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Construction and Empirical Study of Trend Surface for Willingness to Pay Based on Improved Voronoi Method

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Abstract

The study on spatial attributes of willingness to pay(WTP) is meaningful for cost sharing of environmental goods recovery. This paper forces on the rules of spatial variation of willingness to pay in different areas, by division of sub-area and construction of trend surface. It is divided 71 sub-areas by Voronoi Polygon and constructed trend surface of willingness to pay for each sub-area for the non-use value of Songhua River as a study case. The result shows that high WTP areas spatially aggregated around the environmental goods, as low WTP areas dispersed on both sides of the environment goods uniformly. Which influenced the WTP is not only the distance, but the degree of understanding and the use of environment goods, interpretated by Probit models. It's an easier and faster method for the trend surface construction, which has a significant value for the study of spatial attributes of willingness to pay.

Keywords: *Willingness to Pay; Spatial Attributes; Distance Decay Effect; Trend Surface*

1. Introduction

Contingent Valuation Method (CVM) is a standard method for estimating the economic benefit of protection or recovery of environmental article through acquiring the WTP or Willingness to Accept (WTA) of respondents on environmental article by questionnaire [1]. More and more attention is paid to the spatial attribute study of economic benefit on protection and recovery of environmental article, especially much attention has been being paid to such study in recent years, as is significant for both benefit distribution and recovery cost sharing of environmental article[2]. For example, a study of environmental impact assessment of explosion of Jilin Chemical Plant in 2005 for Songhua River Basin lacks of profound exploration of the spatial perspective of impact on different areas in which Songhua River flows through. When WTP is identified by CVM, the survey result of questionnaires handed out in different areas are regional data, and can be analyzed by spatial data analysis method. In order to improve the analysis efficiency of spatial data, the researchers keep exploring flexible and advanced spatial attribute model [3]. Emphases of spatial attribute study of WTP include importance of distance decay effect, scale and range of WTP, interest relation evaluation of geologic clustering, influence of improvement of environmental article on welfare economy and so on[4]. Apparently most spatial attitude studies of WTP center on model study and explore the influence of distance on WTP by distance variable, and lack visualization study of changes of WTP in different areas. Take the non-use value of Songhua River as an example, the paper constructs trend plane, explores the visualization method of law of change of WTP in sub-areas, and analyzes the reason for generation of spatial attribute of WTP in combination with model.

Spatial attribute study of environmental article centers on the model study of distance decay effect. The earliest spatial attribute study of environmental article studied the water

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quality improvement of American rivers by CVM [5], first advanced distance decay effect, and established a signal dimension model for it and visit frequency, the model result shows the significant correlation between them, i.e. the residents farther away from a river is less likely to visit the river. Some later studies show that the quality demand of respondents for an environmental article decreases with the increase of their distance from the environmental resource. Some studies conclude that “distance decay effect” needs special experimental design and model design, and all cases can’t show such character [6]. After Sutherl and Walsh (1985), a lot of studies center on the discussion about distance decay effect in different scales, involving verification of distance decay effect, application scale of distance decay effect, influencing factor of distance decay effect and so on, and most research methods center on the modeling of different experimental designs or different scale variables [7]. Model studies simply discuss the negative correlation between distance variable and WTP, seldom apply GIS data, gridding and other methods, and lack spatial visualization study.

If an environmental article is river, the cost sharing study of its habitat improvement also centers on distance decay effect. Related study shows that, as to the WTP for quality improvement of river water, nonusers of resource show strong distance decay effect, but the researchers didn’t measure the degree of WTP difference between users and non-users[8]. A study defined “user” and “non-user”, and discovered the obvious influence of the two kinds of respondents on structural model. Meanwhile, a study denies the conclusion above, and thinks the users are insensitive to distance change, and only non-users can take on strong distance decay effect [9]. Songhua River, one of the most important rivers and with the widest drainage basin in Northeast China, surely attracts our attention to the spatial attribute of WTP for its water quality improvement.

By improved Voronoi model, the paper provides a construction method of WTP trend plane, and makes statistical analysis for the regional data of WTP. Spatial attribute of WTP is studied by Moran’s Index of trend plane, and influencing factors of spatial attribute of WTP are studied in combination with Probit model. Take non-use value of Songhua River as object of study, the applicability of trend plane construction method is verified. Trend plane of WTP has the characteristics such as small calculated amount, simple application, visible result and convenient analysis. For specific WTP study case, the method widely applies to different research scales and different regional division methods.

