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A framework for measuring global Malmquist–Luenberger productivity index with CO_2 emissions on Chinese manufacturing industries

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A B S T R A C T

China has achieved significant progress in terms of economic and social developments since implementation of reform and open policy in 1978. However, the rapid speed of economic growth in China has also resulted in high energy consumption and serious environmental problems, which hindering the sustainability of China's economic growth. This paper provides a framework for measuring eco-efficiency with CO_2 emissions in Chinese manufacturing industries. We introduce a global Malmquist-Luenberger productivity index (GMLPI) that can handle undesirable factors within Data Envelopment Analysis (DEA). This study suggested after regulations imposed by the Chinese government, in the last stage of the analysis, i.e. during 2011–2012, the contemporaneous frontier shifts towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs, i.e. producing less CO_2 emissions, but the GMLPI drops slightly. This is an indication that the Chinese government needs to implement more policy regulations in order to maintain productivity index while reducing CO_2 emissions.

1. Introduction

China has achieved significant progress in terms of economic and social developments since implementation of reform and open policy in 1978. However, the rapid speed of economic growth in China has also resulted in high energy consumption and serious environmental problems, which hindering the sustainability of China's economic growth. The statistical data from China Statistical Yearbook 2010 shows that China's nominal industrial gross domestic product (GDP) increased by 66.02 times between 1981 and 2009 (204.84 vs. 13523.99 billion RMB Yuan) and the amount of industrial solid waste produced in 2009 (2.04 billion tons) was 5.42 times that of 1981 Bian et al. [7]. BP [6] argued that China's total energy consumption was only half of the United States' about ten years ago but overtook the United States to become the world's largest energy user in 2010. Wang et al. [51] also noted that China has already surpassed the USA and become the world's largest energy consumer and contributor of CO_2 emissions since 2007.

Chinese government has realized the importance of energy conservation and prevention of the climate changes for sustainable development of China's economy. To address this issue, China announces 12th five-year plan intended to establish a “green, low-carbon development concept”, which states that in 2015 China will increase the proportion of non-fossil fuels in energy generation to 11.4%, reduce energy consumption per unit of GDP by 16%, and reduce CO_2 emissions per unit of GDP by 17% from the levels in 2010, especially in manufacturing industries, as the industrial sector contributes most of carbon emissions in China. Moreover in the September 2014, Chinese State Council released officially the “National Climate Change Plan (2014–2020)” and announced China's CO_2 emissions to gross domestic product in 2020 would be reduced by 40%–45% on the basis of 2005.

China Statistical Yearbooks show the annual average growth rate of GDP in China was 10.2%, while the industry expanded by 11.9% on annual average in the period of 1981–2011. Moreover, the share of industrial added value exceeded 40% of GDP in the past three decades, and the industry contributes 84.2% of the total CO_2 emissions in China [11]. Thus it is important to investigate efficiency and productivity evolution in Chinese manufacturing

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industries with CO_2 emissions as an undesirable factor. The results of the analysis could be one of the bases for policy makers in China to develop the relevant policies in the future.

There have been a large amount of literature on environmental issues considering CO_2 emissions in China. See details for literature review in the Subsection 2.1. This paper aims to analyse the productivity evolution of the subordinate sectors (two-digit level) in Chinese manufacturing industries (Decision making units, DMUs) with respect to CO_2 emissions in period of 2004–2012 as an undesirable output using. For this, we employ a global Malmquist–Luenberger productivity index (GMLPI) based on Data Envelopment Analysis (DEA) with selected inputs (asset, labour, and energy consumption) and outputs (gross industrial output and CO_2 emissions) to investigate the components of GMLPI of these two-digit level manufacturing industries in China.

The remainder of the paper is organized as follows: Section 2 reviewed the related literature and presented the development status of Chinese manufacturing industries for this paper. Section 3 describes the methodology used in this paper especially GMLPI with undesirable output. Section 4 gives summary statistics of the data and variables used in this paper. The empirical results of the productivity evolution of Chinese manufacturing industries with some discussions and policy implications are illustrated in Section 5. Section 6 concludes this paper and provides direction for future research.

2. Literature review and the development status of Chinese manufacturing industries

2.1. Literature review

Climate change has become one of the most challenging issues facing the world. More and more countries are concerned with reducing energy consumption and CO_2 emissions while increasing the efficiency and productivity of the industrial sectors. There are many applications of DEA in various areas including environmental efficiency. Arabi et al. [3] investigated the productivity evolution of 18 steam power plants in Iran using a new slacks-based Malmquist-Lunernberg productivity index (MLPI). Cui and Li [12] proposed a virtual frontier DEA which is applied to evaluate transportation carbon efficiencies of 15 countries during the period of 2003–2010. Bruno and Manello [8] used DEA based directional distance function (DDF) to benchmarking and effects of reforms in the fixed telecommunications industry. Martini et al. [31] analysed the efficiency of 33 Italian airports for the period 2005–2008 using a two-stage procedure based on DDF and bootstrapping. Picazo-Tadeo et al. [40] proposed the use of DDF and DEA techniques to assess eco-efficiency of a sample of Spanish olive-growing farms. Sueyoshi and Goto [46] discussed how to use DEA to measure operational and environmental efficiency by considering energy utilization and environmental protection. Molinos-Senante et al. [33] integrated environmental impacts in the assessment of the efficiency of estimating pure and mixed environmental performance indices for a sample of 60 Spanish wastewater treatment plants. Khodakarami et al. [25] proposed a gradual efficiency improvement DEA model to measure sustainability of the community of manufacturing and service businesses. Vlontzos et al. [49] evaluated the energy and environmental efficiency of the primary sectors of the EU member state countries using non-radial DEA model. Picazo-Tadeo and García-Reche [41] used DEA as a tool to show that environmental performance is a matter of major concern both for policy makers and for firm managers. There are still a lot of other literature on this issue, e.g., Environmental productivity of Chinese provinces [36], Productivity growth in OECD countries [62], environmental efficiency industry [35], energy efficiency of Indian manufacturing [34], Korean electric power industry [28], European commercial transport industry [27], electric power sector in Japan [32], and world cement industry [43]. Dakpo et al. [13] proposed a general review the most relevant methods in this field of modelling pollution-generating technologies in performance benchmarking with limits and strengthens. Based on the above analysis, we can see that, DEA technique has been applied broadly in the field of measuring environmental efficiency and productivity. As a nonparametric approach, DEA can easily incorporate undesirable factors based on DDF with specific direction. It is necessary to use DDF since in the standard DEA model (input-based), decreases in outputs are not allowed and only inputs are allowed to decrease. Based on DDF, DEA technique can be used to measure the inefficiency taking undesirable factors into account and then construct MLPI to measure the productivity over different periods.

Currently, China has become one of the world's largest contributors of CO_2 emissions, so the environmental efficiency including CO_2 emission in Chinese industries has been a popular research topic, *e.g.* Zhang et al. [64] proposed a non-radial Malmquist CO_2 emission performance index based on a non-radial directional distance function (DDF) for measuring dynamic changes in total-factor CO_2 emission performance over time in transportation industry. The following Table 1 lists some of previous studies on Chinese environmental efficiency. As seen in Table 1, it is clear that most related works focus on the regional (e.g. province-level and city-level) and industrial environmental efficiency based on DEA. Output-based model and DDF are the most selected way to deal with undesirable factors, e.g. CO_2 emissions or SO_2 emissions. There are some literature dealing with time-series data using Malmquist–Luenberger (ML) productivity index. However, there exist few researches on productivity analysis of Chinese manufacturing industries with CO_2 emissions on using a GMLPI in the time window of recent years.

2.2. Development status of Chinese manufacturing industries

As a developing country, China experiences a rapid growth in manufacturing industries in recent years. According to China Statistical Year Books 2005–2013, the sum of Gross Industrial Output Value (GIOV) of Chinese two-digit level manufacturing industries increased significantly, an increase of about 3.3 times from about 22.8 trillion RMB in 2004 to about 74.8 trillion RMB in 2012. The energy consumption of Chinese Manufacturing industries also increased from about 1.2 billion tons of standard coal equivalent (SCE) in 2004 to about 2.1 billion tons in 2012. In the meantime, the energy intensity (energy consumption per unit GIOV) decreased substantially. At 2004, it costs about 0.51 tons of SCE to produce 10 thousand RMB GIOV, but it only needs about 0.28 ton SCE to produce the same amount GIOV at 2012. However compared with other developed countries, the level of energy intensity is much lower than the average of the world. According to the "World Development Report 2010 of Emerging Industries" (see Asia-Pacific CEO Association (APCA) in 2011), although the level of energy intensity in China has declined significantly, the energy consumption (in term of standard oil equivalent (SOE)) per unit US dollar GDP of China is still much higher than several main countries in the world (See Fig. 1).

Furthermore, the CO_2 emissions in manufacturing industries in China is relatively high in this period, As seen in Fig. 2, the CO_2 emission in manufacturing industries in China is about 2.3 billion tons in 2004 but in 2012 it is estimated to reach more than 4.1 billion tons in China.

Table 1
Previous studies on Chinese environmental efficiency.

