A QUANTITATIVE TRANSPORTATION PROJECT INVESTMENT EVALUATION APPROACH WITH BOTH EQUITY AND EFFICIENCY ASPECTS[1]

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ABSTRACT

The motivation of this study is to develop a comprehensive evaluating approach for transportation investment with consideration of both efficiency and equity aspects, since the projects evaluation methods in practice mostly focus on the efficiency evaluation, while lacking transportation equity issues.

Transportation infrastructures have great impacts on social and economical development, which may be positive or negative. The investment effects should be evaluated impersonally, with consideration of efficiency, equity, as well as environmental effect. Besides the evaluation of the necessity of the project investment, the priority of different construction projects and their effects on different regions and social groups should also be examined. Proper evaluation is essential to ensure the fairest distribution of social benefit from construction projects.

Traditional evaluation methods for transportation projects investment, primarily cost-benefit analysis, emphasize economic efficiency such as government's and users' benefits but disregard equity impacts. This may lead to an incomprehensive or even an unreasonable investment decision. This study thus provides an approach on introducing equity impacts into transportation planning process and explores the concepts of various types of equity. Four quantitative models are proposed to evaluate four types of equity. Parameters reflecting the differences among different development level regions and social compensation of disadvantage groups are discussed in this paper. Hereafter, an evaluation model from both equity and efficiency aspects for highway infrastructure investment appraisement is developed based on the theory of Wilson's entropy. This model takes into account the differences among areas, the differences among social groups. In addition, Lagrangian method is used to testify the model and to prove the result possess optimal benefit distribution. Sensitivity analysis for the evaluation model is also conduct in this paper. Twelve

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highway investment projects in China are studied as an example to test the practicability of the model. The result shows that the priority of these construction projects given out by the model considering both equity and efficiency is observably different from the result of BCA. It shows that the model is practical and applicable. However, further studies about transportation equity still need and the model still needs to be improved.

KEYWORDS

Transportation investment, Equity, Cost-benefit analysis, Wilson entropy

1. INTRODUCTION

Transportation infrastructures have great impacts on social and economic development. In China, development has been the first task for a long time, the constructions of new transportation infrastructures and improvement of transportation system are in great need, i.e., high speed economy are emphasized in almost all social activities. However, transportation projects generally need a large quantity of capital investment that is hardly paid back especially for uncharged transportation facilities. Due to limited financial funds, the society demands that the government implement the more efficient public infrastructure investments firstly. Consequently, various evaluation techniques and manuals are put forward with cost-benefit analysis (CBA) as the most popular method. While CBA is widely used in the decision-making processes of governments in different countries such as the UK (Vickerman, 2000), France (Quinet, 2000), USA (Lee, 2000), Japan (Morisugi, 2000), and some other developing countries (Talvitie, 2000), its limitations are gradually revealed. Particularly, CBA focuses mostly on the efficiency of project investment, but social equity impacts, another significant aspect of social-welfare, are vaguely considered in CBA (GUO, 2001).

Economic development in China should bring advancement and welfare to the whole society fairly and equally. Transportation equity is surely one of the important equity aspects to be kept on. Harmonious development among regions that Chinese government proposed calls for transportation equity, for it emphasizes equitable among regions. The put forward of sustainable transportation and Green Transportation last century also calls for transportation equity, as the use of resource and environment should belong to the whole world. Therefore, this study aims at developing a comprehensive evaluating approach for transportation investment with consideration of both efficiency and equity aspects.

2. LITERATURE REVIEW

It seems not easy for people to judge whether something is fair or unfair, not to mention the degree of fairness or justice which due to the mixture and complexity of equity analysis. The notions of equity and fairness have no universally definitions. This explains why there has been few researches conducted on social equity in the past. John Rawls (1971) set up a typical theory of justice which presents a theory called “justice as fairness.” That theory comprises two principles of justice which are to guide public judgments about their constitution, laws, and basic social rights. The first principle—principle of equal basic liberties—expresses an egalitarian concept of justice. Meanwhile, the second principle—difference principle—states that people who are equally talented and motivated must have equal chances to attain desirable positions—that a person's fate in life should not depend on the social circumstances of his/her birth and upbringing, and the greatest benefit should be arranged to the least advantaged members of society. John Rawls's theory can be introduced into the transportation area since in a modern society; transportation is always treated as people's basic right to gain access to other places. A vague concept of transportation equity was traced in 1770 when the founder of market economics, Adam Smith, mentioned the equity of transportation pricing inadvertently. He thought that luxurious goods should be charged a higher transport tax rate than living necessities to spare the lower classes. O´scar A ´ lvarez (2007), etc. found that people of different income level have different sensitivity on transportation toll. The National Cooperative Highway Research project (1994) defines equity as the distribution of cost and benefit among people of different incomes (Viegas, 2001). The European Union Transport Research Fourth Framework Program (2000) invokes two dimensions of equity, horizontal equity associated with the principle of equality of opportunities, and longitudinal equity associated with the comparison of conditions between present and past, for each individual citizen, and for social groups. And Rune Elvik (2009) also pointed out that transportation infrastructure would affect people's safety in different regions in different degree. Litman (2003) stated that nearly one third of Canadian families are transportation disadvantaged, and inadequate transport sometimes contributes to social exclusion. This is particularly true for people who live in automobile-dependent communities and are physically disabled, have low income, or are unable to own and drive a personal automobile. As to the evaluation model of transportation equity, Silva H. and Tatam C. (1996) made some modifications to the Multi-Criteria Assessment models and selected the criteria to represent regional and community groups' interests. The evaluation results can address both efficiency and equity issues, but the whole procedure is too complex and relies on large-scale investigation of personal intent.

