The historical simulation on energy efficiency in China: an application of the SICGE-1 model

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Abstract: In this paper, we use a dynamic CGE model SICGE-1 to analyze China's energy efficiency issue. The historical simulation is conducted through the 2 phases of 1997-2002 and 2003-2005. We find that the energy consumption per GDP increased during 2003-2005, but the energy consumption technologies in most of industries made great progress. The detailed analysis shows that for most of energy production industries and energy intensity industries, the effectiveness of TFP decreased in 2003-2005, compared with that in 1997-2002; the effectiveness of capital input continuously changed worse and the improvement of labor input changed to moderate; the effectiveness of energy intermediate input in energy intensive industries changed better continuously in 2003-2005 than that in 1997-2002.

Keyword: energy efficiency; Dynamic CGE model; Historical simulation; China's TFP

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1. Introduction

Accompanied with the rapid economic growth, China's total energy consumption is increasing by an unforeseen high speed. From 1997 to 2006, the energy consumption increased 78.7%, from 1.3779 billion ton of coal equivalent (tce) to 2.4627 billion tce, according to the energy consumption data in China's Statistic Yearbook. However, there had been relative low growth of energy consumption through 1997 to 2002, while the energy consumption elasticity to GDP was lower than 0.5. But this trend was terminated in 2003, the elasticity increased to 1.53. During the period from 2003 to 2005, China's energy consumption grew faster than that of GDP all along, which means that the energy consumption elasticity to GDP was over 1. This case confused most of experts taking care about China's energy consumption. Many experts attributed the fall of energy efficiency to the energy intensive industries excessive growth. Large amount of energy intensive product cost too much energy, which lead to the energy efficiency of whole economic system fall.

Under the economic framework, there are many good ways to make energy analysis, among which, the dynamic CGE model has become the main tool. For example, in the latest Energy Modeling Forum (EMF) (Weyant 2004), participants applied MERGE, EPPA (MIT), IGEM, etc., which are all developed based on dynamic CGE model. In the famous climate changing study IPCC, the contribution made by CGE type model can be found also, such as the SGM model in U.S., the GREEN model for OECD, Australia ABARE, Japan AIM / Top-down, etc..

In China there are many relevant energy papers using dynamic CGE model, but the economic analysis still rough. Zhang and Li (2007) analyzed the future of China's energy demand until 2020 by linking CGE model and energy analysis model together, and gave out some comments on energy-saving policy issue. The study highlighted the innovation of connection method, but the CGE model itself was simplified and the analysis to economic system was not sufficiently detailed. Cai and Hu (2007) analyzed the influence of lower energy intensity by technical progress based on dynamic CGE mode. Tan (2007) calculated the economic development scenarios with different electric power policies by using CGE model; Wang (2005) applied CGE model to analyze the influence of China's economy by reducing the emission of greenhouse gas.

In the paper, we adopt a more comprehensive and detailed dynamic CGE model, the SICGE-1, which is built based on MONASH model developed by Monash University, Australia. SICGE-1 model inherits the advantages of MONASH model on detailed description about technical parameters and the method of calibration, historical simulation. Considering the different economic development patterns in China during the two periods from 1997 to 2002 and from 2003 to 2005, the historical simulation has been done separately to this two phases to get different technical parameters.

There are four sections included in this paper. The second section describes the features of SICGE-1; the third section explains the settings to exogenous variables and the calculation results of historical simulation; the last section is the conclusion and discussion.

2. Features and methodology of SICGE-1

2.1 Main features of SICGE-1

SICGE-1 inherits the features of Monash University's dynamic CGE model which is shown in the following four major areas: the detailed technology parameters design enriching the economic explain capability, linearization of the equations, the unique process of policy analysis and mature software design.