2. Theory and Method

2.1. Spatial Attribute of WTP

Spatial attribute is one key direction of value study of environmental article. On one hand, environmental article has external economy of production, and consumer surplus is estimated by WTP. On the other hand, to mitigate the overcrowding of environmental article, environmental article shall be repaired or restored, and relevant cost sharing is also embodied by WTP. Cost sharing principle depends on the degree of environmental article consumption of consumers in different areas. Spatial connection between consumers and an environmental article is that, the shorter the distance is, the stronger the correlation will be, the longer the distance is, the weaker the correlation will be, *i.e.*, the degree of environmental article’s premium consummation by consumers differs in different areas [10].

Different degrees of environmental article consumption cause the WTP difference among the respondents in different areas. Because it’s difficult to measure the degree of environmental article consumption, such degree is embodied by spatial attribute of WTP [11]. Through setting WTP for an environmental article is influenced by respondent attribute A , spatial attribute factor Dis and error term ε , the WTP may be expressed as the function below:

$$WTP = f(A, Dis, \varepsilon) \quad (1)$$

Where, respondent attribute A includes sex, age, education degree, income, cognition of environmental article and other variables; spatial attribute factor Dis isn't a simple distance element, and may be certain definition of spatial attribute, division of spatial area or others; error term ε is a random error conforming to $N(0,1)$. If WTP is viewed as regional data, then the spatial attribute factor of WTP of area i may be expressed as vector (x_i, y_i, WTP_i) , thereof (x_i, y_i) means spatial location information of area i , and WTP_i means WTP of area i .

2.2. Basic Definition of Spatial Attribute Study of WTP

To facilitate the subsequent statement, the following basic definitions are made for spatial attribute study of WTP. (1) Object area (R) means the spatial geologic scope of study or specific boundary of study. When the object of study is an environmental article, the object area may be the environmental article, or the administrative region (city/province) in which the environmental article is, or the environmental article and the regional whole within a fixed distance in its surrounding. (2) Sub-area ($R_i, i = 1, 2, \cdots, k$) means smaller area formed through the regional division of object area. Set of sub-areas is object area ($R = \bigcup_{i=1}^{k} R_i$). (3) Sub-area division principle means the principle for dividing the object area into sub-areas by distance relation, economic distance relation, geologic location relation, gridding, *etc*.

Normally an object area is divided into sub-areas according to the principles below. (1) Distance. The distance between sub-area and an environmental article is taken as regional division standard, sub-areas at the same distance have the same WTP for the environmental article [12]. Advantage of the division method is that, the distance belt division is even and strictly accords with the first law of geography, and its disadvantage is that a natural administrative region may be easily divided into two distance belts, causing a difficulty in questionnaire statistics and modeling. (2) Administrative division. Administrative region is taken as regional division standard. One city/county/district is viewed as an independent area. The advantage is that, respondents in the same administrative region have similar cognition of the environmental article, and it's easy to get an effective result on the control of model variable, and the disadvantage is that, the boundary of administrative division is irregular, and it's difficult to determine the location relation among sub-areas. (3) Adjacency relation. Adjacency relation with an environmental article is taken as division standard, to be exact, the division standards include inside environmental article area, adjacent to the environmental article and not adjacent to the environmental article. The advantage is that, the division combines distance with administrative region, and its variable level can meet the need of statistical analysis, and the disadvantage is that "adjacency" relation is a fuzzy concept that can hardly be defined. (4) Economic distance. Areas in similar economic conditions are viewed the same type and divided into a sub-area. The method eliminates the impact of regional economic imbalance on model, but can't fully embody absolute spatial relation.

2.3. Construction Method of WTP Trend Plane

Spatial attribute analysis of WTP is combined with GIS, and mainly involves in discrete Voronoi model and continuous Kriging model [13]. In Voronoi model, the attribute value of regional variable is constant, and data of different sub-areas are discrete. This model has simple calculation, but doesn't meet the hypothesis of the first law of geography. In Kriging model, the attribute of every point in space is continuous variable, as overcomes the shortcoming of Voronoi model, but the calculation is in large amount, and relies on professional spatial calculation tool or software. Moreover, for spatial attribute data (x_i, y_i, WTP_i), attention is paid to only spatial location information (x_i, y_i) in regional division rather than WTP value, and this is obviously incomplete.

The paper divides areas and constructs WTP trend plane by improved Voronoi method, and obtains a method easy for calculation of spatial attribute analysis of WTP. The construction process of trend plane includes three steps. Step 1: Determine the object area of study, select sub-area division principle, and divide sub-areas. Step 2: Trend plane is constructed for every sub-area, later trend plane of every sub-area is spliced into the set of trend plane of object area. Step 3: According to the result of Step 2, the spatial autocorrelation of object area is calculated to analyze the spatial attribute of WTP. This method not only has simple calculation but also reflects the direction and trend of change of WTP in sub-area.

