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Zhang, Xiaoling; Wu, Yuzhe; Skitmore, Martin; Jiang, Shijie

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Xiaoling Zhang[1]; Yuzhe Wu[2]; Martin Skitmore[3]; Shijie Jiang[4]

[1] Assistant Professor, Department of Public Policy, City University of Hong Kong, Hong Kong; Email: xiaoling.zhang@cityu.edu.hk

[2] Professor, Department of Land Management, Zhejiang University, Hangzhou 310029, China, China; E-mail: wuyuzhe@zju.edu.cn

[3] Professor, School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia , Tel: +61 7 3138 1059; Fax: +61 7 3138 1170, E-mail: rm.skitmore@qut.edu.au

[4] Associate Professor, Department of Construction Management, Chongqing University of Science and Technology, Chongqing, China, Tel: +852 2766 5817, Fax: +852 2764 5131, E-mail: cqaj@163.com

Corresponding author:
Prof. Yuzhe Wu
Professor
Department of Land Management, Zhejiang University
China
E-mail: wuyuzhe@zju.edu.cn
Phone: +86-571-86971987
Fax: +86-571-86971277

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Abstract

In current practice, urban-rural development has been regarded as one of the key pillars in driving regenerative development that includes economic, social, and environmental balance. In association with rapid urbanization, an important contemporary issue in China is that its rural areas are increasingly lagging behind urban areas in their development and a coordinated provision of public facilities in rural areas is necessary to achieve a better balance. A model is therefore introduced for quantifying the effect of individual infrastructure projects on urban-rural balance (e-UR) by focusing on two attributes, namely, efficiency and equity. The model is demonstrated through a multi-criteria model, developed with data collected from infrastructure projects in Chongqing, with the criteria values for each project being scored by comparing data collected from the project involved with e-UR neutral "benchmark" values derived from a survey of experts in the field. The model helps evaluate the contribution of the projects to improving rural-urban balance and hence enable government decision-makers for the first time to prioritize future projects rigorously in terms of their likely contribution too.

Keywords: Infrastructure projects, urban and rural areas, sustainable development, China.

1. Introduction

A growth of urban areas is taking place in many countries at the expense of rural areas, which are increasingly lagging behind urban areas socially, economically and environmentally. This awareness has attracted research efforts in seeking to achieve a sustainable development between urban and rural areas through the provision of public facilities and infrastructure (Williams, 2000; Yuan et al 2013).

Adequately planned and implemented infrastructure projects make an indispensable contribution to development in both urban and rural areas in societal, ecological and economic terms (Li and Liu 1995; World Bank 1994; Shen et al, 2011). In other words, coordinated urban-rural development relies largely on the improvement of infrastructure conditions (Li 2004; Chen 2011). A number of other studies in overseas countries (Aschauer 1989; Gramlich 1994) echo this. Similarly, Leipziger *et al* (2003) examined the impact of expanding infrastructure services on child mortality and educational attainment, and suggested that the infrastructures can help improve health and education for children. Moreover, as endorsed by Démurger (2001), in referring to the rural-urban disparities relating to various infrastructure projects, it is inevitable that a different efficiency in the returns from projects may occur due to different geographical and resource endowments. Infrastructure has therefore become a ubiquitous theme in the policy debate but has yet to receive much attention in the construction literature. For example, there are several papers concerning infrastructure performance evaluation (Ngacho and Das 2013), infrastructure and project governance (Guo et al 2013), infrastructure and BOT (Chen 2009); infrastructure and PPP (e.g. Zhang 2005a-b, 2006a-b, 2007; Aziz 2007, Ke et al 2010); quality (Yung and Yip 2010);

time-quality trade-offs (El-Rayes and Kandil 2005); sustainability (Hendrickson and Horvath 2000); innovation (Slaughter 1998); delays (Lo et al 2006; Kaliba et al 2009); etc, but none relate to the bigger picture of the tradeoff between urban and rural infrastructure provision.

One important aspect is the effect of infrastructure on *growth*, with infrastructure policies that facilitate transport between regions increasing overall growth nationally and with positive effects on reducing regional differences (Démurger 2001; Li 2014). Another important issue concerns the effect of enhanced infrastructure on the relative levels of regional economic development. For example, in recent years government proactive promotion of additional roads, water and electricity supplies and other types of infrastructure projects has contributed greatly to narrowing the urban-rural economic development gap in the USA (Li et al. 2009). Several papers consider this in terms of infrastructure *efficiency*, contending that the effective use of infrastructure resources can help explain the differences in growth between urban and rural areas and between different regions (Hulten 1996; Esfahani and Ramirez 2002).

Of particular interest is the effect on income distribution, with many arguing that generalized access to infrastructure services plays a key role in helping reduce income inequality (Estache *et al*. 2002; Estache 2003; World Bank 2003). For example, enhanced access to roads and sanitation is a key determinant in increasing income parity between the poorer and wealthier regions in Argentina and Brazil (Estache and Fay 1995). In the social and economic sense, the issue of equity concerns the *fairness* of the balance in the distribution of costs and benefits between providers and consumers (Solanes 2006).

Such considerations have led to calls for the prioritization of infrastructure effects on equity and efficiency (López 2004), with Baldwin and Martin (2004) conceptualizing the main policy issue as a spatial equity-efficiency trade-off to achieve an appropriate urban-rural balance or coordinated development. In recent years, there has been some research focusing on the influence of infrastructure projects on this balance (e-UR). For instance, Zhan and Lu (2003) analyzed the significance of regional infrastructure to narrowing urban and rural differences, while Huang (2006) presents measures for weighting this significance. Fu et al. (2006) examine the current status of urban-rural coordinated development in a municipal city and identify some of the *key influencing factors* involved, while Liu (2007) notes the improvements made on urban-rural development by pursuing effective infrastructure investment. Most recently, Shen *et al* (2012) have developed a set of *critical indicators* for assessing e-UR. However, while they address the social, economic and environmental aspects of infrastructure projects from the perspective of contribution to e-UR, none promote the prioritization of equity and efficiency to all parties involved in the process of infrastructure provision. It is therefore necessary to investigate the differences between "equity and efficiency" in coordinating the urban-rural balance by developing infrastructure projects. This could reduce the social conflicts that affect the development of sustainability in the long run.

