China's Regional Balance Development and Objective Investment in Power Grid Infrastructure

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Abstract: Promoting infrastructure construction plays an important role in reducing poverty and decreasing regional development gaps. This paper constructs the "peripheral degree Index" of power grid in order to measure the electricity transmission cost according to the characteristics of regional distribution of energy resource endowment and consumption. Based on the convergence theory of economic growth, the paper carries out an empirical analysis of the impact of power grid infrastructure investment on China's social development using panel data for 1998-2008 from Chinese provinces. In addition, through simulating the effects of different location arrangements of power grid infrastructure investment on the whole country and various regions' social development and comparing the effects, our results indicate that marginal returns of infrastructure investments in power grid are various, and the investments in low developed regions may have stronger effects. Moreover, leading the investments to the central provinces will achieve the coherence of integrative social development and regional balanced growth most effectively.

Keywords: power grid; infrastructure; electricity transmission cost; peripheral degree index

1.Introduction

In three decades of market-oriented reforms, China has achieved great success in economy, education, medical care, etc. However, China's transition to a market-based economy has created an evident problem of regional development disparities, which limits the potential of sustainable development of China's economy and has negative impact on social stability. Therefore, China has to cope with challenges brought by social inequality and re-examine how to coordinate the relations of "Efficiency" and "Equity" in the process of economic growth. Achieving balanced development so as to reduce those disparities appears to be one of the major policy challenges that China now faces and it also constitutes an important part of the realization of the Millennium Development Goals.

Considering China's huge size, regional differences arise naturally in geography and in natural resource endowments.[1] To compensate for these natural constraints, the availability of an appropriate infrastructure might prove helpful in reducing poverty and narrowing the development gap among regions. It helps reducing poverty in three aspects. First, it creates employment opportunities and decreases the costs of labor transfer between urban and rural areas. Second, transportation cost could be cut and production efficiency could be increased. Third, it helps improve social welfare. For instance, infrastructure construction, especially those for basic living needs, such as energy and water supplies plays an important role in improving living quality of poor people. Thus, the three aspects promote social welfare and reduce poverty either by direct effects of income distribution, which increase employment opportunities and raise the income levels for the poor, or by indirect effects which poor people can benefit from economic and social development and increase their real income and consumption.

Infrastructure, such as transportation, energy, communications, etc. has long been considered as the base of economic growth and social development. Following the research of Aschauer (1989), the New Growth Theory Models led by Romer (1986) and Lucas (1988) take account of public infrastructure as a factor for productivity gains and long-term economic growth (Barro,1991). More recent studies of the effects of public expenditure on growth have included Aschauer (2000) and Milbourne et al. (2003). Both test the predictions of a neo-classical growth model in which public capital is a complement to private capital, and find that public investment has a positive and significant impact on economic growth.

A number of studies focus on the relationship between infrastructure investment and China's economic growth. Mody and Wang (1997) conclude that road network length and the level of telecommunication facilities have a positive but subject to diminishing returns effect on

[1] See Fleisher and Chen (1997), Raiser (1998) for a discussion on the existing literature on this issue.

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China's economic growth for a limited time and regional data set. Demurger (2001) argues that transport facilities are a key differentiating factor in explaining the growth gap and telecommunication has significant impact on reducing regional disparities in China since the mid 1980s. However, the above studies haven't concentrated on the impact of investment in power grid infrastructure (**PGI**) on China's development.

Effective investment in power grid infrastructure and improvement of power grids help to optimize allocation of resources, which has dual effects of promoting China's social and economic development, and reducing regional disparity. However, for a long time, especially the last five years, China's construction of power grids has lagged behind the construction of electric power, resulting in serious problems. On one hand, China's large hydropower bases are located in the southwest and main coal bases are distributed in Shanxi and Inner Mongolia. The backwardness of power grid infrastructure hinders the full utilization of generating capacity of energy delivery areas[2], which makes it difficult to give play to resource advantage of western regions. On the other hand, insufficient investment in power grids leads to seasonal power shortages in eastern and middle developed regions where most of electricity demand is seen. Thus, sectional shortage of power supply may remain a problem for these electricity loading centers[3]. Therefore, the key question is how to make use of power grids to optimize allocation of resources and increase energy efficiency with consideration of China's vast land and uneven distribution of energy resources. It is not only a question about the optimization of allocation of limited resources but about how to realize cost minimization in macro economy.

This paper attempts to discuss how to efficiently locate the investment in power grid infrastructure (**PGI**) to optimize the allocation of limited financial resources so as to reduce regional disparities in China and promote the sustainable development of the whole economy. The paper's aims can be explained in three aspects. First, to analyze the role of investment in **PGI** on regional development. Secondly, to simulate the impact of different infrastructure investment distribution on social development and reduction of regional disparity. Thirdly, to explore ways of optimizing the distribution of PGI to balance regional development.

With China's resource distribution characteristics taken into account, this papers studies the role of power transmission cost on social development. Following Luo (2004)'s[4] research method on transportation, this paper constructs a "Peripheral Degree Index" of Power Grid to measure the effective distance between electricity delivering and receiving regions[5], as an indicator of power transmission cost. The paper is organized as follows: Section two analyzes the unbalanced social development among different regions in China and the backwardness and disparities of PGI development. Section three focuses on the role of PGI development on regional social development by constructing the "peripheral degree index" of power grids. Section four simulates the impact of different investment distribution of **PGI** on national social development and reduction of regional disparities. Section five carries out robustness test. Section six presents the conclusion remarks and policy suggestions.

