

## Dynamic network Malmquist model based on green input-output table

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**Abstract:** For revealing the influence of intermediate transactions between industrial sectors to the dynamic performance, this paper develops a framework of dynamic performance with network structure measurement by establishing a dynamic network Malmquist productivity index (DNMPI) model following the dynamic network slacks-based measure (DNSBM) model. In order to explore the performance, we decompose the model to identify the dynamic efficiency (inter-temporal influence) and the network efficiency (sector interaction) based on green accounting. Furthermore, this paper analyzes Chinese dynamic performance with network structure influenced by energy-economy-environment (3E) in the view of industrial chain effect. We apply it to analyze the data of 40 industrial sectors in China from 2002, 2005 and 2007. Based on empirical results, we systematically indicate the influence of energy efficiency and environment efficiency to the economic development in China.

**Keyword:** dynamic network Malmquist, DNSBM, rural bank, green accounting, energy-economy-environment

### 1. INTRODUCTION

Discussion of economic activities, natural resources and environment under sustainable development has received increased attention by the international society. From Kyoto Protocol in 1997 to Copenhagen Climate Council in 2009, Cancun Conference in 2010 and Durban climate conference in 2011, all these emphasis the

importance of energy performance and pollution control. China today is at the stage of industrialize and urbanization. So the demand of energy is increasing. The decision makers face the balance among economy, energy and environment. After almost achieving the target of reducing the energy consumption by 20%, China makes low carbon as the key character of the energy development in a five-year plan for 2011 to 2015.

<1>

Meanwhile, the period is set as the critical period of the energy consumption.

Green performance research based on energy consumption and environment constraint receives widespread attention. Data Envelopment Analysis (DEA) proposed by Charnes et al. [2] is an effective method for evaluating the relative effectiveness of decision making problem with multi inputs and outputs. This method fits the production activities with undesirable outputs and avoids the error from the strong assumption of model design and random interference distribution.

Traditional performance evaluation takes the input-output process as an inseparable black box and doesn't into-depth discuss the intermediate transaction. This cannot use information effectively and pinpoint the performance influence from each stage of the input-output process. So, traditional method cannot find the ineffectiveness source exactly. However, input-output theory points all the industries need to coordinate the development. Any industry is enslaved to others; meanwhile, it will affect others. Based on the concept of embodied energy, industry operation is a complicated process including multi-stages from the original input to final output. An interdependent association exists among different industries. Färe and Grosskopf [5] first purpose network DEA model to decompose the complicated business process in order to investigate the stage influence to the whole performance. And then, they construct the framework of DEA model with network structure. Prieto and Zofio [8] incorporate network DEA model with input-output model to analyze OECD. Bogetoft et al.[1] make an illustration about the dynamic network DEA. Tone [10] introduces the dynamic variables and network variables into Slack-Based Model (SBM) [9] to build dynamic SBM with network structure (DNSBM).

Therefore, no matter in theoretical study or in empirical research, the problem of how to measure the performance in the view of reflecting the complicated quantitative relationship is worth to study. As we know,

traditional Malmquist ignores the network effect. In order to cover this shortage, this paper introduces the intermediate transactions to explore the black box performance. For this purpose, we define link variables to reflect the intermediate transactions among different industries such as intermediate use in green accounting. And then, we build dynamic Malmquist model with network structure by introducing the link variables to clarify the network effect among the whole manufacturing process.

This paper differs from the existing literature in several aspects. First, we construct economy-energy-environment performance which measures the performance influenced by economic efficiency, energy efficiency and environment efficiency based on green accounting. Second, in order to consider the intertemporal effect of carry-over activities and the linkage of intermediate transactions, we build an extended dynamic Malmquist model with network structure to evaluate the energy-economy-environment performance. Third, we apply a cluster analysis to the result of decomposed efficiency scores to distinguish the characteristics of energy performance constrained with environment in Chinese industries.

This paper unfolds as follows. In Section 2, we describe a conceptual DMPI model and discuss the measurement of the DMPI model. In Section 3, we describe the data and research setting. We give an example of 40 Chinese industries with a more dynamic viewpoint using cluster analysis based on the new model in Section 3. We conclude in the last section.

## **2. A dynamic Malmquist productivity index with network structure (DNMPI)**

### **2.1. A conceptual DNMPI model**

Tone and Tsutsui [12] pointed out that traditional Malmquist usually neglects carry-over activities between two consecutive terms and only focuses on the separate

time period independently, so traditional Malmquist model only evaluate local optimization in a single period. Therefore, we analyze performance based on DMPI model. Furthermore, traditional Malmquist ignores the intermediate products or linkage activities [11]. So we further consider the intermediate transaction into DMPI model to construct a new model in order to open the black box performance. Before describing the detailed formulations, we would like to introduce the conceptual framework of our model as described in Fig. 1.