There are other studies in this topic, conducted from a qualitative perspective, relating to the effects of infrastructure on equity and efficiency. For example, Niu *et al*. (2010) analyze an appropriate means of allocation of road construction macroscopically based on demand and cost, in order to reconcile the two goals of equity and efficiency.

As an extension to these studies, this paper introduces a method for quantifying the e-UR of infrastructure projects by focusing on two major attributes, namely the economical aspect of efficiency and social aspect of equity, and comprising multiple dimensional e-UR indicators. The model is applied to two sets of infrastructure projects in the Chongqing municipality– one of the largest cities in China and with a well-known serious urban-rural imbalance - both to demonstrate its use and highlight its potential as an aid to policy decision-making in prioritizing potential future projects in terms of their likely contribution to and improved rural-urban balance through an equity-efficiency matrix.

The paper is organized as follows. First, the research background and significance are identified, while the next section outlines the methods used for data collection and validation. Then, a new mathematical model for evaluating e-UR is presented. This is followed by a Chongqing case study from which policy options are derived for a set of water supply and roads project in order to enable government decision-makers for the first time to prioritize of future such projects rigorously in terms of their likely contribution to improving the region's rural-urban development balance. The findings and implications of different policy options are then discussed, followed by a final section drawing conclusions and providing recommendations for the effective use of the approach.

2. Research methodology

In Shen *et al*'s (2012) study, a comprehensive list of 46 indicators was first identified through the examination of all "relevant literature and official reports" together with "100 feasibility reports involving various kinds of indicators to filter indicators adopted in current practices for evaluating the contribution of infrastructure projects to coordinated urban-rural development" in the Chongqing region. These were scrutinized by 24 "experienced professionals" consisting of government officials, researchers and professionals from companies, as a result of which 42 indicators were retained as they received more than 60% supportive as valid practical assessment indicators. Then, to determine the relative significance of the 42 indicators accurately, a survey was conducted of a further 130 professionals identified from four databases: the Members of The Chinese Research Institute of Construction Management Directory; the China Building and Construction Company Directory; relevant government departments; and university academics. Statistical analysis of the results indicated the survey to be of "sound quality" and Principal Components Analysis (PCA) was then used to eventually identify 19 relatively important orthogonal indicators with a very high percent of variance explained. Therefore, the method used to identify the 42 indicators was clearly self-validating for at least the Chongqing region and, as the PCA simply reorganizes and condenses the variables involved depending upon their inter-correlations, the resulting 19 indicators can also be taken to be self-validating.

<Insert Table 1 here>

The identity and structural arrangement of the 19 indicators is provided in Table 1 (from Shen *et al* 2012: Fig 2), which illustrates the three level hierarchical arrangement involved, comprising an *attribute* level, *dimensional* level, and *indicator* level. As mentioned above, the indicators presented by Shen *et al* (2012) were identified by extensive empirical research from the same city of China as the current study, and therefore no further validation or verification of the indicators was considered necessary.

In order to utilize these indicators to establish the status of infrastructure projects in terms of their e-UR, the research approach comprised a number of key stages:

(i) Data collection to provide (a) the indicator scores for projects and (b) referenced benchmark indicator scores for a typical e-UR neutral project

(ii) Data collection to establish the relative indicator weights

(iii) Formulation of a mathematical model to evaluate a project's e-UR

(iv) Proposal of a policy scenario toolbox to evaluate the effect of different decision options on the equity-efficiency implications. An application of the model is described to two sets of infrastructure projects in Chongqing – one of the largest cities in China, with over 30 million inhabitants, where there is a well-known serious urban-rural imbalance issue.

2.1. Data collection

The data collected for analysis in this study is from the city of Chongqing. Chongqing is a major municipality in Southwest China and, along with Beijing, Shanghai and Tianjin, is one of China’s four autonomous municipalities. The municipal city of Chongqing is the largest of the four in terms of geographical area and population of over 30 million. It has a dual urban-rural economy and is located at the junction of the economically developed eastern region and the richly resourced western region of China. In contrast with Beijing, Shanghai and Tianjin, where urban populations are much larger than their rural populations, Chongqing's metropolis coexists with a large rural area - a typical example of the dual structure of urban-rural areas in China's cities (Shen *et al.*, 2012). Furthermore, the acceleration of urbanization in the past years has enlarged the difference between Chongqing’s urban and rural areas leaving significant differences and gaps in economic and social development across the municipality (Asian Development Bank, 2008), particularly in terms of basic public services and infrastructure construction - a situation considered to be unfair to the people living in rural areas (Zhang, 2007).

In this context, in 2007, the Chinese National Development and Reform Commission issued a policy entitled “The Establishment of a National Pilot Zone for the Overall Reform and Coordination of Urban and Rural Areas in the Chongqing Municipality and Provincial Capital City Chengdu” (Zhang 2007). This was formally endorsed by the State Council through the document “the Policy for Promoting Chongqing’s Urban and Rural Coordinated Development Program” (State Council, 2009). Because of these initiatives, the Chongqing Government developed a two-stage plan to implement the program (Sheng, 2011). The first stage is to make significant changes in various dimensions within the social system, including urban and rural household registration, employment, social security, basic public services and public finance before 2012. The second stage is to establish a new institutional system that fully embodies the concept of harmonious development. This system is expected to become the standard model for achieving e-UR nation-wide

In order to achieve these goals, Chongqing launched the Chongqing Urban-Rural Infrastructure Coordination Demonstration Program (hereinafter termed the "Demonstration Program") with the loan from the Asian Development Bank in 2008. This program is one of the first infrastructure project construction packages designed for urban-rural coordination development. Projects under the program cover 30 subprojects over 8 districts or counties, comprising 9 water supply projects targeted at construction of water plants and 21 newly initiated or expanded road construction projects. These 30 projects form the focus of our study, which is the development of an aid to infrastructure policy makers in pursuing an equitable long run urban-rural economic balance in Chongqing and throughout China in general.