2. Regional Disparities of Social Development and PGI Development

2.1. The Widening Regional Disparities and the "Twin-Peaks" Phenomenon

A number of studies have discussed the problem of the enlarging development gap among regions in China. But research in the past mainly focused on the inequality of income or expenditure and used no other indicator of welfare, which had limitations in measuring the levels of overall development in different regions. Development is a multi-dimensional concept. The Human Development Index (**HDI**) proposed by the United Nations Development Programme (**UNDP**) in 1990 is a comprehensive indicator of measuring social development of a country or a region. It combines three basic dimensions of human development: income, health, and education.

Many scholars have studied regional disparities of social development applying the **HDI** since the mid 1990s. Their conclusion shows that China's social development among different regions is unbalanced, with much higher level of development in the eastern region than in the central and western regions. Lai (2003) use the weighted principal component analysis to measure and analyze the level of social development in Chinese provinces since 1990. The result, which is accordance with Tang (1999), shows evident disparities of economy, education, health, etc. among different regions.

Our paper applies the Kernel density function and

[2] According to State Grid Corporation of China, energy delivering regions in China include Shanxi, Shaanxi, Inner Mongolia, Ning Xia, Xinjiang, Chongqing, Sichuan, and Tibet, which are mainly located in western regions.

[3] Loading centers means major electricity consumption regions.

[4] Luo (2004) constructs an indicator "peripheral degree index" to measure the effective distance of a province to domestic economic centers and examines the role of peripheral degree in regional growth . The peripheral degree is determined by geographic distance between the provinces and the development level of transportation Infrastructure.

[5] According to State Grid Corporation of China, energy receiving regions in China include Liaoning, Jilin, Heilongjiang, Beijing, Tianjin, Hebei, Shandong, Jiangxi, Zhejiang, Jiangsu, Shanghai, Anhui, Fujian, Hunan, Hubei, Henan, Guangdong, Guangxi, and Hainan.

HDI statistics of China's 31 provinces[6] from 1998 to 2008, and discusses the evolution of social development distribution among provinces in China.

Figure 1 represents the Kernel density function[7] graph of the **HDI** in 1998 and 2008. As shown in Figure 1, the distribution of social development in China shifted to the right from 1998 to 2008, meaning an overall improvement of national social development. In 1998, HDI of most provinces was close to 0.68 and only one peak existed. In 2008, the number of provinces whose development levels approached the national average level decreased. The **HDI** of undeveloped provinces was around 0.7 while that of developed provinces reached near 0.78. This movement shows that China's social development distribution has changed from a single peak to twin peaks from 1998 to 2008, indicating that social development in the east and central-west region has converged to two different steady states and the trend of polarization has emerged. This conclusion is consistent with findings of Quah (1996).

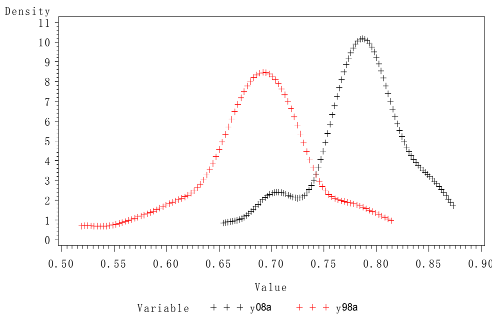

Figure 1. Evolution of Social Development Distribution among Provinces in China from 1997 to 2006

2.2. Lag and Disparities of PGI development in China

Construction of power grid infrastructure is required to adapt to the development of economy and society. However, the investment in China's **PGI** is not consistent with its demand due to the emphasis on power generation rather than transmission because of the long-term electricity shortages in the past. From statistics of the growth rate of power generating capacity in recent years, China's electricity shortages, in the medium to long run, will come from the insufficiency of power supply capability of grid rather than the shortage of power-generating capacity. The backward development of power grid infrastructure and the lack of an effective power network will drag the full use of large incremental installed generation capacity.

Table 1 compares the proportions of investment in generation and power grid in the total power investment in five countries. As shown in Table 1, there is a common feature in developed countries that the proportion of **PGI** in the total power investment is larger than that of generation investment. On the contrary, in China, the proportion of **PGI** is far smaller than that of the generation investment. When it comes to the proportion of transmission and distribution tariff to retail tariff, the proportions in developed countries such as Britain, Canada (Ottawa), Germany, Australia, and Japan are 58.1%, 41.1%, 65.8%, 41.4%, and 49.7%[8]. Whereas, the proportion in China is only 30%[9], markedly lower than the figures of developed countries.