Therefore, the purpose of this study is to establish an evaluation model for transportation projects investment considering equity quantitatively. Parameters reflecting differences among different development level regions and social compensation of disadvantage groups are introduced and different kinds of equity and various equity impacts of transportation investment, explore practical ways of evaluation, and build a quantitative equity evaluation model for transportation projects. Moreover, the results could become useful guidelines for policy makers in the government as they determine future law and investments.

3. CLASSIFICATION AND QUANTITATIVELY MEASURE OF TRANSPORTATION EQUITY

Transportation equity reflects mainly in four aspects (Shi et al, 2009): equity among different traffic modes, different social groups, different regions, and different generations. In this part, four kinds of equity are described and quantitative evaluation models are introduced.

3.1 The equity among different traffic modes

The core of equity among different traffic modes is the unfair social cost sharing. That is what one person pays for his trip is not equal to what he gets from the trip. Some road users bear the extra cost others bring to them, such as traffic congestion, noise, air pollution, traffic accidents, etc.

From the view of equity, one should pay for the social cost he causes. A model measuring difference of cost can be used to evaluate the equity among different traffic modes. The model is as follow.

$$
\begin{aligned}
\min SV &= \sum_i \int SV_i(t)dt \qquad \forall i,t \\
&= \sum_i \int \left| \sum_j CS_{ij}(t) - \sum_j CR_{ij}(t) \right| dt \\
& CS_{ij}(t) > 0, \quad CR_{ij}(t) > 0 \\
& i = 1,2,\dots,I \qquad j = 1,2,\dots,J
\end{aligned}
\tag{1}
$$

In the model:

$SV_i(t)$—the difference between what the users of traffic mode *i* should pay and what he pays indeed in a given time period *t*.

$CS_{ij}(t)$—the social cost *j* that the users of traffic mode *i* should pay in a given time period *t*.

$CR_{ij}(t)$—the personal cost *j* that the users of traffic mode *i* pays in a given time period *t*.

I—the number of kinds of traffic modes.

J—the number of kinds of social cost.

If the difference between $CS_{ij}(t)$ and $CR_{ij}(t)$ is larger, it means other road users pay more extra cost caused by users *i*. Social equity becomes worse. So the smaller *SV* is, the more equity it is.

3.2 The equity among different social groups

Sustainable development of traffic points out that some social groups should not sacrifice other groups' benefits, such as lower income people, handicapped ones, elder ones, children, women, etc, to gain their own traffic benefits.

To compensate transportation disadvantaged groups, the government should improve their travel condition. Lower income people prefer lower expense traffic modes, such as public transit, bicycle, walking, etc. So it is important to develop the condition of these traffic modes.

With social development and population's aging, transportation disadvantage groups attract more and more attention. From the view of equity, they should enjoy the same travel opportunity with others. So the investment of transportation project should focus on benefits distribution among different social groups and the government should compensate the disadvantage groups for their less benefit got from transportation.

Research about equity in traditional economic theory is mainly about income distribution. Classical ways of judging are Lorentz Curve and Geordie Coefficient. With the development of equity, many models are put forward. However, they are mainly based on horizontal equity[1], and the optimal state is absolutely equally benefits distribution. As one problem about equity among different social groups is social compensation for transportation disadvantage people, that is vertical equity[2]. An evaluation model based on Wilson entropy is set up (Shi et al, 2008; Yang et al, 2005).

In thermodynamics, the systemic entropy describes the disordered extent of a system. When the systemic entropy reaches maximum, the system becomes most disordered. In this paper, we use systemic entropy to describe the equilibrium degree of the benefits distribution in a region. The larger the systemic entropy of a region is, the more equity the benefit distribution in the region is.

First, the definition of social compensation α_i will be explained. Benefit groups will be divided according to their benefit and cost brought by the project. And based on the principle of vertical equity, those transportation disadvantaged groups should get benefit compensation. α_i is the weighting coefficient for social compensation. For any group *i*, $\alpha_i \geqslant 1$, the bigger α_i is, the more compensation group *i* should get. The model is as follow.

$$\min R = 1 - \frac{S}{S_{\max}} \tag{2}$$

$$S = \sum_{i=1}^{m} \frac{G_i(\ln G_i - \ln \alpha_i)}{\alpha_i} \tag{3}$$

$$s.t. \begin{cases} \sum_{i=1}^{m} \frac{1}{\alpha_i} G_i = 1 \\ 0 \le G_i \le \alpha_i \end{cases} \tag{4}$$

In the model:

R—the extent of benefit equity among different social groups;

S—the systemic entropy at one benefits distribution state;

G_i—the benefit that the project bring to group *i*, and G_i is normalized;

α_i—the weighting coefficient for social compensation;

S_{max}—subject to equation (4), the maximum systemic entropy at the optimal distribution state;

m—the number of social groups.

