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Conference Paper

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39th Congress of the European Regional Science Association: "Regional Cohesion and Competitiveness in 21st Century Europe", August 23 - 27, 1999, Dublin, Ireland

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Shibusawa, Hiroyuki; Miyata, Yuzuru; Chen, Zili (1999) : An Analysis of Energy Problem in China: An Interregional General Equilibrium Model, 39th Congress of the European Regional Science Association: "Regional Cohesion and Competitiveness in 21st Century Europe", August 23 - 27, 1999, Dublin, Ireland, European Regional Science Association (ERSA), Louvain-la-Neuve

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An Analysis of Energy Problem in China: An Interregional General Equilibrium Model

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Abstract.

Because of the extremely wide land area, study of equilibrating the interregional energy demand/supply is a more practical subject than that of national total energy demand/supply in China. The natural resources for energy are mainly distributed in the undeveloped northwestern area. Therefore the energy demand and supply strongly depend on the long distance transportation system in the area. In this study, to clarify the problem of energy in China, an interregional general equilibrium model is constructed. The demand and supply for energy are calibrated at each region. We analyze the effects of the restriction of long-distance transportation capacity on the interregional multi-sector linkages.

1. Introduction

The rapid growth of Chinese economy began from 1980's. It is forecasted that China would keep on the economic growth until the 21st century. The energy demand/supply is a very important subject to attain the economic growth in China. Since China has an extremely wide land area, the study of equilibrating the interregional energy demand/supply is a more practical subject than that of national total energy demand/supply.

Various factors are widening the economic gaps between the developed and developing regions in China. The southeastern coastal area has developed rapidly in 1980's. However the midland area has developed slowly and the northwestern inland has undeveloped yet. The energy resource is unevenly distributed over the country. However, most of the energy resources are mainly distributed in the northwestern inland area in China. In the developing regions, the energy resource is not enough to satisfy the demand. In China, the energy consumption strongly depends on coal. Thus, the enormous amounts of coal are carried by the transportation sector between consuming regions to production regions through a long distance. With the economic growth, the energy demand increases rapidly in each region. However the energy demand in the southeastern coastal area could not be satisfied due to the undeveloped transportation infrastructure. China faces the imbalance of energy demand/supply difficulties.

In this study, we construct an interregional general equilibrium model for China's energy issues. Furthermore, a restriction on capacity of the long distance transportation is taken into account to compute its effects on the interregional multi-sector linkages.

2. Industry classification and division of region

The Chinese interregional general equilibrium model is one of the class of applied general equilibrium models. Each Chinese region contains 9 industries. These use both primary factors (capital, labor) and intermediate products. The 9 produced goods in each region are treated as qualitatively different from similar commodities produced either in other regions.

Table 1. Industry Classification

No.	Sectors
1	Agriculture

2	Primary Energy Industry
3	Base Industry (materials)
4	Secondary Energy Industry (electricity, oil products)
5	Processing and Manufacturing Industry
6	Construction Industry
7	Transportation and Telecommunications Industry
8	Commerce
9	Services

Let $J = \{1,2,3,4,5,6,7,8,9\}$ denote an index set over industries/commodity groups. Furthermore $J' = \{1,2,3,4,5,6,8,9\}$ denote an index set over industries (sectors) without the transportation and telecommunications industry 7. Taking into account the distribution of the energy resource and the economic situation in China, the economy is subdivided into 8 regions, 7 of which cover China. A model contains 7 Chinese regions: Dongbei, Huabei, Huadong, Huanan, Huazhong, Xibei, and Xinan. Let $S = \{1,2,3,4,5,6,7\}$ denote an index set over regions without the foreign sector.

Table 2. Regional Classification

Regions	Provinces and Cities
1.Dongbei Region	Liaoning province*, Jilin province*, Heilongjiang province*
2.Huabei Region	Beijing city, Tianjin city, Hebei province*, Shandong Province, Inner Mongolia Autonomous region*
3.Huadong Region	Shanghai city, Jiangsu province, Zhejiang province
4.Huanan Region	Fujian province, Guangdong province, Hainan province
5.Huazhong Region	Shanxi province*, Henan province*, Anhui province*
6.Xibei Region	Shanxi province*, Qinghai province, Gansu province
7.Xinan Region	Sichuan province, Guizhou province, Yunnan province Gangxi Autonomous region, Tibet Autonomous region
8.Foreign Sector	Regions other than China

Regions with "*" represent the energy producing area.

Since an interregional industry input-output table in 1992 was not available now, it is estimated by using the Chinese input-output table (SNA) in 1992, Chinese interregional input-output table in 1987 (ref. Ichimura and Ou(1993)) and other data sets. Exogenous parameters such as the distance between regions, a savings rate, and a tax rate were also estimated. Data were quoted from the *China Statistical Yearbook*.

3. Basic assumptions

General assumptions are as follows.

- (1) There are 4 economic agents: general industry, transportation sector, household sector and government.
- (2) The transportation services are treated as the derived demand.
- (3) Commodities produced in different regions are treated as qualitatively different; e.g., Construction Products in Dongbei region are different from those produced in Huabei region.
- (4) The economy is endowed with primary factors, labor and capital. Labor is mobile among industries and regions. Capital is mobile across industries but immobile across regions.
- (5) Chinese economy consists of product markets (62 markets = 9 sectors times 8 regions) and productive factor markets (7 capitals and 1 labor). Perfect competition is assumed in all industries.
- (6) The model has 1992 as its base year.

4. Formulation of the model

(1) Behavior of industries

An industry $j \in J$ in a region $s \in S$ produces a distinct commodity using intermediate inputs, labor and capital. The technology is characterized by constant returns to scale. Commodities produced at a region are sold in all regions, including own region. The industries in a region s get local commodities from other industries while tradable commodities are bought everywhere in the economy. All commodities are transported by the transportation sector. The general industries face the c.i.f. prices including the transportation costs. The production function for industry $j \in J$ in region $s \in S$ takes the nested Leontief-Cobb-Douglas form, as illustrated by the substitution tree in Figure 1.

$$X_j^s = \min \left\{ \frac{f_j^s(K_j^s, L_j^s)}{a_{oj}^s}, \min_i \left[\frac{c_{ij}^s}{a_{ij}^s} \right] \right\} \quad (i \in J'; j \in J; s \in S) \quad (1)$$

$$\text{with } f_j^s(K_j^s, L_j^s) = B_j^s (K_j^s)^{a_{Kj}^s} (L_j^s)^{a_{Lj}^s} \quad (\mathbf{a}_{Kj}^s + \mathbf{a}_{Lj}^s = 1) \quad (2)$$

$$c_{ij}^s = A_{ij}^s \prod_r (x_{ij}^{rs})^{a_{ij}^{rs}} \quad \left(\sum_r a_{ij}^{rs} = 1 \right) \quad (3)$$

where

- X_j^s : output of industry j in region s
- c_{ij}^s : input of intermediate composite good of industry j in region s
- x_{ij}^{rs} : intermediate input of commodity i from region r to industry j in region s
- K_j^s : capital input of industry j in regions s
- L_j^s : labor input of industry j in regions s
- a_{oj}^s : value added ration of industry j in region s
- a_{ij}^s : intermediate input coefficient of industry j in regions s
- A_{ij}^s B_j^s a_{ij}^{rs} a_{Kj}^s a_{Lj}^s : parameters of industry j in regions s .