Authors (year)	Research field and data	Major issues addressed	Methodological approaches			
			Efficiency measure			Time-series measure
			Type	Orientation	Models	
Zhang et al. [64]	Province-level	Total-factor carbon emission performance of the Chinese transportation industry	Non-radial	Output	CCR + DDF	ML index
Yang et al. [58]	Province-level	Regional environmental efficiencies in China	Radial	Input	CCR and super efficiency CCR	Panel-data
Wang et al. [52]	City-level	Environmental protection mechanisms and economic development of 211 cities in China	Non-radial	Output	BCC + DDF	No
Fan et al. [15]	Industrial sub-sectors of Shanghai	Industrial total factor CO2 emission performance	Non-radial	Output	CCR + DDF	ML index
Bian et al. [7]	Regional-level data	Chinese regional industrial systems efficiency	Non-radial	Non-orientation	two-stage SBM DEA	No
An et al. [1]	Plant-level	Environmental efficiency evaluation of thermal power enterprises	Non-radial	Non-orientation	Enhanced Russell measure	No
Zhu et al. [70]	Pesticide-level	Eco-efficiency of Pesticides	Radial	Input	Two-stage DEA	No
Zhou et al. [69]	Plant-level	Energy efficiency performance of China's transport sector	Radial	Input	CCR, BCC, NIRS	No
Zhang et al. [68]	Province-level	Sustainability performance for China	Non-radial	Non-orientation	CCR + DDF	No
Yin et al. [60]	City-level	Eco-efficiency of Chinese cities	Radial	input	CCR	No
Wu et al. [57]	Regional-level	Environmental efficiency evaluation of industry in China	Radial	Input	Fixed sum output DEA	No
Wang et al. [54]	Regional-level	Energy efficiency and energy saving potential	Non-radial	Output	non-radial directional distance function	No
Wang and Wei [50]	City-level	Evaluating the energy and emissions efficiency	Non-radial	Output	DDF	No
Mahdiloo et al. [71]	Regional-level	Environmental quality efficiency	Network DEA	Output	Network DEA	No
Li et al. [29]	Regional-level	Efficiency Measurement of Electric Power Supply Companies	Non-radial	Input	DDF	No
Huang et al. [21]	Regional-level	Regional eco-efficiency in China	Non-radial	Non-orientation	SBM model + DDF	Panel-data
Hou et al. [20]	Agricultural systems-level	Sustainable value of degraded soils	Radial	Input	CCR + DDF	No
Du et al. [14]	Province-level	Measurement of the sources of economic growth	Non-radial	Output	CCR + DDF	ML index
Bi et al. [4]	Thermal power sector	Environmental regulation affect energy efficiency in China's thermal power generation	Non-radial	Input	SBM + DDF	Panel-data
Bi et al. [5]	Province-level	Regional energy and environmental efficiency of China's transportation sector	Non-radial	Output	DEA + MEA	Panel-data
Long et al. [30]	Chinese provinces	Environmental regulatory cost	Non-radial	Output	CCR + DDF	No
Wang et al. [53]	Province-level	Energy and CO2 performance	Non-radial	Input	SFA model	No
He et al. [19]	Iron and steel firm	Traditional energy efficiency, productivity, and environmentally sensitive productivity growth	Non-radial	Output	CCR + DDF	ML index
Yang and Wang et al. [59]	Province-level	Environmental efficiency and regulatory cost	Non-radial	Non-orientation	BCC + DDF	No
Yuan et al. [61]	Prefecture-level	Environmental efficiency and determinants	Non-radial	Output	BCC + DDF	No
Wang et al. [51]	Province-level	CO2 performance and determinants	Non-radial	Output	MEA	No
Zhang and Choi [65]	Plant-level	Total-factor carbon emission change	Non-radial	Non-orientation	CCR + DDF	ML index
Zhang and Choi [66]	Plant-level	Pure CO2 emission change	Non-radial	Non-orientation	CCR + DDF	ML index
Zhang and Choi [67]	Regional-level	Environmental energy efficiency of China's regional economies	Non-radial	Non-orientation	SBM + BCC/CCR	No
Wu et al. [56]	Regional industrial sector	Total-factor energy efficiency change	Radial	Input	CCR + DDF	ML index
Zhang et al. [63]	Province-level	Environmentally sensitive productivity growth and environmental regulatory cost	Radial	Output	CCR + DDF	ML index
Chang and Hu [9]	Chinese provinces	Energy productivity growth	Non-radial	Non-orientation	CCR + DDF	ML index
Kaneko et al. [23]	Thermal power sector	Shadow price of SO2	Non-radial	Output	CCR + DDF	No
Watanabe and Tanaka [55]	Province-level industry	Efficiency with SO2 and determinants	Non-radial	Output	BCC + DDF	No
Kaneko and Managi [24]	Province-level	Environmentally sensitive productivity growth	Non-radial	Output	CCR + DDF	ML index

Note: (1) MEA denotes multi-directional efficiency analysis; (2) ML index denotes Malmquist–Luenberger productivity index; (3) SBM denotes slack-based measure; (4) Panel-data denotes the time analysis is conducted separately year by year.

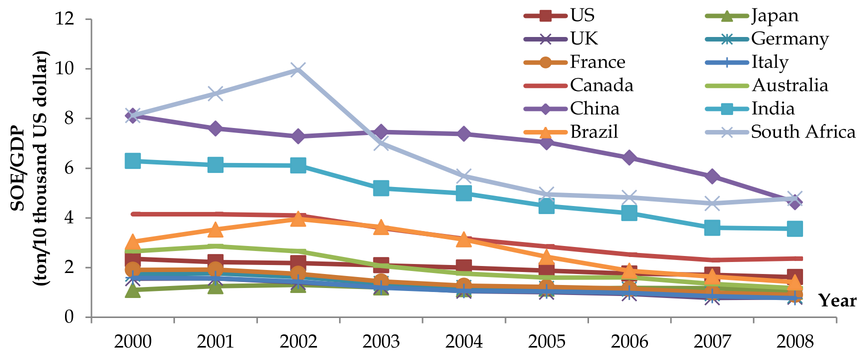

Fig. 1. The energy consumption per unit US dollar GDP of several main countries.
(Data source: http://stats.unctad.org/, World Bank, and BP World Energy Statistics 2009).

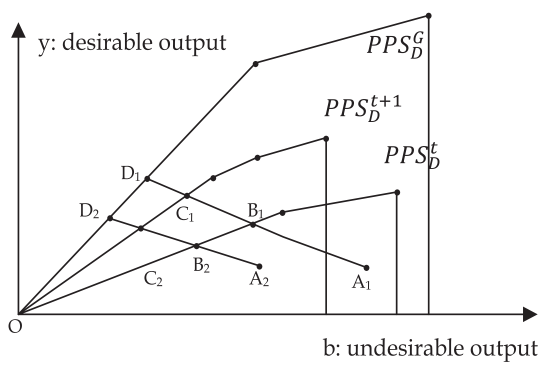

Fig. 2. The illustration of GMLPI based on DDF.

3. Methodology

Let us consider $X = (x_1, x_2, \ldots, x_m)$ and $Y = (y_1, y_2, \ldots, y_s)$ be input and output vectors of m and s dimension respectively. Assume that there are N DMUs ($j = 1,\ldots,N$. DMUj) over T time periods ($t = 1,\ldots,T$), then the Production Possibility Set (P) in period is fined by

$$PPS^t = \{(X^t, Y^t) | X^t \text{ can produce } Y^t\},\ t = 1, \ldots, T. \tag{1}$$

Further, we define output distance function D (e.g., output-orientated radial distance) by

$$D^t(X^t, Y^t) = \inf\{\theta > 0 | X^t, Y^t/\theta \in PPS^t\}, t = 1, \ldots, T. \tag{2}$$

3.1. Directional distance function (DDF) and Malmquist–Luenberger productivity index (MLPI)

Now let us consider a relatively complex productive process that uses a vector of inputs X to obtain a set of desirable outputs denoted by the vector Y and a vector of undesirable outputs denoted by the vector $B = (b_1, b_2, \ldots, b_h)$. Assume that there are N DMUs ($j = 1,\ldots,N$ DMUj) over T time periods ($t = 1,\ldots,T$), we need to expand the definition on PPS in formula (1) as follows:

$$PPS_D^t = \{(X^t, Y^t, B^t) | X^t \text{ can produce } (Y^t, B^t)\},\ t = 1, \ldots, T. \tag{3}$$

This technology gives a description of all technologically feasible relationships between inputs and outputs. In order to model some particular properties of joint production on desirable and undesirable outputs, the technology in model (3) could also be formulated as input sets $I^t(Y^t, B^t)$ or output sets $P^t(X^t)$ as follows:

$$I^t(Y^t, B^t) = \left\{X^t : (X^t, Y^t, B^t) \in PPS_D^t\right\} \tag{4}$$

$$P^t(X^t) = \left\{(Y^t, B^t) : (X^t, Y^t, B^t) \in PPS_D^t\right\} \tag{5}$$

Therefore we can easily see that the following formula holds.

$$X^t \in I^t(Y^t, B^t) \Leftrightarrow (Y^t, B^t) \in P^t(X^t) \Leftrightarrow (X^t, Y^t, B^t) \in PPS_D^t \tag{6}$$

Shephard and Färe [44] introduced the null-joint production assumption which means that if DMUs want to produce a positive amount of desirable outputs some undesirable outputs will also be produced. Thus we have

$$(Y^t, B^t) \in P^t(X^t); B^t = 0 \Rightarrow Y^t = 0 \tag{7}$$

Second, we also assume weak disposability of outputs to consider explicitly that disposal of undesirable outputs is not free-lunch as it is commonly assumed in traditional production theory. The weak disposability of outputs constitutes an appropriate assumption about the technology since reducing undesirable needs resources which could be allocated formerly on desirable outputs [17]. This indicates that it is not possible to reduce undesirable output without reducing desirable output.

The third assumption is known as the strong disposability of desirable output, which implies that it is possible to reduce desirable output without reducing undesirable output.

$$(Y^t, B^t) \in P^t(X^t) \text{ and } Y^{t'} \le Y^t \Rightarrow \left(Y^{t'}, B^t\right) \in P^t(X^t) \tag{8}$$

Thus the output directional distance function is defined as follows:

$$\vec{D}^t_{DDF}(X^t, Y^t, B^t, g_Y, g_B) = \sup\{\beta : (Y^t + \beta g_Y, B^t - \beta g_B) \in P^t(X^t)\} \tag{9}$$

where g_Y and g_B denotes the direction vectors for desirable and undesirable outputs, respectively. The direction vector (g_Y,g_B) determines the direction in which efficiency is measured. The value of $\vec{D}^t_{DDF}$ represents the distance between the observation (Y^t,B^t) and a point ($Y^t + \beta g_Y$, $B^t - \beta g_B$) on the production frontier.

A MLPI (output-oriented) is defined on PPS_D^t as

$$MLPI^k\left(X^t, Y^t, B^t, X^{t+1}, Y^{t+1}, B^{t+1}\right) = \frac{1 + \vec{D}^k_{DDF}(X^t, Y^t, B^t, g_Y, g_B)}{1 + \vec{D}^k_{DDF}(X^{t+1}, Y^{t+1}, B^{t+1}, g_Y, g_B)}, k = t, t+1 \tag{10}$$

However $MLPI^t(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1})$ and $MLPI^{t+1}(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1})$ are not equal in most cases. We define the MLPI in geometric mean form as the following formula:

$$MLPI\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right)=\left(MLPI^t\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right)\times MLPI^{t+1}\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right)\right)^{1/2} \tag{11}$$

3.2. Global Malmquist–Luenberger productivity index (GMLPI)

As fully discussed in previous literatures (see *e.g.*[37] on ML index, there may occur the situations of infeasibility[1] since one or more DMUs can be located beyond the efficiency frontier in certain direction that those DMUs cannot be projected onto the frontier in the presence of undesirable outputs. Färe et al. [16] illustrated this infeasibility problem intuitively. Aparicio et al. [2] summarized the main weaknesses of ML index, including (1) when the estimation of the shift in technology between two periods of time is based on the distance from the period t observation to the period s technology, infeasibility problem may occur; (2) when using DEA model based on DDF, slacks may be neglected, and (3) inconsistency is implied in the postulates set traditionally assumed in the joint production of desirable and undesirable outputs. Färe et al. [37] proposed the GMLPI which is circular and free of infeasibility problem. Aparicio et al. [38] proposed a sequential ML index for measuring environmentally sensitive productivity growth which appropriately considers the nature of technical change. Tohidi et al. [48] proposed a new global cost Malmquist productivity index, which is circular and that gives a single measure of productivity change. Arabi et al. [3] showed the shortcoming of the approach proposed by Aparicio et al. [2] to tackle the infeasible problem based on a new direction function using slacks-based measurement. The definitions of indexes, e.g. GMLPI in Ref. [37]; sequential ML index in Ref. [38]; cost MPI in Ref. [48]; are coincides substantially with the sequential technology introduced by Tulkens and Vanden Eeckaut [47] and Shestalova [45]. Here we restate the GMLPI briefly.