From the model, it is known that $0 \le R \le 1$. A smaller *R* means a bigger *S*, and the bigger *S* is, the larger the systemic entropy of the region is. So the smaller *R* is, the more equity the society is. When *R*=0, the benefit distribution reaches optimal and it is the most equity status. When *R*=1, the society reaches a most inequity status.

3.3 The equity among different regions

Because transportation infrastructure affects people nearby more, the equity among different regions must be considered before the project is decided. Based on the theory of diminishing marginal utility, the same amount of money is usually more useful for regions undeveloped.

[1] Horizontal equity is concerned with the distribution of impacts among individuals and groups considered equal in ability and need.
[2] Vertical equity is concerned with the distribution of impacts among individuals and groups that differ in abilities, needs, income, or social class.

So comparing with transportation investment in developed regions, it makes more sense to improve the traffic condition in undeveloped regions.

The improvement of transportation infrastructure in undeveloped regions will bring more social benefit and it is much fairer. Price index *P*, housing expense *Q*, and average personal income *Y* are used to indicate the economic developed level of different regions. Region *k* is used as a reference to calculate the equity evaluating index β[1] of regions.

$$\beta = \left(\frac{P}{P_k}\right)^{-(1-B)(1-\varepsilon)} \left(\frac{Q}{Q_k}\right)^{-B(1-\varepsilon)} \left(\frac{Y}{Y_k}\right)^{-\varepsilon} \qquad (5)$$

In the model:

β—the equity evaluating index of a region. The bigger β is, the more undeveloped the region is. The project should be constructed earlier;

Y, Y_k—the average personal income of the region studied and that of the reference region;

P, P_k—the price index of the region studied and that of reference region;

Q, Q_k—the housing expense of the region studied and that of reference region;

B—the proportion that the housing expense takes in the family's cost;

ε—the level of equity that population comprehend, between 0 and 1. It can be get from investigation.

In general, the more developed the region is, the bigger the value of ε is and the smaller the value of β is. So those undeveloped regions usually get a greater β.

3.4 The equity among different generations

The analysis of effect that transportation investments and policies bring to people in different societies and sustainable transportation attract us to analyze the equity among different generations. The concept of sustainable development was first put forward in the World Conservation Strategy. It is defined as "The ability to meet the needs of the present without compromising the ability of future generation to meet their own needs." As to the Sustainable Transportation, the definition is "The ability to meet the needs of current society to move freely, gain access, communicate, trade, and establish relationships without compromising the ability of future generation to meet their own needs." The equity among different generations was first put forward by T. R. Page. It mainly involves the distribution of welfare and resource among generations.

Transportation fundamental infrastructure usually needs great investment and has a longer service life. And it has great affection on society, economic, etc. The main points of the equity among different generations are as follow.

1. Transportation fundamental infrastructure usually needs great amount of land. As land resource is rare resource, the conflict between the limited provision of land and the need is always existed. The over use of land resource will deprive our progeny of the developing rights.

[1] The derivation of Regional Equity Coefficient β is explained in the Appendix.

2. Transportation also brings bad on energy use and environmental pollution, such as air pollution, acid rain, noise, photochemical radiation, etc. The pollution decreases population's living quality and damages survival environment of our progeny.

3. Transportation damages the cities traditional culture with the cut off the cities' spatial structure. Cities' spatial structure is the reflection of the cities' history and culture. The carrying out of big traffic facilities should be the continuation of the history and culture. But in reality, cities' spatial structure is often damaged by the instruction of new traffic facilities.

From the analysis above, it is known that to improve the equity among different generations, the optimization of the cities' traffic structure and the mode of land-use is important.

The core of the equity among different generations is chance equality. However, because the difference of information and knowledge, many people still do not recognize it.

At the same time, with the development of economic, people's requirement on resource and environment will be increasing. So the evaluation model is as follow.

$$K_{n,n-1} = \left(\frac{E_n}{E_{n-1}}\right) \Big/ f(i) \tag{6}$$

$$f(i) = f\left(M, S, L\right) \tag{7}$$

In the model:

$K_{n,n-1}$—the index of evaluation for equity among different generations, 10 years as one generation. While $K_{n,n-1}$=1, the next two generations reaches relative equity. While $K_{n,n-1}$<1, it is more beneficial for the former generation. While $K_{n,n-1}$>1, it is more beneficial for the later generation

E_n, E_{n-1}—living quality of generation n and generation $n-1$. It can be reflect by the evaluation indexes of resource and environment.

$f(i)$—the preference rate of generation n and generation $n-1$. It is a function on life level (M), technology level (S), environment level (L). As the increase of these aspects, people are more willing to, and also more capable to increase investment on them, so as the preference rate.