2.3.1. Sub-area Division: First, object area R is defined, if the object of study is an environmental article, normally object area R is the geographic area in which the environmental article is and its extension. Second, for sub-area division principle, related study shows that, taking economic relation as division principle may cause huge deviation when compared with taking geographic location relation as division principle[10], so the paper doesn't discuss the division according to economic distance principle. All of the three subarea division principles distance, administrative division and adjacency relation are related to the geographic location of object area, and this paper only discusses the sub-area division method according to administrative division principle, and other division principles are some published or unpublished conclusions of the author, and won't be detailed in this paper.

After defining the object area and determining the sub-area division principle, the object area is divided into sub-areas. Provided object area R includes k natural administrative regions recorded as R_i ($i = 1, 2, \cdots, k$), apparently $R = \bigcup_{i=1}^{k} R_i$, administrative regions don't coincide besides boundary, the boundary between administrative region R_i and R_j is L_{ij} , apparently $R_i \cap R_j = L_{ij}$. For natural administrative division, boundaries are always nonstandard, and cause a difficulty to subsequent study, so Voronoi method is used to redivide natural administrative regions, and then every sub-area becomes a convex polygon, and regional boundary L_{ij} is a line segment.

Specific division method: Step 1: Object area R is divided into $m \times n$ grids. For any sub-area, the grid in which its government is located is viewed as its geographic coordinate, and mean WTP value of this area is viewed as the WTP of this area, with the coordinate vector $R_i\ (x_i, y_i, WTP_i)$.

Step 2: Delaunay triangular mesh is constructed by the geographic coordinates (x_i, y_i) of every sub-area. Delaunay triangular mesh is a common method for simulating the approach to earth surface, and views known coordinate vector (x_i, y_i, WTP_i) of every sub-area as ground surface information, and Delaunay triangular mesh is used to construct Voronoi polygon for regional division. Because WTP is under a dispute of high estimated value all the time, WTP is considered while constructing Delaunay triangular mesh, and corrected on the basis of construction principle. (1)

Generation of convex hull. For all k sub-area coordinate points, the line segments connecting the coordinate points in other sub-areas are recorded as l_{ij} ($i = 1, 2, \cdots, k$, $j = 1, 2, \cdots, i-1, i+1, \cdots, k$), and $(k-1)!$ line segments in total are connected, l_{ij} may be the common side of two triangles or not. Line segments not common side of triangles are reserved, and other line segments are erased to get initial convex hull set. (2) Convex hull triangulation by scrap edge method. Sub-area with the lowest WTP in convex hull is selected as start point and recorded as R_1, the two points (respectively recorded as R_2, R_3) in the convex hull set and at the shortest distance (l_{1j}) from the start point are calculated to form a triangle, later the triangle is removed to get a new convex hull, by analogy, till all points in convex hull set are triangulated. (3) Discrete interpolation. Normally discrete interpolation adopts Local Optimization Procedure (LOP), and the algorithm is optimized to avoid overhigh WTP in the interpolation result. For a triangulated convex hull set, the triangle formed by the sub-area with the lowest WTP is taken as start point and recorded as $\Delta R_1 R_2 R_3$, and a circumcircle of $\Delta R_1 R_2 R_3$ is made. Provided the circumcircle includes s sub-areas in total, then convex hulls are regenerated for the s sub-areas. The sub-area with the lowest WTP is selected and marked with R_1, and the rest points are marked with $R_2, \cdots, R_s$ anticlockwise in order. Calculation of mean WTP value of any non-neighboring points in the convex hull:

$$\overline{WTP}_{ij} = \frac{1}{2}\left(WTP_i + WTP_j\right), i = 1, \cdots, s,\ j = i+2, \cdots, s \tag{2}$$

Take

$$\overline{WTP}_{\min} = \min\{\ \overline{WTP}_{ij}\} \tag{3}$$

The two sub-areas corresponding to $\overline{WTP}_{\min}$ are connected to get a new triangle, the triangle is removed to get a new convex hull, by analogy (if two convex hulls are gotten after connection, the procedure above shall be repeated for the two convex hulls above respectively.). At last, all sub-areas in the whole object area are connected to get Delaunay triangular mesh.

Step 3: Midperpendicular line segment (L_{ij}) is made for every side (l_{ij}) of triangle in Delaunay triangular mesh, and the convex polygon enclosed by midperpendicular line segments is Voronoi polygon.

After Voronoi polygon is constructed, any sub-area is converted into a convex polygon. If sub-area R_i and R_j have common side L_{ij}, it will be considered that R_i and R_j are neighboring, favorable for subsequent analysis.

2.3.2. Construction of WTP Trend Plane: Sub-area is divided into Voronoi polygon, and sub-area boundary is clear, favorable for subsequent discussion. In traditional Voronoi model, WTP value in sub-area is constant, and doesn't meet the first law of geography, so trend plane of WTP is constructed to explore change of WTP in every sub-area.