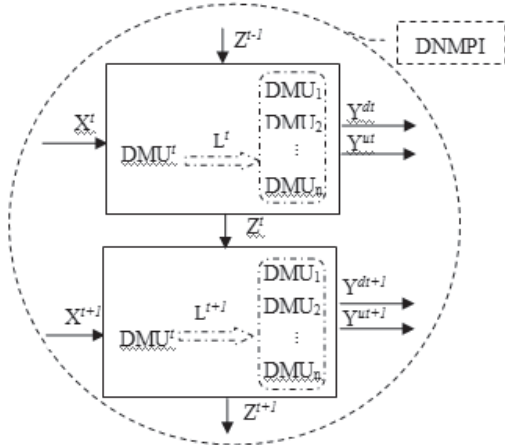


Fig.1 Dynamic Malmquist with network structure

In this figure, at each period  $t$ , each DMU produces desirable output  $Y^{dt}$  and undesirable output  $Y^{ut}$  using input  $X$  along with carry-over activity  $Z$ . Intermediate product  $L$  of DMU means the intermediate transactions between the DMU and others. We assume that the carry-over activity connects time periods  $t-1$ ,  $t$  and  $t+1$ . Tone [10] propose a dynamic DEA model involving network structure in each term within the framework of slacks-based measure approach, called Dynamic SBM with network structure (DNSBM). In this paper, we basically build dynamic Malmquist with network structure model (DNMPI) based on DNSBM. The distinction between the DNMPI model and Malmquist model is the existence of carry-over activities and linkage activities.

**2.2. Basics of decomposing DNMPI**

In order to measure the intertemporal efficiency

change between  $(x^t, y^t)$  and  $(x^{t+1}, y^{t+1})$ , we decomposed the dynamic Malmquist index based on Färe [5]. The method of decomposing the dynamic Malmquist productivity index with network structure follows the process of the traditional Malmquist productivity index. We extend the traditional index into the DNMPI considering the negative externalities, carry-over activities and intermediate products. Thus, we have two indices: overall efficiency changes (OEC) and dynamic technical changes (DTC). Furthermore, both of them can be further decomposed separately with network structures as Fig. 2 shows.

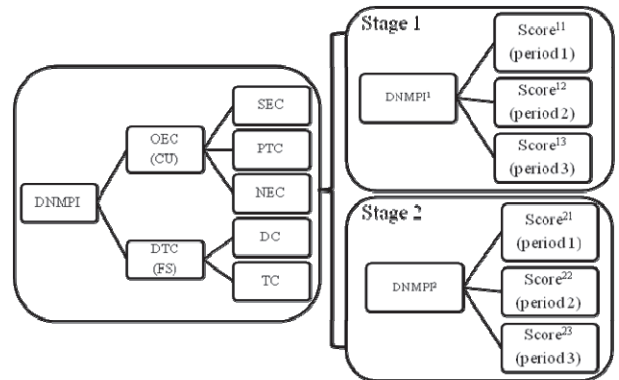


Fig. 2 Evolution of dynamic Malmquist decomposition

Considering the network structure effect, we decompose DNMPI into two stages considering intermediate products. The first stage measures the process of the original inputs to the intermediate transactions. The second stage measures the process of the intermediate transactions to the final outputs. Besides that, we evaluate every period of each stage with score shown as Fig.2. Higher score means that the DMU at this stage of the period has higher performance than the counterparts.

**2.2.1. The first stage of dynamic Malmquist productivity index decomposition**

Therefore, the objectives of this paper are to evaluate the effects of (1) carry-over activity and (2) intermediate transaction based on green accounting.

Throughout this paper we utilize the following notations.

(a)  $D^t \left( (x, y^d, y^u) \middle| (X^t, Y^{dt}, Y^{ut}) \right)$  = Efficiency of an activity  $(x, y^d, y^u)$  evaluated with respect to  $(X^t, Y^{dt}, Y^{ut})$  frontiers. We use the notation  $D^t(x, y^d, y^u)$  for brevity. This corresponds to the traditional efficiency measure.

(b)  $\bar{D}^t \left( (x, z^-, y^d, y^u, z) \middle| (X^t, Z^{t-1}, Y^{dt}, Y^{ut}, Z^t) \right)$  = Efficiency of an activity  $(x, z^-, y^d, y^u, z)$  evaluated with respect to  $(X^t, Z^{t-1}, Y^{dt}, Y^{ut}, Z^t)$  frontiers. We use the notation  $\bar{D}^t(x, z^-, y^d, y^u, z)$  for brevity. This measure takes carry-overs into account.

(c)  $\bar{D}^t \left( (x, l, y^d, y^u, z) \middle| (X^t, L^t, Y^{dt}, Y^{ut}) \right)$  = Efficiency of an activity  $(x, l, y^d, y^u)$  evaluated with respect to  $(X^t, L^t, Y^{dt}, Y^{ut})$  frontiers. We use the notation  $\bar{D}^t(x, l, y^d, y^u)$  for brevity. This measure takes intermediate products into account.