The lag of power grid construction limits not only the development of the power industry but the development of economy and society. The deficiency of investment in power grids led to regional disparities of electricity supply in the country. Some regions see an excess of power-generating capacity while some are faced with electricity shortages. In addition, the accelerating construction of power supply in recent years intensified the imbalance between power supply and power grids, affecting both the security of grids and the cost of economic growth, which remains a problem pressing for solution. However, increasing investment in power grid infrastructure is only part of the solution. For one thing, the policy of investment in PGI which aims at maximizing the whole country's development may not have significant impact on the development of the central-west. For another, preferential policies designed for undeveloped regions may not necessarily play an effective role in promoting the whole country's development. Therefore, we need to examine the conditions and development of China's resources and figure out the best way of distributing **PGI** investment to different regions so as to promote the whole country's development while narrowing China's regional development gap. The following chapters analyze the effect of **PGI** development on China's regional social development and simulate the impact of **PGI** investment distribution on China's social development and the narrowing of China's regional development gap.

[6] Statistics of the HDI of China's 31 provinces come from calculation of the authors.

[7] See Appendix for the detail information of the Kernel density function.

[8] Statistics come from National Economic Research Associates of the UK, as cited in Annual Development Report of China's Electricity Prices and Power Industry by Development Research Center of the State Council in 2004.

[9] According to Report on Regulation of Electricity prices (2007) released by State Electricity Regulatory Commission in September 2008, the average grid tariff and retail tariff in 2007 were 336.28 and 508.51 yuan per MWH , respectively. From 2008 till now, the two prices were up by 37 and 25 yuan, respectively after electricity price adjustment, reaching 373.28 and 533.51 yuan per MWH.

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Table 1. Proportions of Investment in Power generation and Power Grids to Total Power Investment in Five Countries

Country	Proportion of Power Generation Investment (%)	Proportion of Power Grid Investment (%)
The US	47	53
The UK	45	55
Japan（1998-2003）	54	46
France	31	69
China	65	35

Source: State Grid Corporate Social Responsibility Report；FEPC（2005）

3. The Role of PGI Construction in Regional Social Development

Power grid is an important infrastructure which support for social and economic development. For a given geographic distance, the better the development level of power grid facilities is, the lower the power transmission cost is. The cost of power transmission affects the potential of energy sending regions which are less developed to transform resource advantages into economic advantages and also has impact on the economic and social development of loading centers which are relatively developed. In this section, a "peripheral degree index" of power grids is constructed, as an indicator of power transmission cost, to measure the relative distance between energy delivering and receiving regions, and the effect of peripheral degree on regional social development is also analyzed.

3.1. Peripheral Degree index of Power Grids

The cost of power transmission depends on the geographic distance and the development level of power grid facilities between two places. Therefore, the economic and social development of both the energy delivering and receiving regions will be affected by the two factors. Following the method of Luo (2004) on transportation, this paper constructs a "Peripheral Degree Index" of Power Grid with consideration of the characteristics of China's resource distribution to measure the effective distance between electricity delivering and receiving regions, as an indicator of power transmission cost. The index is composed in four steps.

First, a variable measuring the development level of power grid infrastructure, the density of power network in province v in year t, is defined as,

$$D_{v,t} = \frac{L_{v,t}}{S_{v,t}} \tag{1}$$

where $L_{v,t}$ denotes total length of transmission lines and $S_{v,t}$ denotes the area;

Secondly, assume that electricity is transmitted between province i and province j by the way of provinces. The convenience of power transmission between province i and j is defined as,

$$D_{ij,t} = \frac{\sum D_{v,t}}{n} \tag{2}$$

Thirdly, to measure the transmission cost, the adjusted distance of power transmission between province i and province j is defined as,

$$DistA_{ij,t} = \frac{Dist_{ij,t}}{D_{ij,t}} \tag{3}$$

where $Dist_{ij,t}$ is the geographic distance between province i and province j. Thus, the adjusted distance $DistA_{ij,t}$ reflects that the real distance between i and j adjusted by the development level of power grid facilities that connects these two provinces at year t.

Fourthly, the "peripheral degree index" of grid in province i of the energy delivering regions is defined as

$$DP_{i,t} = \sum_j \left[DistA_{ij,t} \times \frac{EC_{j,t}}{\sum_j EC_{j,t}} \right] \tag{4}$$

where $EC_{j,t}$ stands for electricity consumption in province j of the energy receiving regions. It reflects that the further is province i from energy receiving provinces, the less its power-generating capacity could be fully utilized. Then, the "peripheral degree index" of grid in province i of the energy receiving regions is defined as

$$DP_{i,t} = \sum_j \left[DistA_{ij,t} \times \frac{EF_{j,t}}{\sum_j EF_{j,t}} \right] \tag{5}$$

where $EF_{j,t}$ stands for the power-generating capacity of province j of the energy delivering regions. It means that the further is province i from energy delivering provinces, the higher cost of power transmission for province i is.

3.2. Empirical Analysis: Impact of PGI Invest-

ment on Regional Social Development

Using different provinces' **HDI** as the indicator of social development, this section analyzes the determination of annual social development of Chinese provinces during 1998-2008 and focuses on the effect of infrastructure investment in Power Grid by applying the ***β***-convergence model.

The theoretical basis of convergence concept come from the neoclassical growth theory suggested by Solow (1956) and Swan (1956), which emphasizes the role of physical investment rate in economic growth. The Solow-Swan Model argues that, for the same rate of investment, every economy would grow at a similar rate determined by the exogenous technical progress rate and demographic growth rate. Therefore, according to the neoclassical growth model, regions of a country with a lower level of initial productivity often gains a higher growth rate due to the assumption of a production function with diminishing returns of capital. In the long run, less developed regions will eventually catch up with developed ones, reaching steady-state equilibrium.