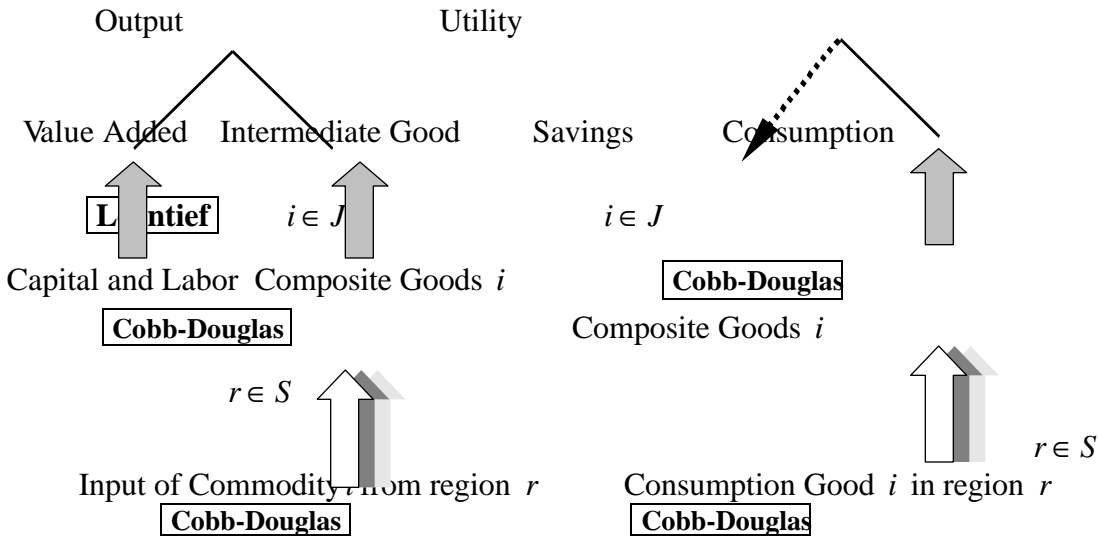


Figure 1. Structure of Production and Utility

The profit of industry j in region s is calculated as

$$p_j^s = p_j^s X_j^s - \sum_{i \in J'} \sum_{r \in S} q_i^{rs} x_{ij}^{rs} - (1 + t_j^s)(r^s K_j^s + w L_j^s) \quad (j \in J; s \in S) \quad (4)$$

where

- p_j^s : producer price of commodity j in region s
- q_i^{rs} : demander price of commodity i from region r to region s
(including the transportation cost)
- t_j^s : net indirect tax ratio of industry j in region s
- r^s : capital rate of return
- w : wage rate.

Given the amount of output X_j^s , the maximization of the profit leads to the demand functions for capital, labor and commodity.

$$K_j^s = \left(\frac{a_{kj}^s w}{a_{Lj}^s r^s} \right)^{a_{Lj}^s} \frac{a_{oj}^s X_j^s}{B_j^s} \quad (i \in J'; j \in J; s \in S) \quad (5)$$

$$L_j^s = \left(\frac{a_{Lj}^s r^s}{a_{Kj}^s w} \right)^{a_{Kj}^s} \frac{a_{oj}^s X_j^s}{B_j^s} \quad (i \in J'; j \in J; s \in S) \quad (6)$$

$$x_{ij}^{rs} = \frac{p_j^s a_{ij}^{rs} c_{ij}^s}{q_i^{rs} a_{ij}^s} \quad (i \in J'; j \in J; s \in S) \quad (7)$$

Since we assumed the transportation services are the derived demand, the transportation sector provides the transportation services so as to satisfy the demand for transportation derived from the demand for other goods

(2) Behavior of households

An aggregate household is assumed. The household maximizes its utility subject to income constraint. We assume that the utility function is the nested Cobb-Douglas form (Figure 1). The utility maximization problem is formulated as

$$\text{Max} \quad U = \prod_{i \in J'} (ch_i)^{b_{ih}} \quad \left(\sum_{i \in J'} b_{ih} = 1 \right) \quad (8)$$

$$\text{with} \quad ch_i \equiv \prod_{r \in S} (ch_i^r)^{b_{ih}^r} \quad \left(\sum_{r \in S} b_{ih}^r = 1 \right) \quad (9)$$

$$\text{subject to} \quad \sum_{i \in J'} \sum_{r \in S} q_i^{rh} ch_i^r = y_h \quad (10)$$

where

- ch_i : consumption of composite good i
- ch_i^r : consumption of commodity i produced in region r
- q_i^{rh} : consumer's price of commodity i in region r
- y_h : disposable income subtracted by savings.

The maximization of the utility U subject to the budget constraint leads to the consumer demand

function for commodity i in region r .

$$ch_i^r = \frac{\mathbf{b}_{ih} \mathbf{b}_{ih}^r y_h}{q_i^{rh}} \quad (i \in J'; r \in S) \quad (11)$$

where \mathbf{b}_{ih} and \mathbf{b}_{ih}^r are distribution parameters.

The aggregate amount of income, H , is consist of the wage, the capital income and the income transfers from the government. It is defined as

$$H = \sum_{s \in S} H^s = \sum_{s \in S} [\mathbf{r}^s (1-\mathbf{h}^s) K^s] + \mathbf{w}L + TrGH$$

where \mathbf{h}^s is the capital depreciation rate in region s and $TrGH$ is the current transfers from the government to the households. The disposable income of household, Y_h , is given as

$$Y_h = (1-\mathbf{t}_D)(H - TrGH) + TrGH \quad (12)$$

where \mathbf{t}_D is a direct tax ratio. Given a saving ratio \mathbf{s} , the available income for consumption is calculated as

$$y_h = (1-\mathbf{s})Y_h. \quad (13)$$

(3) Behavior of government

A single government is assumed. It collects direct and indirect taxes from households in each region. Given a ratio for consumption of government to expenditure and a transfer ratio, the government consumption and income transfer to households are calculated. A government savings is defined as the difference between the revenue and expenditure of government. Its balanced budget is given as

$$\frac{\mathbf{t}_D}{1-\mathbf{t}_D} (Y_h - TrGH) + \left(\sum_{s \in S} [\mathbf{r}^s (1-\mathbf{h}^s) K^s] + \mathbf{w}L \right) \mathbf{t}_j^s = y_g + SG + TrGH$$

where y_g is the consumption expenditure of government and SG is the government savings.