(d)  $\bar{\bar{D}}^t \left( (x, z^-, l, y^d, y^u, z) \middle| (X^t, Z^{t-1}, L^t, Y^{dt}, Y^{ut}, Z^t) \right)$  = Efficiency of an activity  $(x, z^-, l, y^d, y^u, z)$  evaluated with respect to  $(X^t, Z^{t-1}, L^t, Y^{dt}, Y^{ut}, Z^t)$  frontiers. We use the notation  $\bar{\bar{D}}^t(x, z^-, l, y^d, y^u, z)$  for brevity. This measure takes both carry-overs and intermediate products into account.

Analogously, we can extend traditional Malmquist to carry-over, intermediate product and undesirable output cases as follows.

$$\begin{aligned} & \bar{\bar{M}}^t \left( (x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t) \middle| (x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1}) \right) \\ &= \left[ \frac{\bar{D}^t(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\bar{D}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \times \frac{\bar{\bar{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\bar{\bar{D}}^{t+1}(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \right]^{\frac{1}{2}} \\ &= \left[ \frac{\bar{D}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\bar{D}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \right] \quad (1) \\ &\quad \times \left[ \frac{\bar{\bar{D}}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)}{\bar{\bar{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})} \times \frac{\bar{\bar{D}}^t(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\bar{\bar{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})} \right]^{\frac{1}{2}} \\ &= OEC \times DTC = (\text{Catch-up } (CU)) \times (\text{Frontier-shift } (FS)). \end{aligned}$$

As above, OEC measures the catch-up effect of productivity set with a negative externalities constraint

between period  $t$  and period  $t+1$ . Furthermore, DTC measures the shift of the dynamic efficient isoquant line between period  $t$  and period  $t+1$ . This index considers the mixed impact of intertemporal influence proposed by carry-overs and technology changes over time.

### 2.2.2. The second stage of dynamic Malmquist productivity index decomposition

At the first stage of dynamic Malmquist productivity index decomposition, we get the overall technical efficiency change (OEC) considering intermediate transactions and the dynamic technology change (DTC) mixed impacted by intertemporal influence and technology changes over time. This stage we further decompose the catching-up component (CU) and the frontier-shift components (FS) of the DNMPI model.

OEC representing as the catching-up component of dynamic network Malmquist productivity index can be decomposed into technical efficiency changes (TEC) as traditional Malmquist productivity index and network efficiency changes (NEC) as intermediate transactions as follows.

$$\begin{aligned} OEC &= \frac{\bar{\bar{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\bar{\bar{D}}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \quad (2) \\ &= \underbrace{\frac{\bar{D}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)}{\bar{D}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}}_{\textcircled{1}} \cdot \underbrace{\frac{\bar{\bar{D}}^t(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)}{\bar{\bar{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}}_{\textcircled{2}}} \\ &= TEC \cdot NEC. \end{aligned}$$

Furthermore, Catching-up component in the formula (1) can be decomposed as (2). In this formula,  $\textcircled{1}$  above means technical efficiency change (TEC) in the spirit of traditional Malmquist productivity index as catching-up component. Similarity, in the formula is the network efficiency change with negative externalities constraint. Similar with traditional Malmquist productivity index, TEC can be further decomposed into the pure technical efficiency changes (PTC) and scale efficiency changes (SEC). We ellipsis for they are simplify.

DTC representing as the frontier-shift component of dynamic Malmquist productivity index can be

decomposed into technology changes (TC) as traditional Malmquist productivity index and dynamic changes (DC) as intertemporal influence coming from carry-overs as follows.

$$DTC = \left[ \frac{\overline{\overline{D}}(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)}{\overline{\overline{D}}^{t+1}(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \times \frac{\overline{\overline{D}}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\overline{\overline{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})} \right]^{1/2}$$

$$= \left[ \frac{\overline{\overline{D}}(x^t, l^t, y^{dt}, y^{ut})}{\overline{\overline{D}}^{t+1}(x^t, l^t, y^{dt}, y^{ut})} \times \frac{\overline{\overline{D}}(x^{t+1}, l^{t+1}, y^{dt+1}, y^{ut+1})}{\overline{\overline{D}}^{t+1}(x^{t+1}, l^{t+1}, y^{dt+1}, y^{ut+1})} \right]^{1/2} \quad (3)$$

$$= \left[ \left( \frac{\overline{\overline{D}}(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)}{\overline{\overline{D}}^{t+1}(x^t, z^{t-1}, l^t, y^{dt}, y^{ut}, z^t)} \right) / \left( \frac{\overline{\overline{D}}(x^t, l^t, y^{dt}, y^{ut})}{\overline{\overline{D}}^{t+1}(x^t, l^t, y^{dt}, y^{ut})} \right) \times \left( \frac{\overline{\overline{D}}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})}{\overline{\overline{D}}^{t+1}(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})} \right) / \left( \frac{\overline{\overline{D}}(x^{t+1}, l^{t+1}, y^{dt+1}, y^{ut+1})}{\overline{\overline{D}}^{t+1}(x^{t+1}, l^{t+1}, y^{dt+1}, y^{ut+1})} \right) \right]^{1/2} \quad (4)$$

= TC · DC.

