items directly impact the biodiversity and cause environmental degradation.
Concerned with these damages brought by the economic theory, plenty of methods have been adopted to measure the value of ecosystem services. In this way, the capitalists would keep their eyes on the true economic costs of land use projects when ecosystem services are considered.

### 1.2. Problem analysis

According to the research The Value of the World's Ecosystem Services and Natural Capital[1], the whole ecosystem could be divided into 17 categories, which is displayed in appendix1. By analyzing these services separately, we could easily figure out the value each service contributes with the help of substitution method. Through optimization, we simplify this model and retain 10 categories. After this, add all these values up to get a complete ecosystem value of this district. In consideration of time, we decide to build two kinds of model. The first one is a static model, which means the parameters would be static. The second one would be a dynamic model, which means some of the parameters would be dynamic. Under our assumptions, the first model would be used to estimate the instant value of the ecosystem service. When it comes to a project, the market price and the parameters of ecosystem service should be regarded as variable, due to the changes that time could bring.

## 2. Set of the Model

We use the following formulas to estimate the value of different ecosystem service.

### 2.1. Gas regulation

Oxygen released from plants: Using the market value method:

$$U_{O_2} = 1.19 \times A \times B_\alpha$$

According to the photosynthesis, for every 1g of dry matter produced by plants, 1.19g of oxygen is released. In the formula above, $U_{O_2}$ means the oxygen released from plants annually, which unit is $t\cdot\alpha^{-1}$. $B_\alpha$ means the plants' ability of dry matter producing, with the unit: $t\cdot hm^2\cdot\alpha^{-1}$. A means the vegetation area, with the unit: $hm^2$. So, we could find out the equation of the value of released oxygen:

$$V_{O_2}=1.19\times A\times B_\alpha\times C_{O_2}$$

In the formula above, $V_{O_2}$ means the value of oxygen released from plants annually, which unit is \$ or ¥· $a^{-1}$. $c_{O2}$ means the price of oxygen, with the unit: \$ or ¥ $\cdot t^{-1}$.

Carbon sequestration: Plants absorbed large amounts of carbon dioxide during photosynthesis. The value of carbon sequestration from plants, is usually evaluated by carbon tax approach. International carbon tax rate is proposed by the Swedish government :150 usd/t (C). However, this value for developing countries is too high. So, in our model, we would adopt the afforestation cost approach for developing countries to calculate.

Carbon tax approach (for developed countries): Carbon sequestration is divided into two parts: vegetation carbon sequestration and soil carbon sequestration. Vegetation carbon sequestration is the main carbon sequestration, and plants can absorb 1.63g of carbon dioxide when producing 1g of dry matter. The vegetation carbon sequestration model is described as:

$$U_{P_C}=1.63\times R_c\times A\times B_\alpha$$

In the equation above, $U_{P_C}$ means the vegetation carbon sequestration annually, with the unit: $t\cdot\alpha^{-1}\cdot R_c$ is the amount of carbon in carbon dioxide at about 27.29%. $B_\alpha$ means the plants' ability of dry matter producing, with the unit: $t\cdot hm^{-2}\cdot R_c\cdot$. A means the vegetation area, with the unit: $hm^2$.The soil carbon sequestration model is described as:

$$U_{S_C}=A\times X_S$$

In the equation above, $U_{S_C}$ means the soil carbon sequestration annually, with the unit: $t\cdot\alpha^{-1}$.A means the vegetation area, with the unit: $\frac{hm^2}{m^{-2}}$. $X_s$ means the ability of the soil's carbon sequestration, with the unit: $t\cdot hm^{-2}\cdot a^{-1}\cdot$.

