Turnpike Optimality in Environment-Input-Output System: Analysis on the Adjustment Potential of China’s Industry Structure for Carbon Emission Reduction[[1]](#footnote-1)\*

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Abstract: This article works out the China’s potential in industry structure adjustment for carbon emission reduction. We present turnpike optimality in dynamic input-output models and give the reverse algorithm to get the turnpike Optimality of China’s industry adjustment considering carbon emission reduction target on Copenhagen Conference based on a compiled Energy-Carbon-Emission-Economy Input-Output tables and modified technology coefficients and capital formation matrixes. It finds that the turnpike line have better economy performance. Industry structure is improved by increase in the service and decrease in manufacture.

Key words: carbon emission, optimal dynamic input-out model, industry restructuring

**1 Aim**

This article works out the China’s potential in industry structure adjustment toward Copenhagen conference’s target. We present turnpike optimality in dynamic input-output models, with comparing Leontief’s model, Von-Norman’s model, and Hua’s model. We give the reverse algorithm of dynamic environment-input-output model to get the turnpike Optimality of China’s industry adjustment considering carbon emission reduction target on Copenhagen Conference based on a compiled Energy-Carbon-Emission-Economy Input-Output tables and modified technology coefficients and capital formation matrixes.

**2 Turnpike thermo in dynamic input-output system**

The turnpike thermo is first presented by Dorfman, Samuelson, Solow (1949)[1]. It is concerned with efficient paths of accumulation of economic expansion. Efficiency is defined with reference to the terminal stocks paths, namely, a path of accumulation lasting N periods is efficient if no other path, starting from the same initial stocks and complying with the technical restrains, reaches larger terminal stocks after N periods. We connect turnpike thermo to three models, von Neumann model, Leontief’s model, and Hua’s model.

**2.1 Three Models**

von Neumann model is a closed linear model of production in which the output of one period furnish the inputs of the next period, and combining with Turnpike theorem to get the path of proportional expansion of stocks which achieve the largest possible rate of expansion, so called Neumann rays [2,Lionel W. McKenzie].

Leontief’s model is a general form. Hicks[3,1961], Morishima[4,1961] and Mckenzie [5,1963] make the turnpike theorem became the global for disaggregated industries production with variable production coefficients and durable capital goods. Jinkichi Tusukui [6, 1966] applied the turnpike theorem in a computable dynamic Leontief system to the planning of economic growth. For example, planning for efficient accumulation in Japan[7, Jinkichi Tusukui, 1968, 8] and consumption considering international trade [Jinkichi Tusukui & Yasusuke Mutakami, 1979].

Hua’s model considered a close model, in which the initial output should fit characteristic vector. Otherwise, the system will collapse. Plan can made to adjust the output structure to fit characteristic vector. In Leontief trajectory, if the initial output may not fit characteristic vector of output, technical progress and structure adjustment make economy system to meet the Hua’s theorem.

**2.2 Turnpike lane in Leontief’s dynamic input-Output system**

We develop a dynamic input-output model to make the economy growth in the turnpike lane. Comparing the previous model, we introduce the dynamic programming in the model with optimal accumulation of consumption, under the constraints of dynamic input-output equation including international trade, on the target of carbon emission reduction.

**Table 1: present research on planning by meanings of input-output model**

|  |  |  |
| --- | --- | --- |
|  theoremMethods | turnpike theorem | no turnpike theorem |
| linear programming |  筑井(1968); Tusukui & Murakami(1979); J. He (2005) |  H. Zhang (2001);R. Na (1998,a,b) |
| dynamic programming |  |  G. Liu (1998,2009) |

Although there are few researches on the planning, most of them are simple linear programming based on input-output model ( H. Zhang, 2001, R. Na,1998). G. Liu (1998, 2009) gives some algorithms of dynamic input-output model, but it is not base on turnpike thermo. A outstanding work on turnpike theorem was made by Jinkichi Tusukui & Yasusuke Mutakami [1979], but it is still not involved in dynamic programming, and merely maximizes the capital of final year. We develop the model with optimal accumulating of consumption during the planning period.

 It assumed that all economy structure grow at the same speed if economy develop along the turnpike lane. So we modify the structure coefficient in our models. But we should take out of the various structure coefficients at certain year, combining them with the analysis of econometrics and experience of other countries, to modify them to reasonable coefficients. Considering von-Norman model’s close characteristic, we give up this assumption because it doesn’t fit the situation of China’s development, and take use of the solution of balance growth in Leontief dynamic input-output model T to obtain the initial output structure.