Furthermore, frontier-shifting component in the formula (1) can be decomposed as (3). In this formula, ③ above means technology change proposed by traditional Malmquist productivity index as frontier-shift component. It indicates the shift of the production isoquant line caused by quantity allocation of inputs and outputs between period  $t$  and period  $t+1$ . Similarity, in the formula is the dynamic change reflecting the shift of the production isoquant line caused by the intertemporal influence coming from carry-overs.

In a word, the dynamic Malmquist can be decomposed as follows. The dynamic Malmquist index is more than 1 means progress, is less than 1 means regress, and equals to 1 means the productivity is stable.

### 2.3. Measurements of efficiency by SBM

The above formulations include efficiency evaluations within the same period and intertemporal efficiency evaluation.

$$\overline{\overline{D}}(x, z^{-1}, l^t, y^{dt}, y^{ut}, z) = \min \frac{1 - \left( \frac{1}{m+r+p+q} \left( \sum_{i=1}^m \overline{S}_{x_{it}} + \sum_{i=1}^r \overline{S}_{z_{it-1}} + \sum_{i=1}^p \overline{S}_{y_{it}} + \sum_{i=1}^q \overline{S}_{l_{it}(k,h),t} \right) \right)}{1 + \left( \frac{1}{s+r+q} \left( \sum_{i=1}^s \overline{S}_{y_{it}} + \sum_{i=1}^r \overline{S}_{z_{it}} + \sum_{i=1}^q \overline{S}_{l_{it}(k,h),t} \right) \right)}$$

s.t.

$$x_{it} = \sum_{j=1}^n x_{ijt} \lambda_{jt} + S_{it}^- \quad (i=1, \dots, m, t=1, \dots, T)$$

$$z_{it-1} = \sum_{j=1}^n z_{ijt-1} \lambda_{jt-1} + S_{it-1}^- \quad (il=1, \dots, r, t=1, \dots, T) \quad (4)$$

$$y_{it} = \sum_{j=1}^n y_{ijt} \lambda_{jt} - S_{it}^+ \quad (id=1, \dots, s, t=1, \dots, T)$$

$$y_{it} = \sum_{j=1}^n y_{ijt} \lambda_{jt} + S_{it}^- \quad (iu=1, \dots, p, t=1, \dots, T)$$

$$z_{it} = \sum_{j=1}^n z_{ijt} \lambda_{jt} - S_{it}^+ \quad (it=1, \dots, r, t=1, \dots, T)$$

$$\sum_{j=1}^n z_{ijt-1} \lambda_{jt-1} = \sum_{j=1}^n z_{ijt} \lambda_{jt} \quad (\forall i, t=1, \dots, T)$$

$$l_{\alpha(kh),t} = \sum_{j=1}^n l_{\alpha(kh),jt} \lambda_{jt} + S_{\alpha(kh),t} \quad ((kh)in=1, \dots, q)$$

$$l_{\alpha(kh),t} = \sum_{j=1}^n l_{\alpha(kh),jt} \lambda_{jt} + S_{\alpha(kh),t} \quad ((kh)out=1, \dots, q)$$

$$\sum_{j=1}^n l_{\alpha(kh),jt} \lambda_{jt} = \sum_{j=1}^n l_{\alpha(kh),jt} \lambda_{jt} \quad (\forall i, \forall (k,h)_{f_{tw}}; t=1, \dots, T)$$

$$\lambda_{jt-1} \geq 0(\forall j, t), \lambda_{jt} \geq 0(\forall j, t), \lambda_{jt} \geq 0(\forall j, \forall (k,h)_{f_{tw}}, t), \lambda_{jt} \geq 0(\forall j, \forall (k,h)_{f_{tw}}, t),$$

$$S_{it}^- \geq 0(\forall i, t), S_{it}^+ \geq 0(\forall id, t), S_{it}^- \geq 0(\forall iu, t), S_{it}^- \geq 0(\forall it, t), S_{it}^+ \geq 0(\forall il, t).$$

In a similar way, we can evaluate the efficiency of DMU  $(x^{t+1}, z^t, l^{t+1}, y^{dt+1}, y^{ut+1}, z^{t+1})$  with carry-overs, intermediate products and undesirable outputs with respect to the period  $t$  frontiers.

As for  $D'(x, y^d, y^u)$ ,  $\overline{D}'(x, z^-, y^d, y^u, z)$ ,  $\overline{D}'(x, l, y^d, y^u)$  and  $\overline{\overline{D}}'(x, z^-, l, y^d, y^u, z)$ , we can apply the same procedure using the data  $(x, y^d, y^u)$  for the former,  $(x, z^-, y^d, y^u, z)$  and  $(x, l, y^d, y^u)$  for the middle and  $(x, z^-, l, y^d, y^u, z)$  for the later.