The model of the value of carbon sequestration of the area annually is described as:

$$V_c=A\times C_c\times(1.63\times R_c\times B_\alpha+X_s)$$

Afforestation cost approach (for developing countries): The carbon sequestration value of wetland plants was calculated based on the carbon produced by the plants per unit area, afforestation cost and total vegetation area. The afforestation cost in China is 260.9 yuan /t (C)。 The model of the value of carbon sequestration of the area annually is described as:

$$V_c=A\times P_c\times U_p$$

A means the vegetation area, with the unit: $hm^2$. $P_c$ means the carbon produced by the plants per unit area annually, with the unit: $t\cdot hm^{-2}$, $U_p$ is the cost of afforestation, with the unit: \$ or ¥ / t(C).

Climate regulation: Climate regulation functions include the ecosystem of water circulation and the atmospheric composition change. It can also regulate the local temperature, humidity and precipitation condition.

Therefore, we use replacement cost approach to calculate the value of climate regulation. The energy of heating the water till vaporizing under 100 ℃ and 1 standard atmospheric pressure is 2260.0 KJ/KG, then calculate the total quantity of heating energy. The energy of cooling could be replaced by air-conditioned refrigeration. We assume the energy efficiency ratio of air conditioning is 3.0. Converting 1.0m3 of water to steam consumes about 125.0 kW·h(1kW·h=3.6 $\times10^6$ J) energy. In this way, the climate regulation value of the area can be calculated according to the local electricity price standard and the annual evaporation.

Cooling:

$$V_T=S_{eva}\times A_s\times 2260\mathrm{KJ}\cdot\mathrm{Kg}^{-1}\times\frac{1}{C_M\times3.6\times10^6\times3.0}$$

In the formula above, $V_T$ means the value of cooling. $S_{eva}$ means the average annual evaporation, with the unit: mm. $A_s$ is the total ecosystem area with the unit: $m^2$. $C_M$ is the local electricity bill.

Humidifying:

$$V_E=S_{eva}\times A_s\times125\mathrm{KW}\cdot h\cdot m^{-3}\times C_M$$

In the equation above, $V_E$ is the value of humidifying. $S_{eva}$ means the average annual evaporation, with the unit: mm. $A_s$ is the total ecosystem area with the unit: $m^2$. $C_M$ is the local electricity bill.

Waste treatment:

The waste treatment is defined as the ecosystem's ability of re-acquisition of easily lost nutrients, removal or degradation of excessive or extraneous nutrients and compounds. So, we use replacement cost:

$$V_{waste}=\sum Q_i\times P_i$$

In this equation, $V_{waste}$ means the value of waste treatment that the area could provide. $Q_i$ means the quantity of that kind of waste. $P_i$ means the cost of waste treatment in artificial way.

Soil conservation:

The land space of an ecosystem would increase. That means there would be more grounds available. In this situation, we use the market value method to estimate the value of soil conservation.

$$V_{soil}=S\times P_{soil}$$

In this formula, $V_{soil}$ means the value of soil. $S$ means the loss of soil. $P_{soil}$ means the local value of soil per unit area.

Nutrient cycling:

When it comes to the nutrient cycle in soil, we mainly focus on its nitrogen, phosphorus, potassium content. Because the value of these three elements is not easy to judge, we will convert its value into grain income and fertilizer prices.

$$V_{nutrient} = \sum \left[ \frac{\left(A_i \times P_{earning}\right)}{H_{soil}} + \sum \left(A_i \times N_j \times P_j\right) / R_j \right]$$

In this equation, $V_{nutrient}$ means the value of the all the nutrients in the soil. $A_i$ means the reservation of different kinds of soil. $P_{earning}$ means average grain production yield per unit area of this type of land. $H_{soil}$ means average thickness of cultivated land. $N_j$ means the content of organic matter in soil. $P_j$ is the price of fertilizer. $R_j$ is the content of organic matter in fertilizer.

Biodiversity: As for the value of biodiversity, we use Shannon-Wiener index to estimate it. And the model is as follows:

$$U_a = S_s \times A$$

In this formula, $U_a$ is the value of the biodiversity, which unit is: $ or ¥/t(C). $S_s$ is the average value of biodiversity per $hm^2$ each year when using Shannon-Wiener index. A means the vegetation area, with the unit: $hm^2$.And the Shannon-Wiener index table is shown below.

