BENEFIT EVALUATION OF INFRASTRUCTURE IMPROVEMENT USING GIS INTEGRATED SYSTEM*

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1. Introduction

Benefit evaluation of infrastructure improvement is a big issue in infrastructure planning parts. There are many kinds of approaches. In this study, specially, we focus on land market approaches. By capitalization theory, most of the benefits of infrastructure improvement accrue land prices under some limited conditions(small and open). Land market approches are divided into two parts : land price approach and Rosen's Hedonic approach.

In land market approaches, we need land attributes for land price function and benfit evaluation of infrastructure improvement. In geographic information system(GIS), we can directly get the information of land attributes at any sites. And, we can know the area affected by infrastructure improvement, more concreately and objectively. Also, we can display the spatially distributing and changing situation of land price and benefit of improvement, more effectively.

On such a background, in this study, we make GIS integrated benefit evaluation system and apply the proposed system into the benefit evaluation of new urban railway.

2. Benefit Evaluation Approaches Using Land Market Data

(1) Definition of Benefit

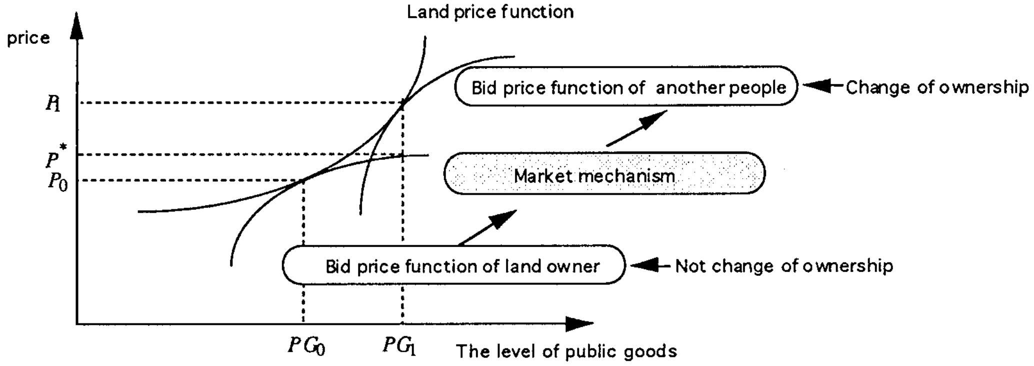

Figure 1: Concept of Benefit in Land Market Approach

a) Land Price Approach

In case of land price approach, benefit is defined as the difference of land price between before and after infrastructure improvement. But this approach has the possibility of overestimation of benefits[1].
In figure 1, the benefit of land price approach by the change of public goods level from PG_0 to PG_1 is $P1-P0$.

b) Rosen's Hedonic Approach

Rosen[2] developed the conceptual framework for analysis of the hedonic approach. He suggested a two-step procedure for estimating the demand for housing characteristics. First step, he estimates land price function and, second step, estimates utility function's parameters. After getting utlilty function's parameters, benefit can be estimated as WTP(willingness to pay). In figure 1, the benefit of Rosen's Hedonic approach is $P^* - P0$.

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(2) Land Price Function

Social-economic phenomena(land price, utility, etc.) can be explained as functions of one or more explanatory variables. Actually, we do not know the appropriate functional form for land price function. If we increase parameters, the output is more accurate, but it also increase the computational cost of estimating parameters and complicates interpretation of parameters. So that, in econometric studies, usually, functional form is decided on the properties of the data and the desired precision. In this study, we use multiple linear regression function, Box-Cox function and neural network(NN)as land price function.

a) Multiple Linear Regression Function

As a land price function, we usually use multiple linear regression model. It is simple and easy to interpretate the parameters. But, in case of linear regression model, when we get derivatives, the value of derivatives is constant. That is, marginal price of variables is constant. It means that the parameters can only explain the absolute magnitude. It can not explain the relative magnitude, depending on other land chacteristic changes.

b) Box-Cox Transformation Function

Many kinds of functional forms can be used as nonlinear land price functions. These days, as a nonlinear land price function, linear Box-Cox transformation function is usually used. In this functional form, nonlinear function is transformed into linear functional form. So, it has the advantage of linear function. And it also has the advatage of nonlinear function. That is, it can explain the relative magnitude, depending on other land chacteristic changes, as well as absolute magnitude.