### 3. Empirical application to the 3E performance

To test our model and to show its application to real practice, we applied our model to the 3E performance in China. In this section, we first describe the data based on green accounting in China; second, we apply the DNMPI model to the data and obtain results, and then, we analyze these results with unitizing cluster analysis. We also make suggestions to improve the 3E performance.

### 3.1. Data explanation

#### 3.1.1.Green accounting

The discussion of linkage analysis for human's economic activities, the natural resources and environment under the framework of sustainable development has received increased attention by the international society, especially after Japan's nuclear leakage. It's necessary relationship between economic development and environment. Nevertheless, traditional national accounting is based on marketing principle. It only considers the pure economic system and regards resource and environment as inexhaustible and worthless. Green accounting not only considers the relation between energy-environment and economic activities, but also regard for the correlation between stock and flow. Since 1970s, in order to study the relationship between economic development and environment, some economists introduce environment factors into traditional input-output analysis and build a series of input-output models including resource and environment factors [3,6,7, 13].

Differing from traditional ones, the green input-output model (as Table 1) introduces the environment pollution and wastage emission, and indicates the influence of economy on natural and environment aspect comprehensively. It reflects the internal relation between each sector, each production and natural environment. Therefore, green input-output model plays a very important role in sustainable development.

Table 1 Green input-output model

	Energy recovery dept.	Energy1 dept.	Energy2 dept.	Other dept.	Pollution abatement dept.	Final output	Total output
Energy used	$U_{ij}^e$	$U_{ij}^{p1}$	$U_{ij}^{p2}$	$U_{ij}^{p3}$	$U_{ij}^m$	$Y_{ij}^e$	$X_{ij}^e$
Energy 1 dept.	$Q_{ij}^{e1}$	$Q_{ij}^{p11}$	$Q_{ij}^{p12}$	$Q_{ij}^{p13}$	$Q_{ij}^{1m}$	$Y_{ij}^{p1}$	$X_{ij}^{p1}$
Energy 2 dept.	$Q_{ij}^{e2}$	$Q_{ij}^{p21}$	$Q_{ij}^{p22}$	$Q_{ij}^{p23}$	$Q_{ij}^{2m}$	$Y_{ij}^{p2}$	$X_{ij}^{p2}$
Other dept.	$Q_{ij}^{e3}$	$Q_{ij}^{p31}$	$Q_{ij}^{p32}$	$Q_{ij}^{p33}$	$Q_{ij}^{3m}$	$Y_{ij}^{p3}$	$X_{ij}^{p3}$
Pollutant emission	$W_{ij}^e$	$W_{ij}^{p1}$	$W_{ij}^{p2}$	$W_{ij}^{p3}$	$W_{ij}^m$	$Y_{ij}^m$	$X_{ij}^m$
Total value added	$N_{ij}^e$	$N_{ij}^{p1}$	$N_{ij}^{p2}$	$N_{ij}^{p3}$	$N_{ij}^m$		
Total input	$Z_{ij}^e$	$Z_{ij}^{p1}$	$Z_{ij}^{p2}$	$Z_{ij}^{p3}$	$Z_{ij}^m$		
Man-made Capital	Fixed assets	$W_{ij}^{e(0)}$	$W_{ij}^{e(1)}$	$W_{ij}^{e(2)}$	$W_{ij}^{e(3)}$	$W_{ij}^m$	
Natural Capital	Material assets	$t_{ij}^{e1}(X_{ij}^e, Z_{ij}^e)$	$t_{ij}^{e2}(X_{ij}^e, Z_{ij}^e)$	$t_{ij}^{e3}(X_{ij}^e, Z_{ij}^e)$			
	Environment assets	$t_{ij}^{m1}(X_{ij}^m, Z_{ij}^m)$	$t_{ij}^{m2}(X_{ij}^m, Z_{ij}^m)$	$t_{ij}^{m3}(X_{ij}^m, Z_{ij}^m)$			

In Table 1, we define ratio of energy use as  $t_{ij}^e = U_{ij}^p / X_{ij}^e$  and that of pollutant emission as  $t_{ij}^w = W_{ij}^p / X_{ij}^w$ .

#### 3.1.2.Variable selection

Parts of our variables come from green accounting which calculates according to input-output calculation of China. Since every five years, there is an input-output table. And between the five years, there is an extended table. Based on this, our study periods are 2002, 2005 and 2007 and we classify all the Chinese industries into forty sectors as our DMUs shown as in Table 2.