4. HIGHWAY INFRASTRUCTURE INVESTMENT EVALUATION MODEL CONSIDERING BOTH EQUITY AND EFFICIENCY

4.1 Traditional evaluation method for highway investment

The widely used Traditional evaluating method is called CBA (cost-benefit analysis). All the cost and benefit that may be take place in the evaluation period are converted to the net present values (NPV). Then the benefit NPV and the cost NPV are used to analysis whether it is worth to invest a highway facility.

$$C = \sum_{j=1}^{T} \frac{C_j}{(1-q_0)^j} \tag{8}$$

$$B = \sum_{j=1}^{T} \frac{B_j}{(1-q_0)^j} \tag{9}$$

j—a single year in the evaluation period, j=1, 2, ⋯, T.

T—the total evaluation period of highway projects

C_j, B_j—costs and benefits in the year j .

q_0—social discount rate

Based on the CBA method and the principle of consumer surplus, time value, operating cost, environmental cost, and expense of accident loss are taken into account in the quantitative analysis of *C*, *B*. While *C*>*B*, usually it is not worth to invest except for some special reasons such as political reasons. While *B*>*C*, the highway facility is worth to invest. But if there are many highway facilities waiting to be chosen, then the value of *B* and the rate of *B* to *C* are considered in the evaluation. Furthermore, costs and benefits are estimated in the whole project lifecycle, which is the construction period plus 30-50 years depending on the service lifespan of the facility. The social discount rate, such as 4% (0-40 years) in Japan and 3.5% (0-30years) in England, is used to convert all the costs and benefits into the Net Present Value (NPV).

4.2 Equity issues impacting on highway infrastructure investment

Initially, the recognition of equity is limited in the judgment of income distribution. With the extension of research area, the concept of equity permeates through various disciplines and social problems. As for the equity impacts of highway infrastructure investment, they could be categorized into three aspects: public involvement and awareness of the decision-making process, regional equity with regard to the differences of economic development among areas, and vertical equity with regard to the differences of social-economic benefits distribution between advantaged and disadvantaged groups.

4.2.1 Public involvement and awareness

The Intermodal Surface Transportation Efficiency Act (ISTEA) advocates that transportation infrastructure decisions should involve public participation. This is because the traditional planning system merely includes experts and governors in the decision-making process and excludes the public. Since highway projects influence people of various social backgrounds and economic status, social welfare could not be fully promoted if different benefit groups do not have equal right of participation and expression.

4.2.2 Regional equity among different areas

According to the principle of diminishing marginal utility, 100 dollars has a higher value for low-income groups than high-income ones. Thus, most people would prefer public policies promoting the economic status of the low-income class rather than the high-income class

(Almeida et al., 2004). With the comparison of highway infrastructure investment in developed areas, it is easy to get public agreement on similar investment in undeveloped areas.

Based on such agreement, it is important to consider the differences of economic development among areas, the public recognition of equity, and the like to make a wise decision concerning highway infrastructure investment. Progressive policies and measurements should be taken to compensate for overall inequities, reduce the economic gaps among different areas, and therefore promote fair and reasonable development of society and economics.

4.2.3 Equity among different benefit groups

Sustainable transportation development indicates that some groups or individuals should not benefit at the expense of others, especially the disadvantaged groups or individuals (Sanchez et al., 2003). For example, in recent years, high-income private car users (only 20% in Beijing) unfairly enjoy the greatest share of benefits from transportation projects at the expense of the low quality of other transportation modes, such as transit service and facilities for walking and cycling (Zhu and Li, 2003). Transit punctuality is affected by the traffic congestion caused by masses of cars. Current street design tends to reduce the size and quality of sidewalks and bike paths. Moreover, wider roads for cars create barriers to walking and bicycling.

An increasing concern is the inequity of the transport projects that impose costs but provide few direct benefits to neighbourhoods. Urban neighbourhoods are negatively impacted by highway improvements that primarily benefit commuters. Therefore, when making transportation infrastructure investment, it is necessary to ensure an acceptable share of benefits among different groups.

4.3 Social groups division

Social groups can be divided according to benefit and cost caused by highway infrastructure. The division of benefit groups is not a fixed one. It varies with different features of highway infrastructure and maybe the particular concern of a certain group. Take the construction of a new road or highway for example. Different groups, such as road users, roadside residents, local government, and project contractor can get benefit from and pay cost for such a project, that is, the interest of these people can be influenced after the new road or highway is built. For instance, after the project is accomplished, road users will largely benefit from the project because they will save travel time and enjoy a higher service level for using it. However, roadside residents may suffer from decrease in accessibility due to the cut-off of the two sides of the road. They will likely suffer also from the increase in noise and air pollution. In general, social groups can be divided into four, road users, roadside residents, local government, and project contractor. The cost and benefit for group *i* will be calculate for evaluation of highway project investment.