Advantage of trend plane: (1) WTP in every sub-area is not constant but a continuously changing trend plane; (2) WTP differs in different sub-areas; (3) Median of trend plane in sub-area represents mean WTP in sub-area; (4) Dip angle direction of trend plane represents the change direction of WTP, and value of dip angle represents the intensity of WTP change.

It's critical for the construction of trend plane to calculate the degree and direction of dip angle of trend plane by the algorithm below. First, provided t sub-areas are adjacent to sub-area R_i and recorded as R_{i1}, R_{i2},…, R_{it}, WTP of sub-area R_i is WTP_i, and WTPs of neighboring sub-areas are WTP_{i1}, WTP_{i2}, …, WTP_{it} respectively. Rate of relative WTP change of sub-area R_i to neighboring sub-areas is recorded as

$$\varepsilon_j = \frac{|WTP_{ij} - WTP_i|}{WTP_i}, \quad (j = 1, \cdots, t) \tag{4}$$

For $\varepsilon_j^* = \max\{\varepsilon_j\}$ thereof, sub-area R_{ij}^* direction is determined as the most intensive direction of WTP change, Delaunay triangle side (perpendicular to the common side of R_i and R_{ij}^* polygons) connecting sub-area R_i and R_{ij}^* is the change direction of WTP and recorded as $\vec{\alpha}_k$. Dip angle θ_j of sub-area R_i to sub-area R_{ij}^* is calculated according to the formula below:

$$\tan\theta_j = \frac{WTP_{ij} - WTP_i}{d_j} \tag{5}$$

Where, d_j is the side length of Delaunay triangle of sub-area R_i and R_{ij}^*. The final result is a slant top cylinder taking sub-area R_i polygon as bottom, the height corresponding to (x_i, y_i) is mean WTP WTP_i of sub-area, its slant top is plane, the larger the plane dip angle θ_k is, the larger the WTP difference between the area and its neighboring area will be, dip angle direction vector $\vec{\alpha}_k$ is perpendicular to one side of sub-area polygon, as shows WTP changes the most intensively in this direction.

2.3.3. Global Spatial Autocorrelation of Object Area: Spatial weight matrix is constructed according to the picture of Voronoi polygon, and the spatial weight matrix of k sub-areas is $W_{k\times k} = (\omega_{ij})$,

Where,

$$\omega_{ij} = \begin{cases} 1, & \text{If sub-area } R_i \text{ and } R_j \text{ have common boundary} \\ 0, & \text{If sub-area } R_i \text{ and } R_j \text{ dont have common boundary} \end{cases} \tag{6}$$

Spatial weight matrix represents the adjacency relation between sub-areas, and takes the result of Voronoi polygon as judgment basis to avoid fuzzy boundary of sub-area generated by the adoption of different sub-area division principles.

Global spatial correlation Moran's I coefficient is adopted. The coefficient can be used to judge whether the WTP of every sub-area in the object area shows spatial clustering or mutual independence. For WTPs of sub-area R_i and R_j WTP_i and WTP_j, their spatial distance weight is ω_{ij}, and the spatial correlation Moran's I coefficient of WTPs of two sub-areas can be expressed as

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(WTP_i - \overline{WTP})(WTP_j - \overline{WTP})}{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\sum_{i=1}^{n}(WTP_i - \overline{WTP})^2} \tag{7}$$

Moran's I coefficient is in the range of [-1, 1], 1 means spatial positive correlation, -1 means spatial negative correlation, and 0 means spatial independence.

3. Empirical Study

3.1. WTP Survey of Non-use Value of Songhua River Basin

The paper takes WTP for non-use value of Songhua River as object of study, and the object area includes 71 places in total in North Jilin Province and Heilongjiang Province in Songhua River Basin. Open double boundary two column questionnaire is designed. Guiding questions of the questionnaire are shown in Figure 1. Question 12 in Figure 1 has 7 different initial bid values, including RMB 1, 5, 10, 20, 50, 100 and 200[14]. If a respondent selects “Agree” (Yes) or “Disagree” (No) to paying the bid value, next lower/higher bid value (Question 13, 14) will be asked, finally the respondent is asked to answer his or her true WTP (Question 15).