Table 2 The sectors of DMUs

Num.	Sectors	Num.	Sectors
DMU1	Agriculture	DMU21	Manufacture of Artwork, Other Manufacture
DMU2	Mining and Washing of Coal	DMU22	Production and Supply of Electric Power and Heat Power
DMU3	Extraction of Petroleum and Natural Gas	DMU23	Production and Distribution of Gas
DMU4	Mining of Metal Ores	DMU24	Production and Distribution of Water
DMU5	Mining and Processing of Nonmetal Ores and Other Ores	DMU25	Construction
DMU6	Manufacture of Foods and Tobacco	DMU26	Traffic, Transport and Storage
DMU7	Manufacture of Textile	DMU27	Post
DMU8	Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather(Down) and Its products	DMU28	Information Transmission, Computer Services and Software
DMU9	Processing of Timbers and Manufacture of Furniture	DMU29	Wholesale and Retail Trades
DMU10	Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports Activities	DMU30	Hotels and Catering Services
DMU11	Processing of Petroleum, Coking, Processing of Nuclear Fuel	DMU31	Financial Intermediation
DMU12	Chemical Industry	DMU32	Real Estate
DMU13	Manufacture of Nonmetallic Mineral Products	DMU33	Leasing and Business Services
DMU14	Smelting and Rolling of Metals	DMU34	Research and Experimental Development
DMU15	Manufacture of Metal Products	DMU35	Comprehensive Technical Services
DMU16	Manufacture of General Purpose and Special Purpose Machinery	DMU36	Management of Water Conservancy, Environment and Public Facilities
DMU17	Manufacture of Transport Equipment	DMU37	Services to Households and Other Services
DMU18	Manufacture of Electrical Machinery and Equipment	DMU38	Education
DMU19	Manufacture of Communication Equipment, Computer and Other Electronic Equipment	DMU39	Health, Social Security and Social Welfare
DMU20	Manufacture of Measuring Instrument and Machinery for Cultural Activity & Office Work	DMU40	Culture, Sports and Entertainment

All the inputs, carry-overs, links and outputs are summarized in Table 3. All the data is comparable data which eliminates the price influence.

Table 3 Data description

	Variable	Unit	Sample	Mean	SD	Min	Max
Inputs	Complete energy	10000 SCE	120	79283.67	116833.66	1186.46	691406.64
	Staff	Thousand	120	2851.95	3150.41	169.00	15209.00
Carry-overs	Capital stock	100 millions	120	9788.51	22439.72	91.32	143685.29
	Intermediate use 1	100 millions	120	424.30	747.69	0.01	3939.17
links	Intermediate use 2	100 millions	120	4364.61	4819.74	7.24	24369.53
	Intermediate use 3	100 millions	120	1146.49	1190.12	7.26	5459.07
Outputs	Output value	100 millions	120	12597.92	11752.44	363.78	51531.81
	Complete pollution	10000 tons	120	206675.32	240704.88	3368.34	1200521.42

### 3.2. Empirical result

#### 3.2.1.OEC V.S. DTC

For identifying the influence of the structure,

technology and dynamic, from the points of catching-up effect and frontier-shifting effect, we analyze energy-economy-environment (3E) dynamic performance with network structure. As shown in Fig. 3, the dynamic performances of all the forty sectors during 2002 to 2007 in China are in ascending order. As a whole, the dynamic technology changes (DTC) drive the whole performance, especially for the DMUs which have lower performances.

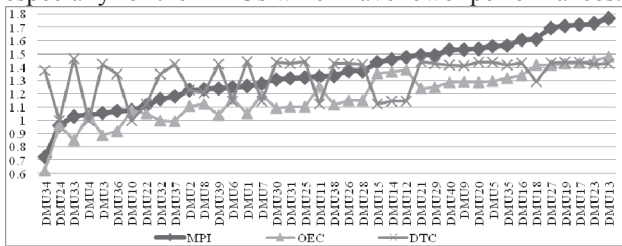


Fig. 3 Decomposed efficiency indices of 3E performance

From the catching-up effect view, we represent this effect by OEC which means overall technical efficiency changes. Furthermore, we decompose it into two indices which are scale efficiency changes (SEC) and pure technical efficiency changes (PTC). As Fig.3 shown, the catching-up effect trend follows that of MPI. However, the OEC of almost DMUs are lower than those of MPIs which mean the catching-up effect restricting the performance, especially for the DMUs which have low performances. For example, DMU3 (Extraction of Petroleum and Natural Gas) retrogresses both on scale and technology (SEC=0.95, PTC=0.93). This disadvantage makes DMU3 fall behind other DMUs. From the three industries perspective, most sectors of tertiary industry have lower OEC. So do primary industry. Most sectors of secondary industry have higher OEC, especially for the new industrial sectors such as DMU19 (1.43) and DMU23 (1.45). This phenomenon reveals sectors of secondary industry are still at the stage of overall technical efficiency growth which means quantity accumulation. However, those of primary industry and tertiary industry gradually close to saturation and transit to the stage of qualitative leap.