2.1.1. Project indicators and scores

Clearly, what is first needed in order to quantify a project's e-UR is for each of the 19 indicators to be given an appropriate score for that project. The data from the Chongqing projects concern the economic internal rate of return, economic net present value, overall benefit-cost ratios, employment provision and the amount of compensation to stakeholders and disadvantaged groups for each project. However, it was necessary to go further afield for several of the other indicators, and content analysis was used to analyze Statistical Yearbooks (manuals), specifications and standards (China International Engineering Consulting Corporation 2004; Chongqing Construction Statistical Manual 2007 and 2008; Chongqing Statistical Yearbook 2008; Chongqing Yearbook 2008; National Development and Reform Commission 2006; Standard and Norm Institute of the Ministry of Construction 2006; Lin and Chen 2006). This provided such information as the standard and quality of living (represented by Engel's coefficients), proportion of investment policy support, investors, land resources, public resources and energy supply between urban and rural areas.

However, it was difficult to find the scores for some of the indicators in terms of the project attributes due to limited statistical scope, overlapping statistical coverage, urban-rural differences or unavailability of statistical data for the location of projects. Many alternative approaches to derive the indicator scores were investigated. For example, the data for the *Energy saving percentage* indicator (X_{EE4}) was expressed in terms of the average national annual energy saving rate. Likewise, it was sometimes necessary to average the indicator scores lying within a range, such as occurred with the *EIRR* indicator (X_{BE2}) for water supply, with a minimum and maximum of 16.3 and 24.8 respectively.

2.2.2. e-UR neutral benchmarks for determining the indicator scores

It should be noted that the scores for all the 19 indicators are not measured on the same scale. For example, indicator X_{BE1} is scored by *IRR (Internal Rate of Return)* which, in the case of the Chongqing projects, is a percentage figure of around 7-8%. Indicator X_{BE3}, on the other hand, is scored by *ENPV (Economic Net Present Value)*, which is a currency figure of up to RMB50million. Therefore, a simple summation of indicator scores would bias the total almost completely in terms of *ENPV*. To remove this biasing effect, the scores need to be standardized. It is also important that the total of these standardized scores provides some indication, or index, of the degree of e-UR involved.

One approach is to compare the scores for each indicator with an e-UR neutral benchmark score for that indicator. Therefore, for example, if the score for the *IRR* (X_{BE1}) indicator for a project is 7%, while the e-UR neutral benchmark for *IRR* is 5%, then the project indicator score shows the project to be producing a higher e-UR than the benchmark. Extending this approach to all the indicators will therefore, when standardized and totaled, provide a good measure of a project's e-UR compared with an e-UR neutral benchmark project.

As it is necessary to obtain e-UR neutral benchmarks scores for each of the 19 indicators, a survey was conducted of the 130 experienced Chongqing professionals previously contacted. The respondents were provided with the range of indicator scores obtained as described in the last section and asked to determine an indicator score that would denote an e-UR neutral benchmark value. As a result, a total of 32 sets of scores were returned, including 2 invalid responses. The average of these e-UR neutral scores for each indicator was then used as a *referenced e-UR neutral benchmark* score in the standardization process described later.

2.2. Weightings between indicators

The final issue in calculating the project e-UR index concerns the relative contribution of each indicator to the index at each hierarchy level, as some, such as X_{FIE1} *Proportion of rural-urban natural resources*, are likely to be much more influential than others such as X_{BE3} *ENPV (Economic Net Present Value).* To incorporate this into the assessment involves the use of weightings, in such a way as to enable the summation of the weighted scores into a weighted composite measure.

The Analytical Hierarchy Process (AHP), developed by Saaty in 1970s, an effective method to solve multi-criteria decision-making problem, has been applied in many areas of project management, such as the efficient prioritization of infrastructure projects (Karydas and Gifun, 2006; Ziara *et al*., 2002), strategic decisions in managing infrastructure projects (Nyström and Söderholm, 2010; Dias *et al*., 1996), project delivery measurement (Mahdi and Alreshaid, 2005; Lin et al., 2008) and measurement of infrastructure projects' risk or uncertainties (Zayed et al., 2008; Wang and Chou, 2003). As it has been stressed (Tsamboulas *et al*., 1999) that AHP is a common method used for prioritization when having a wide variety of possible choices. It decomposes a complex problem into component factors that form a hierarchy according to the relationships involved, compares the elements two by two according to their relative importance and finally integrates all the judgments into a prioritized list of alternatives (Saaty 1980). The strength of this approach is that it organizes tangible and intangible factors in a systematic manner, and provides a structured yet relatively simple solution to the decision-making problems (Skibniewski and Chao, 1992).

Though there are criticisms of the AHP method, e.g., incapable of handling the ambiguity associated with the mapping of one's perception to an exact number (Pan, 2008; Zhang *et al*., 2011), AHP contributes to overcoming the disadvantage in subjectivity by deriving weights in a quasi-independent manner, using pair-wise comparisons that make difficult to promote open biases towards specific criteria (Tsamboulas, 2007). It is therefore considered an ideal method for weighting the various levels involved in the indicator hierarchy, as it enables the weightings at the indicator level and dimension level to be established without the need to make any allowance for possible double counting.

2.2.1. Weightings at the dimension level

Based on Table 1, a second questionnaire survey was conducted. This required experts to judge the relative importance of the indicators at the dimension level by pairwise comparison using the principle of AHP. This pairwise comparison makes it easier for the participants to isolate and express a level of preference for one decision alternative against another (Badri 1999). Firstly, a judgment is needed concerning the relative importance of each dimension in terms of its contribution to project e-UR. From this, the weightings given were simply averaged to obtain the weighting of each indicator. To do this, the 130 professionals were again contacted and 85 completed responses were received, of which seven were considered to be invalid due to the failure to meet the requirements of the AHP for scoring the intensity of importance.