SICGE-1 model contains a whole set of parameters to describe economic system's technological progress. These technical parameters can be used to specify the changes of production input and product demands leading by non-price factors. Although they are totally named as "technical parameters", some parameters play the role describing the substitution effect arising from non-price factors. On production side, there exist technical parameters describing the effectiveness of total production input, the ones describing the effectiveness of total initial input and total intermediate input and also the technical improving parameters directly augmenting capital, labor input, as well as the other intermediate inputs. In the consumption, import and export sectors, there are parameters describing kinds of savings, including different merchandise's preference changing parameters (twist) as well. These parameters have obvious economic significance and benefit to make reasonable explanation under different scenarios.

The traditional form of CGE model is nonlinear equations from multiplying the variables of price by the variables of quantity, but there is a big uncertainty in the process of solution. SICGE-1 utilizes differential method to transform nonlinear equations for linear equations, and adopts the way of Eurla to approximate the true value linearly step by step. On the one hand, it is easy to solve, and enhance the robustness of solution, on the other it also guarantees the accuracy of the results and makes it possible to construct large-scale CGE model.

SICGE-1 model could adopt "historical simulation" to do the parameters calibration, offer the improvement of base scenario with " forecast simulation", then calculate the effects under various scenarios based on" Policy simulation ". Such running mode can not only make full use of historical data in calculation of parameters in the model to ensure the rationality, but also carry out analysis under various policies and scenarios.

GEMPACK is used currently in the model as software platform. It is convenient to write the program code, read and analyze the calculation results.

2.2 Methodologies for energy efficiency simulation

To carry out the energy efficiency simulation, we adopt the methodologies as follows.

1) Confirm appropriate sector classification according to the energy balance sheet, especially focusing on the high-energy-consuming industries and fast-growing energy consumption industries. Ultimately we classified 37 sectors including 32 mining, manufacturing and energy production sectors. The energy intensive industries are chemicals, nonmetallic mineral products, iron and steel industry, non-ferrous metals, and transportation. The energy production are classified into five industries, which are coal mining and washing, crude oil production, gas production, the electricity generation and petroleum processing& coal products.

2) Simulate the features of the "technical changes" during the two periods from 1997 to 2002 and from 2003 to 2005 by historical simulation. The economic development

in China from 1997 to 2005 can be divided obviously into two phases, which are the first one from 1997 to 2002 and the second one from 2003 to 2005, from the view of energy consumption. The energy consumption per GDP was declining continuously in the previous phase, but increasing in the latter stage. While in the first phase the average GDP annual increasing rate was 8.3%, but in the second one, it changed to 10.2%. The acceleration of economic growth accompanied by the decrease of efficiency level of energy using has gained great attention from all over the world. Many experts analyzed the issue from the perspective of energy efficiency, including the adjustment of industrial structure and the influence of energy efficiency by specific energy-using technology changing in industry and so on. However, there is still fewer in-depth analysis about the change of various efficiencies contained within each industry and in the economic system itself. This study describes the features of the two stages from 1997 to 2002 and from 2003 to 2005 respectively, makes simulations to various technical parameters in China's economic system.

3. Historical simulations on China technologies changes in 1997-2005

The main features of historical simulation method are to try to use more economic action information in real world to calibrate the technologies changes parameters. According to Dixon and Rimmer（2002）, we mainly gave the historical data on eight kinds of exogenous variable, shown as follows:

Table 1. Exogenous variables list in historical simulation

Categories of Variables	Categories of Variables
Consumption by commodity	Export volumes and f.o.b prices
Total intermediate usage by commodity	Macro variables, e.g. aggregate consumption
Employment and capital inputs by industry	population
Imports by commodity	c.i.f import prices in foreign currency

To make the model gives more “accurate” descriptions on energy production and consumption; we try to collect the historical data on five kinds of energy production industries and five energy intensive industries. The detailed data works are shown in

3.1, and the results of historical simulation are shown in 3.2.