4.4 Evaluation model

While investments in different regions are compared, regional equity index β and social compensation coefficient α should be considered together. Equity among different groups and different regions are considered in the model.

$$\min R = 1 - \frac{S}{S_{\max}} \tag{10}$$

$$S = \beta_j \sum_{i=1}^{m} \frac{G_i(\ln G_i - \ln \alpha_i)}{\alpha_i} \tag{11}$$

$$\beta_j = \left(\frac{P_j}{P_k}\right)^{-(1-B)(1-\varepsilon)} \left(\frac{R_j}{R_k}\right)^{-B(1-\varepsilon)} \left(\frac{Y_j}{Y_k}\right)^{-\varepsilon} \tag{12}$$

$$s.t. \begin{cases} \beta_j \sum_{i=1}^{m} \frac{1}{\alpha_i} G_i = 1 \\ 0 \le G_i \le \alpha_i \end{cases} \tag{13}$$

β_j —the equity index of region j.

m—the number of social groups in region j.

Other parameters have the same meanings as chapter 3.

In this model, public participation and awareness ε, regional equity among different areas β_j, and vertical equity among different benefit groups α_i are all included.

4.5 Optimal benefit distribution

To calculate the model, Lagrangian method is used and a parameter λ is introduced. Then the follow equation could be got.

$$L = S + \lambda\left(\beta_j \sum_{i=1}^{m} \frac{1}{\alpha_i} G_i - 1\right) \tag{14}$$

$$\begin{aligned} \frac{\partial L}{\partial G_i} &= \frac{\partial S}{\partial G_i} + \lambda \frac{\beta_j}{\alpha_i} \\ &= -\frac{\beta_j}{\alpha_i}(\ln G_i - \ln \alpha_i) + \frac{\beta_j}{\alpha_i}(\lambda - 1) \end{aligned} \tag{15}$$

Let $\frac{\partial L}{\partial G_i} = 0$, we can get the point where *L* gains extreme value and gain the optimal benefit distribution. If one social group gets more social compensation, they will gain more benefit from the project. So this model could reflect the vertical equity.

Let $\frac{\partial L}{\partial G_i} = 0$, thus

$$-\frac{\beta_j}{\alpha_i}(\ln G_i - \ln \alpha_i) + \frac{\beta_j}{\alpha_i}(\lambda - 1) = 0 \Rightarrow G_i = \alpha_i e^{(\lambda - 1)} \tag{16}$$

With the constraint of Equation (13), we can get $e^{(\lambda-1)} = \frac{1}{m\beta_j}$. Thus,

$$G_i^o = \frac{1}{m}\frac{\alpha_i}{\beta_j} \tag{17}$$

$$S_{\max} = -\beta_j \sum_{i=1}^{m} \frac{\frac{\alpha_i}{m\beta_j}\left(\ln \frac{1}{m\beta_j}\right)}{\alpha_i} = \ln(m\beta_j) \tag{18}$$

$$R = 1 - \frac{\beta_j}{\ln\left(m\beta_j\right)} \sum_{i=1}^{m} \frac{-G_i\left(\ln G_i - \ln \alpha_i\right)}{\alpha_i} \tag{19}$$

In Equation (17), G_i^0 is the optimal distribution of benefit-cost rate (BCA). We know from Equation (17), 1/*m* is the optimal distribution without any compensation, that is, the BCR of each benefit group is equal. The optimal distribution G_i^0 is in direct proportion with α_i The larger the value of α_i is, the larger the distribution of G_i^0 is. The disadvantaged groups must obtain a relatively higher BCR than other groups to reach the optimal status, which is defined as the status of equity. This result satisfies the concept of equity among different regions and different benefit groups.

4.6 Sensitivity analysis

The optim*al d*istribution G_i^0 is inversely proportional with β_j, and this can be reflected by the differential coefficient of equity index *R*:

$$\frac{\partial R}{\partial \beta_j} = \left(\sum_{1}^{n} \frac{-G_i(\ln G_i - \ln \alpha_i)}{\alpha_i}\right)\frac{1 - \ln n - \ln \beta_j}{[\ln(n\beta_j)]^2} \tag{20}$$

The value of β_j is determined by the relative developed level of the region *j* and the reference region. So we can choose such a reference region that makes each β_j >1. Since *n* is the number of social groups, so in general, *n*⩾3. And as β_j >1, that is $\ln n > 1$, $\ln \beta_j > 0$, $1 - \ln n - \ln \beta_j < 0$. So $\frac{\partial R}{\partial \beta_j} < 0$.

The increase of β_j will lead to the decrease of *R*. Undeveloped areas have larger β_j and thus smaller *R*. The equity evaluation result of such highway infrastructure investment for these regions is preferential, so the project is easier to be accepted, and the compensation for undeveloped areas could be realized.

Equations (14) – (18) are used to calculate the potential max value of the *S* in a special region, so β_j could be treated as a constant for region *j*.

Consider the sensitivity of the systematic entropy to the group's benefit and cost in equation (21).