2.2.2. Weightings at the indicator level

Because there are 19 indicators classified into 6 sub-categories, with 1-5 indicators within each sub-category, the weighting process using the AHP would be very complicated. In view of the relative weakness of the correlations at this level and the independency of the experts involved, a third questionnaire survey was administered, where experts were invited to assign a priority *and* weight to each indicator. Therefore, by comparing the ranking of the weights with their priority values, it was also possible to verify the reasonableness of the weights (that is, the indicators ranked high in priority should have a larger weight than those ranked lower). The final weighting for each indicator was then obtained by simply averaging the weighting values provided by the respondents. To ensure the continuation and consistency of the survey, the questionnaire was delivered to the same respondents who had provided valid responses in the previous round. As a result, 47 valid responses were obtained.

3. Results

3.1. Project indicator scores

The mean and range of the indicator scores for the 30 infrastructure projects are summarized in Table 2.

<Insert Table 2 here>

3.2. e-UR neutral benchmark scores

As shown in Table 2, with a few exceptions, the e-UR neutral benchmark scores are largely consistent with the indicator scores. The reason the *IRR* (X_{BE1}) benchmark for the water supply projects is slightly lower than the project indicator scores is that the rural water supply is lower in terms of coverage and utilization rate, therefore it receives a lower internal rate of return than that of the urban water supply. For similar reasons, the benchmark for *Amount of benefit compensation of project stakeholders and underprivileged groups* (X_{SE3}) is lower than the project indicator scores, while the road project benchmark is the opposite. Likewise, although the mean project indicator score for the *Proportion of rural-urban natural resources* (X_{FIE1}) was 1.52 in 2006 and 1.59 in 2007, the benchmark value of 1.69 reflects the urbanization trend of increased urban population and decreased per capita land occupation.

Of special interest here are the two equitable investment indicators of *Proportion of rural-urban support degree of investment policies* (X_{FIp1}) and *Proportion of rural-urban investors* (X_{FIS1}), with benchmark values for the water supply projects for the first two being well in excess of those for road projects. The reason is that water supply projects are much more demanding in terms of agricultural irrigation in rural areas than that in urban areas. In China, more than 80 million people in rural areas have to walk more than a mile for drinking water (Hays, 2008). Water shortages also raise irrigation costs, which results in the need for higher e-UR neutral benchmark values to achieve the desired coordinated urban-rural development balance.

3.2.1. Project Indicator weights

Table 1 lists the average of the weights obtained. In applying AHP, it is important for the value of the consistency index (CI) to be less than 0.10 (Lin et al 2008). By referring to this, for the *dimension* level, it was found that, of the 78 responses received, 36 had an acceptable consistency for the *efficiency* indicators, while 43 have an acceptable consistency for the *investment balance* indicators, with 26 having an acceptable consistency for both. The AHP was therefore used to analyze these 26 responses to obtain the indicator weightings. The results are summarized in Table 1.

3.2.2. Evaluation model

Letting Y denote the index value of the project e-UR, then

$$\mathrm{Y} = \alpha E + (1-\alpha)F \qquad \textbf{(1)}$$

where E and F, represent infrastructure efficiency and equitable investment contribution respectively, such that

$$\mathrm{E} = \mathrm{w}_{\mathrm{BE}}\sum_{\mathrm{i=1}}^{4}\mathrm{w}_{\mathrm{BEi}}\mathrm{a}_{\mathrm{BEi}} + \mathrm{w}_{\mathrm{SE}}\sum_{\mathrm{i=1}}^{5}\mathrm{w}_{\mathrm{SEi}}\mathrm{a}_{\mathrm{SEi}} + \mathrm{w}_{\mathrm{EE}}\sum_{\mathrm{i=1}}^{4}\mathrm{w}_{\mathrm{EEi}}\mathrm{a}_{\mathrm{EEi}} \qquad \textbf{(2)}$$

$$\mathrm{F} = \mathrm{w}_{\mathrm{FIP}}\sum_{\mathrm{i=1}}^{1}\mathrm{w}_{\mathrm{FIPi}}\mathrm{a}_{\mathrm{FIPi}} + \mathrm{w}_{\mathrm{FIS}}\sum_{\mathrm{i=1}}^{2}\mathrm{w}_{\mathrm{FISi}}\mathrm{a}_{\mathrm{FISi}} + \mathrm{w}_{\mathrm{FIE}}\sum_{\mathrm{i=1}}^{3}\mathrm{w}_{\mathrm{FIEi}}\mathrm{a}_{\mathrm{FIEi}} \qquad \textbf{(3)}$$

with $a_i = \frac{w_i}{b_i} - 1$, w and b being the indicator value and reference e-UR neutral benchmark scores respectively as mentioned earlier, and subscripts as assigned in Table 1. Other codes in the models can be found in Table 1. α is a parameter $(1 \geq \alpha \geq 0)$ representing the weighting for the *attribute* level of *efficiency*.

There are three scenarios to consider from equation **(1):**

1. When Y≥0, the project is considered acceptable as it has a good e-UR. In other words, when the value of Y is positive, the e-UR is positive; indicating that the effect of individual infrastructure projects on urban-rural balance is good. This implies that the construction of the individual infrastructure project will help narrow the urban-rural development gap.
2. When Y=0, the e-UR is neutral, meaning that the urban-rural gap remains unchanged.
3. When Y<0, the project is unacceptable, since the e-UR is negative, indicating that the effect of individual infrastructure projects on urban-rural balance is undesirable, as it will lead to a wider urban-rural gap.