Assuming that the government expenditure system is characterized by Cobb-Douglas form, the demand function for commodity i from region r is given as

$$cg_i^r = \frac{\mathbf{b}_{ig} \mathbf{b}_{ig}^r y_g}{q_i^{rg}} \quad (i \in J'; r \in S) \quad (14)$$

where \mathbf{b}_{ig} and \mathbf{b}_{ig}^r are distribution parameters of the government consumption.

(4) Investment expenditure

Household savings, government savings, savings of foreign sector, and capital depreciation determine the total investment expenditure. Its balance equation is given as

$$p_I I = \mathbf{s} Y_h + SG + SO + \sum_{s \in S} \sum_{j \in J} D_j^s \quad (15)$$

where

p_I : price of the investment commodity

I : gross investment

D_j^s : capital depreciation of industry j in region s

The gross investment is characterized by Leontief type technology.

$$I = \min_{i \in J'} \left\{ \frac{cI_1}{b_1}, \dots, \frac{cI_9}{b_9} \right\} \quad (16)$$

$$\text{with } cI_i = \prod_{r \in S} (cI_i^r)^{b_{ir}^r} \quad \left(\sum_{r \in S} b_{ir}^r = 1 \right) \quad (17)$$

where

cI_i : composite good of good i corresponding the investment I

cI_i^r : demand for commodity i in regions r related cI_i

b_i \mathbf{b}_{ir}^r : technical parameters

Minimization of the investment cost leads to the demands of production commodity.

$$cI_i = b_i I \quad (18)$$

$$cI_i^r = \frac{\mathbf{b}_{ir}^r p_{ii} b_i I}{q_i^{rI}} \quad (19)$$

where p_{ii} is the price of composite good i for the investment.

(5) Behavior of transportation sector

The transportation demand is derived from the movements of commodities among regions and in own region. It is assumed that the transportation cost is paid to the transportation sector in the shipping region. The aggregate demand for transportation services in region r , T_r , is calculated as

$$\begin{aligned} T^r &= \sum_{j \in J} \sum_{s \in S} x_{7j}^{rs} + ch_7^r + cg_7^r + cI_7^r + e_7^r - m_7^r \\ &= \sum_{i \in J'} \sum_{j \in J} \sum_{s \in S} x_{ij}^{rs} d^{rs} \mathbf{q}_i^r \\ &\quad + \sum_{i \in J'} (ch_i^r d^{rh} + cg_i^r d^{rg} + cI_i^r d^{rI} + e_i^r d^{r8} - m_i^r d^{8r}) \mathbf{q}_i^r \quad (r \in S) \end{aligned} \quad (20)$$

where variable x_{7j}^{rs} represents the transportation services derived from the transportation of x_{ij}^{rs} . Variables ch_7^r , cg_7^r , cI_7^r , e_7^r , and m_7^r represent the transportation services derived from ch_i^r , cg_i^r , cI_i^r , e_i^r , and m_i^r , respectively. ch_i^r , cg_i^r , cI_i^r , e_i^r , and m_i^r are the demands for commodity i of households, the government consumption, the investment expenditure, the export and the import in region r respectively. Since the commodities are differentiated from each region, the amount of transportation services per unit differs from each region. In this study, parameters $\mathbf{q}_i^r (i \in J'; r \in S)$ are introduced. These parameters convert differentiated unit into common unit. By applying the Least Squares method, these values are estimated by using the cross-section data of intermediate inputs of the interregional input-output table in 1992 (see Appendix).

d^{rs} is the distance from the central city in region r to that of region s . d^{rh} is the distance from region r to a representative household in region r . d^{rg} is the distance from region r to a government in region r . d^{rI} is the distance from region r to an investment provider in region r . d^{r8} is the distance from a port in region r to the foreign sector. d^{8r} means the distance from

the foreign sector to a port in region r . Using the estimated data in base year, d^{rh} , d^{rg} , and d^{rl} are defined as

$$d^{rh} = \sum_{i \in J'} ch_i^r \mathbf{q}_i^r / ch_7^r, \quad d^{rg} = \sum_{i \in J'} ch_i^r \mathbf{q}_i^r / cg_7^r, \quad d^{rl} = \sum_{i \in J'} ch_i^r \mathbf{q}_i^r / cl_7^r. \quad (21)$$

Assuming that the transportation sector has the same type of production function as other industries, the cost minimization problem subject to a constraint of transportation services is formulated as

$$\text{Min} \quad \sum_{i \in J'} \sum_{r \in R} q_i^{rs} x_{i7}^{rs} + (1 + \mathbf{t}_7^s) (\mathbf{r}^s K_7^s + \mathbf{w} L_7^s) \quad (22)$$

$$\text{subject to} \quad X_7^s = T^s \quad (s \in S). \quad (23)$$

The optimization problem leads to the demand functions for capital, labor and commodity i .

$$K_7^s = \left(\frac{\mathbf{a}_{k7}^s \mathbf{w}}{\mathbf{a}_{L7}^s \mathbf{r}^s} \right)^{a_{i7}^s} \frac{a_{07}^s X_7^s}{B_7^s} \quad (s \in S) \quad (24)$$

$$L_7^s = \left(\frac{\mathbf{a}_{L7}^s \mathbf{r}^s}{\mathbf{a}_{k7}^s \mathbf{w}} \right)^{a_{i7}^s} \frac{a_{07}^s X_7^s}{B_7^s} \quad (s \in S) \quad (25)$$

$$x_{i7}^{rs} = \frac{p_7^s \mathbf{a}_{i7}^{rs} \mathbf{c}_{i7}^s}{q_i^{rs} a_{i7}^s} \quad (i \in J'; s \in S). \quad (26)$$

(6) Prices of commodities

Using zero profit conditions, the price equation is derived as

$$p_j^s = \sum_{i \in J'} \sum_{r \in S} p_i^r a_{ij}^{rs} + \sum_{i \in J'} \sum_{r \in S} p_i^r a_{ij}^{rs} \mathbf{q}_i^r d^{rs} + (1 + \mathbf{t}_j^s) (\mathbf{w} l_j^s + \mathbf{r}^s k_j^s) \quad (27)$$

$$\mathbf{P} = [\mathbf{I} - \mathbf{A}^T(\mathbf{P})]^{-1} (1 + \mathbf{t}_j^s) (\mathbf{w} l_j^s + \mathbf{r}^s k_j^s) \quad (28)$$

where

\mathbf{P} : vector of producer prices

l_j^s : labor input per unit output

k_j^s : capital input per unit output

$\mathbf{A}^T(\mathbf{P})$: the transposed matrix of input coefficient.