3.1 Data collection for historical simulation

The important technology parameters we want to calibrate are all located in the production process, which include two categories: one category includes the technology parameters those save all kinds of inputs in energy industries and energy intensive industries. The other category includes those save the energy inputs in the producing process in energy intensive industries.

For calibrating these technology parameters, we will swap those exogenous parameters to endogenous; correspondingly swap the relevant endogenous variables to exogenous. For example, to calibrate the parameter *a1tot(“col”)*, we swap that with the endogenous variable *x1tot(“col”)* ,the total output of coal industry.

To calibrate the parameter *a1_s(“col”,”ely”)*, we swap that with the endogenous variable *x1_s(“col”, ”ely”)*, the intermediate input of coal product to electricity industry.

The codes written in our simulation are as follows:

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Swap a1tot(“col”) = x1tot(“col”);
Swap a1_s(“col”, ”ely”) = x1_s(“col”, ”ely”).
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To do a more accurate calibration, we should try to use more “correct information” about the swapping variables, like *x1tot(“col”)*, and *x1_s(“col”,”ely”)*. Table 2 shows all the swapping variables we pay more attentions to.

Table 2. Swapping variables exogenous in terms of energy utilization

Variables	Variables
Percentage change of total output by industries	
x1tot("oil")	x1tot("crp")
x1tot("gas")	x1tot("nmm")
x1tot("col")	x1tot("i_s")
x1tot("p_c")	x1tot("nfm")
x1tot("ely")	x1tot("fmp")
Percentage change of energy intermediate input in industries	
x1_s("col","crp")	x1_s("p_c","i_s")
x1_s("col","nmm")	x1_s("p_c","ely")
x1_s("col","i_s")	x1_s("p_c","nmm")
x1_s("col","ely")	x1_s("ely","crp")
x1_s("oil","crp")	x1_s("ely","nmm")
x1_s("p_c","otp")	x1_s("ely","i_s")
x1_s("p_c","crp")	x1_s("ely","nfm")
Percentage change of energy import	
x0imp("col")	x0imp("oil")

Variable *"x1tot(i)"* means the percentage change of total output of industry *i*. Here we keep eyes on five energy production industries, which are coal production industry (*col*), crude oil production industry (*oil*), gas production industry (*gas*), petroleum product and coal product industry *(p_c*), electricity industry (*ely*); and five energy intensive industries, which are Chemical-rubber-plastic products industry(*crp*), non-metal mineral products industry(*nmm*), ferrous metals industry(*i_s*), non-ferrous metals(*nfm*) and metal products(*fmp*).

Variable "*x1_s(c, i)*" means the percentage change of commodity *c* as the intermediate input to industry *i*. We keep eyes on the energy intermediate input in energy intensive industries, which are *"col"* product input to *"crp"* industry, *"col"* product input to *"nmm"* industry, *"col"* product input to *"i_s"* industry, *"col"* product input to *"ely"* industry, *"oil"* product input to *"crp"* industry, *"p_c"* product input to transport industry *(otp*), *"p_c"* product input to *"crp"* industry, *"p_c"* product input to *"i_s"* industry, *"p_c"* product input to *"ely"* industry, *"p_c"* product input to *"nmm"* industry, *"ely"* product input to *"crp"* industry, *"ely"* product input to *"nmm"* industry, *"ely"* product input to *"i_s"* industry, and *"ely"* product input to *"nfm"* industry.

Variable *"x0imp(c)"* means the percentage change of import quantity of commodity c. Here we need two kinds of energy data, which are *"col*" and*"oil"*. There is little gas import from 1997 to 2005 according to the statistical data in China Energy Statistical Yearbook, and the amount of gasoline, diesel and kerosene import were all very small, and decrease quickly during the period 1997-2005. Any small difference of the quantity will lead to a relative large percentage change, on which we have no confidence, so we just use the import data about *"col*"and *"oil"*.

The above percentage change variables are all calculated based on the value at constant price.