**3. Turnpike Optimality based on dynamic input-output model by dynamic programming**

This section builds the optimization input-output model. The goal is to accumulation of consumption of time 1 to time T. The process of resolving mode is divided into tows parts:

First, according to the dynamic input-output model’s structure coefficients, to obtain the output structure on the growth balance lane. Secondary, we resolve the solution of linear programming. From the economy output structure after (T+1), we get the output structure backward step by step. For example, we make use of the model

**3.1 Model characteristics**

This model has several characteristics:

1. It is an optimal accumulating of consumption, it make the consumer has maximal benefit. Most turnpike model considers the capital maximal in the planning year. But considering the environment factor, a social’s benefit is embodied in consumer actual benefit, but not the capital. The model takes the objective as the maximal accumulated GDP from the initial year until the planning year.
2. It considers the environment factor. The model includes the constraint of carbon emission as independent constraint equation. It is put into the production not only in the household’s consumption because carbon dioxide emitted by industries is largest part of source of carbon emission from fossil energy consumption.
3. The algorithm of this model is dynamic programming, not linear programming. Most optimal models are to make maximal GDP of one year (Zhang, 2001, Na Risa, 2000, Global). Even involving in the turnpike lane, those models make maximal GDP or capital at planning year as objective (He Jin, 2003). However this dynamic model makes the sum of consumption maximal as objective. So it uses dynamic programming. Reverse algorithm can be applied to get solution of this model.
4. It is an international model. The model includes export and import.

**3.2 Dynamic Model**

The dynamic model is established in equation (4.1) as objective function, and equation (4.2) as constraints.

 (4.1)

  (4.2)

Here,  is the input-output coefficient matrix,  is the coefficient matrix of capital formation, is the output vector, is the change of output,is the consumption of household, is the export vector, is the import vector,  is the vector of carbon intensity of industry,  is the vector of carbon emission of household,  is the carbon emission at target year,  is unit vector, the subscript u is the up bound of the variable, the low script is the low bound of variable, t is the time variable, t=1,…,T, T is the planning year.

 is the terminal constraint at time T, is the objective, i.e. cost function at time t, is the state variable,  is the control variable, control variable in this model. We deduce a reverse algorithm to get solution of this dynamic IO model in the following section 4.

**3.3 The determination of total carbon emission of each year TC(t)**.

Target of carbon emission reduction is assumed to be achieved through linear decline. The reduction of carbon emission intensity at t year to the based year is $γ\_{t}^{}$. Target of reduction of carbon intensity decrease 40% for 15 years so the constraints of reduction of carbon emission is: the reduction of carbon emission intensity in 2020 to that in 2005 $γ\_{15}^{}\in (40\%, 45\%)$. The carbon emission intensity is denoted as , the reduction of carbon emission intensity between 15 years is,. The reduction of carbon emission per year in average from 2005 to 2020 is , . Reduction of carbon emission for t years is , for example,. The computation process is as follows (up script *l* means low constraint, up script *u* means up constraint),

1. Intensity reduction per year: , ,
2. Intensity reduction for three years:, 



The carbon emission constraint in time is



**4. Reverse Algorithm in Turnpike Optimality in Environment-Input-Output System**

Assumed the initial output as, the control variable is defined as the increase of output, . The output at time *t* is state variable, , so we denote . Then we rewrite the equations (4.1) and (4.2) into equations (4.3) and (4.4).

 (4.3)

 We simplify the constraints (4.4) as the following equation

 We make use of reverse algorithm to obtain the solution of dynamic IO model. Computation starts from the year T-1. Then cost function (4.3) and constraint (4.5) at time T-1 is written as

 (4.6)

According to the deduction which combines the cost function at time t with terminal condition[[2]](#footnote-2), equation (4.6) can be written

  (4.7)

From equations (4.7), we induce the control vector,, and cost function at time T-1,

 (4.8)

Here, (4.9)

Next, we come to the cost function and constraints at time T-2,

 (4.10)

The equations (4.10) can be simplified, so that we can introduce control variable,, and the cost function at time T-2 in equation (4.11) [[3]](#footnote-3)

  (4.11)

Here 

Introducing control variable,, we come to the cost function and constraint at time T-3, and can obtain simplified version of cost function.[[4]](#footnote-4)

 (4.12)

Here,

, (4.13)

From above deduced equations, we further get the model at  step. Given , the cost function and constraints at time is shown as in the equation (4.14)[[5]](#footnote-5).

Here, 

Cost function with constraints at time () as format of (4.14) satisfies all models at time .

(4.15)

 From equation (4.15), we determine the optimal strategy. Given the initial output, we know the vector of output at each year, , , . The detail format is shown in equation (4.16).