Note that the element associated with the price of transportation sector p_j^s in $\mathbf{A}^T(\mathbf{P})$ is $\sum_i \mathbf{q}_i^r a_{ij}^{rs} d^{rs}$. $\mathbf{A}^T(\mathbf{P})$ is a function of the price system \mathbf{P} because there are substitution between regions. The demander prices of commodity i in region s supplied from region r are given as

$$\text{intermediate input :} \quad q_i^{rs} = p_i^r + p_7^r \mathbf{q}_i^r d^{rs} \quad (i \in J'; r, s \in S) \quad (29)$$

$$\text{final consumption :} \quad q_i^{rh} = p_i^r + p_7^r \mathbf{q}_i^r d^{rh} \quad (i \in J'; r \in S) \quad (30)$$

$$q_i^{rg} = p_i^r + p_7^r \mathbf{q}_i^r d^{rg} \quad (i \in J'; r \in S) \quad (31)$$

$$q_i^{rl} = p_i^r + p_7^r \mathbf{q}_i^r d^{rl} \quad (i \in J'; r \in S) \quad (32)$$

(7) Foreign Sector

The foreign sector gets its income from the import commodity and then expends the income to the export commodity. Savings of foreign sector are defined as the difference between import income and export expenditures. The import and export commodities are given as

$$e_i^r = e_i^{r*} (q_i^{r8*} / q_i^{r8}) \quad (i \in J; r \in S) \quad (33)$$

$$m_i^r = m_i^{r*} (X_i^r / X_i^{r*}) \quad (i \in J; r \in S) \quad (34)$$

where

e_i^{r*} : the amount of export commodity of industry i in base year

m_i^{r*} : the amount of import commodity of industry i in base year

q_i^{r8*} : price in base year

X_i^{r*} : output in base year

The balance equation of the foreign sector is given as

$$\sum_{r \in S} \sum_{i \in J} (q_i^{8r} m_i^r - q_i^{r8} e_i^r) = SO \quad (35)$$

where

e_i^r : the amount of export commodity i in region r

m_i^r : the amount of import commodity i in region r

SO : savings of foreign sector.

q_i^{8r} is the demand price of import commodity i in region r . It is defined as the import price of commodity i , p_i^e , plus the transportation cost from a port, $p_7^8 d^{8r} \mathbf{q}_i^e$. The import and export commodities are not differentiated, i.e. $q_i^{8r} = q_i^{rr}$. The transportation cost of import commodity is paid to the foreign sector. $q_i^{r8} = p_i^r + p_7^r d^{r8} \mathbf{q}_i^r$ means the demander price of commodity i in region r . Using the estimated data in base year, d^{r8} and d^{8r} are defined as

$$d^{r8} = \sum_{i \in J^r} e_i^r \mathbf{q}_i^r / e_7^r, \quad d^{8r} = \sum_{i \in J^r} m_i^r \mathbf{q}_i^r / m_7^r \quad (36)$$

e_7^r is the derived demand for transportation corresponding to the amount of transportation of export commodity in region r . m_7^r is the derived demand for transportation corresponding to the import commodity in region r .

5. Equilibrium conditions

Let $\mathbf{i} (p_i^r, \mathbf{r}^r, \mathbf{w})$ denote a generalized price vector. Equilibrium in the model is characterized by the following conditions.

(1) Commodity Markets

General Goods ($i \in J^r; r \in S$)

$$X_i^r(\mathbf{m}) + m_i^r(\mathbf{m}) = \sum_{s \in S} \sum_{j \in J^s} x_{ij}^{rs}(\mathbf{m}) + ch_i^r(\mathbf{m}) + cg_i^r(\mathbf{m}) + cL_i^r(\mathbf{m}) + e_i^r(\mathbf{m}) \quad (37)$$

Transportation Services ($r \in S$)

$$X_7^r(\mathbf{m}) = \sum_{j \in J} \sum_{s \in S} x_{7j}^{rs}(\mathbf{m}) + ch_7^r(\mathbf{m}) + cg_7^r(\mathbf{m}) + cL_7^r(\mathbf{m}) + e_7^r(\mathbf{m}) - m_7^r(\mathbf{m})$$

$$\begin{aligned}
&= \sum_{i \in J'} \sum_{j \in J} \sum_{s \in S} x_{ij}^{rs}(\mathbf{m}) d^{rs} \mathbf{q}_i^r + \sum_{i \in J'} (ch_i^r(\mathbf{m}) d^{rh} \\
&\quad + cg_i^r(\mathbf{m}) d^{rg} + cI_i^r(\mathbf{m}) d^{rl} + e_i^r(\mathbf{m}) d^{r8} - m_i^r(\mathbf{m}) d^{8r}) \mathbf{q}_i^r
\end{aligned} \tag{38}$$

(2) Productive Factor Markets

$$\text{Labor Market : } \quad \overline{LS} = \sum_{r \in S} \sum_{j \in J} L_j^s(\mathbf{m}) \tag{39}$$

$$\text{Capital Rental Market : } \quad \overline{KS}^s = \sum_{j \in J} K_j^s(\mathbf{m}) \quad (r \in S) \tag{40}$$

6. Analysis of the simulation

The simulation years are 1992 and 2002. Two following cases have been considered. In Case 1, an economic situation in 2002 is estimated. In Case 2, the transportation constraints of primary energy are applied to the base case. Simulation scenarios are summarized in Table 4.

(1) Transportation Constraint

In China, most of the transportation of primary energy among different regions deeply depends on the railway. The amount of transportation of primary energy accounts for 50% of the total amount of railway transportation. Furthermore, the transported coal accounts for 57.4% of the total output of coal. The transportation services concentrates on the same routes where connect the production regions and the consumption regions. In this study, the transportation restriction is imposed to those routes between the production and consumption regions, because supply and demand for primary energy between different regions deeply depend on the railway transportation.

Table 4. Cases of the Simulation

Cases	Description
Base case	No modification is made on the model. Model outputs show the same as those in the benchmark year.
Case 1	A situation in 2002 is considered. Using the empirical date, average growth rates of labor and capital are estimated as follows : Labor Supply 1.139%. Capital Supplies Dongbei region 7.582% Huabei region 11.722% Huadong region 15.732% Huanan region 16.297% Huazhong region 10.038% Xibei region 7.938% Xinan region 9.735%
Case 2	The average growth rates of labor and capital are the same as that of Case 1. Due to the delay of expansion of railway capacity, the transportation services of primary energy on 8 routes are constrained (one way). Routes with transportation constraint Dongbei region -> Huadong region d^{13} Dongbei region -> Xinan region d^{17} Huabei region -> Huadong region d^{23} Huabei region -> Xinan region d^{27} Huazhong region -> Huadong region d^{53} Huazhong region -> Xinan region d^{57} Xibei region -> Huadong region d^{63}

The JingGuang railway line operating from south and north(Beijing-Guangzho) and the JingHu line operating from east and west(Beijing-Shanghai) are main routes in China. These are life lines in the energy transportation. Since the opening of the JinJiu line between Beijing and Hong Kong in 1997, the transportation from south to north was relieved. Therefore, in Case 2, we impose constraint conditions on the transportation routes of energy in Xibei region, Huadong region, and Xinal region.

(2)Performance Function

If the amount of transportation exceeds the capacity of the railway, waiting time on railway would become more important. If the congestion occurs on the routes, the transportation time would increase. In this study, the total distance of transportation includes the time cost for transportation. By the increase in the transportation distance in time, the demander prices of primary energy increases. As a result, the equilibrium solution is greatly influenced by the congestion in each region.