**Table 1. Shannon-Wiener index classificatio**

| Index | $S_s$ ($\$ \cdot hm^{-2} \cdot a^{-1}$) |
|---|---|
| Index ≤ 1 | 3000 |
| 1 ≤ Index ≤ 2 | 5000 |
| 2 ≤ Index ≤ 3 | 10000 |
| 3 ≤ Index ≤ 4 | 20000 |
| 4 ≤ Index ≤ 5 | 30000 |
| 5 ≤ Index ≤ 6 | 40000 |
| 7 ≤ Index | 50000 |

Food production and raw materials: When talked about food production and raw materials, we found it was easily to get the market price of these items. So, we use the following equation to describe the value.

$$V_{supply} = \sum P_i \times B_i$$

In this equation, $V_{supply}$ is the total value of food and raw materials. $P_i$ means the market value of the commodity. $B_i$ is the stock of the commodity.

Water supply: It is hard to describe the true value of the ecosystem due to its complexity, so we use the Shadow engineering approach to estimate the value. Instead of calculating the value directly, imagine we build a reservoir to recover the original water supply. In this situation, the value of water supply is replaced by the cost of the reservoir. And the model is as follows:

$$V_{water} = V_{loss} \times P_c$$

In this model, $V_{water}$ means the value of water supplying, including water regulation. $V_{loss}$ means the loss of the whole ecosystem. $P_c$ means the cost of building and maintenance of a reservoir.

Leisure and entertainment: Generally speaking, it is impossible to figure out the value of leisure and entertainment. But there is a way to estimate it by connecting it to travel cost. That is how we use the Travel cost method to build the model.

$$V_e = F_{direct} + F_{cost} + F_{time}$$

In this model, $V_e$ means the total value of entertainment. $F_{direct}$ is the travel cost including tickets, hotels and commodity. $F_{cost}$ means the cost including transportation and eating. $F_{time}$ means the value of travelling time which is related with the average salary.

## 3. Results for Static Model

The model we set above is a static model, which means it could only reflect the instant value of the ecosystem service.

We choose the Hangzhou Bay area as the district of our model. Hangzhou bay, located in the northeast of Zhejiang province, is a trumpet-shaped estuary formed by the Qian tang river entering the sea. It is a world-renowned estuary of strong tidal river. Our model choose Cixi city administrative region as the study area (121 ° 04 '~ 121 ° 39 E, 30 ° 04' ~ 30 ° 31 'N). Area belongs to the subtropical Marine monsoon climate, four seasons, the annual average temperature is 16 ℃, for many years an average drop of water is 1273 mm annual average sunshine hours 244.0 days, frost-free period of about 2038 hours. Cixi's population is 1.0471 million people, 2015.The main data sources include multi-source remote sensing data, wetland monitoring data, geographic auxiliary data and socio-economic statistics data. Remote sensing data from the website https://glovis.usgs.gov/ track number 118/39.

**Table 2. The value of Hangzhou Bay**

| Ecosystem Functions | | | Total (billion yuan) |
|---|---|---|---|
| Gas regulation | The value of carbon sequestration: 1.156 billion yuan | The value of oxygen released: 0.465 | 1.621 |
| Waste treatment | Market price of waste treatment: 50 yuan/t | Waste quantity：4.5e^9t | 23.156 |
| Climate regulation | Humidifying: 3.929 billion yuan | Cooling: 24.683 billion yuan | 28.612 |
| Soil conservation | Increasing area: 1320 $hm^2$ | Market price of the soil: 750 yuan· $m^{-2}$ | 9.90 |
| Nutrient cycling | The loss of soil: 4.983 billion yuan | The loss of nutrient: 17.832 billion yuan | 22.815 |
| Biodiversity | Shannon-wiener index: 1 | Value of biodiversity: 3000yuan· $m^{-2}$ | 0.131 |
| Food production and raw materials | Food: 9.257 billion yuan | Raw materials: 2.384 billion yuan | 11.641 |
| Water supply | The amount of water: 1.153 billion m3 | Unit cost: 15.29yuan· $m^{-2}$ | 17.629 |
| Leisure and entertainment | Person-time: 8.7282 million | Income: 7.412; Cost: 5.194; Time value: 3.4.23; billion yuan | 16.029 |