The concept of convergence is mainly discussed in the literature in the context of income indicator usually measured in terms of **GDP** per capita. As the **HDI** is a composite index of income, life expectancy and education, which has two non-income components, it may be useful to explore the relevance of convergence to this index. Based on the above analysis, the neoclassical growth model considers the theoretical assumption of the diminishing returns of capital as the source of the convergence of economic growth. As suggested by Farhad (2006), the concept of diminishing returns of capital could also apply to component of education and life expectancy. For two regions that are different in initial development levels, equal investment in education and medical care brings unequal returns. As the rate of return decreases as the investment increases, higher growth rate can be seen in the region with a lower level of initial development, thus resulting in convergence. Hence, it can be expected that regions with a lower level of social development in the initial period would enjoy a higher growth rate in **HDI** in the long run than those with a higher level of initial social development.

The analysis of the **HDI** convergence has received attention from scholars outside China. Farhad (2006) studies the inequality in social development between countries and conducts empirical analysis about international convergence in **HDI**. Under the model framework of Farhad (2006), we test the role of infrastructure investment in regional social development by employing the following ***β***-convergence models in **HDI**:

$$\frac{1}{T}\log(\frac{hdi_{it+T}}{hdi_{it}}) = \alpha + \beta\log(hdi_{it}) + \sum_{j=1}^{j_k}\lambda_{ij}S_{ij} + \mu_{it},$$

$$\text{for } k = 0,1,2,\ldots,K \qquad (6)$$

where $hdi_{it} = \frac{HDI_{it}}{HDI_t}$ is the ratio of **HDI** in the i^{th} province to the average for all the provinces under consideration. The standardized **HDI** could reflect the change of these provinces' relative positions and actual social development levels during their development process. $\frac{1}{T}\log(\frac{hdi_{it+T}}{hdi_{it}})$ is the annual growth of **HDI** of province i over the period of t and $t+T$. There is an evidence of ***β***-convergence in the range of $-1 \prec \beta \prec 0$, meaning that the growth rate of a province's **HDI** is inversely proportional to its initial **HDI** level. That is, the rate of convergence becomes faster when β gets closer to -1 and slower when β approaches 0[10]. S_{ij} stands for the j^{th} structural condition variable and λ_{ij} is the respective parameter. When the structural conditional variables change, there will be K different models.

The data for **HDI** during the period of 1998 to 2008 comes from author's calculation. We have selected the variables to reflect conditional convergence according to the contribution to the three components of the **HDI**: the ratio of physical investment to **GDP** (*TZL*), the ratio of public expenditures on education and medical services to the total fiscal expenditure (*JW*) [11]and the variable of peripheral degree index (*DP*) to reflect the level of power grid infrastructure.

The above convergence model is estimated by a fixed effect model with panel data. While a random effect model that implies no correlation between the individual effects and the unobserved independent variables is inappropriate for this convergent regression, a fixed effect model including such correlation accords well with economics theory. Moreover, the econometric test with Hausman method comparing fixed effects and random effects shows that the fixed model is better. The resulting estimations of the fixed effect model are presented in Table 2.

First, we start by testing the absolute convergence hypothesis of **HDI** in Model 1[12]. As shown in Table 2, the negative sign of β is as expected and it is significant at the 1% level, showing that the initial development level of province plays a significant role on regional social development and indicating a trend to convergence amongst the provinces in the sample, which agrees with

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[10] When $\beta = 0$, there is no convergence. When $\beta \succ 0$, divergence appears.

[11] The data for *TZL* and *JW* during the period of 1997 to 2006 comes from the China Statistical Yearbook issues (2009).

[12] To smooth short-term cycle variations, *T* is set as two to study the annual growth rate of the **HDI** in every three years during the period 1997 to 2006.

the above analysis.

Model 2 introduces the conditional ***β***-convergence. According to the neoclassical growth model, a higher ratio of physical investment to GDP brings about higher productivity of effective labor force in the long run, other things being equal. Therefore, the ratio of physical investment to GDP (*TZL*) is introduced to reflect the contribution to the income component in **HDI**. In Model 2, the variable $\ln(hdi)$ continues to be significantly negative, which indicates conditional convergence. The significance of the investment ratio and its positive coefficient in Model 2 is in accordance with the prediction of growth theory.

Model 3 introduces the ratio of public expenditures on education and medical services to the total fiscal expenditure (*JW*) which is relevant to the education and life expectancy components of HDI. In Model 3, *JW* has a positive coefficient significant at the 5% level, indicating that the increase of investment in education and medical services plays an important role in promoting regional convergence within China.