Based on the usual BPR curve, the performance function is formulated as

$$d^{rs} = \begin{cases} d_0^{rs} & x^{rs} \leq x_0^{rs} \\ d_0^{rs} \left[\frac{x^{rs}}{x_0^{rs}} \right]^g & x^{rs} > x_0^{rs} \end{cases} \quad (r, s \in S) \quad (41)$$

where

- x_0^{rs} : the transportation capacity of railway between region r and region s
- x^{rs} : the amount of transportation between region r and region s
- d_0^{rs} : the physical distance from region r to region s
- d^{rs} : the adjusted distance from region r to region s (including time cost)
- g : parameter

In this study, the value of capacity x_0^{rs} is given as the actual supply of primary energy between region r and region s in base case. Based on the situation of long distant transportation in China, parameter g is estimated as 3.2. The performance function with $g = 3.2$ is shown in Figure 2.

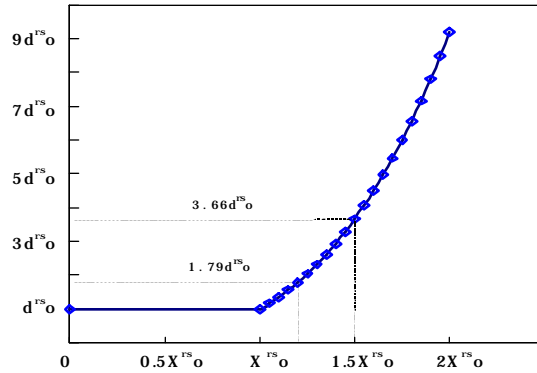


Figure 2. Performance Function ($g = 3.2$)

(3) Results of the Simulation

The main indices of the whole country and each region are described. The change of the welfare level is evaluated using the equivalent variation, EV. EV is defined as

$$EV = e[P_i^h(1), w, U_2] - e[P_i^h(1), w, U_1]$$

where $e[P_i^h, w, U]$ is the expenditure function. $P_i^h(1)$ is the price of composite good i corresponding the household consumption of Case 1. U_1 and U_2 are indirect utility functions of Case 1 and Case 2 respectively.

(a) Main Economic Indices

As shown Table 5, the growth of labor is the same as that of capital in Case 1 and Case 2. Compared with Case 1, the national production level decreases and EV decreases about 11.05 billion yuan in Case 2. Using the values of the prices in Case 1, the value of EV is recalculated as 15.5 billion yuan. Therefore, the welfare loss of Case 2 accounts for a little over 60 % of the deficit of national finance in China. The deficit is 46 billion yuan now. There is a considerable welfare loss in absolute unit.

Table 5. Main Economic Indices (million yuan: nominal)

	Base Case	Case 1	Case 2
Household : Income	1,742,253	1,877,715	1,873,725
Consumption	1,389,149	1,502,402	1,498,907
Savings	49,659	53,707	53,582
Government : Revenue	626,365	695,567	692,906
Direct Tax	303,445	321,606	321,236
Net Indirect Tax	322,920	373,961	371,670
Expenditure	225,322	250,216	249,259
Savings	-214,936	-238,683	-237,770
Transfers from government	615,979	684,035	681,417
Total Investment	1,018,435	1,024,857	1,021,607
Labor supply	350,138	386,770	386,770
Capital supply	1,986,907	6,269,621	6,269,621
Wage rate	1.0	1.0	1.0
Equivalent Variation (EV)	-	-	-11,047

Note: Labor and capital demands are normalized by output of one million yuan.

(b) Interregional Economic Indices

In Figure 3, the gross output is larger than that of the base case in each region due to the growth of capital and labor in Case 1. With the economic growth in coastal area, the output of primary energy increases in Dongbei, Huabei and Huazhong regions. Due to the shortage of supply of primary energy, the potential output of the primary energy increases in Huadong and Xinan regions where the energy resources are relatively poor.

In Case 2, output in each region is greatly influenced by the transportation constraint. There are remarkable changes in the movement of labor between regions as well as in the change of labor demand. In this simulation, since the wage rate is given as one unit, the rate of return on capital in each region is shown in Figure 6. By the transportation constraint of primary energy, the aggregate output decreases and the productivity increases in Huadong region. Those effects lead to the decrease in the rate of return on capital. The surplus labor in Huadong region moves to Dongbei and Xibei regions where the rate of returns on capital is relatively high.

(c) Production and Demand in Dongbei and Huadong regions

Figures 7, 8, and 9 show the economic growth and the effects of transportation restriction of primary energy on capital and labor demands in Dongbei region. The main industry in Dongbei region is the base industries. Figures 10, 11, and 12 show the economic growth in Huadong region and the ripple effects of shortage of energy. Huadong region is a representative of leading

region in China.

In Case 2, the output of primary energy decreases 3.9% by the transportation constraint. On the other hand, the output of secondary energy increases by 1.77% due to the increase in the supply of the transportation sector. The increase in the total distance leads to the increase in the transportation services. The gross output increases by 12.24% and the capital and labor move to the transportation sector in Dongbei region.

In Case 2, the output of primary energy increases by 21% in Huadong region due to the lack of supply of primary energy. However, it is still quite insufficient to satisfy the demand of primary energy in Huadong region because the output in the benchmark year is very small. As a result, the outputs of the secondary energy and the processing industries decrease and the aggregate output also decreases.

7. Conclusion

In this paper, we constructed an interregional general equilibrium model for China's energy issues and analyzed the diseconomies due to the congestion of the long distance transportation by numerical simulation. We assumed that there is the substitution of commodities between regions even if the commodities are produced at the same industry. The transportation constraint of primary energy is applied to 8 routes. The numerical simulation showed the effects of the transportation constraint on the industrial structure and the welfare in China. It is forecasted that the transportation constraint will become more severe in the near future. This study suggests that a delay of the development of the long distance transport system in China largely obstructs the preferable economic growth.