<Insert Table 3a here>

<Insert Table 3b here>

The application of the above models leads to the results shown in Tables 3a and 3b. These two Tables show the project e-UR index calculations for the Gaotang and Caotang water supply projects respectively for an assumed α weighting of 0.5 (the implications of setting $\alpha \neq 0.5$ are discussed in the next section). Each row denotes one of the 19 indicators; with its score shown in the column marked (A) and e-UR neutral benchmark value (B). The next column provides the raw (unweighted) indicator e-UR, followed by the weights for the indicator, dimension and attributes levels respectively. The combined weights follow, which, when multiplied by the raw indicator e-UR, provide the weighted indicator e-UR in the final column. The final two rows show the average raw e-UR project index to be 0.219 and 0.225 for Projects 1 and 2 respectively, with the desired weighted equivalents being 0.542 and 0.550 indicating these two projects, for reasons given above, to both provide a good e-UR.

4. α settings

In the previous section, the value of α was set to 0.5 to simplify the demonstration of the model. However, recall that that α is a parameter $(1 \geq \alpha \geq 0)$ representing the weighting for the *attribute* level of *efficiency*, and that $1-\alpha$ therefore represents the weight for *equitable rural-urban investment proportion*. By manipulating the value of α, the effects of different attribute level weightings on e-UR can be investigated as in Tables 4a and 4b for all the water supply and road projects respectively. This shows that, for the water supply projects, good e-UR is provided by all α values except for three projects at $\alpha = 1$, with $\alpha = 0$ providing the best e-UR. In contrast, good e-UR is obtained for the road projects only for α values over 0.7, with $\alpha = 1$ providing the best e-UR this time.

<Insert 4a here>

<Insert 4b here>

Now, considering the α parameter as a form of local government *policy* coefficient, it is possible to treat the five different values in Tables 4a and 4b as having discrete meanings. For example:

- Scenario 1: α =0, policy favors only equitable rural-urban investment proportion indicators;
- Scenario 2: α =0.3, policy prioritizes equitable rural-urban investment proportion indicators higher than efficiency indicators
- Scenario 3: α =0.5, policy considers that equitable rural-urban investment proportion and efficiency indicators to be equally important;
- Scenario 4: α =0.7, policy equitable prioritizes efficiency indicators higher than rural-urban investment proportion indicators
- Scenario 5: α =1, policy favors only the efficiency indicators

As can be seen from Table 4a, this indicates that when government policy places a higher priority on *equitable rural-urban investment proportion*, the good effects of water supply infrastructure projects on urban-rural balance are maximized. That is, the urban-rural development gap will be narrowed. For road projects (Table 4b), the converse is true, where not only are the good effects of road projects on urban-rural balance maximized when government policy places a higher priority on *efficiency*, but that when government policy places a higher priority on equitable rural-urban investment proportion, the effect on urban-rural balance is undesirable as the urban-rural gap would be widened.

5. Discussion

It is important to discuss the prioritization of “efficiency” and “equitable rural-urban investment proportion” between urban and rural regions in China. As is well known, China has an urban and rural binary structure caused by the government placing a higher priority on allocating resources to urban and industrial development. This has resulted in the allocation of public goods and infrastructure project investment in rural, agricultural and farming being ignored for a long period. Both the two case study project types of water supply and road projects presented here rely on public infrastructure investment. Over the years, this investment has become seriously out of balance, with a low priority of public infrastructure investment in rural areas has severely affected agricultural development, the efficiency of agricultural production and has led to falling farm revenues. The gap between urban and rural regions is therefore widening, prompting Calderon and Serven (2004), for example, to conclude that ‘increasing the quantity and quality of [rural] public infrastructure projects’ provision would help reduce the gap between urban and rural areas’.

To date, the government does not have any rigorous means, or tools, for rectifying this situation and just have to rely on 'gut feel' or intuition (Shen et al. 2012). However, it is clear that intuition in this case can be misleading, e.g., the sample of roads contracts in the above evaluation (Table 4b). While intuition informs us that an equitable rural-urban investment proportion should result in a better rural-urban balance, the model indicates completely the opposite and that prioritizing equitable rural-urban investment proportion as a goal for roads contracts would result in a *widening* of the rural-urban gap instead of narrowing it as is desired.

As the five scenarios proposed in this study, the more the government focuses on equitable urban-rural investment proportion, the wider the gap between them will be. Therefore, it is highly recommended that the government should design a set of policies in line with theoretical and practical findings instead of intuition or experience. In fact, what government policy should do until the rural-urban balance is restored is to prioritize roads contracts that score far more on efficiency measures than equitable rural-urban investment proportion measures, and reject all other proposals for roads contracts. However, it might be noted that this rule may not be suitable for other instrument investments.

Also worthy of mention is the significance in the above analysis of the major discriminating roles played by the two equity indicators of *Proportion of rural-urban support degree of investment policies* (x_{FIP1}) and *Proportion of rural-urban investors* (x_{FIS1}) in the case studies, both of which, as noted earlier, have e-UR neutral benchmark values for the water supply projects far in excess of those for the road projects. An obvious reason for this, as mentioned earlier, is that water supply projects are much more demanding in terms of agricultural irrigation in rural areas than in urban areas. Water shortages also raise irrigation costs. In addition, China has no history of the central government providing large subsidies for financing rural water supply and sanitation. Instead, there is greater emphasis on self-reliance, with rural people providing their own contributions and resources to improve water supply (World Bank 1999). As a result, few public resources have yet been allocated to supporting rural water supply projects. As for urban road projects, in the 20 years prior to its open-reform policy, the Chinese government implemented an economic development strategy of heavy industrialization, impacting greatly on infrastructure investment in urban areas. In this respect, urban road projects were very much favored in order to speed industry development. For example, the length of railway tracks was expanded from 22,900 kilometers in 1952 to 48,600 kilometers in 1978 (Démurger, 2001). However, rural road projects in Chongqing Province for example, are much needed. This indicates the urgent need for the greater prioritization of both rural water supply and road projects in order to best help narrow Chongqing's urban-rural gap.