First we define global *PPS* with undesirable output as $PPS_D^G=conv\{PPS_D^1,PPS_D^2,\ldots,PPS_D^T\}$, where $conv\{*\}$ denotes the convex hull. Thus a GMLPI is defined on PPS_D^G as

$$GMLPI^G\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right)=\frac{1+\vec{D}^G_{DDF}(X^t,Y^t,B^t,g_Y,g_B)}{1+\vec{D}^G_{DDF}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)} \tag{12}$$

where $\vec{D}^G_{DDF}(X^k,Y^k,B^k,g_Y,g_B)=sup\{\beta:(X^k,Y^k+\beta g_Y,B^k-\beta g_B)\in PPS_D^G\},k=t,t+1$

.

If we further assume the direction vector $(g_Y,g_B)=(Y^k,B^k)$ and constant returns to scale (CRS) on the technology PPS_D^G, thus we have

$$\vec{D}^G_{DDF,c}\left(X^k,Y^k,B^k,g_Y,g_B\right)=\max\beta$$
$$s.t.\begin{cases}\sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}X_j^t\le X^k\\ \sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}Y_j^t\ge(1+\beta)Y^k\\ \sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}B_j^t=(1-\beta)B^k\\ \lambda_{jt}\ge0,j=1,\ldots,N;t=1,\ldots,T\end{cases} \tag{13}$$

and under VRS technology:

$$\vec{D}^G_{DDF,v}\left(X^k,Y^k,B^k,g_Y,g_B\right)=\max\beta$$
$$s.t.\begin{cases}\sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}X_j^t\le X^k\\ \sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}Y_j^t\ge(1+\beta)Y^k\\ \sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}B_j^t=(1-\beta)B^k\\ \sum_{t=1}^T\sum_{j=1}^N\lambda_{jt}=1\\ \lambda_{jt}\ge0,j=1,\ldots,N;t=1,\ldots,T\end{cases} \tag{14}$$

The GMLPI (output-oriented) can be decomposed into components of productivity growth under CRS and VRS assumptions as follows:

Under CRS assumption:

$$GMLPI_c^G\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right)=\frac{1+\vec{D}^G_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)}{1+\vec{D}^G_{DDF,c}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}=\frac{1+\vec{D}^t_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)}{1+\vec{D}^{t+1}_{DDF,c}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}$$
$$\times\left[\frac{\left(1+\vec{D}^G_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)\right)/\left(1+\vec{D}^t_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)\right)}{\left(1+\vec{D}^G_{DDF,c}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)\right)/\left(1+\vec{D}^{t+1}_{DDF,c}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)\right)}\right]=\frac{TE^{t+1}}{TE^t}\times\left[\frac{BPG_{t+1}^{t,t+1}}{BPG_t^{t,t+1}}\right]=EC^{t,t+1}\times BPC^{t,t+1} \tag{15}$$

[1] In this paper we have not observed any infeasibility issue with the data we have.

where $TE^t = \frac{1}{1+\overrightarrow{D}^t_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)}$ and $EC^{t,t+1} = \frac{TE^{t+1}}{TE^t}$ denote the technical efficiency (TE) in period t and the efficiency change (EC) in period t to $t+1$. Variable $BPG_t^{t,t+1} = \frac{1}{(1+\overrightarrow{D}^G_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B))/(1+\overrightarrow{D}^t_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B))}$ denotes the best practice gap between traditional technology frontier and global technology frontier. Thus $BPC^{t,t+1} = \frac{BPG^{t,t+1}_{t+1}}{BPG^{t,t+1}_t}$ denotes the best practice gap change, which measures technical change between two time period t and $t+1$.

Under VRS assumption:

$$\begin{aligned} GMLPI_v^G\left(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1}\right) &= \frac{1+\overrightarrow{D}^G_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)}{1+\overrightarrow{D}^G_{DDF,v}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)} \times \left(\frac{SE^{t+1}\ (X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}{SE^t(X^t,Y^t,B^t,g_Y,g_B)}\right) \\ &= \frac{1+\overrightarrow{D}^t_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)}{1+\overrightarrow{D}^{t+1}_{DDF,v}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)} \\ &\times \left[\frac{\left(1+\overrightarrow{D}^G_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)\right)/\left(1+\overrightarrow{D}^t_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)\right)}{\left(1+\overrightarrow{D}^G_{DDF,v}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)\right)/\left(1+\overrightarrow{D}^{t+1}_{DDF,v}(X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)\right)}\right] \\ &\times \left(\frac{SE^{t+1}\ (X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}{SE^t(X^t,Y^t,B^t,g_Y,g_B)}\right) \\ &= \frac{PTE^{t+1}}{PTE^t} \times \left[\frac{BPG^{t,t+1}_{t+1}}{BPG^{t,t+1}_t}\right] \times \left(\frac{SE^{t+1}\ (X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}{SE^t(X^t,Y^t,B^t,g_Y,g_B)}\right) = PEC^{t,t+1} \times BPC^{t,t+1} \times SCH^{t,t+1} \end{aligned} \tag{16}$$

where $PTE^t = \frac{1}{1+\overrightarrow{D}^t_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)}$. and $PEC^{t,t+1} = \frac{PTE^{t+1}}{PTE^t}$. denote the pure technical efficiency (PTE) in period t and the pure efficiency change (PEC) in period t to $t+1$. . Variable $BPG_t^{t,t+1} = \frac{1}{(1+\overrightarrow{D}^G_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B))/(1+\overrightarrow{D}^t_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B))}$ denotes the best practice gap between traditional technology frontier and global technology frontier. Thus $BPC^{t,t+1} = \frac{BPG^{t,t+1}_{t+1}}{BPG^{t,t+1}_t}$. denotes the best practice gap change, which measures technical change between two time period t and $t+1$. Variable SE^t means the scale efficiency on global benchmark in period t and

$$SE^t(X^t,Y^t) = \left(1+\overrightarrow{D}^G_{DDF,v}(X^t,Y^t,B^t,g_Y,g_B)\right)/\left(1 + \overrightarrow{D}^G_{DDF,c}(X^t,Y^t,B^t,g_Y,g_B)\right) \tag{17}$$

Variable $SCH^{t,t+1} = \frac{SE^{t+1}\ (X^{t+1},Y^{t+1},B^{t+1},g_Y,g_B)}{SE^t(X^t,Y^t,B^t,g_Y,g_B)}$ is the ratiocale efficiencies of the two bundles from the two periods as the global benchmarks under the VRS assumption.

It should be noted that the infeasibility problem does not happen in this model since we use global technology.

T GMLPI can be illustrated through the following Fig. 2. In gure 2 PPS_D^t and PPS_D^{t+1} denote the traditional PPS of period t and $t+1$ We can see that the $GMLPI^G(X^t,Y^t,B^t,X^{t+1},Y^{t+1},B^{t+1})$ for DMU A_1 cld be represented as $\frac{A_2D_2}{A_1D_1} = \frac{A_2B_2}{A_1B_1} \times \frac{A_2D_2/A_2B_2}{A_1D_1/A_1B_1}$. . It should be noted that we assume the technology in Fig. 2 is CRS. If we assume VRS technology, there should be a factor $SCH^{t,t+1}$.which reflects the changes of scale efficiencies in different periods and cannot be illustrated in this figure.

4. Data and indicators

4.1. Dataset

The data of Chinese manufacturing industries from 2004 to 2012 used in this study is derived from China Statistical Year Book 2005–2013, China Industry Statistical YeaBk 2013, and China Energy Statistical Year Book 2005–2013. We selected the two-digit manufacturing industries in China as the DMUs.

In the period of 2004–2012, there are some changes on the statistical coverage of industries in China. Before 2007, the industry statistics cover all state owned and non-stated owned above designated size (which is 5 million Yuan of annual revenue from primary business). From 2007 to 2010, the industry statistics cover all industries above designated size (5 million Yuan). From 2011 on, the standard starting point of industrial enterprises above designated size was adjusted to 20 million Yuan of annual revenue from primary business.

From 2012, National Bureau of Statistics of China (NBS) enforces new standard on Industrial Classification for National Economic Activities (GB/T4754-2011). The number of two-digit manufacturing industries changed from 30 to 31. The Manufacture of Rubber and the Manufacture of Plastics merged into Manufacture of Rubber and Plastics Products. The Manufacture of Transport Equipment is split into Manufacture of Automobiles and Manufacture of Railway, Ship, Aerospace and Other Transport Equipment. Furthermore Repair Service of Metal Products, Machinery and Equipment are a new two-digit manufacturing industry from 2012. See details in Table A-1 in Appendix A.

It should be noted that, in some cases the dataset containing missing values in DEA will happen. Kuosmanen [26] presented a first systematic attempt to address the issue of missing data in DEA. They showed that DEA can automatically exclude the missing data from the analysis if blank data entries are coded by appropriate numerical values. However in our case on Chinese manufacturing industries, the Repair Service of Metal Products, Machinery and Equipment is a new sub-level manufacturing industry from 2012,

Table 2
The inputs and outputs indicators used in literature on Chinese environmental efficiency.