 (4.16)

Here, 

The process of resolving solution is shown in Appendix 1.

**5 Data**

We take the date from the Energy-carbon-economy input-output table, which is shown as appendix 2.

The core of environment dynamic input-output model is non-linear coefficients. So we require modifying the direct input coefficient, capital coefficient and carbon emission coefficient. Leontief dynamic input-output model requires capital coefficient matrix, while input-output table issued by the Statistic Bureau in various countries merely reflect the capital formation vector. So the dynamic model was studied theoretically, but not applied in general [Duchin Fayer]. Some application is in Ten Raa (1986a, b) and education (Zhang, H.,2003, He, J., 2005, Fu, X.,2006). In general, input-output table issued in various countries merely reflect the capital formation as column vector. Chinese Statistic Bureau investigated the capital formation matrix in 2000, which is also fit the requirement of Leontief dynamic model. Moreover, Chen X(2005) also built input-occupied-output model, which investigate the fixed capital occupied matrix. The capital formation is flow while the fix capital is the stock. The capital formation coefficient is the *k*th capital product at time t for the *j*th output increased at time t . The fixed capital occupied coefficient is the *k*th capital occupied at time t for the *j*th output at time t . Fixed capital occupied  is the fix capital is acuminated capital, so  the capital coefficient in average. Take the occupied capital coefficient to adjust or replace capital formation coefficient, it will help to establish the dynamic model.

Because of capital formation data is available in 2000, so we take the data from 2000 to 2002 as an example for the new model, and then find the turnpike optimality in environment-input-output system. The indirect coefficient and capital coefficient are fix in this model, and the initial output and final demand is the real data from 2000, 2001, 2002 and 2003 input-output table. The 2000 and 2002 input-output table are obtain from the Chinese Statistics Bureau. 2001 and 2003 input-output table is extended table we compile according to combination the date from national accounting.

**6 Turnpike Optimality in Environment-Input-Output System**

We find the turnpike optimality from the environment-input-output system. Table 2 gives the adjusted output, which is compared to original output, table 3 gives the adjusted industry structure is compared to original output.

The optimal structure in 2001 to 2003 is different with the structure in 2000 on the aspects:

1. On the turnpike line, optimal structure of manufacture in 2001 (60%) is less than the actual structure in 2001 (68%). However, optimal structure of service in 2001 (28%) is larger than the actual structure in 2001 (22%).
2. Optimal Consumption in 2001 and 2002 are 0.40 billion and 0.4 billion larger than the actual comsumption in 2001 and 2002. It means that China should increase the consumption instead of merely dependency on the investment and export.
3. Optimal total output in 2001 and 2002 are 0.13 billion and 0.7 billion larger than the actual total output in 2001 and 2002. It means the turnpike lane will improve the economy much better.
4. Because of we take the fix structure coefficient, the optimal structure is fixed. For example, agriculture as 10%, manufacture as 60% and service as 28%. If we modify the technical coefficient and capital coefficient. The optimal structure will be changed.

Table 2: The adjusted output comparing to original output

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| actual data | 2000  | 2001  | 2002  | 2003  |
| agriculture | 264482669.9  | 258565469.3  | 285787423.0  | 357949104.5  |
| manufactures | 1729696512.3  | 1889139358.0  | 1905590585.0  | 2386754590.0  |
| services | 653753201.9  | 622103604.2  | 942927008.7  | 1181017257.0  |
| output | 2647932384.0  | 2769808431.0  | 2191378008.0  | 3925720951.0  |
| consumption | 375538540.9  | 638339569.1  | 792857986.4  |  |
| adjustment |  |  |  |  |
| agriculture | 264482669.9  | 330603337.5  | 330933940.8  | 331264874.8  |
| manufactures | 1729696512.3  | 1755862433.0  | 1757618295.0  | 1759375913.0  |
| services | 653753201.9  | 817191502.4  | 818008693.9  | 818826702.6  |
| output | 2647932384.0  | 2903657273.0  | 2906560930.0  | 2909467491.0  |
| consumption | 375538540.9  | 1127383296.0  | 1195709282.0  |  |
| output difference |  | 133848841.2  | 715182921.7  |  |
| consumption difference |  | 489043727.1  | 402851296.1  |  |

Note: The actual data of output by industry and consumption is from the Statistic Year book in 2001, 2002 and 2003, and the input-output table from 2000 to 2003.