Therefore, it is suggested that the central and local governments need to better balance public infrastructure provision between urban and rural areas in order to coordinate urban-rural development and gradually narrow the gap. There are several strategies available to achieve this goal. One is to emphasize the role of government in allocating public resources. If 'efficiency' is focused on elementary resource distribution driven by market forces, the government role in "equity investment allocation" involves paying more attention to balancing the region's urban and rural development. The role of government is critical in this, requiring a fundamental change in the traditional strategy of relying solely on county, township and village investment. Therefore, there is a need to implement a proactive fiscal policy, jointly funded by the central and local governments to contribute more to investing in the construction of rural infrastructure.

Another strategy is to prioritize the investment in rural infrastructure resources and supply more highly. In particular, for public infrastructure resources (such as water supply and road projects) those are urgently needed. The synergy between public infrastructures should be well coordinated to improve the efficiency of public expenditure in the rural areas. Since the financial resources of the state and local governments are still limited compared with the large demand for public infrastructure in rural areas, the inherent priority order of rural public infrastructure options need to be identified first.

Infrastructure project development should determine the priority of 'efficiency' and 'equity' by taking into account the characteristics of the areas, development stages and projects involved. The discussion above indicates the different roles played by 'efficiency' and 'equity' in the different stages of social-economic development and it can be concluded that 'efficiency' is more important in the initial stage when the economy is booming. For example, placing a high priority on 'efficiency' should guarantee the concentration of limited resources on urban infrastructure projects, as these are more efficient than those in rural areas. However, after a period, the gap between urban and rural areas becomes too large, resulting in social conflicts that impact on the development of sustainability. Therefore, both 'equity' and 'efficiency' in rural areas should be accorded equal priority when this stage is reached.

6. Conclusions

As is well known, urban areas are predominantly overprovided relative to rural areas in terms of services such as medicine and education development. There is a potential, however, to redress this balance by a more strategic and coordinated approach to infrastructure provision. The primary aim of this paper is to enable this through a new mathematical model quantifying e-UR by focusing on the two attributes of efficiency and equity in order to measure the contribution of infrastructure projects in balancing urban-rural development. This enables government decision-makers for the first time to prioritize projects rigorously according to their likely contribution to improving rural-urban balance. Applying the model to the case of Chongqing indicates that the effects of individual infrastructure projects on the urban-rural balance in Chongqing can be improved more by an emphasis on equity attributes for water supply projects and emphasis on efficiency for roads projects. In this case, the result is affected greatly by the two equitable investment indicators of *Proportion of rural-urban support degree of investment policies* (X_{FIp1}) and *Proportion of rural-urban investors* (X_{FIp2}) due to the substantial differences in their urban and rural e-UR neutral benchmark values. However, this is attributable to the situation that exists in Chongqing rather than any inherent bias in the method.

The research findings of this study also provide a number of practical implications for the decision-making involved in coordinating urban-rural development in developing countries. The Chongqing case reflects the fact that Chongqing should implement a 'coordinated urban-rural' strategy by taking into account both of the two attributes. It is therefore highly recommended that Chongqing should first assess the e-UR values of the infrastructure projects involved and implement those projects with better e-UR values with a higher priority. On the other hand, it is suggested that reforms should also be conducted to the process of urban-rural integration of public infrastructure services in those rural areas with better social-economic conditions. The practical implications in proposing development strategies include, 1) actively adjusting national income distribution, 2) the initial establishment of public financial schemes that cover both urban and rural areas, 3) a balanced urban and rural employment system, 4) an improved social security system, and 5) an increased effort to explore new initiatives to break down institutional barriers in urban and rural areas.

Chongqing is typical of the more backward regions in China, both in terms of its rate of urbanization and social conscience. The coexistence of its metropolis and extensive rural areas is a particular current issue, with the dual structure of urban and rural areas being a prominent contradiction. It is therefore a typical microcosm of China in terms of coordinated urban-rural development (Shen *et al*., 2012). Hence, if Chongqing succeeds in forging a new path to achieving a coordinated urban-rural development, it can serve as a representative model and drive national reform in general. For the Chongqing situation, it is important to establish a systematic development model that covers the suburbs, outer suburbs and mountainous areas in order to improve coordinated urban-rural development by establishing a mechanism for interaction and cooperation between urban and rural areas. In these terms, therefore, Chongqing represents an archetypal conurbation and so the results obtained from this study are likely to be indicative of similar studies in other regions in China and developing countries in general. The e-UR indicators used in this study can therefore be adapted for regions or countries as a basis for the selection of those more specific to the local situation and which meet the quality and availability of statistical data needed at each level.

Of course, it can be argued that the empirical results of using the method are based largely on the subjective views of the experts involved in the e-UR neutral benchmarking and weighting of the indicator hierarchy. There is a need for more objective data, in case the experts are biased in some way. One approach to this is to measure the *actual* e-UR that is occurring over time for these projects for comparison with the e-UR index predictions. In this way, it will be possible to further validate the method and provide a means of making suitable adjustments where appropriate.

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Table 1

A framework for evaluating project e-UR.