Table 2. Determination of Provincial Social Development——Role of Power Grid Infrastructure

Model/ Variable	Model 1	Model 2	Model 3	Model 4
Constant	-0.0000 (-0.524251)	0.0673 (2.8806)***	0.0037 （7.4758）***	0.1428 (3.9087)***
Ln(hdi)	-0.1081 (-5.462406)***	-0.0639 (-2.8170)***	-0.0508 （-19.6079）***	-0.083513 (-3.4421)***
Ln(TZL)		0.0032 (2.4735)***	0.0061 （4.3840）***	0.007665 (4.2686)***
Ln(JW)			0.0061 （2.4721）**	0.00508 (2.0154)**
Ln(DP)				-0.004744 (-2.5935)**
Adjusted R^2	0.5927	0.6778	0.6954	0.70445
F Statistics	12.5956***	17.1536***	18.0853***	18.0815***

Note: t-students are in brackets. ***,**,and * show the results significant at the level of 1%, 5%, and 10%, respectively

Finally, the variable of peripheral degree index (*DP*) is introduced into Model 4. As mentioned, investment in power grid infrastructure directly affects the cost of power transmission, thereby playing an important part in economic growth and social development. From the estimated results in Model 4, it can be noted that the variable *DP* has a negative impact on regional social development. For this reason, to strengthen power grid construction so as to improve the operation of power grids and reduce power transmission cost could play a positive role in promoting a region's social development. Because the geographic distance between two provinces is constant, without objective investment in PGI, energy deliver provinces can hardly make use of their resource advantages and economic growth and social stability of energy receivers may be limited due to the shortage of power supply.

4. Objective Investment in Power Grid Infrastructure

China is a huge geographical country with unbalanced distribution of energy resources. Investing in power grid infrastructure tending toward effectively reducing electricity transmission cost and optimizing of resource allocation is essential for regional development in China. Based on above analysis, the following section using method of simulation will discuss what impact of locating grid investment has on social development among regions.

4.1. Simulation Methodology

Improving grid infrastructure could reduce the cost of electricity transmission, and therefore promote regional social development. As discussed above, the "peripheral degree index" of grid is determined by geographical distance and grid quality between energy deliverers and receivers. Improves the development of grid infrastructure in one province can reduce its own peripheral degree as well as those of others connected to it.

If the power network density in province v connecting province i to province j changes, the peripheral degrees of both i and j will also change. In fact, the higher operation level of grid in province v would decrease peripheral degrees of all the provinces whose energy delivery will pass by v. Moreover, the larger quantity of electricity pass by, the stronger impact the grid improvement of province v has on the peripheral degrees of its connected provinces.

First, we use the parameter estimations from model 4 in table 2 and observed value of correlated independent variables, including peripheral degree index, the physical investment rate and the ratio of public expenditure on education and medical services to the total fiscal expenditure, to calculate the value of $\frac{1}{T}\ln(\frac{hdi_{it+T}}{hdi_{it}})$ and mark it as $g1$.

Secondly, by using a new peripheral degree (*DP*) resulting from simulating change of grid density in province v, we re-calculate $\frac{1}{T}\ln(\frac{hdi_{it+T}}{hdi_{it}})$ and mark it as $g2$. The difference is marked as $\text{Gadif}(v)_{i,t}=\text{g1-g2}$, which reflects the change in HDI growth of province i resulting from the change of grid density.

Since the change of grid density in province v will affect social development of its connected provinces, the impact of this change on **HDI** growth of the whole country or regions will depend on weighted average growth effects of the **HDI** of all provinces which are affected. We use development levels(which is denoted by **HDI**) of each province as the weights, and denote as,

$$gaeff(v)_t = \sum_i^n \left[gadif(v)_{i,t} \times \frac{HDI_{i,t}}{\sum_t^n HDI_{i,t}} \right] \quad (7)$$

a) if i represents a province of all Chinese provinces, $gaeff(v)_t$ then represents impact of grid density change in province v in year t on the national HDI growth, and the weight is denoted as $gaeff0(v)_t$.

b) if i refers a province of energy delivering regions, $gaeff(v)_t$ then represents impact of grid density change of province v in year t on the HDI growth of energy delivering region, and the weight is denoted as $gaeff1(v)_t$.

c) if i means a province of energy receiving regions, $gaeff(v)_t$ then represents impact of grid density change of province v in year t on the HDI growth of energy receiving region, and the weight is denoted as $gaeff2(v)_t$.

For the sake of simplicity，we use average weights on the whole period from 1998 to 2008, as follows:

$$gaeff_i(v)m = \frac{\sum_{2000}^{2008} gaeff_i(v)}{8}, \quad i = 0,1,2 \quad (8)$$

Finally, on the basis of simulating absolute and relative effect of changes in provincial grid density on national and regional social development, we will discuss the impact of investment in grid infrastructure with particular objective on regional development, that is how to guarantee the consistency between overall social development and regional inequality reduction.

4.2. Empirical Results

If grid density in a certain province is increased by 10% based on its initial density when other provinces are kept constant, which means $Dnew1_{v,t} = 110\% \times D_{v,t}$, then what impact would this change have on the national and regional social development?

The results in Table 3 indicate that the density increase in one province will have larger positive effect for energy delivering regions than for both energy receiving regions and the whole country, when grid densities in the other provinces are kept constant. The energy delivering regions are mostly less developed western provinces while the receiving regions are mostly eastern and central developed provinces, which means strengthening infrastructure across the country may generate higher marginal benefits in poverty-stricken areas. And they also indicate that locating the investment in those provinces at nationwide grid junctions, such as Henan, Shanxi, Hubei and Hebei would have most significant effect for promoting national and regional development; and moreover, comparing to investing intently in several provinces in the delivering region, this location choice will benefit more for the integrated development of the delivering region, and therefore have more significant impact on promoting regional coordinative development and optimizing resource allocation.