The functional form of Box-Cox transformation function is like below.

$$P(\lambda)=\begin{cases}(P^{\lambda}-1)/\lambda & \lambda\neq 0\\ \ln(P) & \lambda=0\end{cases}\qquad(2-1)\qquad\qquad h_i(\lambda)=\begin{cases}(h_i^{\lambda}-1)/\lambda & \lambda\neq 0\\ \ln(h_i) & \lambda=0\end{cases}\qquad(2-2)$$

$$P(\lambda)=\beta_0+\sum_{i=1}^{n}\beta_i h_i(\lambda)\qquad(2-3)$$

c) Neural Network(NN)

We try making land price function using neural network(NN). In NN, parameters are trained by back-propagation algorithm. Functional form of back-propagation is like below.

$$w_{ij}(i+1)=w_{ij}-\eta\frac{\partial E}{\partial w_{ij}}\qquad(2-4)$$

where $\eta=$ *gain factor*, $E=$ *error between output of NN and supervised data*

(3) Utility Function

As a utility function, Cobb-Douglas utility function, C.E.S. (constant elasticity substitution) utility function, G.C.E.S(general constant elasticity substitution) utility function and Trans-Log utility function are usually used. In this study, G.C.E.S is used as utility function. The functional form of G.C.E.S is specified like below.

$$U=\left[\sum_{i=1}^{n}\alpha_i h_i^{\gamma_i}+X^{\varepsilon}\right]^{\phi}\qquad(2-5)$$

(4) General Inverse Matix for Multicollinearity Problem of Multiple Linear Function

When strong multicollinearity is present, we can use general inverse matrix to calculate point estimates that are "closer" to the true values of model parameters than are usual least square point estimates[3]. When we estimate the parameters of multiple linear regression function (2-3) and (2-10), we use general inverse matrix concept. The mathmatical form of normal equation suggested by Moore Penrose is like below.

$$\beta X+\varepsilon=Y\rightarrow\qquad\begin{cases}X=(\beta'\beta+cI)^{-1}\beta' Y\\ where\ \ usually\ c=0.001\end{cases}\qquad(2-6)$$

(5) Robust Estimation Solving Data Outlier Problem

When we estimate land price, some data of land price are occasionally just way off. Data like this are called outliers. They can easily turn a least squares estmates into nonsense. Using weights decided by robust statistics, we can deal with cases where the normal or Gaussian model is a bad approximation. In this study, we use Turkey's biweight method as weight deciding method. Functional form is like below.

$$w_i=\begin{cases}[1-(z_i/cs)^2]^2 & |z_i|<sc\\ 0 & |z_i|<0\end{cases}\qquad(2-7)$$

where $z_i=\upsilon_i/\sigma$, $s\equiv median\{|z_i|\}$, $c=$ *selection from 5 to 9*, $\upsilon_i=$ *residual of data i*, $\sigma=$ *standard deviation*

(6)Mathmatical Expression of Benefit

a) Benefit of Land Price Approach

Using cross-sectional analysis, we estimate land price function under unimprovement condition and using this function, we can calculate land price after infrastructure improvement. If we could assume that land price is LP, before infrastructure improvement, and land price is LP^*, after infrastructure improvement. Then, in land price approach, the benefit of infrastructure improvement is specified like below .

$$Benefit = LP^*_{after\ improvement} - LP_{before\ improvement} \qquad (2-8)$$

b) Benefit of Rosen's Hedonic Approach

The theoretical framework explained here follows Quigley's application of Rosen's two-step procedure[4]. First step land price function is estimated and Second step, utility function is estimated. Each household consumes $H(h_1, h_2, \ldots\ldots, h_n)$, a vector of housing characteristics, and X, a composite of all other goods, which is numeraire. The price of each characteristic that makes up the housing bundle is not directly observed. Only market rent or land price(or housing price) $P(H)$, is observed. A GCES utility function is assumed. The representative household must choose its consumption bundle (X, H) by solving the following constrained maximization problem:

$$\max_{hi,X}\ U = \left[\sum_{i=1}^{n} \alpha_i h_i^{\gamma_i} + X^{\varepsilon}\right]^{\phi} + K[I - P(H) - X] \qquad (2-9)$$

where $K = Lagrange\ multiplier$

The first-order maximization conditions subject to the budget constraint yield the form for log-linear estimation.

$$\ln(\partial P / \partial h_i) = \ln(\gamma_i \alpha_i / \varepsilon) + (\gamma_i - 1)\ln h_i + (1 - \varepsilon)\ln\{I - P(H)\} \qquad (2-10)$$

Using multiple linear resgression, we can identify the parameters of utility function. Then, we can get CV and EV as a benefit.