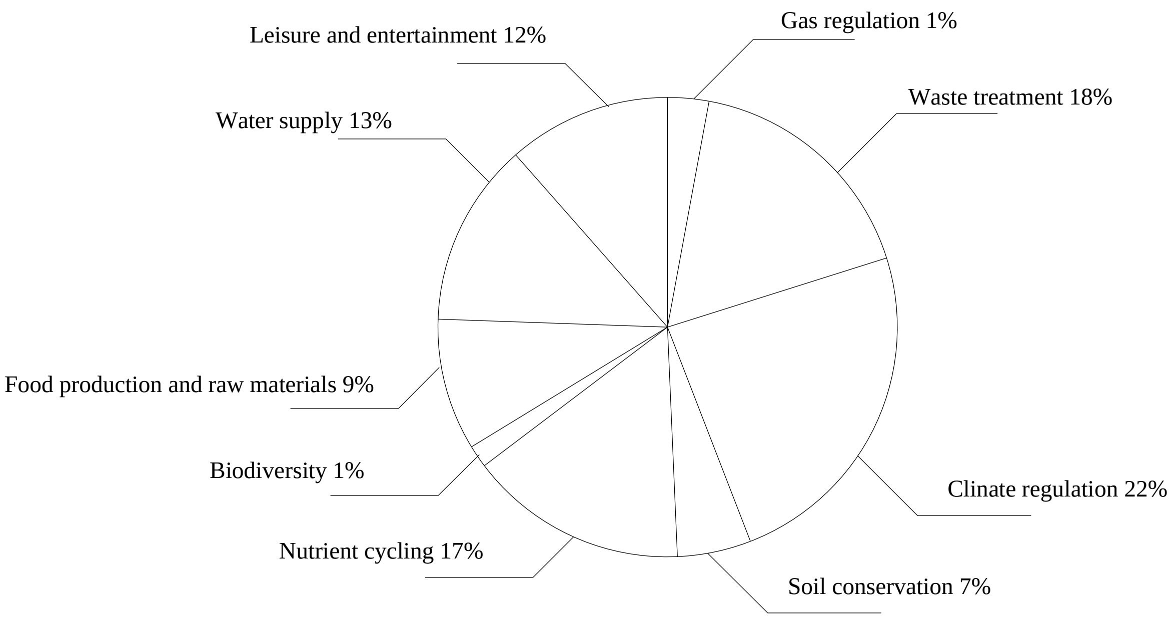


**Figure 1. The reasons for the value changes**

After we calculate all the values, we could get a pie chart. As the pie chart shown, the most precious value of the Hangzhou Bay is the value of climate regulation. However, the value of biodiversity is very poor, which is not what we expect.

The static model cannot explain the change of the market price which is caused by the ecosystem service changes. In this case, this model couldn't evaluate the future value due to the changes of ecosystem services. So we should look at how to deal with this problem.