From equation (16), $G_i = \alpha_i e^{(\lambda-1)}$, we can get $\ln G_i - \ln \alpha_i = \lambda - 1$. So:

$$\frac{\partial S}{\partial G_i} = -\frac{\beta_j}{\alpha_i}\left(\ln G_i - \ln \alpha_i + 1\right) = -\frac{\beta_j}{\alpha_i}(\lambda - 1 + 1) = -\frac{\beta_j}{\alpha_i} \times \lambda < 0 \quad (21)$$

$$\frac{\partial^2 S}{\partial G_i^2} = -\frac{\beta_j}{\alpha_i G_i} < 0 \quad (22)$$

Then, it is known that the increase of G_i leads the decrease of *S*, and as G_i becomes larger, the decreasing rate becomes larger. That is, when α_i is fixed, the increase of benefit of one social group will lead the relative decrease of others and lead the decrease of equity. And the benefit increase of these originally benefit more whose G_i is larger will lead more imbalance among different groups.

5. MODEL APPLYCATION

5.1 Process of evaluation

Twelve highway project examples are taken to validate the availability of the new equity evaluation model. Those projects are differently located in developed regions or undeveloped regions, and range from east district (E1~E4), middle district (M5~M8) to west district (W9~W12) of China. The benefit-cost ratios (BCR) of each project are also given (Table.1). The main steps of the evaluation process are as follows.

Step1: Divide the local people mostly influenced by the project into several main social groups. The influences of those projects are practically analyzed in four community groups – road users, roadside residents, project contractor and government as shown in Figure 1.

Step 2: Calibrate the parameters α, ε. In the model, parameters α and ε reflect the compensation and social awareness of equity respectively. Their values depend on people's subjective perceiving, and should be obtained from questionnaire. Therefore, we designed a investigation in order to get the current status of public recognition of equity problems and gain the value of parameters with statistical methods. The data are collected from specialists, officials and citizens via web or face-to-face interview.

Step 3: Calculate β. Regional status of project location is taken into account (Table.2) and β is calculated as shown in table 3.

Step 4: Use the evaluation model to calculate the equity index R of each project and draw a ranking according to the value of R. The smaller the value of R is, which means the project is relatively more fair, the higher the rank is.

5.2 Comparison of investment priority with different principles

We make final estimation from three different viewpoints – efficiency, equity, both efficiency and equity, and the priority ranking of those projects is listed in table 5.

Principle 1: efficiency

Traditional estimation methods of highway projects mainly pay attention to the efficiency of investment. CBA is used to rank the priority of those projects, and its rule is that the larger the value of BCR of a project, the higher rank the priority of this project investment gets.

Principle 2: equity

Another important object of public project investment is to improve social equity. The equity estimation of highway projects is based on the benefit incidence of various community groups and regional equity of project locations. Its rule is that the smaller the value of equity estimation index R (see table 4) of a project, the higher rank the priority of this project investment gets.

Principle 3: both efficiency and equity

Only when both efficiency and equity aspects of highway projects are taken into account, a comprehensive and reasonable conclusion can be drawn. To adjust the result based on BCR, we define the division of benefit-cost ratio and equity estimation index (BCR/R) as the final index, therefore, a project with larger value of BCR/R should be given higher priority when making investment decisions.

5.3 Evaluation result

The estimation results of equity principle are quite different from those of efficiency principle, especially for those projects W9~W12 located in west undeveloped regions. The most important comparison is between the estimation results of efficiency principle and those of both efficiency and equity principle. The rank of project E1 drops from No.3 to No.5, and the rank of project E2 drops from No.5 to No.9. In contrast, the rank of project M6, M7, and W9 increases obviously. The new estimation method concerning both efficiency and equity proves to be effective to reflect the compensation for disadvantaged groups and undeveloped regions. Figure 2 describes the results in another form. The both efficiency and equity curve/rank is below the efficiency curve/rank for projects located in east developed regions, and above the efficiency curve/rank for projects located in middle and west undeveloped regions. This conclusion verifies the equity aspect of the new estimation method again.

6. CONCLUSIONS

In China, transportation infrastructure investment is of greatness. Construction of transportation infrastructure generally brings transportation convenient and economic development. However, Construction needs cannot be fully satisfied because of the limitation of capital and resource. Hence, the priority evaluation of transportation infrastructure investment is very necessary. However, the usual evaluation method is BCA which ignores the impact of equity.

As an important aspect of sustainable transportation, transportation equity has gradually become the focus of attention from all evaluation aspect. Although some researchers began the theoretical study on transportation equity, but practical and quantitative evaluation methods need to be studied. This paper therefore attempted to study the transportation equity quantitatively. Four quantitative evaluating models are founded to analyze the issues of four transportation equity separately. Based on these models, an entropy type model with consideration of both efficiency and equity is proposed, and which is used for highway investment evaluation. This model evaluates different highway investment in different regions based on the result of BCA. Hence, a comprehensive and reasonable judgment of highway investment can be made to take into account both efficiency and the equity aspects of projects. It is proved that the model has sensitivity, and the model is practical and applicable.