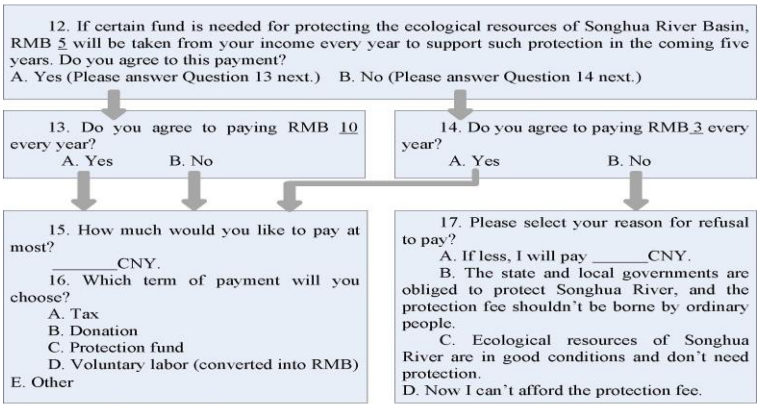


Figure 1. Design of Guiding Questions of WTP Questionnaire

In Sep and Oct 2012, 1660 copies of the questionnaire in total were handed out in Songhua River Basin covering 71 places (city/prefecture-level city/county) inclusive of Harbin, Kiamusze and Fuyuan. At last, 1,386 copies of questionnaire inclusive of 1,273 valid copies were recovered at the recovery rate of 76.68%. Mean WTP of every place is shown in Table 1.

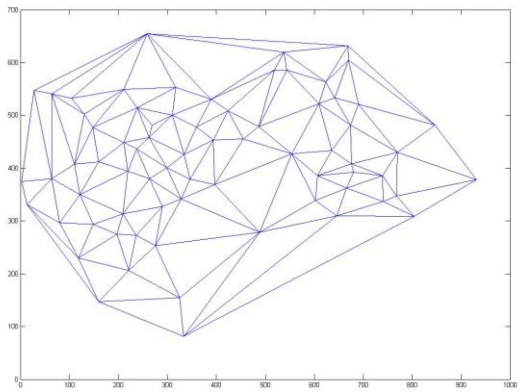
Table 1. Average WTP of Each Sub-area (CNY/person/year)

Residence	Mean value	Residence	Mean value	Residence	Mean value	Residence	Mean value
Acheng	154.55	Anda	45.00	Dumeng	142.22	Baiquan	27.50
Bayan	226.44	Baoqing	43.89	Hailun	83.50	Bei’an	200.33
Binxian	163.50	Daqing	188.27	Hulin	200.00	Dongning	82.14
Chaganhu	177.25	Hailin	220.83	Jidong	45.90	Fuyu	60.17
Fangzheng	60.95	Hegang	212.33	Jixi	177.27	Heihe	28.38
Fuyu	160.00	Huanan	87.67	Lindian	56.46	Kedong	100.00
Fujin	117.08	Jixian	62.50	Mudanjiang	154.50	Keshan	10.63
Harbin	196.55	Lanxi	62.14	Muleng	38.58	Longjiang	132.81
Hulan	148.04	Linkou	47.00	Ning’an	38.18	Nehe	280.00
Huachuan	70.00	Luobei	75.00	Qitaihe	75.38	Nenjiang	90.00
Jilin	100.43	Qing’an	31.25	Qinggang	191.67	Qiqihar	86.00
Kiamusze	241.66	Raohe	58.57	Shuangyashan	95.00	Suifenhe	93.33
Mulan	195.00	Shangzhi	60.00	Suileng	84.86	Sunwu	117.27
Qianguo	98.25	Suihua	307.58	Wangkui	64.00	Wudalianchi	101.54
Shuangcheng	192.63	Tieli	225.56			Yi’an	46.67
Songyuan	149.41	Wuchang	72.86				
Suibin	160.00	Yanshou	316.25				
Tonghe	281.54	Yichun	200.00				
Tongjiang	357.50	Youyi	421.92				
Yilan	94.71	Zhaozhou	91.60				
Zhaodong	292.58						
Zhaoyuan	95.21						

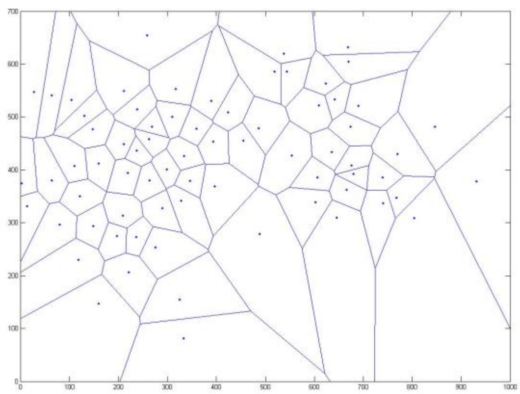
The first line of sub-areas in Table 1 belong to Songhua River Basin, and it's obvious that the mean WTP of such sub-areas is overhigh. The calculated result of mean WTP of whole river basin is 160.86 CNY per person a year.