## 4. Solution for Dynamic Model

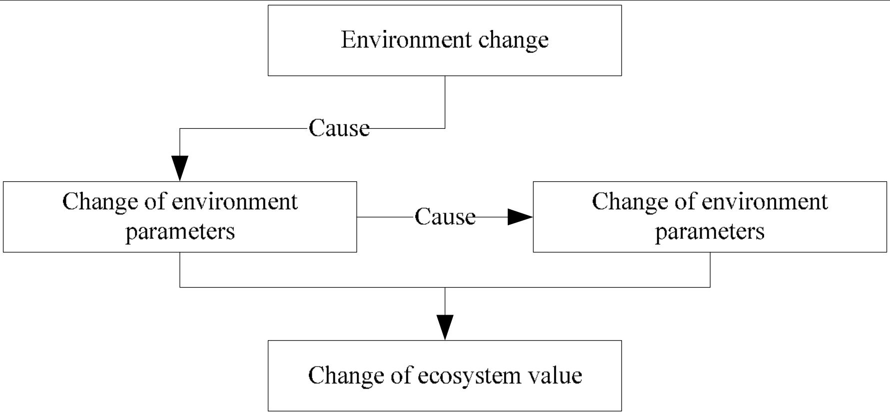


**Figure 2. How to deal with this problem**

When a project is about to set, no matter what its scale is, our model should able to reflect the changes it brings to the ecosystem. In this case, we set a dynamic model based on the static model. Besides, the influence brought by time is not negligible. So, our model should also have the capability to reflect with time.

However, there isn't a perfect way to describe the relationship between the market price and change of the environment parameters. That means some of the methods we used before may not be appropriate anymore. Due to this dilemma, we have to make some assumptions. Under these assumptions, we could fix our dynamic model.

As time goes by, the construction of the project would bring different kinds of changes to the ecosystem. We simplify it and then get 3 kinds of changes, which could be defined as positive changes, negative changes and constant.

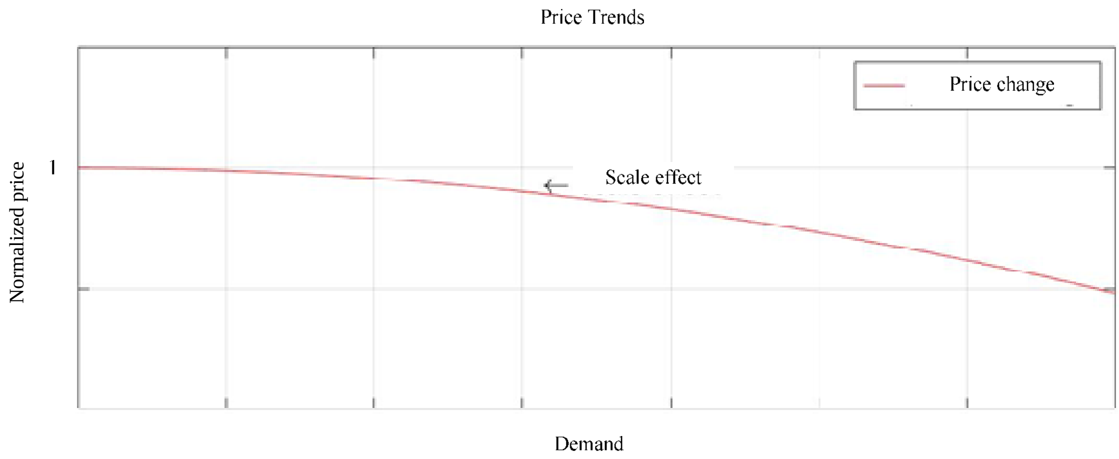


**Figure 3. Price trends**

Price trend, which is the most complex parameter to describe. A mass of factors would affect the price. So, in our model, we assume that the demand is the only factor that could affect the market price. And under this assumption, according to scale effect, we have the following Price-Demand curve.