From the frontier-shifting view, we represent this

effect by DTC which means dynamic technology change. As Fig. 3 shown, DTC is the main factor to improve MPI, especially for that of lower MPI. As a whole, all the sectors have dynamic technology progress except three sectors (DTCs=1) as (DMU24, DMU4 and DMU10) which are stable. This phenomenon reveals the background of sectors such as human resource, technology level and dynamic effect improves the performance. From the three industries perspective, most sectors of tertiary industry have higher DTC. So do primary industry. Most sectors of secondary industry have lower DTC, especially for the traditional industrial sectors such as DMU4 and DMU10. This phenomenon is consistent with the results of OEC. This means redundancy inputs of secondary industry lead to rely on efficiency pursue and ignore the increase of technology level in some way.

### 3.2.2. Cluster analysis

As mentioned, a more sustainable development strategy can be evaluated from two sides in our new DNMPI model: carry-over activities and intermediate transactions. However, how do carry-over activities and intermediate transactions affect 3E performance? How do we identify the performance with the decomposed efficiency scores? To answer these two questions, we incorporated hierarchical cluster analysis to classify the different characteristics of 40 sectors using six decomposed scores including different divisions and different periods. We have used cosine method of the hierarchical cluster analysis. We try several other methods based on the theory of hierarchical cluster analysis. We found the discrimination of DMUs is very low using other methods. So this distance method is best suitable for our empirical research comparing with other distance methods. Based on the results of the six scores, we classify sectors into four groups by hierarchical cluster as shown in Fig. 4.

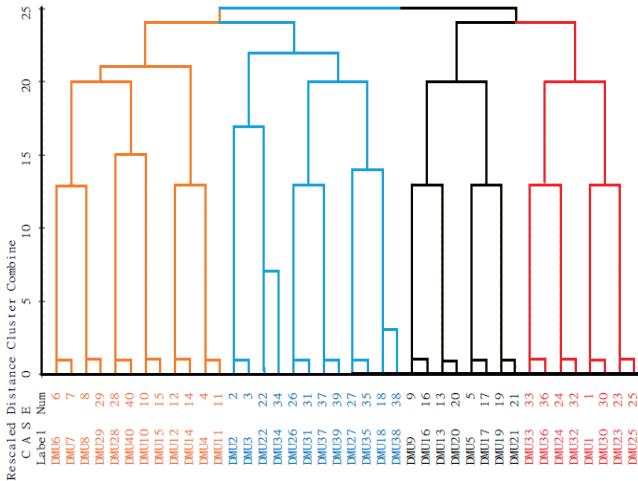


Fig. 4 Dendrogram (Centroid method)

As shown in Fig. 4, we found all the forty sectors are almost equally distributed into the four groups. Each group has its own sector character. For example, almost sectors of group 1 belong to traditional secondary industry such as DMU7, DMU10 and DMU12. They always are recognized as traditional heavy pollution sectors. Most sectors of group 2 belong to tertiary industry such as DMU31 and DMU38. Three energy sectors also belong to this group (DMU2, DMU3 and DMU22). Comparing with other groups, group 3 is absolute secondary industry group. All sectors in this group belong to manufacture industry except DMU5. Group 4 is a combination group. This group includes all the three industries.

Based on the results of cluster analysis, we classified the six decomposed scores of the four groups into a radar chart as shown in Fig. 5. Compared with the group2 and group4, group 1 is nearly at the innermost layer of the radar chart. The average levels of decomposed scores in group 1 (total scores=0.26) are lower than those of other groups. This innermost layer group indicates this group experiences the worst situation, since group 1 has no obvious advantage compared with the other groups. Group 2 (total scores=0.31) has a stronger improvement in distribution division at period 1. However, score in generation division at period 3 is weaker for group 2, which indicates the performance control is lost in this

group. This group nearly envelops group 1 and is enveloped by group 4. This means group 2 is better than group 1 and worse than group 4. Group 3 (total scores=0.30) is a special group comparing with others for its advantage at another side which is in generation division at period 3. This is an absolute advantage. However, its disadvantages at generation division at period 1 and distribution at period 2 to period 3 are also absolute. Compared with the other three groups, group 4 (total scores=0.39) is largely at the outermost layer of the radar chart except for having a lower score in generation division at period 3 than that of group 2. This group has an absolute advantage in generation division at period 1 which is the very beginning of the whole process. Because the DNMPI for group 4 is far ahead, we can see Group 4 is the best one among the four groups.

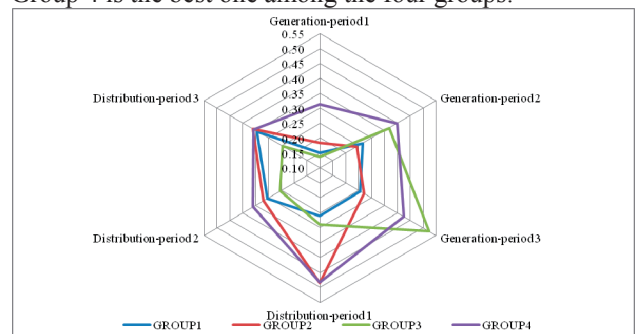


Fig. 5 Radar chart

The average and ranking of these scores are classified as shown in Table 4. Numbers in circles represent the ranking of these scores in the four groups. The results in Table 4 indicate that the performance of whole process has a worried situation for all groups, whereas individual indices and rankings are diversified among the groups. On average, all groups have two relatively similar characters among the six decomposed scores. The first characteristic is that all groups fall backwards in generation at period 1 which means there is a bad very beginning for all the groups. The other familiar characteristic is that the sub-period performances of the four groups are gradually better. This suggests that current changes in 3E



performance control have been a big step towards in the productivity growth of sectors.