3.2. Division of Sub-areas

Sub-area division takes administrative division as basic principle, to be exact, Songhua River Basin is divided into 700×1000 grids, coordinates of sub-area R_i is determined by the grid in which the government of relevant administrative region is located, Delaunay triangular mesh and Voronoi polygon are constructed. Figure 2 shows the division result of Delaunay triangular mesh and Voronoi polygon for the sub-area division of Songhua River Basin. As to coordinate marking, grid division method simplifies coordinate expression method on the premise of not changing the location relation among sub-areas, favorable for subsequent calculation.



(a) Delaunay Triangular Mesh



(b) Voronoi Polygon

Figure 2. Division of Sub-areas for Songhua River Basin

3.3. Construction of Trend Plane

Trend plane is constructed again according to the division result of Voronoi polygon in Figure 2(b). First, the adjacency relation among areas is determined according to Voronoi polygon result, then degree and direction of dip angle of every sub-area are further calculated to construct trend plane. To facilitate observation, this paper does not directly give 3D image of trend plane but adopt more visible observation method. WTP is divided into four levels in descending order, and expressed by rings in four kinds of color, dip angle of every sub-area is marked in ring by short line and uniformly depicted in Voronoi polygon picture. According to the statistical result of WTP of sub-area, 25%, 50% and 75% quantiles are used for division: red ($WTP \geq 192.63$), yellow ($100 \leq WTP < 192.63$), green ($62.5 \leq WTP < 100$), blue ($WTP < 62.5$). See Figure 3.

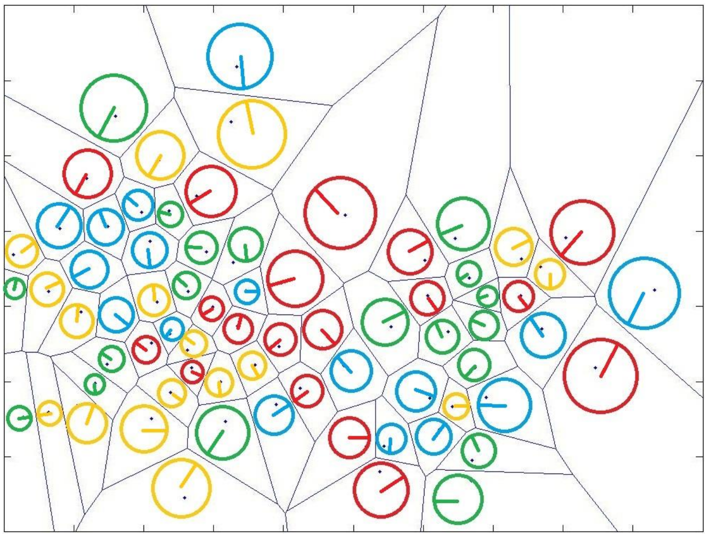


Figure 3. Trend Plane Effect of WTP for the Non-use Value of Songhua River

Through comparing Figure 2 with Figure 3, it's found that Songhua River flows from the lower left corner to top right corner in Figure 3. From Figure 3, it can be seen that, red and yellow areas are mainly distributed on the "lower left - top right" line, at high WTP, especially WTP in the upstream area (lower left) is much in the yellow area, while WTP in the downstream area (top right) is much in the red area, and this result may reflect the urgent demand of consumers in the downstream for water quality improvement of polluted Songhua River. Green area and blue area are evenly distributed on both sides of Songhua River. In view of clustering degree, red and yellow areas are dispersed. Green area is relatively closer to Songhua River, and blue area is relative farther away. Such distribution conforms to the conclusion of the first law of geography, also embodies the spatial attribute of WTP, *i.e.*, the closer a consumer is to an environmental article, the higher his or her WTP for the environmental article will be. In view of the dip angle of trend plane, most dip angles in red and yellow areas point to green and blue areas, similarly, most dip angles in green and blue areas point to red and yellow areas. This shows that payment amount is closer and doesn't fluctuate intensively in high WTP areas, so it's seldom that red and yellow point to each other; a similar conclusion is drawn for low WTP areas. For the transition from high WTP areas (red and yellow areas) to low WTP areas (green and blue areas), the speed of WTP fall is high, and the decrease trend is strong, so many high WTP areas and low WTP areas point to each other.

3.3.1. Spatial Autocorrelation of WTP of Different Sub-areas: For sub-areas in different colors, it can be seen that red and yellow areas are relatively centralized, while green and blue areas are relatively dispersed. In order to measure the spatial autocorrelation of every color area, Moran's I coefficient of global spatial correlation is adopted. Moran's I coefficient of seven sub-area sets are measured to describe WTP change in different spatial scales.