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Appendix

Table A- 1. Parameters of Production Function

Dongbei	a_{oi}^1	B_i^1	$f_{\alpha_i}^1$	$f_{\beta_i}^1$
Sector 1	0.537783	1.215209	0.964395	0.035605
Sector 2	0.476619	2.229998	0.774157	0.225843
Sector 3	0.199186	2.229998	0.774157	0.225843
Sector 4	0.497879	2.229998	0.774157	0.225843
Sector 5	0.270388	2.229998	0.774157	0.225843
Sector 6	0.237277	1.482688	0.913313	0.086687
Sector 7	0.588620	1.963561	0.733333	0.266667
Sector 8	0.499033	1.350293	0.924327	0.075673
Sector 9	0.554248	1.736469	0.809344	0.190656

Huabei	a_{oi}^2	B_i^2	$f_{\alpha_i}^2$	$f_{\beta_i}^2$
Sector 1	0.563389	1.215209	0.964395	0.035605
Sector 2	0.341470	2.229998	0.774157	0.225843
Sector 3	0.189214	2.229998	0.774157	0.225843
Sector 4	0.391891	2.229998	0.774157	0.225843
Sector 5	0.246041	2.229998	0.774157	0.225843
Sector 6	0.243826	1.482688	0.913313	0.086687
Sector 7	0.522903	1.963561	0.733333	0.266667
Sector 8	0.509644	1.350293	0.924327	0.075673
Sector 9	0.545610	1.736469	0.809344	0.190656

Huadong	a_{oi}^3	B_i^3	$f_{\alpha_i}^3$	$f_{\beta_i}^3$
Sector 1	0.446855	1.215209	0.964395	0.035605
Sector 2	0.026954	2.229998	0.774157	0.225843
Sector 3	0.304764	2.229998	0.774157	0.225843
Sector 4	0.372055	2.229998	0.774157	0.225843
Sector 5	0.274598	2.229998	0.774157	0.225843
Sector 6	0.174784	1.482688	0.913313	0.086687
Sector 7	0.495770	1.963561	0.733333	0.266667
Sector 8	0.556990	1.350293	0.924327	0.075673
Sector 9	0.482968	1.736469	0.809344	0.190656

Huanan	a_{oi}^4	B_i^4	$f_{\alpha_i}^4$	$f_{\beta_i}^4$
Sector 1	0.692556	1.215209	0.964395	0.035605
Sector 2	0.319887	2.229998	0.774157	0.225843
Sector 3	0.194727	2.229998	0.774157	0.225843
Sector 4	0.280948	2.229998	0.774157	0.225843
Sector 5	0.159615	2.229998	0.774157	0.225843
Sector 6	0.457350	1.482688	0.913313	0.086687
Sector 7	0.654546	1.963561	0.733333	0.266667
Sector 8	0.556979	1.350293	0.924327	0.075673
Sector 9	0.752497	1.736469	0.809344	0.190656

Huazhong	a_{oi}^5	B_i^5	$f_{\alpha_i}^5$	$f_{\beta_i}^5$
Sector 1	0.582321	1.215209	0.964395	0.035605
Sector 2	0.532485	2.229998	0.774157	0.225843
Sector 3	0.178562	2.229998	0.774157	0.225843
Sector 4	0.439671	2.229998	0.774157	0.225843
Sector 5	0.274455	2.229998	0.774157	0.225843
Sector 6	0.249597	1.482688	0.913313	0.086687
Sector 7	0.561045	1.963561	0.733333	0.266667
Sector 8	0.437201	1.350293	0.924327	0.075673
Sector 9	0.582971	1.736469	0.809344	0.190656

Xibei	a_{oi}^6	B_i^6	$f_{\alpha_i}^6$	$f_{\beta_i}^6$
Sector 1	0.593291	1.215209	0.964395	0.035605
Sector 2	0.444014	2.229998	0.774157	0.225843
Sector 3	0.186203	2.229998	0.774157	0.225843
Sector 4	0.466028	2.229998	0.774157	0.225843
Sector 5	0.312658	2.229998	0.774157	0.225843
Sector 6	0.312191	1.482688	0.913313	0.086687
Sector 7	0.578574	1.963561	0.733333	0.266667
Sector 8	0.653363	1.350293	0.924327	0.075673
Sector 9	0.542406	1.736469	0.809344	0.190656

Xinan	a_{oi}^7	B_i^7	$f_{\alpha_i}^7$	$f_{\beta_i}^7$
Sector 1	0.673856	1.215209	0.964395	0.035605
Sector 2	0.344746	2.229998	0.774157	0.225843
Sector 3	0.233634	2.229998	0.774157	0.225843
Sector 4	0.700335	2.229998	0.774157	0.225843
Sector 5	0.375837	2.229998	0.774157	0.225843
Sector 6	0.389210	1.482688	0.913313	0.086687
Sector 7	0.638663	1.963561	0.733333	0.266667
Sector 8	0.713181	1.350293	0.924327	0.075673
Sector 9	0.611256	1.736469	0.809344	0.190656

Table A- 2. Parameters of Utility Function

f_A	Dongbei	Huabei	Huadong	Huanan	Huazhong	Xibei	Xinan	f_A
Sector 1	0.103834	0.153941	0.113473	0.136248	0.246093	0.069680	0.176731	0.307872
Sector 2	0.148201	0.220452	0.104162	0.091990	0.224134	0.100694	0.110368	0.010299
Sector 3	0.107254	0.170398	0.195301	0.158335	0.187238	0.051899	0.129575	0.268630
Sector 4	0.140394	0.172961	0.159995	0.137355	0.187409	0.079005	0.122881	0.015722
Sector 5	0.143215	0.158352	0.166083	0.133149	0.220086	0.067089	0.112026	0.150929
Sector 6	0	0	0	0	0	0	0	0
Sector 7	0.125404	0.155256	0.161040	0.162868	0.200894	0.072468	0.122070	-
Sector 8	0.091914	0.154325	0.172178	0.158897	0.200624	0.076953	0.145109	0.121383
Sector 9	0.112654	0.165806	0.157515	0.194679	0.205901	0.061569	0.101876	0.125165

Table A- 3. Parameters of Government

f_{A_t}	Dongbei	Huabei	Huadong	Huanan	Huazhong	Xibei	Xinan	f_{A_t}
Sector 1	0.099321	0.211092	0.101836	0.113512	0.236005	0.089589	0.148645	0.000611
Sector 2	0	0	0	0	0	0	0	0
Sector 3	0.105183	0.232428	0.17489	0.132286	0.178140	0.066568	0.110504	0.041607
Sector 4	0	0	0	0	0	0	0	0
Sector 5	0.142691	0.211085	0.14458	0.108393	0.209189	0.085078	0.098983	0.001905
Sector 6	0	0	0	0	0	0	0	0
Sector 7	0.122802	0.210178	0.143006	0.135329	0.190599	0.093706	0.104381	-
Sector 8	0.092380	0.207982	0.151488	0.129775	0.181836	0.105398	0.131141	0.134200
Sector 9	0.110595	0.224755	0.139806	0.159669	0.19758	0.079714	0.087881	0.821678

Table A- 4. Parameters for Investment Expenditure

f_A	Dongbei	Huabei	Huadong	Huanan	Huazhong	Xibei	Xinan	b_i
Sector 1	0.060763	0.242593	0.202581	0.121513	0.216039	0.065649	0.090863	0.005189
Sector 2	0	0	0	0	0	0	0	0
Sector 3	0.058320	0.242881	0.316284	0.128657	0.148305	0.044347	0.061207	0.007185
Sector 4	0	0	0	0	0	0	0	0
Sector 5	0.082981	0.231752	0.274703	0.110985	0.182663	0.059481	0.057436	0.056451
Sector 6	0.112895	0.186378	0.147443	0.179577	0.179177	0.075281	0.119249	0.076286
Sector 7	0.071120	0.229610	0.270401	0.137545	0.165833	0.065197	0.060295	-
Sector 8	0.053111	0.225717	0.284528	0.131439	0.157642	0.072513	0.075050	0.011777
Sector 9	0.063162	0.242006	0.260554	0.160241	0.169313	0.054660	0.050064	0.000476