To calculate *"x1tot(i)*", we have to find out the total output value of industry *i* in 1997, 2002 and 2005. However there is no such statistic caliber of total output covering the whole industry, except the IO table data. In China, the National Statistical Bureau has compiled the 122 sector IO table for 1997 and 2002, but not for 2005. To keep the same caliber for these three years' data, we have to choose other data sources. For the energy intensive industries, we find the statistical data of *"Main Indicators of Large and Medium-sized Industrial Enterprises by Industrial Sector"* in the China Statistical Yearbook from 1998-2006, in which, we can find the index *"gross industrial output value"* by industry. The caliber does not cover the whole industry, but most enterprises in the energy intensive industry are large or medium-sized, so these indices are quite similar to that we want. However, the data are based on the current price; we have to convert them to the value base on constant price by introducing the price indices to get rid off the price effect. The price indices by industry we used are from the data *"Ex-Factory Price Indices of Industrial Products by Sector"* from China Statistical Yearbooks.

For the total output of five energy industries, we change the data sources, because we can get the quantitative gross output data from the *"energy balance sheet"* every year. We also get the four kinds of energy import data from *"energy balance sheet"* every year. It should be noted that there is no integrated index of *"p_c"*, which includes the normal oil products, like gasoline, diesel, kerosene, fuel oil, and normal coal product, coke. In this case, we need to sum up the percentage change of these indices weighted by amount to get the percentage change of *"p_c"*.

For the data of energy intermediate input to energy intensive industries, we choose the statistical indices *"Consumption of Energy by Sector"* in China Statistical Yearbooks from 1998-2006.

The data calculation results, which we use in the historical simulation, are shown in Table 3 to 6 of the total output of energy intensive industries, total output of energy product industries, energy intermediate input to energy intensive industries and the energy import.

Table 3. Total output of energy intensive industries (10^8rmb 1997 price)

Name of sector	1997	2002	2005	Percentage change 1997-2002	Percentage change 2002-2005
crp	4915.3	9558.2	17180.6	14.23	21.59
nmm	1182.3	1825.6	4022.2	9.08	30.12
i_s	2982.9	5604.9	14209.3	13.44	36.35
nfm	917.5	1722.3	3865.4	13.42	30.93
fmp	515.5	1070.3	2667.6	15.73	35.58

Table 4. Total output of energy products industries

Name of sector	1997	2002	2005	Percentage change 1997-2002	Percentage change 2002-2005
Oil(10^4 ton)	16074.1	16700	18135.3	0.77	2.79
Gas(10^8 cu m)	227	326.6	493.2	7.55	14.73
col(10^4 ton)	137282	145456	220472.9	1.16	14.87
Gasoline(10^4 ton)	3517.8	4320.8	5433	4.2	7.93
diesel(10^4 ton)	4924.5	7706.1	11090.2	9.37	12.9
kerosene(10^4 ton)	577	826.1	1006.5	7.44	6.81
Fuel oil(10^4 ton)	2311.2	1845.5	1767.4	-4.4	-1.43
coke(10^4 ton)	13653.1	14253.3	25411.7	0.86	21.26
p_c	-	-	-	3.17	15.45
ely(10^8 kwh)	11344.7	16540	25002.6	7.83	14.77

Table 5. Energy intermediate inputs to energy intensive industries

Energy products	sectors	1997	2002	2005	Percentage change 1997-2002	Percentage change 2002-2005
Oil(10^4 ton)	crp	2015.29	2523.91	2524.60	4.60	0.01
Col(10^4 ton)	crp	11580.30	9090.24	13129.47	-4.73	13.04
	nmm	12792.10	8868.88	16764.28	-7.06	23.64
	i_s	12673.30	11845.42	19186.70	-1.34	17.44
	ely	50706.60	65173.60	105441.07	5.15	17.39
P_c	crp	-	-	-	0.75	3.998
	nmm	-	-	-	2.64	-3.87
	i_s	-	-	-	4.10	9.33
	ely	-	-	-	-7.63	2.93
	otp	-	-	-	10.38	13.59
Ely(10^8 kwh)	crp	1506.83	1912.35	3040.65	9.15	14.94
	nmm	608.08	879.64	1416.13	9.69	17.53
	i_s	934.16	1323.10	2544.40	11.96	22.59
	Nfm	513.52	823.81	1469.60	14.75	19.47