(1) Moran's I coefficient in red area: 0.756; (2) Moran's I coefficient in yellow area: 0.531; (3) Moran's I coefficient in green area: 0.419; (4) Moran's I coefficient in blue area: 0.207; (5) Moran's I coefficient in red+yellow area: 0.881; (6) Moran's I coefficient in green+blue areas: 0.492; (7) Moran's I coefficient in all areas: 0.174.

Red and yellow areas have higher coefficient showing that WTP of these areas have strong spatial clustering, red + yellow area has the highest coefficient showing that high WTP sub-areas have very high spatial clustering. According to previous analysis, the coincidence degree between high WTP area and Songhua River Basin is very high, as shows that the WTP of consumers near the environmental article is high and stable, these consumers can recognize own demand for the environmental article, and have high appeal for the sustainability and recovery of the environmental article.

Green and blue areas have relatively lower coefficient showing such areas are independent from each other, coefficient of green+blue area also doesn't exceed 0.5, as shows that interplay between low WTP areas is low. Blue and green areas are staggered on both sides of Songhua River, as shows that the cognition of the consumers farther away from the environmental article to the non-use value of environmental article widely differs and doesn't embody spatial clustering. Overall, the coefficient of all areas is only 0.174, basically taking on mutual independence.

3.3.2. Study of Influencing Factors of Distance Decay Effect on WTP: Many research findings show that distance decay effect exists in theory, as is also verified by empirical analysis. Which factors cause the distance decay effect on WTP? Does WTP simply change with distance or for certain reasons embodied in distance? This paper tries explaining them by the Probit model below:

$$WTP = \beta_0 + \sum_{i=1}^{n} \beta_i A_i + \sum_{j=1}^{m} \beta_j C_j + \varepsilon \tag{8}$$

First, for model variable, because variable is payment condition (WTP), 0 means refusal to pay; 1 means positive payment. Explanatory variables include two types. The first type is basic variable, *i.e.*, the respondent's basic social attribute variable (A_i), including:

(1) Sex: 0 means female; 1 means male.

(2) Age: 1-18 years old and below; 2-19 to 25 years old; 3-26 to 35 years old; 4-36 to 45 years old; 5-46 to 55 years old; 6-55 years old and above.

(3) Education degree (Edu): 1 means primary school and below; 2 means junior high school; 3 means senior high school; 4 means college or university; 5 means postgraduate or above.

(4) Annual income (Inc): RMB 10,000-3,000 or below; RMB 20,000-3,000 to 6,000; RMB 30,000-6,000 to 12,000; RMB 40,000-12,000 to 24,000; RMB 50,000-24,000 to 36,000; RMB 60,000-36,000 to 48,000; RMB 70,000-48,000 to 60,000; RMB 80,000-60,000 to 120,000; RMB 90,000-120,000 or above.

The second type is cognitive variable representing the respondent's degree of familiarity (C_j) with Songhua River, including

(5) Does Songhua River flow through the city in which you live?(Flow) 0 - no; 1 - yes.

(6) Do you know Songhua River (Cogn)? 1 - not at all; 2 - no; 3 - ordinary; 4 - very much; 5 - extremely familiar.

(7)Dip angle of sub-area (Theta): calculated value. The variable is a spatial attribute variable incorporated into the model as cognitive variable to explain the reason for influencing distance decay effect.

β_0 is constant term, β_i and β_j are regression coefficients of variables A_i and C_j respectively, and ε is random error conforming to $N(0,1)$. Five Probit models including different variable combinations are established, thereof Model1 only includes basic variable, Model2~Model4 increase one variable respectively on the basis of basic variable, *i.e.*, Folw, Cogn and Theta, and Model5 includes all of seven variables in total.

Regression coefficients of model are shown in Table 2. First, the basic variables of five models are compared. Although variables Sex and Edu of five models didn't pass significance testing, their coefficients keep stable basically, and fluctuate around -0.19 and 0.12 all the time. This result is consistent with the conclusions of most researchers [15-16], *i.e.*, female respondents and high education level respondents have high WTP for the environmental article. The stability of the two variables also shows degree of cognition and distance don't significantly influence another two variables sex and education level. For variable Age, all regression coefficients of five models pass significance testing and are stable around -0.24. The result shows that degree of cognition and distance don't significantly influence the age variable, and younger respondents have higher WTP.

Table 2. Result of Probit Model for the WTP of Songhua River Basin

	Model1		Model2		Model3		Model4		Model5	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Constant	2.673***	0.000	2.095***	0.000	2.396***	0.000	3.168***	0.000	2.104***	0.001
Sex	-0.206	0.201	-0.215	0.182	-0.198	0.216	-0.192	0.236	-0.186	0.253
Age	-0.252***	0.000	-0.234***	0.001	-0.246***	0.000	-0.256***	0.000	-0.225**	0.002
Edu	0.113	0.237	0.124	0.200	0.134	0.168	0.108	0.262	0.152	0.126
Inc	0.266**	0.048	0.068	0.134	0.070	0.126	0.062	0.175	0.072	0.120
Flow			0.337**	0.028					0.555**	0.001
Cogn					0.066	0.317			0.093*	0.099
Theta							-0.257**	0.002	-0.398***	0.000

Note: *, ** and *** mean a coefficient is significant on the level of 0.1, 0.05 and 0.01 respectively.