Attribute level (weight)	Dimension level (weight)	Indicator level		
		weight	code	Description
Efficiency indicators (α)	Economic efficiency evaluation (0.40)	0.27	X_{BE1}	The discount rate at which the accumulated net present value of net cash flows is 0 for the calculation years of the project.
		0.24	X_{BE2}	The discount rate at which the accumulated present value of economic benefit flow is 0 for the calculation years of the project.
		0.22	X_{BE3}	The sum of present values of the net benefit flows converted at social discount rate to the beginning of the period for the calculation years of the project.
		0.27	X_{BE4}	The ratio between the present value of benefit flows and the present value of expenses for the calculation years of the project.
	Social efficiency evaluation (0.34)	0.20	X_{SE1}	The ratio between the number of jobs created by the project and the total investment of the project.
		0.27	X_{SE2}	The Engel coefficient of the local residents in the project region (the proportion of spending on food out of the total consumption).
		0.20	X_{SE3}	The compensations to the direct or indirect beneficiaries, involuntary migrants, women, children and disabled disadvantaged groups.
		0.17	X_{SE4}	The compatibility between the project and the local environment, stakeholders, organizations, technical and cultural conditions.
		0.16	X_{SE5}	Project influence over local ethnic groups, religion and social stability
	Environmental and ecological efficiency evaluation (0.26)	0.21	X_{EE1}	LAeq of the local noise and as per the noise emission (or environmental quality) standards
		0.30	X_{EE2}	Reflection of the impact of the project upon water and soil erosion, from *Cost-Benefit Analysis of Water and Soil Conservation*
		0.22	X_{EE3}	The ratio between the amount (value) of protected relics and the amount (or value) of excavated relics.
		0.27	X_{EE4}	The ratio between the amount of conserved energy in the (annual) report period and the comparable energy consumption in the base period.
Equitable investment indicators (1-α)	Equitable investment policies (0.44)	1.00	X_{FIP1}	The ratio between rural per capita infrastructure investment (or classified infrastructure investment) and urban per capita infrastructure investment (or classified infrastructure investment) in the project's region
	Equitable investment system (0.32)	0.46	X_{FIS1}	The ratio between rural infrastructure investor (government) and urban infrastructure investor (government) in the project's region
		0.54	X_{FIS2}	The ratio between perfection of rural infrastructure investment review and supervision system and perfection of urban infrastructure investment review and supervision system in the project's region
	Equitable investment environment (0.24)	0.34	X_{FIE1}	The ratio between rural per capital land occupation and urban per capital land occupation in the project's region
		0.39	X_{FIE2}	The ratio between rural per capital public resources (water supply pipeline, road area) and urban per capital public resources in the project's region
		0.27	X_{FIE3}	The ratio between rural per capital energy supply proportion (water and power) and urban per capital energy supply proportion in the project's region

Unit□ *Thousand Yuan; #People/ Thousand Yuan; &Thousand Yuan / People

Table 2

Indicator and benchmark scores.

Indicator No	Indicator	Unit	Indicator score range (mean value)		Benchmark score mean value	
			water	road	water	road
X_{BE1}	IRR (Internal Rate of Return)	%	8	7	7.25	7.27
X_{BE2}	EIRR (Economic IRR)	%	16.3-24.8	15.3-18.5	16.97	15.8
X_{BE3}	ENPV (Economic Net Present Value)	¥1k	2477-47071	2870-59624	17939.8	24561.5
X_{BE4}	(Direct and indirect) benefit-cost ratio of project		1.88-4.53	2.81-12.36	2.72	5.74
X_{SE1}	Employment status	Popn/¥1k	0.66-2.62	0.54-4.22	1.22	1.97
X_{SE2}	Living standard and quality (expressed by Engel Indicator)	%	37-54.5(Urban-Rural)		42.16	42.16
X_{SE3}	Amount of benefit compensation of project stakeholders and underprivileged groups	Popn/¥1k	3.1	3.4-5.1	2.77	6.1
X_{SE4}	Mutual adaptability indicator		0-1(Unfit –Fit)		0.73	0.73
X_{SE5}	Social risk level (expressed by social risk evaluation value)		0-1(Low-High)		0.41	0.41
X_{EE1}	Noise pollution indicator		0-1(Low-High), Limit value = 1		0.63	0.63
X_{EE2}	Water and soil loss impact indicator		0.1-0.2	0.2-0.4	0.13	0.3
X_{EE3}	Cultural relic and heritage preservation percentage (value)		0-1(Bad-Good)		0.54	0.54
X_{EE4}	Energy saving percentage	%	3.22		4.71	4.71
X_{FIP1}	Proportion of rural-urban support degree of investment policies		0.34-14.2	0.06-0.15	0.56	0.09
X_{FIS1}	Proportion of rural-urban investors		0.14-0.87	0.02-0.08	0.26	0.04
X_{FIS2}	Proportion of rural-urban investment supervision and administration		Assumed the complete rate of rural area is 1,0-∞		0.13	0.13
X_{FIE1}	Proportion of rural-urban natural resources		1.52-1.59		1.69	1.69
X_{FIE2}	Proportion of rural-urban public resources		3.33-3.70	1.11-12.50	3.57	12.50
X_{FIE3}	Proportion of rural-urban energy supply		0.40-0.53		0.48	0.48

Table 3a
Project 1 (Gaotang water supply) IU-RB index calculation.

Indicator code	**Unit**	**Project value (A)**	**Indicator benchmark value (B)**	**Raw indicator e-UR {A/B}-1**	**Indicator level weight (C)**	**Dimension level weight (D)**	**Attribute level weight (α=0.5) (E)**	**Combined weight (CDE)**	**Weighted indicator IU-RB {A/B}-1)CDE**
X_{BE1}	%	7.25	7.25	0.000	0.27	0.40	0.50	0.054	0.000
X_{BE2}	%	17.40	16.97	0.025	0.24	0.40	0.50	0.048	0.001
X_{BE3}	¥1k	3910.00	17939.80	-0.782	0.22	0.40	0.50	0.044	-0.034
X_{BE4}		2.46	2.72	-0.096	0.27	0.40	0.50	0.054	-0.005
X_{SE1}	Popn/¥1k	2.62	1.22	1.155	0.20	0.34	0.50	0.034	0.039
X_{SE2}	%	39.60	42.16	-0.061	0.27	0.34	0.50	0.046	-0.003
X_{SE3}	Popn/¥1k	2.77	2.77	0.000	0.20	0.34	0.50	0.034	0.000
X_{SE4}		0.73	0.73	0.000	0.17	0.34	0.50	0.029	0.000
X_{SE5}		0.41	0.41	0.000	0.16	0.34	0.50	0.027	0.000
X_{EE1}		0.63	0.63	0.000	0.21	0.26	0.50	0.027	0.000
X_{EE2}		0.13	0.13	0.000	0.30	0.26	0.50	0.039	0.000
X_{EE3}		0.54	0.54	0.000	0.22	0.26	0.50	0.029	0.000
X_{EE4}	%	4.71	4.71	0.000	0.27	0.26	0.50	0.035	0.000
X_{FIP1}		1.51	0.56	1.718	1.00	0.44	0.50	0.220	0.378
X_{FIS1}		0.87	0.26	2.280	0.46	0.32	0.50	0.074	0.168
X_{FIS2}		0.13	0.13	0.000	0.54	0.32	0.50	0.086	0.000
X_{FIE1}		1.58	1.69	-0.070	0.34	0.24	0.50	0.041	-0.003
X_{FIE2}		3.74	3.57	0.046	0.39	0.24	0.50	0.047	0.002
X_{FIE3}		0.45	0.48	-0.049	0.27	0.24	0.50	0.032	-0.002
Totals				*4.166*	*6.000*	*6.140*	*9.500*	*1.000*	***0.542***
Average				***0.219***	*0.316*	*0.323*	*0.500*		

Table 3b
Project 2 (Caotang water supply) e-UR index calculation.