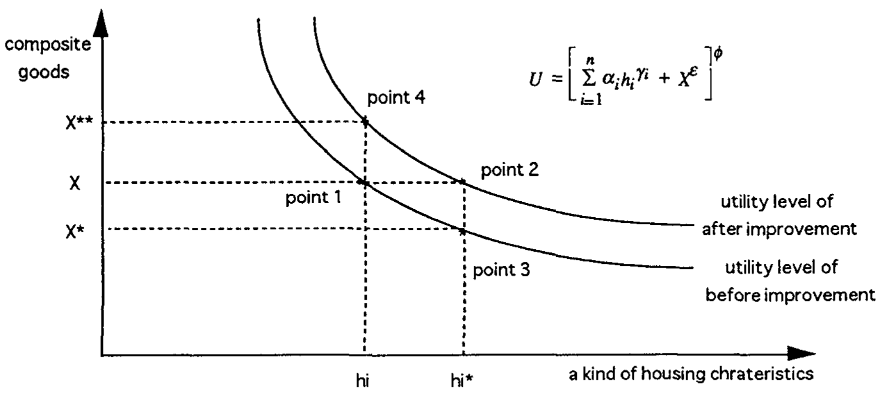

Figure 2: Concept of CV and EV in Rosen's Hedonic approach

$$CV = X - X^* = X - [\sum_{i=1}^{n} \alpha_i h_i^{\beta_i} - \sum_{i=1}^{n} \alpha_i h_i^{*\beta_i} + X^{\varepsilon}]^{1/\varepsilon} \qquad (2-10)$$

$$EV = X^{**} - X = [\sum_{i=1}^{n} \alpha_i h_i^{*\beta_i} - \sum_{i=1}^{n} \alpha_i h_i^{\beta_i} + X^{\varepsilon}]^{1/\varepsilon} - X \qquad (2-11)$$

3. Obtaining Land Attributes for Land Price Function in GIS

(1) Land Attributes for Land Price Function Estimation

For estimation of land price function, many kinds of land attributes are used. As a typical examples, accessibility conditions(distance to CBD, distance to station, distance to school, etc.), road conditions(road network condition, road width, pavement condition, etc.), residential environmental conditions(gas service, water service, sewer service, aspect of house, slope of ground, neighborhood park, etc.), and administration conditions(land use constraints, administration boundary, etc.) are used.

(2) Obtaining Land Attributes in GIS

a) Land Attributes Related Accessibility Conditions

GIS is the computer software tools with georeference system. Using georeference system, we can calculate the Euclidean distance of two points. But, actually, time distance of two points is more important factor as land attributes. Using some tools(networking function and shortest path function of time distance) in GIS, we can also easily calculate time distance of two points. And using voronoi map, we can decide the influence boundary of each station.

b) Road Conditions

we can also know road network condition with networking function in GIS. Road width and pavement condition can retrieve and be used as attributes in database management system of GIS. The distance from road can be calculated using buffer function.

c) Residential Environmental Conditions

Gas service, water service, and sewer service condition can be managed as maps with attribute data in GIS. And aspect of house and slope of ground can be calculated with DEM(digital elevation model) data in GIS. Also, accessibility to neighborhood park can be calculated as Euclidean distance or time distance.

d) Administration Conditions

Land use constraints can be also managed as maps with attribute data in GIS. And, administration boundary can be defined as a polygon and a map with attribute data in GIS. So we can get some land attributes related administration condition.

4. Overview of GIS Integrated Benefit Evaluation System

Using background theories and idea discussed in 2. and 3., we make GIS Integrated Benefit Evaluation System. Overview of GIS Integrated Benefit Evaluation System is like below.

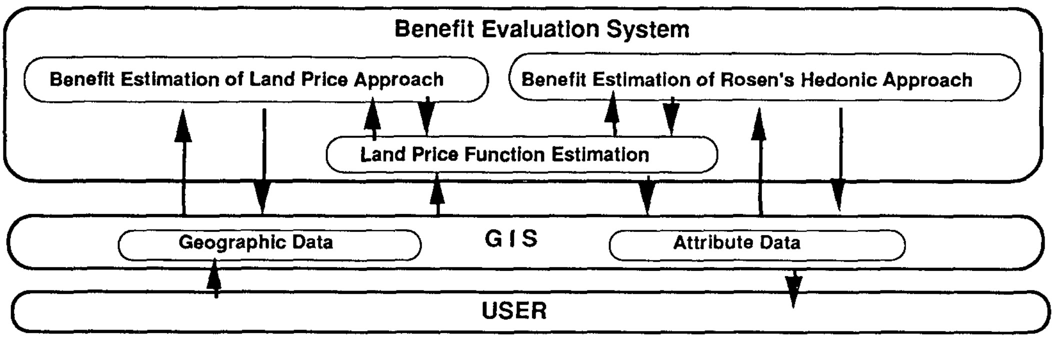

Figure 3: Overview of GIS integrated benefit evaluation system

5. Conclusion

Economic information(e.g., potential benefits or costs, etc.) associated with projects can play an important role in the infrastructure planning process. In this paper, we try to make GIS integrated benefit evaluation system, using land market approaches. In case of Non-GIS method, it is very difficult to estimate the effect of infrastructure improvements at all sites. Only we can check sample points and make average of effect. And collecting land attributes is also burden in Non-GIS. But, in GIS integrated system, we can directly get the information of land attributes at any sites. So, all sites can be checked and estimated for the effect of improvement, more concreately and objectively. From social justice point, this is very important advantage that we can prepare the basis of fairy and reasonable benfit estimation about the sites undertaking improvement gains. And this system can be also used as project simulation system, when we compare each option of many projects.

References

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