For variable Inc, regression coefficient 0.266 in Model1 is significantly higher than that of the rest four equations inclusive of cognitive variable, moreover, regression coefficient of Inc in Model1 is significant, but that of any of the rest models is insignificant. We guess the reason may be that degree of cognition and distance influence WTP, when a model excludes such variables, their influence is embodied in income variable. In other words, when a model includes degree of cognition and distance variables, the influence of income variable on WTP is weakened.

For cognitive variable, variable Flow is significant in both Model2 and Model5. Regression coefficient shows that Flow positively influences WTP, *i.e.*, a respondent who lives in Songhua River Basin has high WTP. Variable Cogn passes significance testing in Model5, its regression coefficients in Model3 and Model5 are positive, showing that the more the respondents know about Songhua River, the higher their WTP will be. Regression coefficients of variable Theta in Model4 and Model5 are negative, and pass significance testing, it's noteworthy that, the WTP is high in Songhua River Basin in Figure 3, the dip angle points to low WTP direction, consistent with negative dip angle, so variable Theta also shows that the respondents closer to the environmental article have higher WTP.

Explanation of the three variables Flow, Cogn and Theta shows the existence of distance decay effect, next the causes of distance decay effect are analyzed. In Model5, the significance of regression coefficients of the three variables above is no less than that of Model2 to Model4, moreover, the absolute values of regression coefficients also increase. The result shows that degree of use and degree of cognition of Songhua River are in positive promotion relation with distance. Hence the real reason for distance decay effect on WTP is not simply distance but degree of use of and familiarity with the environmental article embodied in distance.

For an environmental article, consumers closer to it can enjoy higher external economic benefit of environmental article, causing higher consumer surplus, so they are likely to have higher WTP. On the other hand, consumers closer to it are under the largest direct influence of quality of environmental article, so they more clearly recognize current damage degree of environmental article, have higher demand for protection and recovery and higher WTP. Both the two variables degree of use of and familiarity with an environmental article are directly influenced by the distance between consumers and the environmental article, so distance decay effect appears in the model, *i.e.*, distance variable is in obviously negative correlation to WTP.

4. Conclusions

Taking the non-use value of Songhua River as object of study, the paper studies the spatial attribute of WTP through constructing trend plane, and explores the influencing factors of distance decay effect on WTP.

In theory, the paper first demonstrates the regional difference in cost sharing of environmental article, to be exact, consumers in different regions have different degrees of consumption, so their cost sharing should differ. Such difference is embodied in WTP difference, *i.e.*, distance decay effect on WTP.

Second, the paper provides division principle of sub-areas and construction method of trend plane based on Voronoi polygon. The method combines the advantages of Voronoi model and Kriging model, with small calculated amount, simple application and visible result, favorable for analysis. Through Voronoi polygon, spatial weight matrix of sub-area is determined, and spatial autocorrelation coefficient of object area is calculated.

Trend plane of WTP in spatial perspective is constructed through studying the WTP for non-use value of Songhua River. The construction result of trend plane shows that the WTPs of 71 sub-areas can be classified into four different levels, high WTP sub-areas are mainly centralized at Songhua River Basin, *i.e.*, the WTP of upstream is slightly smaller than that of downstream; low WTP sub-areas are dispersed on both sides of Songhua River. Moran’s I coefficient result shows the high WTP areas take on obvious spatial clustering, low WTP areas have low correlation and are independent from each other. Overall, the object area doesn’t show strong spatial clustering.

Distance decay effect on WTP in spatial perspective is explained by Probit model. The model result shows that, when the model excludes cognitive variable, a consumer’s cognition level on environmental article is mainly embodied by annual personal income; when the model includes cognitive variable, the significance of annual personal income decreases. The distance decay effect on WTP, in essence, is a consumer’s familiarity with and degree of cognition of an environmental article, the closer a consumer is to the environmental article, the more urgent his or her demand for sustainability and recovery of the environmental article will be, as is embodied in distance decay effect.

The paper puts forward and verifies a method for spatial attribute study of WTP. When the regional WTP data of a sub-area includes geographic coordinates, WTP, dip angle, direction vector and other multidimensional information, how to model WTP in higher dimension space and verify the model? These problems are not explored in this paper, and will be further demonstrated in the future.

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