Authors	Year	Input variables	Outputs variables
Zhang et al.	2015	(1) Employees, (2)Total fixed assets, (3) Energy consumption	(1) Gross product, (2) CO_2 emissions
Yang et al.[a]	2015	(1) Capital, (2) Labour input, (3) Energy consumption, (4) CO2 emission, (5) SO2 emission	(1) GDP
Wang et al.	2015	(1) Labour, (2) Capital, (3) Energy	(1) GDP, (2) SO_2 emission
Fan et al.	2015	(1) Capital stock, (2) Labour force, (3) Energy consumption	(1) Gross industrial output; (2) CO_2 emissions
Bian et al.	2015	(1) Fixed assets, (2) Labour, (3) Energy consumption, (4) Industrial pollution abatement investment	(1) GDP, (2) COD (chemical oxygen demand); (3) SO_2; (4) ammonia nitrogen (NH4eN); (5) output value of products made from comprehensive utilization of industrial waste (OPUW)
An et al.	2015	(1) Production time, (2) Coal consumption	(1) Total industrial output value, (2) Electric energy production, (3) Solid waste
Zhu et al.	2014	(1) Environmental impact quotient (EIQ), (2) Chemical oxygen demand (COD), (3) ammonia nitrogen (AN), (4) hazardous solid waste (HSW)	(1) The average market price, (2) The area treated
Zhou et al.	2014	(1) Labour, (2) Capital stock, (3) Transport fuel	(1) Transport services, (2) CO_2 emissions
Zhang et al.	2014	(1) Labour, (2) Capital, (3) Energy	(1) GDP, (2) SO2 emissions, (3) COD, (4) CO_2 emissions
Yin et al.	2014	(1) Total water consumption, (2) Comprehensive energy consumption, (3) Construction land area, (4) Total investment in fixed assets, (5) Numbers of employed person	(1) Waste water emission, (2) COD emission, (3) CO_2 emission, (4) SO_2 emission, (5) Soot emission, (6) Industrial dust emission, (7) Solid waste emission, (8) Gross domestic production
Wu et al.	2014	(1) Total investment in fixed assets of industry, (2) Electricity consumption by industry	(1) Gross regional product of industry, (2) total volume of nitrogen dioxide pollutant emissions
Wang et al.	2014	(1) Capital Stock, (2) Labour, (3) Energy consumption	(1) GDP
Wang and Wei	2014	(1) Net value of fixed assets of industrial enterprises, (2) Number of employed person of industrial enterprises, (3) Total energy consumption of industrial enterprises	(1) Value-added of industrial enterprises, (2) Total volume of industrial sulphur dioxide emissions, (3) Total volume of industrial carbon dioxide emissions
Mahdiloo et al.	2014	(1) Water resource, (2) Fixed assets, (3) Number of entities, (4) Energy	(1) Gross regional product, (2) Chemical oxygen demand (COD), (3) Sulphur dioxide emission, (4) Soot, (5) Dust, (6) Solid waste
Li et al.	2014	(1) Network length above 35 kV, (2) Transformers capacity above 35 kV, (3) Number of employees, (4) Cost of the main business	(1) Electric power supply amount, (2) Power supply reliability, (3) The quality of the voltage, (4) Line loss
Huang et al.	2014	(1) Capital, (2) Labour input, (3) Land input, (4) Energy	(1) GDP, (2) Environmental pollutants
Hou et al.	2014	(1) Cost except Labour, (2) Labour	(1) Revenue, (2) Soil loss, (3) Nitrogen loss
Du et al.	2014	(1) Labour, (2) Capital stock, (3) Energy consumption	(1) Gross regional product, (2) Carbon dioxide emissions
Bi et al.	2014a	(1) Installed capacity, (2) Labour, (3) Coal total, (4) Gas total	(1) Annual net electricity generated, (2) Sulphur dioxide emission, (3) NOx, (4) Soot
Bi et al.	2014b	(1) Labour, (2) Capital, (3) Energy	(1) Value-added, (2) CO_2 emissions
Long et al.	2013	(1) Capital stock, (2) Human resources stock, (3) Employment, (4) Coal consumption	(1) Gross Regional Product (GRP), (2) SO_2 emissions
Wang et al.	2013a	(1) Capital Stock, (2) Labour, (3) Energy	(1) GDP, (2) CO_2
He et al.	2013	(1) Net fixed assets, (2) Employees, (3) Energy	(1) Value added, (2) Waste gas, (3) Waste water, (4) Solid Waste
Yang and Wang	2013	(1) Capital investment, (2) Labour, (3) Energy	(1) GDP, (2) CO_2 emission
Yuan et al.	2013	(1) Employees, (2) Fixed assets, (3) Current assets	(1) Gross output value, (2) Wastewater, (3) SO_2, (4) Soot
Wang et al.	2013b	(1) Energy consumption, (2) Labour, (3) Capital stock	(1) GDP, (2) CO_2 emissions
Zhang and Choi	2013a	(1) Capital, (2) Labour, (3) Energy	(1) Regional GDP, (2) CO_2 emissions
Zhang and Choi	2013b	(1) Capital, (2) Fossil fuel, (3) Labour	(1) The electricity output, (2) CO_2 emissions
Zhang and Choi	2013c	(1) Labour, (2) Capital, (3) Energy consumption	(1) GDP, (2) industrial value added, (3) the employment rate, (4) SO_2 emissions, (5) COD, (6) CO_2 emissions
Wu et al.	2012	(1) Industrial capital stock, (2) Industrial Labour force, (3) Industrial energy consumption	(1) Industrial value added, (2) Industrial CO_2 emissions
Zhang et al.	2011	(1) Capital stock, (2) Labour force	(1) GDP, (2) An integrated environmental factor (IEF)
Chang and Hu	2010	(1) Capital stocks, (2) Labour, (3) Energy consumption, (4) Total sown area of farm crops	(1) GDP
Kaneko et al.	2010	(1) Amount of Labour, (2) Net value of fixed assets	(1) Value added, (2) SO_2 emissions
Watanabe and Tanaka	2007	(1) Capital, (2) Labour, (3) Materials	(1) Industrial products, (2) SO_2 emissions
Kaneko and Managi	2004	(1) Labour, (2) Capital, (3) Pollution abatement cost and expenditure (PACE)	(1) Gross Regional Product (GRP), (2) Wastewater, (3) Waste gas, (4) Solid wastes

[a] In this research the authors used undesirable outputs as inputs.

i.e. there is no data on this industry before 2011. Thus, in this study we remove this industry from our time-series dataset and we have 29 manufacturing industries in total. Otherwise, if we set all the inputs and outputs of this industry as zero, the objective function in

Model (13) or Model (14) would be unbounded.

4.2. Variables

Table 2 shows the summary of input and output indicators used in previous studies on Chinese environmental efficiency. From this table we can see that labour, capital and energy consumption are the most frequently used input indicators and GDP and CO_2 emission are the most frequently used desirable and undesirable outputs respectively in measuring Chinese environmental efficiency. Let us consider a paper mill production where paper is produced with undesirable outputs of pollutants (e.g. biochemical oxygen demand, suspended solids, particulates and SO_2 emissions). If inefficiency exists in the production, the undesirable pollutants should be reduced to improve the inefficiency. In other words, when we evaluate the production performance of paper mills, the undesirable and desirable outputs should be treated differently. However, in the standard DEA model, decreases in outputs are not allowed and only inputs are allowed to decrease in input-based models, or inputs are not allowed and only outputs are allowed to increase in output-based models, respectively. Thus DDF should be used to measure the inefficiency. As we discussed in Subsection 2.1, there are few existing researches and it is important to measure the productivity evolution with CO_2 emissions on Chinese manufacturing industries using GMLPI based on DDF.

When investigating Shanghai's industrial total factor CO_2 emission performance, Fan et al. [15] argued that "*We choose gross industrial output that contains the intermediate input rather than industrial added value as the desirable output since the industrial CO_2emission mainly come from fossil fuel consumption, which is an intermediate input.*". In this paper we follow this idea to use GIOV instead of industrial added value as the desirable output to investigate the productivity evolution of two-digit Chinese manufacturing industries.

We select three input variables including Labour, Asset and Energy and two output variables, including Gross Industrial Output Value (GIOV) as a desirable output and CO_2 emissions as an undesirable output.

(1) **Labour**: Labour input refers to the amount of Labour in Chinese manufacturing industries. Due to the mobility of Labour, the amount of Labour input is different at different time in one year, so the number of annual average employed persons is taken as the indicator. This indicator is from China Statistical Year Books 2005–2012 directly. In China Statistical Year Book 2013 the data of Labour indicator is not reported, which is the latest Statistical Year Book published at the time we wrote this paper. Therefore we use the average ratio of GIOV to Labour of all the provinces in China to estimate this indicator for the last year in this study by sub-level manufacturing industries respectively under the assumption that the technology level of the whole country is the average of all provinces.

Table 3
The CPI of China.

Date	Value
2003	81.8313
2004	85.0227
2005	86.5673
2006	87.8369
2007	92.0238
2008	97.4532
2009	96.7834
2010	100.0000
2011	105.4706
2012	108.2221
2013	111.0703

Table 4
Coefficients of transforming different types of energy into SCE.

Energy types	Coefficients of transforming	Units
Coal	0.7143	kg SCE/kg
Crude Oil	1.4286	kg SCE/kg
Natural Gas	1.3300	kg SCE/cm

Note: This data is derived from China Energy Statistical Yearbook 2013.

(2) **Asset**: Asset refers to the amount of total assets in Chinese manufacturing industries. Total Assets input is from China Statistical Year Books and refers to all resources that are owned or controlled by enterprises through previous trades or transactions with expectation of making economic profits. Classified by the degree of liquidity, total assets include current assets, and non-current assets. Current assets can be classified into monetary assets, trading financial assets, notes receivable, accounts receivable, advanced payments, other prepaid money and inventories. Non-current assets can be divided into long-term equity investment, fixed assets, intangible assets and other non-current assets. Data on this indicator are obtained by the year-end figures of total assets in the Assets and Liability Table of accounting records of enterprises. In order to ensure the comparability, we transformed the value of this indicator to constant price in 2010 using the Consumer Price Index (CPI) of China, as shown in the following Table 3. The CPI data is derived from Ref. [39].

(3) **Energy**: We use Total Energy Consumption from China Statistical Year Book 2005–2012 as the indicator for Energy in our study. Total Energy Consumption refers to the total consumption of energy of various kinds by the production sectors in the country in a given period of time. It is a comprehensive indicator to show the scale, composition and pace of increase of energy consumption. Total energy consumption includes that of coal, crude oil and their products, natural gas and electricity. However, it does not include the consumption of fuel of low calorific value, bio-energy and solar energy. According to China Energy Statistical Yearbook 2013, the coefficients of transforming different types of transforming different types of energy into SCE are shown in the following Table 4.

(4) **GIOV**: In this paper the GIOV is used as a desirable output and can be obtained from China Statistical Year Books 2005–2012 Note that this indicator is not reported in China Statistical Year Book 2013. However we can estimate this from other information provided, for example by dividing Industrial Sales Output Value (ISOV) to Sales Ratio of Products (SRP), as both variables are available for each sub-level manufacturing industry for the year 2013. In order to ensure the comparability, we also transform the value of this indicator to constant price in 2010 using the CPI of China, as shown in Table 3.

(5) **CO_2emissions.** The CO_2 emission is the undesirable output in our study. The data for this indicator is not provided directly in China Statistical Year Books or China Industry Statistical Year Books. Hence we estimated it based on the consumption of different types of energy. The main source of (net) global CO_2 emissions to the atmosphere is the use of fossil fuels (see, [18]. Thus the most widely used method for the estimation of CO_2 emissions is based on the consumption of fossil fuels including coal, crude Oil and natural gas. These three types of oil fount for more than 85% CO_2 emission in China [10]. In our study, we also use the CO_2 emission from

Table 5
The coefficients for the estimation of CO_2 emissions.

Energy types	The coefficients of transforming different types of energy into SCE		Estimated CO2 emission factors	
	Value	Units	Value	Units
Coal	0.7143	kg SCE/kg	2.763	kg/kg SCE
Crude oil	1.4286	kg SCE/kg	2.145	kg/kg SCE
Natural gas	1.3300	kg SCE/cm	1.642	kg/kg SCE

Table 6
Descriptive statistics of input/output variables in 2012.