The infrastructure construction of grid in one province could play a role in promoting social development in two ways: for the province itself, and for the others. In order to study what effect the increase of provincial local grid density will have on other region's social development, as well as to test the robustness of simulation results, we will calculate its weighted sum of impact from which the impact on the province itself is excluded. For details, see the following equation:

$$gaeff(v)_t = \sum_i^n \left[gadif(v)_{i,t} \times \frac{HDI_{i,t}}{\sum_t^n HDI_{i,t}} \right], i \neq v \quad (9)$$

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Table 3. Impact of provincial grid density increased by 10% on regional social development （province in question included）

National		Energy delivering regions		Energy receiving regions	
Province	Gaeff0(v)m	Province	Gaeff1(v)m	Province	Gaeff2(v)m
Shanxi	4.2	Henan	8.2	Shanxi	4.2
hubei	4.1	Hubei	8.0	Hebei	4.1
henan	4.1	Shanxi	7.9	Henan	4.1
hebei	3.8	Hebei	7.2	Hubei	3.8
shaanxi	2.8	Shaanxi	4.8	Shaanxi	2.8
Anhui	2.0	Guangdong	4.0	Tianjin	2.0
Sichuan	2.0	Hunan	3.7	Anhui	2.0
Tianjin	1.9	Anhui	3.5	Sichuan	1.9
Hunan	1.8	Liaoning	3.3	Beijing	1.8
Guangdong	1.6	Chongqing	3.2	Hunan	1.6
Chongqing	1.6	Shandong	3.0	Chongqing	1.6
Liaoning	1.5	Jilin	2.5	Liaoning	1.5
Beijing	1.4	Jiangsu	2.5	Shandong	1.4
Shandong	1.4	Tianjin	2.2	Shanghai	1.4
Jiangsu	1.3	Guangxi	2.1	Jilin	1.3
Shanghai	1.3	Sichuan	2.1	Guangdong	1.3
Jilin	1.2	Heilongjiang	2.0	Jiangsu	1.2
Guangxi	1.2	Beijing	1.8	Guangxi	1.2
Heilongjiang	0.9	Ningxia	1.8	Heilongjiang	0.9
Jiangxi	0.9	Zhejiang	1.7	Jiangxi	0.9
Zhejiang	0.8	Shanghai	1.2	Zhejiang	0.8
Inner Mongolia	0.7	Jiangxi	1.2	Inner Mongolia	0.7
Ningxia	0.7	Inner Mongolia	1.2	Ningxia	0.7
Fujian	0.6	Fujian	1.0	Fujian	0.6
Xinjiang	0.4	Xinjiang	0.5	Xinjiang	0.4
Hainan	0.3	Hainan	0.1	Hainan	0.3
Tibet	…	Tibet	…	Tibet	…

Note: the units for all data are 1/10000; "…" indicates the value is less than 0.01. eg, if the grid density in Shanxi Province is increased by 10% while other provinces are kept constant, the national HDI will rise up by $4.2*10^{-4}$

Table 4. Impact of provincial grid density increased by 10% on regional social development （province in question excluded）

National		Energy delivering regions		Energy receiving regions	
Province	Gaeff0(v)m	Provinces	Gaeff1(v)m	Provinces	Gaeff2(v)m
Shanxi	4.1	Henan	8.2	Shanxi	3.8
Hubei	3.5	Hubei	8	Henan	3.2
Henan	3.5	Hebei	7.2	Hubei	3.1
Hebei	3.3	Guangdong	4	Hebei	3
Shaanxi	2.6	Hunan	3.7	Shaanxi	2.5
Sichuan	1.9	Shanxi	3.6	Sichuan	1.8
Anhui	1.5	Anhui	3.5	Anhui	1.6
Chongqing	1.4	Liaoning	3.3	Chongqing	1.4
Jilin	1.3	Shandong	3	Hunan	1.1
Hunan	1.3	Jilin	2.5	Tianjin	1
Guangdong	1.1	Jiangsu	2.5	Inner Mongolia	0.7
Tianjin	0.9	Tianjin	2.2	Shandong	0.6
Liaoning	0.8	Guangxi	2.1	Guangdong	0.6
Shandong	0.8	Shaanxi	2.1	Guangxi	0.6
Guangxi	0.8	Heilongjiang	2	Ningxia	0.6
Jiangsu	0.7	Beijing	1.8	Liaoning	0.5

Inner Mongolia	0.6	Zhejiang	1.7	Jilin	0.5
Jiangxi	0.5	Shanghai	1.2	Jiangsu	0.5
Ningxia	0.5	Jiangxi	1.2	Beijing	0.4
Beijing	0.4	Fujian	1	Jiangxi	0.4
Xinjiang	0.4	Chongqing	0.9	Xinjiang	0.4
Heilongjiang	0.3	Sichuan	0.8	Heilongjiang	0.2
Zhejiang	0.3	Inner Mongolia	0.4	Shanghai	0.2
Shanghai	0.2	Ningxia	0.2	Zhejiang	0.1
Fujian	0.2	Hainan	0.1	Fujian	…
Hainan	…	Xinjiang	…	Hainan	…
Tibet	…	Tibet	…	Tibet	…

Note：the units of all data are 1/10000；"…"indicates the value is less than 0.01.