Table 6. Main energy imports data

Name of commodities	1997	2002	2005	Percentage change 1997-2002	Percentage change 2002-2005
Oil(10^4 ton)	3547	6940.6	12681.7	0.77	2.79
col(10^4 ton)	201	1125.7	2617.1	1.16	14.87

3.2 Comparison on results of technology changes parameters in two phases

The technology change parameters in production process used in SICGE-1 are shown as the following functions:

$$Z(i) = \frac{1}{A1tot_i} F\left(\frac{PRInput_i}{A1prim_i}, \frac{InterInput_{1,i}}{A1\_s_{1,i}}, \frac{InterInput_{2,i}}{A1\_s_{2,i}} \cdots, \frac{InterInput_{n,i}}{A1\_s_{n,i}}\right)$$

$$PRInput_i = F\left(\frac{K_i}{A_{ki}}, \frac{L_i}{A_{Li}}, \frac{Lnd_i}{A_{Lndi}}\right)$$

in which, *Z(i)* shows the total output of industry *I*, *A1tot(i)* shows the total input augmenting technology. *PRInputi* is the composition input of *Ki*, *Li* and *Lndi*, *A1prim(i)* means the total primary factor input augmenting technology in industry *i*. *A1_s(j,i)* is the augmenting technology of intermediate input *j* to industry *i*. *Ak,i*, *Al,i*, *Alnd,i* are respectively the augmenting technologies of *Ki*, *Li* and *Lndi*.

From the view of economy, the technology parameter *A1tot(i)* could be seen as industrial total factor productivities (TFP), the effectiveness of total composition of primary input and intermediate input. The improvement of TFP in an industry shows that less composed input can produce the same amount of output. Comparing these two column results in table 7, it is easy to find that during the period 2003-2005, for most of energy production industries and energy intensity industries, the effectiveness of TFP decreased.

For example, there was an average improvement of TFP by 5.69% in iron and steel industry during 1997-2002, however it changed to deterioration by 2.48% in 2003-2005. In fact, to meet the sharply increasing domestic demands of steel products in China from 2003, hundreds of new steel factories were established, however the production technology did not improve, some even deteriorated, so more part of total input was squandered to the whole iron and steel industry, comparing with that in 1997-2002. Most energy intensive industries shown the similar change.

Table 7. Percentage Changes of industrial TFPs

Industries	1997-2002	2003-2005
Col	-1.73	1.68
Oil	-0.97	1.14
Gas	-2.87	0.74
P_c	-1.60	3.45
Crp	-5.58	-2.37
nmm	-4.73	0.13
I_s	-5.69	2.48
nfm	-4.49	2.01
fmp	-5.41	-0.81
ely	-14.24	45.28
trd	-1.49	3.27
trp	-0.94	-0.25

Note: negative value means improvement, according to the above function.

Then we consider the technology change parameters in primary factor input side, mainly including *Ak* and *Al*, which can be seen as the measurement of effectiveness for capital input and labour input.

The two period simulation results are shown in table 8. More negative value shows more improvement of effectiveness, and vice versa. In terms of the effectiveness about capital input, we find both of them deteriorated, which means that the redundant production capacity kept increasing from 1997-2005. The deterioration trend was relaxed to some extent in 2003-2005, which probably because that the demand of energy intensive product increased faster from 2003 than that in 1997-2002. To the industries of trade and transport, the effectiveness of capital input changed to increase in the period of 2003-2005, but it means that the investment to the service industries was of deficiency in that period, since more investment flew to other industries.