Indicator code	Unit	Project value (A)	Indicator benchmark value (B)	Raw indicator e-UR {A/B}-1	Indicator level weight (C)	Dimension level weight (D)	Attribute level weight (α=0.5) (E)	Combined weight (CDE)	Weighted indicator IU-RB {A/B}-1)CDE
X_{BE1}	%	7.35	7.25	0.014	0.27	0.40	0.50	0.054	0.001
X_{BE2}	%	18.50	16.97	0.090	0.24	0.40	0.50	0.048	0.004
X_{BE3}	¥1k	8745.00	17939.80	-0.513	0.22	0.40	0.50	0.044	-0.023
X_{BE4}		2.63	2.72	-0.033	0.27	0.40	0.50	0.054	-0.002
X_{SE1}	Popn/¥1k	2.25	1.22	0.848	0.20	0.34	0.50	0.034	0.029
X_{SE2}	%	39.60	42.16	-0.061	0.27	0.34	0.50	0.046	-0.003
X_{SE3}	Popn/¥1k	2.77	2.77	0.000	0.20	0.34	0.50	0.034	0.000
X_{SE4}		0.73	0.73	0.000	0.17	0.34	0.50	0.029	0.000
X_{SE5}		0.41	0.41	0.000	0.16	0.34	0.50	0.027	0.000
X_{EE1}		0.63	0.63	0.000	0.21	0.26	0.50	0.027	0.000
X_{EE2}		0.13	0.13	0.000	0.30	0.26	0.50	0.039	0.000
X_{EE3}		0.54	0.54	0.000	0.22	0.26	0.50	0.029	0.000
X_{EE4}	%	4.71	4.71	0.000	0.27	0.26	0.50	0.035	0.000
X_{FIP1}		1.51	0.56	1.718	1.00	0.44	0.50	0.220	0.378
X_{FIS1}		0.87	0.26	2.280	0.46	0.32	0.50	0.074	0.168
X_{FIS2}		0.13	0.13	0.000	0.54	0.32	0.50	0.086	0.000
X_{FIE1}		1.58	1.69	-0.070	0.34	0.24	0.50	0.041	-0.003
X_{FIE2}		3.74	3.57	0.046	0.39	0.24	0.50	0.047	0.002
X_{FIE3}		0.45	0.48	-0.049	0.27	0.24	0.50	0.032	-0.002
Totals				*4.270*	*6.000*	*6.140*	*9.500*	*1.000*	***0.550***
Average				***0.225***	*0.316*	*0.323*	*0.500*		

Table 4a
e-UR index values (Y) for water supply projects.

District	Location	α=0.0	α=0.3	α=0.5	α=0.7	α=1.0
Chengkou	Gaoguan	1.09	0.76	0.54	0.33	0.00
Fengjie	Caotang	1.09	0.77	0.55	0.34	0.01
	Hongtu	1.09	0.75	0.52	0.30	-0.04
Youyang	Longtan	1.09	0.88	0.74	0.60	0.39
	Mawang	1.09	0.81	0.62	0.44	0.16
Yunyang	Jiangkou	1.09	0.80	0.61	0.42	0.13
	Nixi	1.09	0.72	0.48	0.23	-0.14
	Yanglu	1.09	0.74	0.50	0.27	-0.08
Wushan	Longjing	1.09	0.76	0.55	0.33	0.00

Table 4b
e-UR index values (Y) for road projects.

District	Location	α=0.0	α=0.3	α=0.5	α=0.7	α=1.0
Chengkou	Chengguan 2	-0.24	-0.02	0.13	0.28	0.50
Fengjie	Caotang	-0.24	-0.16	-0.10	-0.04	0.04
	Hongtu	-0.24	-0.15	-0.09	-0.03	0.06
	Qinglong	-0.24	-0.14	-0.08	-0.02	0.08
	Tuxiang	-0.24	-0.15	-0.10	-0.04	0.04
Fuling	Baisheng	-0.24	-0.14	-0.08	-0.01	0.08
	Wubai	-0.24	-0.06	0.06	0.19	0.37
Qianjiang	Houhuang	-0.24	-0.08	0.02	0.13	0.29
Wushan	Baiquan	-0.24	-0.16	-0.10	-0.05	0.03
	Baishui	-0.24	-0.15	-0.09	-0.03	0.05
	Hongmiao	-0.24	-0.15	-0.09	-0.03	0.06
	Shili	-0.24	-0.17	-0.12	-0.07	0.00
	Xiping	-0.24	-0.13	-0.06	0.01	0.12
Xiushan	Meiyun	-0.24	-0.03	0.10	0.24	0.44
Youyang	Ganhuo	-0.24	-0.05	0.08	0.20	0.39
	Heimao	-0.24	-0.15	-0.10	-0.04	0.04
	Shuiyao	-0.24	-0.17	-0.12	-0.07	0.00
Yunyang	Nixi	-0.24	-0.18	-0.14	-0.11	-0.05
	Nongba	-0.24	-0.15	-0.09	-0.03	0.06
	Yanglu	-0.24	-0.17	-0.12	-0.08	-0.01
	Yaoqing	-0.24	-0.14	-0.08	-0.01	0.08