As Table 4 shown, after the impact on local social development is excluded, while other provinces are kept constant, the results have no great difference from those in Table 3. Investing intently in central provinces locating at grid conjunctions, such as Henan, Hubei, Hebei and Shanxi will boost not only local social development but also that of others and especially the delivering region.

5. Robustness test for simulation results

It is necessary to test the robustness of the simulation results. The investment in China's power grid infrastructure is mainly financed by the central government, and it is uniformly planned by the State Grid Company. Assuming that additional investment in grid is independent of local initial development level of grid infrastructure, in which the investment with absolute equal quantity will be most effective for boosting balanced social development of the country? Under this assumption, and with investment intently being located in the central areas, whether the optimization of resource allocation as well as balanced social development among regions would be still effectively achieved?

Table 5 . Impact of provincial grid density increased by 10% of the country's average density on regional socia了 development（province in question included）

National		Energy delivering regions		Energy receiving regions	
Province	Gaeff0(v)m	Province	Gaeff1(v)m	Province	Gaeff2(v)m
Inner Mongolia	2.5	Inner Mongolia	4.4	Inner Mongolia	2.7
Xinjiang	2.3	Shanxi	3.7	Xinjiang	2.6
Shaanxi	2.1	Shaanxi	3.6	Shaanxi	2.1
Shanxi	2.0	Hubei	3.3	Shanxi	2
Hubei	1.7	Henan	3.1	Sichuan	1.8
Sichuan	1.7	Xinjiang	3.0	Hubei	1.6
Henan	1.6	Hebei	2.8	Hebei	1.5
Hebei	1.5	Heilongjiang	2.1	Henan	1.5
Chongqing	1.1	Chongqing	2.1	Heilongjiang	1.0
Heilongjiang	1.0	Jilin	1.8	Jilin	1.0
Jilin	0.9	Hunan	1.8	Chongqing	1.0
Hunan	0.9	Sichuan	1.8	Anhui	0.9
Anhui	0.8	Guangdong	1.5	Hunan	0.8
Guangxi	0.8	Ningxia	1.5	Guangxi	0.7
Guangdong	0.6	Anhui	1.4	Liaoning	0.5
Ningxia	0.6	Guangxi	1.3	Guangdong	0.5
Liaoning	0.5	Liaoning	1.2	Jiangxi	0.5

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Jiangxi	0.5	Shandong	0.8	Ningxia	0.5
Shandong	0.4	Jiangxi	0.7	Shandong	0.4
Beijing	0.3	Jiangsu	0.5	Beijing	0.3
Tianjin	0.3	Zhejiang	0.5	Tianjin	0.3
Jiangsu	0.3	Fujian	0.4	Jiangsu	0.3
Fujian	0.3	Beijing	0.3	Zhejiang	0.2
Zhejiang	0.2	Tianjin	0.3	Fujian	0.2
Hainan	0.2	Shanghai	0.1	Hainan	0.2
Tibet	0.2	Hainan	…	Shanghai	0.1
Shanghai	0.1	Tibet	…	Tibet	0.1

Table 6. Impact of provincial transmission length increased by 1% of the country's average length （province in question included）

National		Energy delivering regions		Energy receiving regions	
Province	Gaeff0(v)m	Province	Gaeff1(v)m	Province	Gaeff2(v)m
Tianjin	17.2	Chongqing	22.8	Tianjin	20.6
Shanxi	11.9	Shanxi	22.2	Shanghai	13.5
Chongqing	11.5	Ningxia	19.9	Beijing	13.1
Beijing	11.2	Tianjin	18.9	Shanxi	11.8
Shanghai	11.2	Henan	17.2	Chongqing	10.8
Shaanxi	9.7	Shaanxi	16.6	Shaanxi	9.6
Henan	8.7	Hubei	16.4	Henan	8.3
Hubei	8.5	Hebei	13.6	Hubei	8.1
Ningxia	7.8	Beijing	13.1	Hebei	7.6
Hebei	7.3	Anhui	9.4	Ningxia	7.0
Anhui	5.5	Shanghai	9.1	Anhui	5.7
Jilin	4.2	Jilin	8.4	Hainan	4.9
Hainan	4.2	Hunan	7.8	Jilin	4.4
Hunan	3.8	Liaoning	7.6	Sichuan	3.6
Liaoning	3.4	Guangdong	7.5	Hunan	3.4
Sichuan	3.4	Guangxi	5.0	Liaoning	3.3
Guangdong	3.1	Shandong	4.9	Jiangxi	3.0
Guangxi	3.0	Jiangsu	4.4	Guangxi	2.8
Jiangxi	2.9	Heilongjiang	4.3	Guangdong	2.5
Shandong	2.3	Zhejiang	4.3	Shandong	2.3
Jiangsu	2.3	Jiangxi	3.7	Jiangsu	2.3
Zhejiang	2.1	Inner Mongolia	3.6	Inner Mongolia	2.2
Fujian	2.0	Sichuan	3.6	Heilongjiang	2.0
Inner Mongolia	2.0	Fujian	3.2	Zhejiang	2.0
Heilongjiang	1.9	Xinjiang	1.7	Fujian	1.9
Xinjiang	1.4	Hainan	1.0	Xinjiang	1.5
Tibet	0.2	Tibet	…	Tibet	0.1

Above all, we will simulate its impact on national and regional social development to increase local grid density by 10% of the country's average density, which is independent of the initial density of the province in question[13]. Then, we have the following equation:

[13] If the construction cost per unit length of transmission line in different provinces is equal, the assumption implies that new investment in any province is in proportion to its land area

$$D2_{v,t} = D_{v,t} + 10\% \times \frac{\sum_{i=1}^{n} S_{i,t}}{\sum_{i=1}^{n} area_{i,t}} \quad (10)$$

where $S_{i,t}$ denotes the length of transmission lines.