In order to study the change of environment parameters over time, which also shows the change of ecosystem value over time, we need to define some parameters: The dynamic degree of the environment parameters: K. The parameter K is defined as the changes of a certain environment parameter within a certain time range in a research area, and the definition formula is shown below:

$$K=\frac{U_b-U_\alpha}{U_\alpha}\times\frac{1}{T}\times 100\%$$

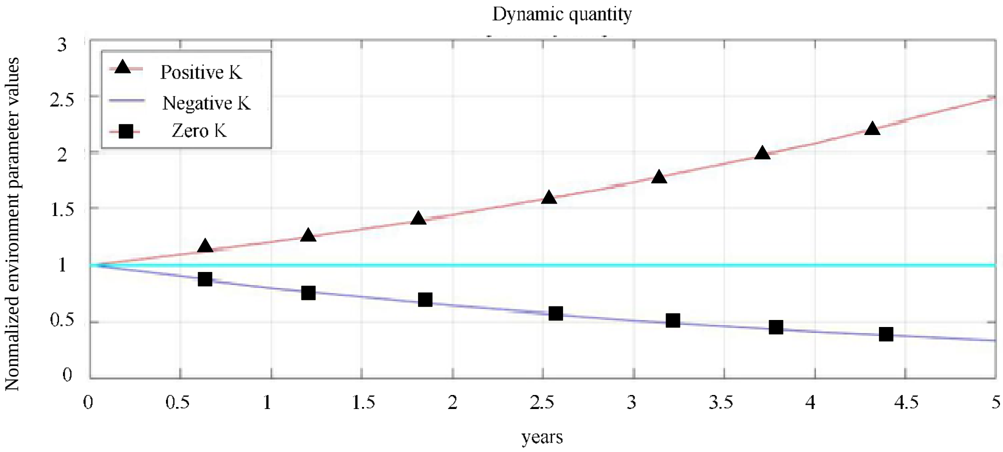


**Figure 4. Dynamic quantity**

In the formula, $U_\alpha$ and $U_b$ represents the number of one kind of environment parameter at the beginning and the end of our research separately. T is the time of our research. So, K is the dynamic degreed of this kind of environment parameter.

Under these assumptions, we could establish another dynamic model. Noticed that nearly all the changes of environment parameters could be described with same equations. So, we list them before, and all the following parameters named with" **V** " could be calculated in this way, except some special parameters. We would notice them when encountering.

$$F_s = F_{so} + F_{consumption} \times T$$

$$VA = A_0 \times (1+K)^t - F_s$$

$F_s$ is the total consumption of the project. $F_{so}$ is the original consumption of the project itself. $F_{consumption}$ is the consumption that the project would cause during its operation. T is the time of the project's operation. Other parameters have already defined before. VA is the environment parameter in the next years. $A_0$ is the environment parameter in reference year. It should be noted that in a given project, its $F_{so}$ and $F_{consumption}$ would have different changes, which means we should treat this model separately. In some conditions, they may even equal to zero. We assume that external disturbance is exerted on environment (such as construction project), so the change of environment parameters is mainly related to external disturbance. Then we could get a disturb model.

## 5. Sensitivity Analysis

In the model we established, we did not consider the other factors' influence of market price, the government regulation when no project was established. Therefore, the stability analysis here mainly focuses on the actual acquisition of ecological data and price changes. Except the recreation value in our model, the others are all converted into the product of the loss amount and unit price. And market price is affected by the change of society very unsteadily. Reservoir prices, for example, have nearly tripled in the past decade[8]. Let us consider the influence of other factors. Society is developing very fast, so it makes no sense for us to use this year's growth rate to predict the value of next year. However, the economic changes caused by national policies are uncontrollable and have a huge impact on values. The model is highly sensitive, so the price prediction stability deviation of leisure and entertainment and water supply is really big. Although the price is stable, it is difficult to quantify the impact of the model on biodiversity and the degree of soil pollution. Due to the development of measurement means, these errors will not be large, so the stability is quite good. Other predictions such as waste-disposal prices are hard to shift and extremely stable.

## 6. Future Works

To meliorate our model, we need to distinguish the functions of the ecosystem service clearly. That would help to make the estimation to be more accurate. Besides, if there is a way to find the true relationship of price and demand and the changes of environment parameters, our dynamic model would have greater ability to predict the value in the future.

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