Variables	Mean	Standard deviation	Median	Max	Min
Labour (10,000 persons)	306.3098	238.8076	224.7844	1025.5532	16.6161
Asset (100 million yuan)	18617.8521	16211.9261	14570.5136	54604.5324	1304.7432
Energy (10,000 tons of SCE)	7089.1843	13408.8460	1781.8390	59668.1020	107.3564
GIOV (100 million yuan)	25756.6250	20727.4247	16352.1515	65532.4499	1931.8864
CO2 emission (10,000 tons)	14256.4279	39985.8291	1099.6471	204067.5735	32.8249

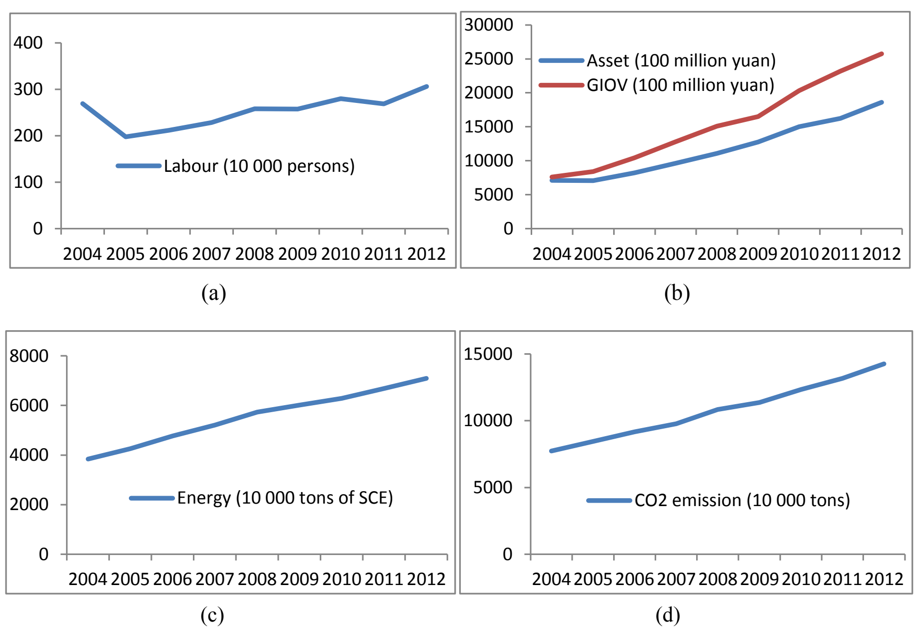

Fig. 3. The changes of the means of five indicators.

coal, crude oil and natural gas as the total CO_2 emissions of sub-level Chinese manufacturing industries.

Iergovernmental Panel on Climate Change [22] published IPCC Guidelines for National Greenhouse Gas Inventories, in which the equation for calculating CO_2 emissions from fossil fuels is provided as follows:

$$CO_2 = \sum_{i=1}^{3} CO_{2,i} = \sum_{i=1}^{3} E_i \times NCV_i \times CEF_i \times COF_i \times (44/12). \tag{18}$$

where $CO_{2,i} (i = 1, 2, 3)$. denote the CO2 emissions of coal, crude oil and natural gas, respectively. Variables E_i, NCV_i, CEF_i, and COF_i denote the total consumption (E), net calorific value (NCV), Carbon Emission Factors (CEF), and carbon oxidation factor (COF) of these three types of energy. Constant values of 44 and 12 are the molecular weights of CO_2 and carbon respectively. Furthermore we need to transform different types of energy into SCE, whose coefficients are provided by China Energy Statistical Yearbook 2005–2013. According to the above formula and Chen [10]'s research, we list the coefficients for CO_2 emissions estimation of Chinese manufacturing industries in Table 5.

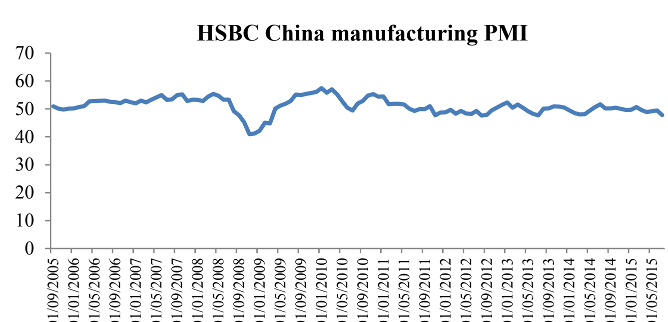

Fig. 4. PMI of Chinese manufacturing industries.
Data source: http://value500.com/PMI.asp.

Table 7
The GMLPI index and its components of Chinese manufacturing industries under CRS technology.

Years	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
GMLPI	1.0870	1.0672	N/A	0.9978	1.0034	1.0614	N/A	0.9786
EC	0.9441	1.0439	N/A	1.0911	0.9931	0.9225	N/A	0.9726
BPC	1.1573	1.0235	N/A	0.9173	1.0135	1.1569	N/A	1.0067

Note. N/A denotes “not available”.

4.3. Descriptive statistics

Descriptive statistics of variables used in this study are presented in Table 6. The summary statistics of variables in 2011 and before are listed in Appendix B.

The following Fig. 3(a)–(d) show the changes of the means of five indicators in this period. We can see that the inputs and outputs all increased significantly over this period, especially GIOV, Asset, Energy, and CO_2 emission. There is a slight drop in the input Labour in the year 2005. After this year, the Labour also has been growing continuously. From Fig. 3 we know that Chinese manufacturing industries has achieved significant progress in terms of GIOV and Asset over the investigated period. However, the rapid growth has also resulted in high energy consumption and serious increasing of CO2 emission, which hinder the further sustainable development of those industries due to more and more strict regulations on the environment both in the world and in China.

5. Empirical results

In recent year, there are severe development problems facing by Chinese manufacturing industries. The following Fig. 4 shows the developmental status of Chinese manufacturing industries in recent years. From this figure we can see that the HSBC China Manufacturing Purchasing Managers' Index (PMI)[2] is going down in recent years. One of the main reasons is the overcapacity of Chinese manufacturing industries. According to the third national industrial census, the nation's major industrial products have more than 80% excess capacity or severe overcapacity.

5.1. GMLPI analysis on Chinese manufacturing industries

In this paper we conduct GMLPI analysis on Chinese manufacturing industries under the CRS and VRS assumptions, respectively. As discussed in Subsection 4.1, due to the adjustments of statistical coverage of Chinese manufacturing industries, we separate our study periods into three clusters/stages: (1) 2004–2006, (2) 2007–2010, and (3) 2011–2012.

First we use the GMLPI index in Model (15) on these three clusters/stages and have the averages of GMLPI index and its components of all Chinese manufacturing industries as shown in Table 7. The detailed data for each sub-level manufacturing industry is shown in the Table C Appendix C.

In the first stage (2004–2006), the GMLPI declined slightly from 1.0870 to 1.0672, which reflected the productivity of Chinese manufacturing industries increased in this stage but the speed declined. The technical efficiency changes (EC) increased from 0.9441 to 1.0439, which indicated the catching-up with the contemporaneous benchmark technology frontier. However the best practice gap changes (BPC) declined significantly from BPC = 1.1573 to BPC = 1.0235, which indicated the contemporaneous frontier shifted towards the global technology frontier in the direction of less desirable outputs and more undesirable outputs. Combining the above information we can conclude that the average technical efficiency of Chinese manufacturing industries increased in this period. However the contemporaneous frontier shifted towards the direction of less GIOV and more CO_2 emission. In this period Chinese manufacturing industries experienced an extensive growth, which produced a large number of GIOV with more rapid increased CO_2 emission.

In the second stage (2007–2010), the GMLPI increased slightly from 0.9978 to 1.0614. The EC dropped significantly, which indicated the average technical efficiency (TE) or catching-up with the contemporaneous benchmark technology frontier decreased significantly. However the BPC increased significantly from BPC = 0.9173 to BPC = 1.1569, which indicated the Chinese government paid much attention on CO_2 emission and the contemporaneous frontier shifts towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs.

In the third stage (2011–2012), the GMLPI is 0.9786, which shows that the productivity of Chinese manufacturing industries went down in this period. Also the TE change (EC = 0.9726) illustrates that the average TE also dropped. However the BPC is 1.0067 which means the contemporaneous frontier still shifts towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs. That means Chinese government has made great efforts to reduce CO_2 emission in Chinese manufacturing industries.

Second we use the proposed GMLPI index in Model (16) under VRS assumption on these three clusters/stages and have the averages of GMLPI index and its components of all Chinese manufacturing industries as shown in Table 8. According to Ray and Desli [42]'s research, the GMLPI productivities under CRS and VRS are the same. We can also verify their conclusions from our results.

In the first stage (2004–2006), the pure technical efficiency (PTE) change (PEC) increased from 1.0063 to 1.0209, which indicated the PTE of Chinese manufacturing industries increased a lot in this period. However the BPC declined significantly from BPC = 1.0842 to 1.0613, which indicated the contemporaneous frontier shifted slightly towards the global technology frontier in the direction of less desirable outputs and more undesirable outputs. Also the scale efficiency change factor (SCH) decreased from SCH=0.9984 to SCH=0.9845 which indicated the scale economies of Chinese manufacturing industries dropped slightly in the first period.

In the second stage (2007–2010), the PEC increased from 1.0076 to 1.0102, which indicated the PTE of Chinese manufacturing industries increased a lot in this period. Also the BPC increased slightly from BPC = 1.0155 to BPC = 1.0616, which indicated the contemporaneous frontier shifted slightly towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs. Also the scale efficiency change factor (SCH) decreased from SCH=0.9984 to SCH=0.9845 which indicated the scale economies of Chinese manufacturing industries dropped slightly in the second period.

In the third stage (2011–2012), the PTE change (PEC = 0.9826) illustrated that the average technical efficiency also dropped. However the BPC is 1.0047 which means the contemporaneous

[2] HSBC China Manufacturing Purchasing Managers' Index is published by CLSA Asia-Pacific Markets and is developed by HSBC Bank and UK Markit Group Ltd.

Table 8
The GMLPI index and its components of Chinese manufacturing industries under VRS technology.

Years	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
GMLPI	1 0870	1.0672	N/A	0.9978	1.0034	1.0614	N/A	0.9786
PEC	1.0063	1.0209	N/A	1.0076	1.0269	1.0102	N/A	0.9826
EPC	1.0842	1.0613	N/A	1.0155	0.9967	1.0616	N/A	1.0047
SCH	0.9984	0.9845	N/A	0.9762	0.9815	0.9908	N/A	0.9922

Note: N/A denotes "not available".