As a case study, the proposed model is applied to 12 highway projects in different areas in China to judge the the priority of them. The evaluation result shows that the priority order changes a lot when evaluate from the view of both efficiency and equity comparing to the result of that of efficiency evaluation. The model is proved to be available by the government when decision making.

This study made an initial study on transportation equity in a quantitative way. However, further study is needed to improve the model, such as the precision of the model, as well as the practicability of it..

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APPENDIX DERIVATION OF A REGIONAL EQUITY COEFFICIENT β

A regional coefficient β is introduced to the evaluation model, the theoretical discussion of which is well explained in the Guide for Road Projects Evaluation Part 2 Integrated Evaluation (Committee of Road Projects Evaluation, 1999).

In different regions, a one-unit increase in average personal income may lead to a different amount of social welfare increase. Based on this fact, the coefficient β of region *j* is defined as the ratio of the social welfare increase caused by a one-unit increase in personal income of region j and that of the standard region *i*.

Let *I* be the set of regions under evaluation. For $j \in I$, let Y_j be the average personal income of region j with the utility function V_j. Then let $W = W\left(V_1, \cdots, V_i, \cdots, V_I\right)$ be the social welfare function. Thus, the social welfare increase of region *j* due to a one-unit increase in personal income can be represented as follows:

$$\frac{\partial W}{\partial Y_j} = \frac{\partial W}{\partial V_j} \cdot \frac{\partial V_j}{\partial Y_j} \tag{1}$$

Then the coefficient β can be represented as follows:

$$\beta = \left(\frac{\partial W}{\partial Y_j}\right) \Bigg/ \left(\frac{\partial W}{\partial Y_i}\right) = \left(\frac{\partial W}{\partial V_j} \cdot \frac{\partial V_j}{\partial Y_j}\right) \Bigg/ \left(\frac{\partial W}{\partial V_i} \cdot \frac{\partial V_i}{\partial Y_i}\right) \tag{2}$$

Here, the social welfare function is set to be the function of CES type society:

$$W = \left[\sum_{i \in I} V_i^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{3}$$

where $\varepsilon \geq 0$ is a parameter which represents the social awareness of equity.
The utility function is set to be the Cobb-Douglas type function as

$$V_j = V\left(P_j, R_j, Y_j\right) = P_j^{-(1-B)} R_j^{-B} Y_j \tag{4}$$

where P_j is the price index of region *j*, Q_j is the housing expense of region *j*, and Y_j is the average personal income. *B* is the proportion of housing expense to the total family expenditure. Thus, with Equation (2)~(4), the regional equity coefficient *β* can be represented as follows:

$$\beta = \left(\frac{P_j}{P_i} \right)^{-(1-B)(1-\varepsilon)} \left(\frac{Q_j}{Q_i} \right)^{-B(1-\varepsilon)} \left(\frac{Y_j}{Y_i} \right)^{-\varepsilon} \tag{5}$$

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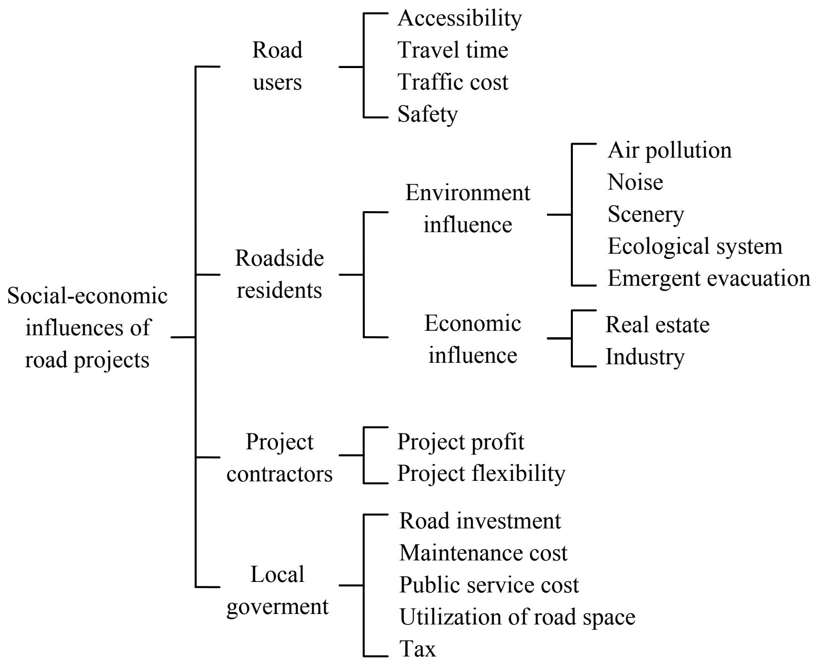