Table A-5. Parameters q_i^r ($\times 10^{-2}$)

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7
Sector 1	0.003	0.002	0.002	0.002	0.002	0.002	0.002
Sector 2	0.055	0.040	0.107	0.039	0.040	0.039	0.040
Sector 3	0.001	0.001	0.001	0.003	0.003	0.003	0.003
Sector 4	0.020	0.035	0.013	0.026	0.027	0.027	0.027
Sector 5	0.016	0.015	0.010	0.015	0.015	0.015	0.015
Sector 6	0	0	0	0	0	0	0
Sector 7	-	-	-	-	-	-	-
Sector 8	0.016	0.017	0.138	0.001	0.005	0.003	0.005
Sector 9	0.006	0.005	0.077	0.004	0.004	0.004	0.004

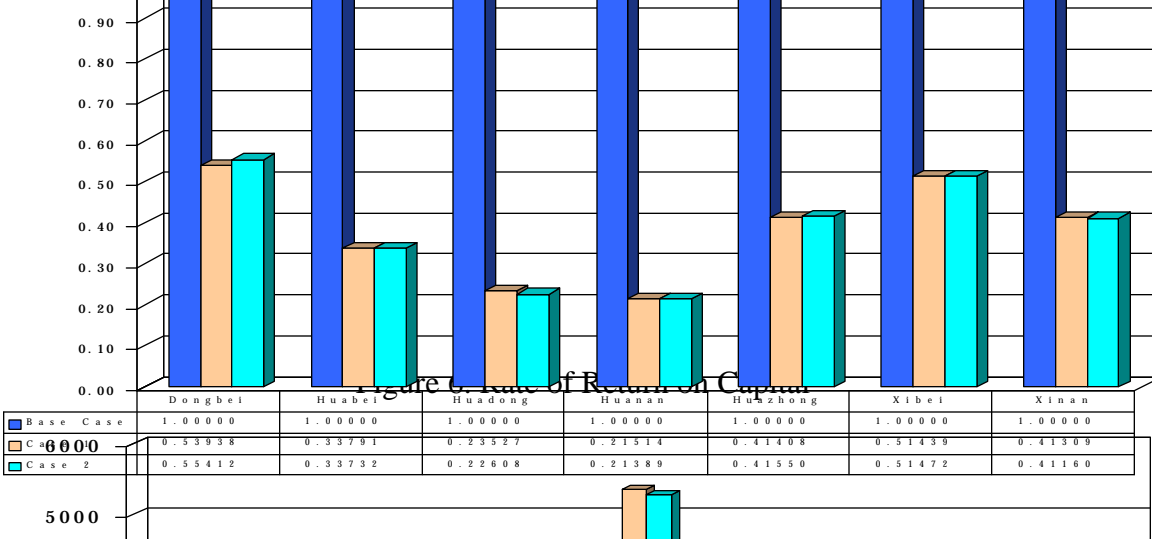
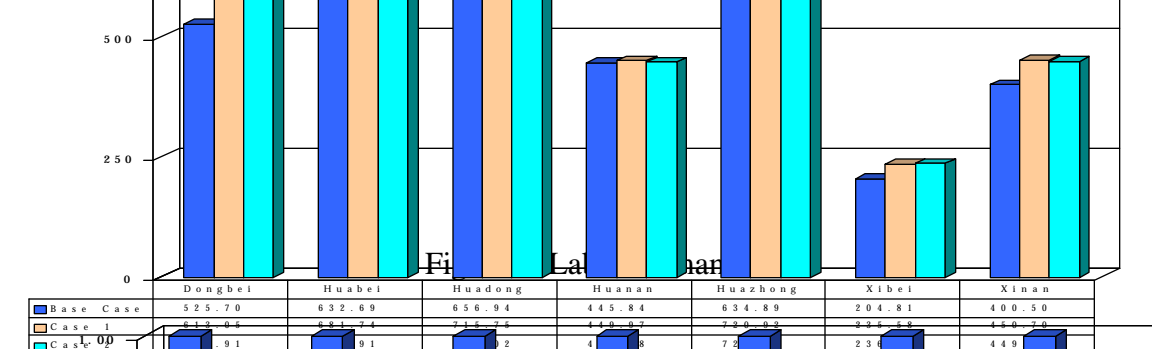
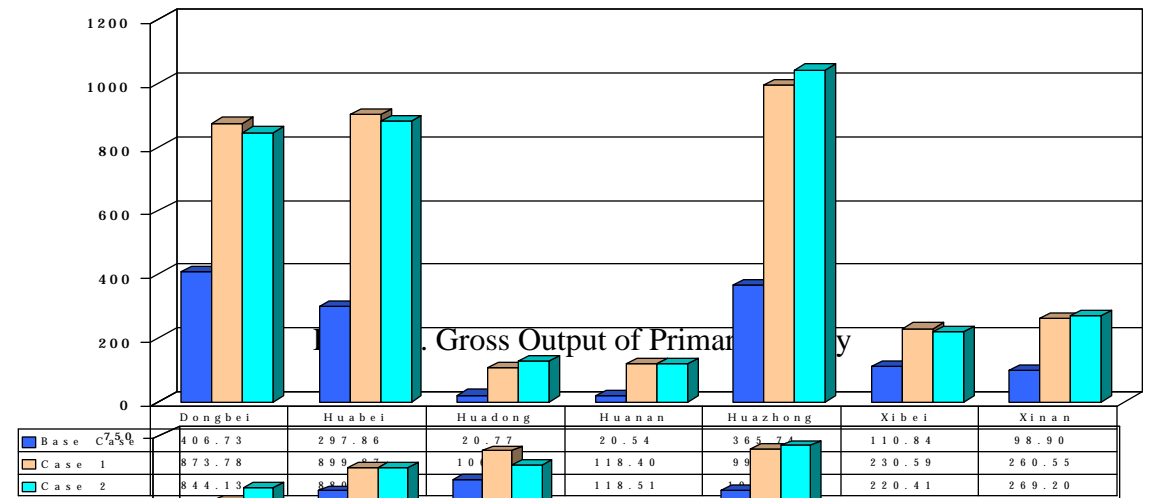
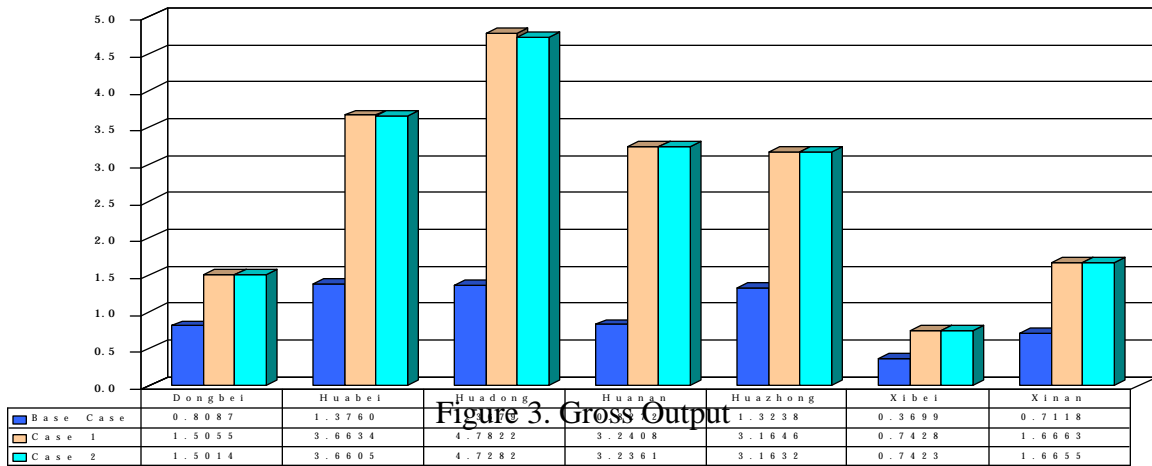