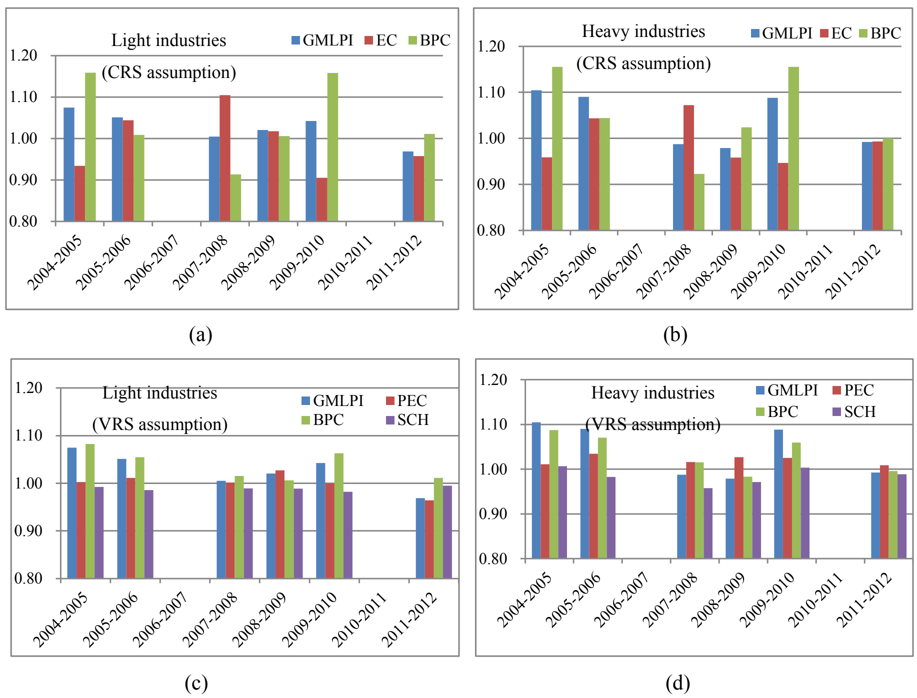

Fig. 5. Heterogeneity of light and heavy manufacturing industries.

frontier still shifted towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs. Furthermore we can see SCH=0.9922 which indicated the scale economies of Chinese manufacturing industries dropped slightly in the third period.

5.2. Heterogeneity of light and heavy manufacturing industries

In this subsection, we further investigate the heterogeneity of light and heavy manufacturing industries in terms of GMLPI and its decompositions. We categorize all 29 Chinese manufacturing industries into light and heavy industries respectively according to the classification guidance of Chinese manufacturing industries from National Bureau of Statistics of China[3]. Fig. 5(a) and (c) show the changes of GMLPIs and their decompositions EC and BPC for light and heavy manufacturing industries, respectively, under CRS assumption. Similarly, Fig. 5(b) and (d) illustrate the changes of GMLPIs and their decompositions PEC, BPC, and SCH under VRS assumption for light and heavy manufacturing industries, respectively. We can see from Fig. 5 that the GMLPIs of both light and heavy manufacturing industries show a S-shape curve and demonstrate relatively negative developmental trends, especially in the period of 2011–2012. In 2004–2006, the decline status of GMLPIs for both light and heavy industries is emerging. In 2007–2010, the GMLPI keep increasing in light industries, however, GMLPI of heavy industries first dropped to below unity before 2009 and then recover in 2009–2010 mainly due to the bailout plan of Chinese government in the end of 2008. However, in 2011–2012, the GMLPIs of both light and heavy industries are decline and below unity again. Similarly we can see the changes of the decompositions of GMLPIs. See Fig. 5 for details.

5.3. Discussions and policy implications

The main reasons of the negative trends of Chinese manufacturing industries are probably as follows: (1) *Low average personal efficiency*. The average personal efficiency in Chinese manufacturing industries only accounts for 4.38%, 4.37%, and 5.56% of those of United States, Japan, and Germany, respectively[4]. (2) *Low value-added*. The value-added in Chinese manufacturing industries accounts for only about half of the United States and Germany, about two-thirds of Japan. (3) *Overcapacity of low-level production and lack of high-level one*. According to the third national industrial census, the nation's major industrial products have more than 80% excess capacity or severe overcapacity. In contrast, a number of high-tech and high value-added industrial products had to be imported large quantities, and even some products have been dependent on imports seriously. (4) *Irrational industrial structure*.

[3] Interested readers can refer to the following link for more information: http://www.sc.stats.gov.Cn/tjzs/cswd/201504/t20150401_181042.html.

[4] http://finance.sina.com.cn/review/hgds/20121221/031814073050.shtml.

China's manufacturing industry is in the state of lightness, and the strength of large equipment manufacturing is weak, is a "virtual fat." (5) *Huge amount of CO_2emissions into the atmosphere*. Since 2007, China has surpassed United States and become the largest contributor of CO_2 emissions in the world. Therefore, China is a big country in manufacturing, but it is not a strong one. So, it will undoubtedly be an important part of China's future economic development to improve the management level of Chinese industries and promote their upgrade to more value-added and greener production to develop sustainably.

It is important for policy makers to note that the scale economies of Chinese manufacturing industries dropped gradually during this period 2004–2012, which illustrates that Chinese manufacturing industries went away farther and farther from their optimal operation scale size. In other words, Chinese manufacturing industry encountered severe overcapacity issue currently since of the lack of consumption in the sense of the total retail sales of consumer goods and too much CO_2 emissions. Therefore, based on the analysis in this paper, we propose the following policy suggestions for Chinese manufacturing industries as follows: (a) Chinese government can encourage domestic manufacturers in China to allocate more resources into the research and development (R&D) on advanced manufacturing technology to increase the value-added of their products to produce more GIOV and less CO_2 emissions using the limited resources. (b) Chinese government can provide incentives for CO_2 emissions reduction for domestic manufacturers, e.g. Chinese government can provide specific fund for manufacturers with relatively low energy consumption and CO_2 emissions to support them improve their competitiveness in the market and to promote the economic growth mode to shift from conventional high energy consumption and CO_2 emissions to clean and green production with low energy consumption and CO_2 emissions. (c) Domestic manufacturers can be encouraged to learn and introduce advanced experiences and equipment from other industrialized countries to help improve their own production technology and management. (d) Chinese government should give full play to the binding role of laws and regulations and the threshold role of technical standards, strictly implement laws, regulations and technical standards on environmental protection and clean production, and eliminate backward production capacities gradually.

6. Conclusions

In this study we analysed and reported the productivity evolution of the subordinate sectors (two-digit level) in Chinese manufacturing industries with respect to CO_2 emissions in period of 2004–2012 using the Data Envelopment Analysis (DEA). Due to the changes on the statistical coverage of industries in China in the period of 2004–2012, we separate these 9-year dataset into three clusters/stages: (1) 2004–2006, (2) 2007–2010, and (3) 2011–2012. The main findings includes: (1) In the first stage the average GMLPI drops and the average technical efficiency (TE) of Chinese manufacturing industries increases during 2004–2006. However the contemporaneous frontier shifts towards the direction of less GIOV and more CO_2 emissions. (2) During 2007–2010 the Chinese government pay much attention on CO_2 emissions and the contemporaneous frontier shifts towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs. (3) Finally during 2011–2012 the contemporaneous frontier still shifts towards the global technology frontier in the direction of more desirable outputs and less undesirable outputs, i.e. producing less CO_2 emissions while the GMLPI drops slightly. Hence we concluded the Chinese government should carefully implement more policy regulations for industries to maintain productivity index while reducing CO_2 emissions. Furthermore, we showed the heterogeneity of light and heavy manufacturing industries in this paper in terms of GMLPI and its decompositions. At last this paper analyses the possible reasons for the dilemma of Chinese manufacturing industries and proposes some policy suggestions. The future research can be extended into specific manufacturing industry (e.g. Manufacturing of Automobiles) to investigate the efficiency or productivity evolution of a group of big enterprises in this industry.

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Appendix A

Table A-1
The comparison of two-digit manufacturing industries in 2011 (and before) and 2012[a].

2012 No.	2012 Two-digit manufacturing	2011 and before No.	2011 and before Two-digit manufacturing
1	Processing of Food from Agricultural Products	1	Processing of Food from Agricultural Products
2	Manufacture of Foods	**2**	Manufacture of Foods
3	Manufacture of Liquor, Beverages and Refined Tea	3	Manufacture of Beverages
4	Manufacture of Tobacco	4	Manufacture of Tobacco
5	Manufacture of Textile	5	Manufacture of Textile
6	Manufacture of Textile, Wearing Apparel and Accessories*	6	Manufacture of Textile Wearing Apparel, Footwear and Caps*
7	Manufacture of Leather, Fur, Feather and Related Products and Footwear	**7**	Manufacture of Leather, Fur, Feather and Related Products
8	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	**8**	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products
9	Manufacture of Furniture	9	Manufacture of Furniture
10	Manufacture of Paper and Paper Products	10	Manufacture of Paper and Paper Products
11	Printing and Reproduction of Recording Media	11	Printing, Reproduction of Recording Media
12	Manufacture of Articles for Culture, Education, Arts and Crafts, Sp ort and Entertainment Activities	12	Manufacture of Articles For Culture, Education and Sport Activities
13	Processing of Petroleum, Coking and Processing of Nuclear Fuel	13	Processing of Petroleum, Coking, Processing of Nuclear Fuel
14	Manufacture of Raw Chemical Materials and Chemical Products	14	Manufacture of Raw Chemical Materials and Chemical Products
15	Manufacture of Medicines	15	Manufacture of Medicines
16	Manufacture of Chemical Fibres	16	Manufacture of Chemical Fibers

(*continued on next page*)

Table A-1 (*continued*)

2012		2011 and before	
17	Manufacture of Rubber and Plastics Products	17	Manufacture of Rubber
18	Manufacture of Non-metallic Mineral Products	18	Manufacture of Plastics
19	Smelting and Pressing of Ferrous Metals	19	Manufacture of Non-metallic Mineral Products
20	Smelting and Pressing of Non-ferrous Metals	20	Smelting and Pressing of Ferrous Metals
21	Manufacture of Metal Products	21	Smelting and Pressing of Non-ferrous Metals
22	Manufacture of General Purpose Machinery	**22**	Manufacture of Metal Products
23	Manufacture of Special Purpose Machinery	**23**	Manufacture of General Purpose Machinery
24	Manufacture of Automobiles	24	Manufacture of Special Purpose Machinery
25	Manufacture of Railway, Ship, Aerospace and Other Transport Equipments	25	Manufacture of Transport Equipment
26	Manufacture of Electrical Machinery and Apparatus	26	Manufacture of Electrical Machinery and Equipment
27	Manufacture of Computers, Communication and Other Electronic Equipment	**27**	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
28	Manufacture of Measuring Instruments and Machinery*	28	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work*
29	Other Manufacture*	29	Manufacture of Artwork and Other Manufacturing*
30	Utilization of Waste Resources	30	Recycling and Disposal of Waste
31	Repair Service of Metal Products, Machinery and Equipment		

Note: * means that there are minor changes of industries' name at the beginning of 2012.
[a] For details, please refer the following link: http://www.stats.gov.cn/tjsj/tjbz/hyflbz.

Appendix B

Table B-1
Descriptive statistics of input/output variables in 2011 and before.