All provinces are ranked according to their benefit from the investment (see table 5). The results show that an absolutely equal increase of grid density in one province while other provinces being kept constant would play a greater part in energy delivering regions than for both receiving regions and the whole country. In addition, intent investment in Inner Mongolia, Xinjiang, Shaanxi, Shanxi, Hubei, Henan and Hebei will promote the national and regional development to the most degree. Investing in Inner Mongolia, Xinjiang and Heilongjiang are of stronger effect partially because the grid densities in those provinces are lower so that an equal increase in term of absolute quantity will make a higher increase in term of proportion. The result in Table 5 indicates that to locate the investment in central areas would be a better choice, including Shanxi, Henan, Hebei and Hubei.

Next, we simulate the impact on national and regional social development to increase the length of local transmission lines by equal portion (that is 1% of the country's average length, which is independent of local initial length)[14],as the following equation shown:

$$D3_{v,t} = D_{v,t} + 1\% \times \frac{\sum_{i=1}^{n} S_{i,t}}{\sum_{i=1}^{n} area_{i,t}} \quad (11)$$

The results in Table 6 show that to invest intently in central provinces at grid conjunctions, such as Shanxi, Henan, Hubei and Hebei, would have significant effect mainly for energy delivering areas. The effect of investment in Beijing, Shanghai, Tianjin and Ningxia are large partly because their land areas are very small that an equal increase in their grid length means a higher increase in their density.

In conclusion, the robustness test indicates that grid infrastructure investment in central provinces at grid conjunctions has larger impact for national and regional development and higher marginal benefit for less developed areas, and thus helps to reduce regional inequality.

6. Conclusions and Policy Suggestions

The enlarging gap of regional social development in China is an essential restrict for its sustainable economic growth. This paper studies the impact of objective grid investment in different provinces on national and regional social development. The results show that investment in power grid infrastructure has higher marginal benefit for less developed provinces in energy delivering regions; and more importantly, improvement of the grid infrastructure in central areas which connect energy receiving and delivering regions, including Shanxi, Henan, Hubei and Hebei, is essential for effectively promoting regional balanced development and optimizing allocation of resources.

Firstly, since the distribution of China's resource endowment is not in accord to that of energy consumption, and therefore, to invest in central provinces would help to make full use of the electricity generating capacity of energy delivering regions, transform their resource advantage into economic advantage and meet the electricity demand in load areas effectively.

Secondly, to improve the grid facilities in the central areas could reduce electricity transmission cost and helps to alleviate the railway strain for coal transportation.

Thirdly, because of the multiplier effect of grid investment on local development and the radiant effect of central development on western region, to invest in the central areas is not only favorable to themselves but also helpful to narrow the gap in development among regions.

Giving priority to locate investment in power grid infrastructure of western provinces is unable to generate the best effect of balancing regional development for the following reasons: On one hand, if the investment is only used for the outlying western provinces, the other provinces may not achieve corresponding improvement; On the other, without the improvement of grid facilities connecting the east to the west, the generation capacity in the west could only meet local electricity demand and not be able to effectively deliver energy to the central and eastern regions; and therefore, the nationwide resource allocation could not be optimized. However, the present infrastructures in the west are so excessively far behind that it has limited local economic growth and social development. In order to make the best use of the multiplier effect of grid construction, it is still necessary to invest reasonably in the west. Particularly, the simulation results indicate that the priority should be put on developing grid infrastructures in the western provinces which locate in grid conjunctions, such as Shaanxi, Sichuan and Chongqing.

Furthermore, investing in coastal region would have less positive effect and not be beneficial to regional balanced development for couple of reasons: On one hand, infrastructure investment is generally characterized by diminishing marginal returns, namely an additional investment will generate lower returns in more-developed regions than in less-developed regions; On the other, the positive function of infrastructure would make the accumulative economic effect stronger and then widen the gap between coastal and inland regions. Therefore, our conclusion is that, to take the two criteria, equity and effi-

when its grid density is increased with an absolutely equal extent.

[14] If the construction cost per unit length of transmission line in different provinces is equal, the assumption implies that the new investment incremental in any provinces is equal.

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ciency, into account at the same time, it is more advisable to locate the investment of power grid infrastructure in the central provinces that locate at strategic conjunctions of the nationwide power grid, including Shanxi, Henan, Hubei and Hebei.

7. Acknowledgements

This work was supported by grants from the National Social Science Foundation of China (07BJY065), the National Natural Science of China (70671086), the New Century Talents Advocacy Project of Minster of Education of China (NCET–07–0727), and Phase III of 211 Project of University of International Business and Economics.

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