Figure 7. Gross Output of Industry in Dongbei Region

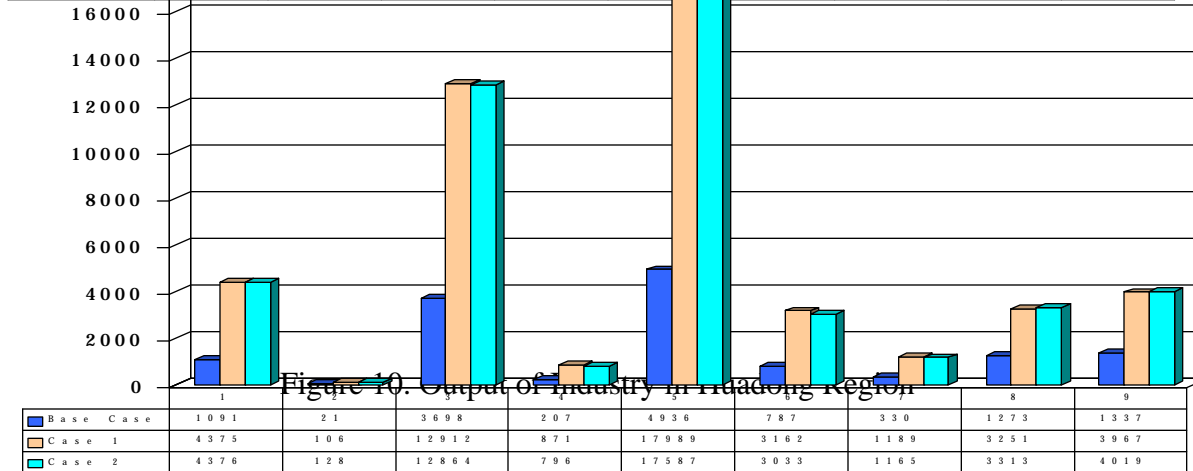
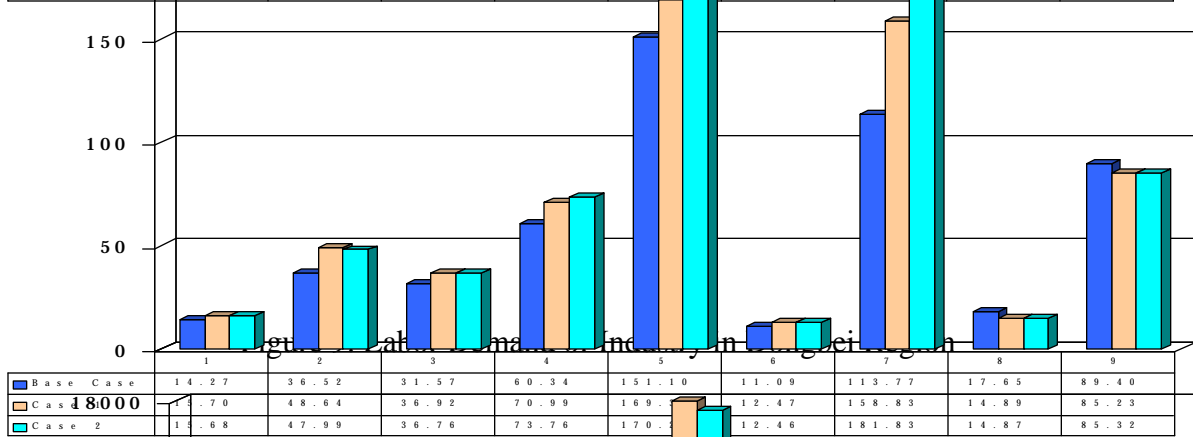
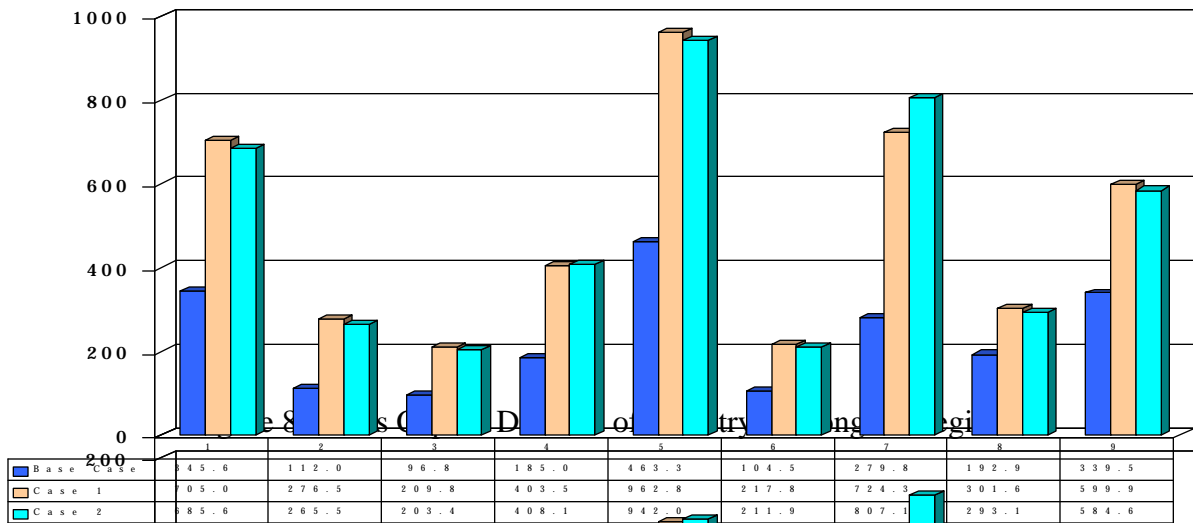


Figure 10. Output of Industry in Haidong Region