Figure1 An example of benefit groups for road construction projects

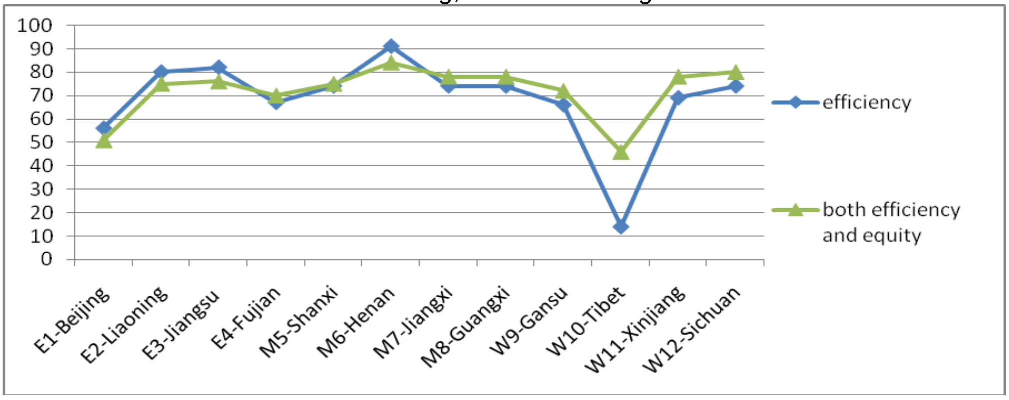

Figure 2 priority ranking curve of project investment

Table 1 Benefit estimation of twelve project examples

project	E1	E2	E3	E4	M5	M6
location	Beijing	Liaoning	Jiangsu	Fujian	Shanxi	Henan
benefit-cost ratio (BCR)	2.12	1.78	2.35	1.96	2.25	1.66
project	M7	M8	W9	W10	W11	W12
location	Jiangxi	Guangxi	Gansu	Tibet	Xinjiang	Sichuan
benefit-cost ratio (BCR)	1.43	1.27	1.40	1.35	1.36	1.52

Table 2 Regional economic status of twelve project examples
China Statistical Yearbook. (2005)

	location	price index P	housing expense Q	personal income Y	proportion of housing expense B (%)
E1	Beijing	100.2	4737	10584	8.6
E2	Liaoning	101.7	2291	5159	10.4
E3	Jiangsu	101.0	2197	5274	10.7
E4	Fujian	100.8	2297	5324	11.9
M5	Shanxi	101.8	1611	2934	11.0
M6	Henan	101.6	1388	3129	11.5
M7	Jiangxi	100.8	1210	2739	11.6
M8	Guangxi	101.1	1883	2567	13.9
W9	Gansu	101.1	1275	2171	9.5
W10	Tibet	100.9	1753	2825	5.8
W11	Xinjiang	100.4	1817	3237	9.0
W12	Sichuan	101.7	1421	2839	10.1

Note: the housing expense R is the average selling price of houses with the unit of yuan/square mile. The unit of personal income Y is yuan/person/year.

Table 3 The modified coefficient of regional equity

project	E1	E2	E3	E4	M5	M6
location	Beijing	Liaoning	Jiangsu	Fujian	Shanxi	Henan
β	1.00	1.58	1.57	1.56	2.25	2.19
project	M7	M8	W9	W10	W11	W12
location	Jiangxi	Guangxi	Gansu	Tibet	Xinjiang	Sichuan
β	2.39	2.46	2.71	2.25	2.11	2.30

Table 4 Standard benefit ratio and equity estimation index

	standard benefit ratio of four groups G_i^*				systemic entropy S	equity estimation index R
	road users	roadside residents	project contractor	government		
E1	0.759	0.174	0.114	0.030	0.789	0.431
E2	0.526	0.058	0.063	0.016	1.081	0.414
E3	0.456	0.118	0.096	0.023	1.329	0.277
E4	0.486	0.107	0.078	0.019	1.237	0.325
M5	0.338	0.068	0.057	0.014	1.598	0.273
M6	0.371	0.067	0.041	0.007	1.440	0.336
M7	0.328	0.056	0.052	0.010	1.602	0.291
M8	0.329	0.049	0.049	0.003	1.545	0.324
W9	0.298	0.045	0.036	0.012	1.687	0.292
W10	0.366	0.029	0.066	0.004	1.406	0.360
W11	0.388	0.035	0.070	0.004	1.355	0.365
W12	0.350	0.042	0.056	0.010	1.514	0.318

*The data of benefits and costs of each group are provided by China International Engineering Consulting Corporation (CIECC)

Table 5 priority ranking of project investment

efficiency estimation		equity estimation		both efficiency and equity	
E3	Jiangsu	M5	Shanxi	E3	Jiangsu
M5	Shanxi	E3	Jiangsu	M5	Shanxi
E1	Beijing	M7	Jiangxi	E4	Fujian
E4	Fujian	W9	Gansu	M6	Henan
E2	Liaoning	W12	Sichuan	E1	Beijing
M6	Henan	M8	Guangxi	M7	Jiangxi
W12	Sichuan	E4	Fujian	W9	Gansu
M7	Jiangxi	M6	Henan	W12	Sichuan
W9	Gansu	W10	Tibet	E2	Liaoning
W11	Xinjiang	W11	Xinjiang	M8	Guangxi
W10	Tibet	E2	Liaoning	W10	Tibet
M8	Guangxi	E1	Beijing	W11	Xinjiang