Table 4 Average indices and rankings in the four groups

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
Total scores	0.2637 ④	0.3052 ②	0.3026 ③	0.3887 ①
Generation-period 1 scores	0.1520 ③	0.1835 ②	0.1369 ④	0.3132 ①
Generation-period 2 scores	0.2647 ③	0.2418 ④	0.3675 ②	0.3992 ①
Generation-period 3 scores	0.2554 ④	0.2709 ③	0.5229 ①	0.4263 ②
Distribution-period 1 scores	0.2598 ④	0.4860 ①	0.2891 ③	0.4840 ②
Distribution-period 2 scores	0.3047 ③	0.3201 ②	0.2540 ④	0.3594 ①
Distribution-period 3 scores	0.3457 ③	0.3597 ①	0.2451 ④	0.3567 ②

On the group perspective, group 1 is worst group comparing with others. All the scores (generation score=0.22, distribution score=0.30) are lagged behind and have large distance with better groups. As mentioned above, almost sectors of group 1 belong to traditional secondary industry. Their industry features make them as higher energy and higher pollution. So the performances at every divisions and periods have a bad situation comparing with those of other groups. However, for themselves, they gradually change better on the view of sub-period performance.

Group2 has a better total scores which reveals this group is litter better than group3 and still has large distance comparing with the best one—group 4. We found its advantage is distribution division performance (distribution score=0.39). This phenomenon means they focus on output value. Most sectors of this group belong to tertiary industry. Their industry features make them have congenital advantage. The other energy sectors are benefit from their energy profit as their output value. Although the generation division (generation score=0.23) is their disadvantage comparing with that of other group, there is a progress for itself on the view of sub-period.

Group 3 keeps in step with group 2. Different with group 2, this group is benefit from the generation division (generation score=0.34), though this group has a real bad very beginning in this division. All the sectors of this group are absolute secondary industry group. This phenomenon makes them face the same situation with group 1. We found this group focuses on the input control since this group makes great progress in generation division. However, the output value is also their fatal

bottleneck which reveals the pollution control is worried.

Group 4 is the best one of the four groups. Its total score is much higher than any other group. As we know, group 4 is a combination group. This group includes all the three industries which belong to clean industry. So both in generation division and distribution division, this group has absolute advantage (generation score=0.38, distribution score=0.40). This phenomenon reveals this group not only focuses on the input control, but also does not lose the output value. The strategy of working along both lines makes this group hold a safe lead.

#### 4. Conclusion

This paper develop a dynamic energy-economy-environment Malmquist productivity index by incorporating dynamic effect and network effect to measure the performance based on dynamic Malmquist productivity index with network structure (DNMPI). Based on green accounting, this paper incorporates the dynamic variables representing intertemporal effect and the linkage variables considering undesirable outputs which symbiotic with desirable outputs into dynamic Malmquist model with network structure. We aim at constructing "dynamic energy-economy- environment performance with intermediate production" which means total factor productivity influenced by energy efficiency, economy efficiency and pollution efficiency. For this purpose, we develop a dynamic Malmquist productivity index (DMPI) with network structure in order to consider the intertemporal effect of carry-over activities and the effect of intermediate outputs. Furthermore, DNMPI can be decomposed it into OEC and DTC, and then OEC is decomposed into network efficiency change (NEC), scale efficiency change (SEC) and pure technical efficiency change (PTC). DTC is decomposed into dynamic change (DC) and technical change (TC). And then, we reveal the new dynamic performance considering the intermediate productions to identify the reciprocal sustainable development relationships among energy efficiency,

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economy efficiency and environment efficiency.

By applying the DNMPI model, we analyze the panel data of 40 industries in China from 2002 to 2007 based on green accounting. Based on hierarchical cluster analysis, all DMUs are categorized into four groups. Some interesting findings about the dynamic performance of each group are summarized, such as dynamic technical change plays a leading role in promoting dynamic performance, especially for that of lower MPI and the catching-up effect restricting the performance, especially for the DMUs which have low performances.

Based on the empirical analysis, all the DMUs should pay attention on long-term development in energy-economy-environment allocation. Considering own characters, they should improve the management skill and play a role of high technology input in energy efficiency and pollution efficiency control. Green accounting contains energy, economy and environment is another way to promote the harmonious development on dynamic energy-economy- environment performance. Future research topics that could follow this study include:

- 1). Incorporate dynamic cost revenue and profit efficiencies into our model;
- 2). Incorporate the round intermediate transactions to extend the network structure.

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