Years	Variables	Mean	SD	Median	Max	Min
2011	Labour (10,000 persons)	268.4653	206.20	185.61	819.48	15.68
	Asset (100 million yuan)	16222.59	14809.43	9753.35	51522.27	1243.75
	Energy (10,000 tons of SCE)	6680.11	12950.11	1764.47	58896.58	89.29
	GIOV (100 million yuan)	23197.12	19570.00	13742.67	60743.93	2488.10
	CO2 emission (10,000 tons)	13169.63	36771.85	1056.48	188760.00	28.72
2010	Labour (10,000 persons)	279.72	209.35	183.74	772.75	13.92
	Asset (100 million yuan)	15001.12	13743.03	9433.13	47981.05	923.56
	Energy (10,000 tons of SCE)	6283.26	12241.12	1679.86	57533.71	77.49
	GIOV (100 million yuan)	20318.62	17138.88	12036.28	55452.63	2306.13
	CO2 emission (10,000 tons)	12335.99	34534.91	1012.24	178010.60	25.78
2009	Labour (10,000 persons)	257.32	188.55	170.17	663.64	13.65
	Asset (100 million yuan)	12749.26	11616.56	8115.43	42372.71	771.10
	Energy (10,000 tons of SCE)	6019.87	11947.04	1617.43	56404.37	61.11
	GIOV (100 million yuan)	16504.20	13878.67	10274.54	46043.66	1491.85
	CO2 emission (10,000 tons)	11370.63	31236.00	942.04	158609.40	20.44
2008	Labour (10,000 persons)	257.72	189.67	169.88	677.31	14.20
	Asset (100 **million yuan**)	11061.83	9836.48	7423.23	36116.82	563.30
	Energy (10,000 tons of SCE)	5736.88	11175.58	1587.47	51862.92	56.84
	GIOV (100 **million yuan)**	15096.42	13037.02	8881.57	45896.36	1167.52
	CO2 emission (10000 tons)	10838.38	29321.75	976.96	148368.30	18.83
2007	Labour (10,000 persons)	228.52	169.23	147.29	626.26	6.64
	Asset (100 million yuan)	9617.19	8580.62	6564.50	31619.47	295.87
	Energy (10,000 tons of SCE)	5207.29	10190.13	1492.28	47774.37	49.45
	GIOV (100 million yuan)	12809.40	11158.14	7586.23	42623.50	739.71
	CO2 emission (10000 tons)	9774.51	27863.16	819.82	144092.00	12.10
2006	Labour (10,000 persons)	211.56	156.23	136.42	615.43	5.51
	Asset (100 million yuan)	8223.52	7229.46	5960.78	26318.81	223.00
	Energy (10,000 tons of SCE)	4768.38	9239.34	1333.61	42812.32	50.35
	GIOV (100 million yuan)	10419.75	9211.10	6372.22	37657.95	478.24
	CO2 emission (10,000 tons)	9181.39	25862.23	854.68	133276.80	11.90
2005	Labour (10,000 persons)	197.84	145.99	130.44	590.96	4.24
	Asset (100 million yuan)	7048.72	6137.30	5251.63	21891.24	145.98
	Energy (10,000 tons of SCE)	4256.13	8039.80	1261.60	35988.23	34.06
	GIOV (100 million yuan)	8387.92	7542.01	5328.27	31183.13	338.41
	CO2 emission (10,000 tons)	8450.91	23080.22	846.70	117503.50	11.88
2004	Labour (10,000 persons)	269.35	205.66	200.13	839.75	8.66
	Asset (100 million yuan)	7115.66	5739.38	5873.16	19589.29	189.48
	Energy (10,000 tons of SCE)	3842.05	7015.96	1137.90	29702.49	30.35
	GIOV (100 million yuan)	7604.29	6470.69	5080.86	26574.11	306.41
	CO2 emission (10,000 tons)	7742.35	21330.84	321.17	109666.70	12.61

Appendix C

Table C-1
Productivity growth, efficiency change and technical changes of Chinese manufacturing industries (CRS technology).

DMUs	2004–2005			2005–2006			2007–2008			2008–2009			2009–2010			2011–2012		
	GMLPI	EC	BPC	GMLPI	EC	BPC	GMLPI	EC	BPC	GMLPI	EC	BPC	GMLPI	EC	BPC	GMLPI	EC	BPC
Processing of Food from Agricultural Products	1.2005	0.8123	1.4780	1.0147	1.0957	0.9261	1.0966	1.2539	0.8746	0.9608	1.0000	0.9608	0.9961	0.8386	1.1879	1.0062	1.0000	1.0062
Manufacture of Foods	1.0254	0.8724	1.1754	1.0367	1.0994	0.9430	1.0713	1.2447	0.8607	1.0177	1.0571	0.9627	1.0487	0.8708	1.2043	0.9644	0.9578	1.0069
Manufacture of Beverages	1.0127	1.0155	0.9972	1.0460	1.0231	1.0224	0.9980	1.1395	0.8759	1.0108	0.9755	1.0362	1.0110	0.9005	1.1228	0.9802	0.9511	1.0306
Manufacture of Tobacco	1.0494	1.0000	1.0494	1.0772	1.0000	1.0772	1.0338	1.0000	1.0338	1.0335	1.0000	1.0335	1.0786	1.0000	1.0786	1.0253	1.0000	1.0253
Manufacture of Textile	1.0242	0.8326	1.2300	1.0252	1.0869	0.9432	1.0229	1.2045	0.8493	1.0084	1.0523	0.9583	1.0792	0.8799	1.2265	0.9772	0.9569	1.0212
Manufacture of Textile Wearing Apparel, Footware and Caps	1.0943	0.9755	1.1218	1.0262	1.0156	1.0104	1.0009	1.0463	0.9566	1.0531	1.1180	0.9420	0.9993	0.7853	1.2724	0.9806	0.9721	1.0088
Manufacture of Leather, Fur, Feather and Related Products	1.0868	0.9738	1.1160	1.0458	1.0269	1.0185	0.9977	1.0182	0.9799	1.0046	1.0701	0.9388	1.0370	0.8106	1.2792	0.9705	0.9683	1.0022
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	1.0850	0.8150	1.3314	1.1014	1.1902	0.9254	1.0182	1.1770	0.8651	1.1049	1.1378	0.9711	1.0798	0.9092	1.1876	1.0000	1.0000	1.0000
Manufacture of Furniture	1.0610	0.9603	1.1049	1.0663	1.0275	1.0378	0.9611	0.9599	1.0013	1.0650	1.0061	1.0586	1.0485	0.9566	1.0961	0.9912	0.9785	1.0130
Manufacture of Paper and Paper Products	1.0034	0.9416	1.0657	1.0059	1.0007	1.0052	1.0004	1.1425	0.8756	1.0001	0.9051	1.1050	1.0020	0.9655	1.0378	0.9863	0.9551	1.0327
Printing, Reproduction of Recording Media	0.9595	0.9149	1.0488	1.0277	0.9904	1.0377	1.0055	1.0513	0.9564	1.0320	1.0210	1.0108	1.0029	0.9766	1.0269	1.0191	1.0513	0.9693
Manufacture of Articles For Culture, Education and Sport Activities	1.1077	1.0055	1.1017	1.0415	0.9671	1.0769	1.0101	1.0565	0.9561	1.0136	1.0133	1.0003	1.0194	0.9429	1.0811	1.1093	1.0420	1.0647
Processing of Petroleum, Coking, Processing of Nuclear Fuel	1.0936	1.0000	1.0936	1.0835	1.0000	1.0835	1.0000	1.0000	1.0000	0.8844	1.0000	0.8844	1.1308	1.0000	1.1308	1.0000	1.0000	1.0000
Manufacture of Raw Chemical Materials and Chemical Products	1.1554	0.8828	1.3088	1.1089	1.0583	1.0478	1.0002	1.2283	0.8143	1.0065	0.9223	1.0913	1.1337	0.8293	1.3671	0.9667	0.9374	1.0312
Manufacture of Medicines	1.0114	1.0182	0.9933	1.0302	1.0086	1.0215	0.9980	1.0627	0.9391	1.0141	0.9557	1.0612	1.0124	0.9886	1.0241	1.0063	0.9898	1.0167
Manufacture of Chemical Fibers	1.2526	0.9672	1.2951	1.1509	1.0904	1.0555	0.9354	1.0974	0.8523	1.0280	0.9175	1.1204	1.1387	0.8436	1.3498	0.9226	0.8943	1.0317
Manufacture of Rubber and Plastics Products	1.0240	0.9247	1.1074	1.0440	1.0111	1.0325	0.9900	1.1315	0.8749	1.0237	1.0878	0.9411	1.0494	0.8328	1.2600	0.9767	0.9506	1.0274
Manufacture of Non-metallic Mineral Products	1.0001	0.9519	1.0506	1.0032	1.0011	1.0021	0.9998	1.0774	0.9280	1.0008	1.0598	0.9444	1.0017	0.8762	1.1432	0.9575	0.9470	1.0110
Smelting and Pressing of Ferrous Metals	1.1778	0.9232	1.2757	1.0515	0.9916	1.0604	1.1662	1.2236	0.9530	0.8944	0.8383	1.0670	1.0891	0.8903	1.2232	1.0178	0.9902	1.0280
Smelting and Pressing of Non-ferrous Metals	1.2843	0.9326	1.3771	1.4066	1.3364	1.0526	0.9296	1.0707	0.8682	0.9749	0.8605	1.1330	1.1811	0.8963	1.3177	0.9124	0.8853	1.0307
Manufacture of Metal Products	1.0640	0.9347	1.1384	1.0676	1.0190	1.0477	1.0017	1.1218	0.8929	0.9994	1.0006	0.9987	1.0468	0.8712	1.2015	0.9941	0.9627	1.0326
Manufacture of General Purpose Machinery	1.0498	0.9602	1.0934	1.0649	1.0109	1.0535	0.9949	1.0325	0.9636	1.0210	1.0031	1.0178	1.0478	0.9923	1.0559	1.0474	1.0924	0.9588
Manufacture of Special Purpose Machinery	1.0265	0.9658	1.0629	1.0431	1.0097	1.0331	1.0096	1.0521	0.9596	1.0140	0.9884	1.0259	1.0195	0.9843	1.0358	1.0571	1.0808	0.9780
Manufacture of Transport Equipment	1.0943	0.9488	1.1533	1.1408	1.0811	1.0552	0.9983	1.0207	0.9781	1.0430	0.9841	1.0598	1.0539	0.9312	1.1318	0.9839	0.9970	0.9869
Manufacture of Electrical Machinery and Equipment	1.0699	1.0032	1.0665	1.0937	1.0151	1.0774	0.9740	1.0374	0.9388	0.8317	0.8424	0.9874	1.1851	1.0900	1.0873	1.0193	1.0285	0.9911
Manufacture of Communication Equipment, Computers and Other Electronic Equipment	1.0091	1.0000	1.0091	1.0184	1.0000	1.0184	0.9325	1.0000	0.9325	1.0233	1.0000	1.0233	1.0480	1.0000	1.0480	0.9511	1.0000	0.9511
Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	1.0640	0.9957	1.0686	1.1065	1.0132	1.0921	0.9012	0.9929	0.9076	1.0135	0.9745	1.0400	1.0585	1.0045	1.0538	0.8399	0.9165	0.9164
Manufacture of Artwork and Other Manufacturing	1.2040	0.8512	1.4145	1.0208	1.1023	0.9261	1.0423	1.1983	0.8699	0.9662	1.0083	0.9582	1.0608	0.8861	1.1972	0.7146	0.7000	1.0209
Recycling and Disposal of Waste	1.2320	1.0000	1.2320	1.0000	1.0000	1.0000	0.8447	1.0000	0.8447	1.0552	1.0000	1.0552	1.1220	1.0000	1.1220	1.0000	1.0000	1.0000

Table C-2
Productivity growth, pure efficiency change, technical changes and scale efficiency change of Chinese manufacturing industries (VRS technology).