In terms of labor input, almost all industries' labor productivity had increased, while the pace getting moderate during 2003-2005. The trade and transport sectors had absorbed a great amount of labor force, especially the unskilled ones, to keep the increase of output. However it deteriorated the average labor productivity, which could lead to the real wage lower and then brought the negative effect to the income of poverty population group.

Table 8. Percentage Changes of Technology Parameters for Primary Input

Industries	Capital augmenting		labour augmenting	
	1997-2002	2003-2005	1997-2002	2003-2005
Col	3.26	2.40	-5.73	-5.29
Oil	1.03	0.78	-7.81	-6.82
Gas	1.50	1.05	-7.37	-6.56
P_c	13.59	9.49	-19.32	-12.82
crp	18.81	12.96	-15.52	-9.87
nmm	21.92	14.80	-13.26	-8.30
I_s	24.94	16.65	-11.05	-6.74
nfm	22.62	15.28	-12.75	-7.90
fmp	23.18	15.66	-12.34	-7.58
ely	0.37	0.03	-0.74	-0.11
trd	7.60	-10.76	-4.61	6.88
trp	6.55	-9.84	-5.48	7.89

In our historical simulation, in order to estimate the technology change of energy inputs to industries, we swapped the change of energy input in the energy intensive industries exogenous, as shown in table 9.

Table 9. Percentage change of technology for energy inputs to industries

energy input	industries	1997-2002	2003-2005
col	crp	-12.10	-5.26
	nmm	-10.87	-5.51
	I_s	-8.30	-17.28
	ely	-18.00	-33.93
	trd	-13.52	-16.79
oil	crp	-2.29	-23.14
P_c	crp	-6.94	-13.16
	nmm	-1.46	-27.85
	I_s	-3.15	-23.50
	ely	-28.55	-43.32
	trp	-2.43	-0.20
Ely	crp	0.98	-3.60
	nmm	5.38	-10.50
	I_s	4.30	-13.32
	nfm	5.75	-11.45
	Trd	0.69	-3.92

It shows that more efficient utilization of diversified energy input in energy intensive industries in 2003-2005 than that in 1997-2002. For instance, the effectiveness of coal input to electricity production increased by 18% in 1997-2002, but increased by 33.93% in 2003-2005. The probable reason is that the continuous effect of national energy saving policy, and the market-oriented reformation stimulate the company saving energy input.

4. Conclusion and discussion

In this paper, we introduced a dynamic CGE model SICGE-1, which was built based on the MONASH model developed by Monash University. Using SICGE-1, we analyzed China's energy efficiency issues under the whole economic framework. Through two stages historical simulation for 1997-2002 and 2003-2005, we find that:1) for most of energy production industries and energy intensity industries, the effectiveness of TFP decreased in 2003-2005, compared with that in 1997-2002; 2) the effectiveness of capital input continuously changed worse and the improvement of labor input also changed to moderate; 3) the effectiveness of energy intermediate input in energy intensive industries changed better continuously in 2003-2005 than that in 1997-2002.

In terms of energy efficiency, the results show a better promotion during 2003-2005 than that in 1997-2002. However, there are still large gap between domestic technological average level and international advanced level, in the future, we are assure that the technology of energy utilization will change better all along.

During the period 2003-2005, the effectiveness of integration input at industrial level changed worse than that in 1997-2002, the main reason probably is that the effectiveness of capital input changed worse in most of industries. The effectiveness of labor inputs and some intermediate inputs changed better, but this could not offset the negative effect in capital side. The low effectiveness of investment broadly exists in China. Large amount of investment flew into the energy intensive industries, hundreds of large and middle-sized and even small-sized coal-fired power plants, iron and steel plants, non-ferrous metal smelt plants were built almost simultaneously in the whole country. Hence, whether the investment change to rational in the future or not will be the key point to determine the transformation of pattern of economic growth successful or not.

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