Table 2: The adjusted industry structure comparing to original output

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| actual data | 2000  | 2001  | 2002  | 2003  |
| agriculture | 10% | 9% | 13% | 9% |
| manufactures | 65% | 68% | 87% | 61% |
| services | 25% | 22% | 43% | 30% |
| output | 1.0  | 1.0  | 1.0  | 1.0  |
| adjustment |  |  |  |  |
| agriculture | 0.1  | 0.1  | 0.1  | 0.1  |
| manufactures | 65% | 60% | 60% | 60% |
| services | 25% | 28% | 28% | 28% |
| output | 1.0  | 1.0  | 1.0  | 1.0  |

Note: The actual data of output by industry and consumption is from the Statistic Year book in 2001, 2002 and 2003, and the input-output table from 2000 to 2003.

**6 Conclusion**

This article works out the China’s potential in industry structure adjustment for carbon emission reduction. We present turnpike optimality in dynamic input-output models and give the reverse algorithm to get the turnpike Optimality of China’s industry adjustment considering carbon emission reduction target on Copenhagen Conference based on a compiled Energy-Carbon-Emission-Economy Input-Output tables and modified technology coefficients and capital formation matrixes. It finds that the turnpike line have better economy performance. Industry structure is improved by increase in the service and decrease in manufacture. The optimal consumption and total output should increase much more than the actual data. If we modify the structure coefficient, the results will be improved.

**Appendix**

We will resolve the solution of the following model,





As for the dynamic IO model, we can compile the matlab program to resolve the solution of the model (4.16). The method is realized through some transformation of this model.

Set 

Equation (4.16) is rewritten as



Taking  , n=3 for example, the model is shown as follows:





Table A.1 Energy-carbon emission-economy input-output table

|  |  |  |  |
| --- | --- | --- | --- |
| outputinput | Intermediate usage | Final usage | Total output |
| energy | Non-energy |  Consumptionof household | energy | Non-enery | … |
| input | Intermediate input | Energy industry | Coal producing and selection | 104 Yuan |  |  |  |  |  |  |  |
| Coal(usage/consumption)Carbon | ton/ton standard coalmetric ton |
| … | … |
| … | … |
| Gas production and supplying | 104 Yuan |
| Gas(usage/consumption)Carbon | M3/ton standard coalmetric ton |
|  |  |
| Total Usage of energy Total consumption ofenergyCO2 emission | ton standard coal ton standard coalmetric ton |
| Non energy industry | agriculture | 104 Yuan |  |  |  |  |  |  |  |
| … | … |
| … | 104 Yuan |
| The third industry |
| Intermediate input in total | 104 Yuan |
| Value added | Fix capital depreciation | 104 Yuan |  |  |  |
| Remuneration of labor | 104 Yuan |
| Tax and profit | 104 Yuan |
| Value added in total | 104 Yuan |
| Total input | 104 Yuan |  |  |

 The energy unit of value is 104 Yuan. The energy unit of volume is measured both as physic quantity and transferred standard unit. Physic quantity unit is denoted for raw coal, crude oil, Petroleum products, Coking products as ton, for natural gas, oven gas, LPG as cube meter, for hydro power and nuclear, and thermal power respectively as kW•h, heat kJ. Consistent unit, energy of various types can be measured as standard coal. The carbon dioxide unit is metric ton.

1. \* Supporting foundation: “Dynamic Programming on Industry Structure of Low carbon Economy based on Multiregional Input-Output Model”, National Social Science Foundation, 2010, 7, No.10CJL033, (hosting); “Research on the strategy of low carbon development during China’s urbanization”, Key grant of project of National Social Science Foundation, 2010, 7, No. 10zd&032, (participating).” [↑](#footnote-ref-1)
2. We know the index function (4.3) at time T-1 as

 (D-1)

From the terminal condition,

 (D-2)

 we get the index function at time T-1 as

  (D-3)

Thus the index function (4.3) and constraints at time T-1 is

 (D-4) [↑](#footnote-ref-2)
3. The index function at time T-2 in equation (4.3) is simplified after introducing equation (4.8)as (D-5)

Hence, the index function at time T-2 and constraints in time T-2 are shown as.

 (D-6)

Here  and  [↑](#footnote-ref-3)
4. The index function at time T-2 in equation (4.3) is simplified after introducing equation (4.11) as

 (D-7)

Let, , and,

Then  (D-8) [↑](#footnote-ref-4)
5. We can get the general version of the model at  step, the index function at time T-k.

From the above deduction, we further know the cost function

 (D-9)

Hence, 

Here,

From (D-4),(D-6), (D-8) and (D-9), we can assumed the cost function at step as

 (D-10)

Here,

When k=T-1,

From equation (4.3) we get the cost function at  step as

 (D-11)

Let , then the model at step take the version as

 [↑](#footnote-ref-5)