DMUs	2004–2005				2005–2006				2007–2008				2008–2009				2009–2010				2011–2012			
	GMLPI	PEC	BPC	SCH	GMLPI	PEC	BPC	SCH	GMLPI	PEC	BPC	SCH	GMLPI	PEC	BPC	SCH	GMLPI	PEC	BPC-	SCH	GMLPI	PEC	BPC	SCH
Processing of Food from Agricultural Products	1.2005	1.0000	1.1726	1.0238	1.0147	1.0000	1.0161	0.9987	1.0966	1.0000	1.0799	1.0154	0.9608	1.0000	0.9859	0.9745	0.9961	1.0000	1.0143	0.9821	1.0062	1.0000	1.0058	1.0004
Manufacture of Foods	1.0254	1.0257	1.1200	0.8926	1.0367	1.0439	1.0414	0.9536	1.0713	0.9955	1.0590	1.0162	1.0177	1.0383	0.9956	0.9844	1.0487	1.0153	1.0276	1.0052	0.9644	0.9555	1.0074	1.0019
Manufacture of Beverages	1.0127	1.0848	0.9624	0.9700	1.0460	1.0541	1.0700	0.9274	0.9980	0.9966	1.0221	0.9797	1.0108	1.0594	1.0245	0.9313	1.0110	0.9981	1.0633	0.9526	0.9802	1.0030	1.0250	0.9535
Manufacture of Tobacco	1.0494	1.0000	1.0381	1.0110	1.0772	1.0000	1.0736	1.0033	1.0338	1.0000	1.0324	1.0013	1.0335	1.0000	1.0363	0.9973	1.0786	1.0000	1.0739	1.0043	1.0253	1.0000	1.0000	1.0253
Manufacture of Textile	1.0242	0.9909	1.1281	0.9162	1.0252	1.0013	1.0762	0.9514	1.0229	0.9488	1.0707	1.0070	1.0084	1.0173	1.0049	0.9865	1.0792	1.0422	1.0558	0.9808	0.9772	0.9646	1.0297	0.9839
Manufacture of Textile Wearing Apparel, Footware and Caps	1.0943	1.0338	1.1192	0.9458	1.0262	0.9639	1.0621	1.0023	1.0009	0.9987	1.0298	0.9732	1.0531	1.0705	0.9927	0.9910	0.9993	0.9770	1.0438	0.9798	0.9806	1.0052	1.0247	0.9520
Manufacture of Leather, Fur, Feather and Related Products	1.0868	1.0000	1.0935	0.9939	1.0458	1.0000	1.0451	1.0007	0.9977	1.0000	1.0063	0.9914	1.0046	1.0000	1.0146	0.9901	1.0370	1.0000	1.0534	0.9844	0.9705	1.0000	1.0000	0.9705
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	1.0850	0.9700	1.1793	0.9485	1.1014	1.0813	1.0213	0.9974	1.0182	0.9665	1.0674	0.9871	1.1049	1.1538	0.9614	0.9960	1.0798	1.0224	1.0673	0.9895	1.0000	1.0000	1.0000	1.0000
Manufacture of Furniture	1.0610	0.9554	0.9616	1.1549	1.0663	1.0165	1.0394	1.0092	0.9611	0.9500	1.0664	0.9486	1.0650	1.0496	1.0008	1.0139	1.0485	0.9519	1.1447	0.9623	0.9912	0.8760	1.1326	0.9990
Manufacture of Paper and Paper Products	1.0034	1.0130	1.0260	0.9655	1.0059	1.0094	1.0658	0.9351	1.0004	1.0114	1.0045	0.9847	1.0001	0.9822	1.0233	0.9951	1.0020	1.0396	1.0625	0.9071	0.9863	0.9396	1.0216	1.0276
Printing, Reproduction of Recording Media	0.9595	0.9204	1.0482	0.9946	1.0277	0.9867	1.0401	1.0014	1.0055	1.0592	0.9476	1.0019	1.0320	1.0203	1.0112	1.0003	1.0029	0.9631	1.0390	1.0023	1.0191	1.0678	0.9603	0.9939
Manufacture of Articles For Culture, Education and Sport Activities	1.1077	0.9548	1.0853	1.0690	1.0415	0.9739	1.0752	0.9946	1.0101	1.0863	0.9207	1.0099	1.0136	0.9813	1.0317	1.0012	1.0194	0.9434	1.0745	1.0057	1.1093	1.0411	1.0004	1.0651
Processing of Petroleum, Coking, Processing of Nuclear Fuel	1.0936	1.0000	1.0878	1.0053	1.0835	1.0000	1.0738	1.0090	1.0000	1.0000	1.0000	1.0000	0.8844	1.0000	0.8973	0.9856	1.1308	1.0000	1.1145	1.0146	1.0000	1.0000	1.0000	1.0000
Manufacture of Raw Chemical Materials and Chemical Products	1.1554	1.0167	1.1126	1.0214	1.1089	1.0553	1.0868	0.9668	1.0002	1.0075	1.0972	0.9048	1.0065	1.0852	0.9429	0.9837	1.1337	1.0514	1.1043	0.9764	0.9667	1.0000	1.0273	0.9409
Manufacture of Medicines	1.0114	1.0165	0.9944	1.0007	1.0302	1.0190	1.0219	0.9894	0.9980	1.0648	0.9862	0.9504	1.0141	1.0496	1.0189	0.9483	1.0124	1.0232	1.0498	0.9425	1.0063	0.9927	1.0147	0.9990
Manufacture of Chemical Fibers	1.2526	1.0876	1.1192	1.0290	1.1509	1.0076	1.1349	1.0065	0.9354	0.9707	0.9774	0.9860	1.0280	0.9723	1.0308	1.0257	1.1387	0.9851	1.1476	1.0073	0.9226	0.9055	1.0233	0.9957
Manufacture of Rubber and Plastics Products	1.0240	0.9867	1.1148	0.9309	1.0440	1.0220	1.0603	0.9633	0.9900	0.9936	1.0209	0.9761	1.0237	1.0485	0.9851	0.9912	1.0494	1.0287	1.0259	0.9943	0.9767	0.9797	1.0211	0.9764
Manufacture of Non-metallic Mineral Products	1.0001	0.9022	1.1165	0.9928	1.0032	1.0452	1.0694	0.8976	0.9998	1.0284	1.0916	0.8907	1.0008	1.1116	0.9990	0.9013	1.0017	1.0444	1.0939	0.8767	0.9575	0.9839	1.0577	0.9201
Smelting and Pressing of Ferrous Metals	1.1778	1.0156	1.1958	0.9698	1.0515	1.0000	1.0923	0.9627	1.1662	1.0000	1.1525	1.0119	0.8944	1.0000	0.9184	0.9739	1.0891	1.0000	1.0889	1.0002	1.0178	1.0000	1.0173	1.0005
Smelting and Pressing of Non-ferrous Metals	1.2843	1.0928	1.0721	1.0962	1.4066	1.1342	1.1510	1.0775	0.9296	1.0000	0.9389	0.9901	0.9749	1.0000	0.9886	0.9861	1.1811	1.0000	1.0774	1.0963	0.9124	1.0000	0.9741	0.9367
Manufacture of Metal Products	1.0640	1.0576	1.1177	0.9001	1.0676	0.9999	1.0635	1.0039	1.0017	1.0076	1.0187	0.9758	0.9994	0.9960	0.9705	1.0340	1.0468	1.0449	1.0137	0.9883	0.9941	1.0210	0.9793	0.9943
Manufacture of General Purpose Machinery	1.0498	1.0013	1.0963	0.9564	1.0649	1.0192	1.0752	0.9718	0.9949	1.0171	1.0104	0.9681	1.0210	1.0540	0.9582	1.0109	1.0478	1.0682	1.0281	0.9541	1.0474	1.0461	0.9303	1.0763
Manufacture of Special Purpose Machinery	1.0265	1.0078	1.0616	0.9595	1.0431	1.0202	1.0664	0.9588	1.0096	1.0510	0.9729	0.9874	1.0140	1.0759	1.0023	0.9403	1.0195	1.0533	1.0411	0.9298	1.0571	1.0556	0.9689	1.0335
Manufacture of Transport Equipment	1.0943	1.0353	1.1138	0.9490	1.1408	1.1283	1.0698	0.9451	0.9983	1.0535	0.9546	0.9927	1.0430	1.0000	1.1362	0.9180	1.0539	1.0000	1.0846	0.9717	0.9839	1.0000	1.0000	0.9839
Manufacture of Electrical Machinery and Equipment	1.0699	1.0058	1.0649	0.9989	1.0937	1.0144	1.0787	0.9996	0.9740	1.0287	0.9732	0.9728	0.8317	0.9991	0.9933	0.8381	1.1851	1.0423	1.0419	1.0913	1.0193	1.0000	0.9918	1.0277
Manufacture of Communication Equipment, Computers and Other Electronic Equipment	1.0091	1.0000	1.0073	1.0018	1.0184	1.0000	1.0166	1.0017	0.9325	1.0000	1.0000	0.9325	1.0233	1.0000	0.9718	1.0530	1.0480	1.0000	1.0290	1.0184	0.9511	1.0000	1.0000	0.9511
Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	1.0640	1.0000	1.0348	1.0283	1.1065	1.0000	1.0770	1.0274	0.9012	1.0000	0.9071	0.9935	1.0135	1.0000	1.0133	1.0002	1.0585	1.0000	1.0562	1.0022	0.8399	0.9377	0.9053	0.9894
Manufacture of Artwork and Other Manufacturing	1.2040	1.0065	1.1996	0.9972	1.0208	1.0107	1.0144	0.9957	1.0423	0.9842	1.0642	0.9951	0.9662	1.0146	0.9706	0.9812	1.0608	0.9999	1.0706	0.9910	0.7146	0.7212	1.0163	0.9749
Recycling and Disposal of Waste	1.2320	1.0000	1.0000	1.2320	1.0000	1.0000	1.0000	1.0000	0.8447	1.0000	0.9771	0.8644	1.0552	1.0000	1.0234	1.0310	1.1220	1.0000	1.0000	1.1220	1.0000	1.0000	1.0000	1.0000

Note: According to OECD statistics, we set Index 2010 = 100.

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