Study on energy productivity of patent-intensive industries

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Abstract. Based on the panel data of patent intensive-industries from 2007 to 2016, this paper utilized the Biennial Malmquist-Luenberger (BML) productivity index model to measure and decompose the energy efficiency. The results showed that the energy efficiency of patent-intensive industries showed growth trend on the whole and its growth rate was higher than non-patent-intensive industries and the overall industry. Besides, the contribution of structure effect (SE) was the largest and that of total factor productivity (TFP) was the least. Moreover, different industries had different sources of energy efficiency growth. For most industries, technical change (TC), labor-energy substitution effect (LE), and output structure effect (OSE) increased energy efficiency. Therefore, it is necessary to further accelerate the pace of energy conservation, optimize the industrial structure, promote technological progress, and increase the substitution effect of labor on energy for patent-intensive industries.

1. Introduction
Patent-intensive industries are emerging industries driven by intellectual property (IP), characterized by high technology, high growth and high added value, which promote independent innovation of the whole industrial chain. In December 2015, the opinions of the state council on accelerating the construction of a powerful country with intellectual property rights under the new situation clearly pointed out that it is necessary to cultivate IP-intensive industries and promote the vigorous development of emerging industries. By the end of 2015, the added value of China's patent-intensive industries reached 13.1 trillion yuan, an increase of 8% year on year, of which the sales revenue of new products accounted for 23.4% of the main business revenue, nearly 1.5 times more than that of non-patent-intensive industries. It can be seen that patent-intensive industries have become the key of promoting the economic quality and efficiency. At the same time, patent-intensive industry belongs to the secondary industry and is also energy-intensive industry, which plays an important role in the field of energy consumption. Due to the late start of China's patent-intensive industries, the energy consumption is still mainly non-renewable fuels and the development lacks sustainability. Therefore, it is difficult to rely on the adjustment of energy structure in the short term. Improving energy productivity has become an inevitable requirement for patent-intensive industries to reduce energy consumption and promote sustainable development under increasingly severe energy constraints. Therefore, this paper focused on the measurement and analysis of the energy productivity of patent-intensive industries, by using the Biennial Malmquist-Luenberger (BML) productivity index model, and studied the changing trend and sources of differences of energy productivity in different industries, with a view to finding the focus of energy saving and consumption reduction in patent-intensive industries.
industries, and providing certain reference for China to accelerate the construction of a powerful country with intellectual property rights under the new normal.

2. Literature review

To define the connotation of patent-intensive industries is the premise of studying the energy productivity of patent-intensive industries[1]. The United States was the first country to judge industries in which the number of invention patents per employee was higher than the average of the whole industry as patent-intensive industries[2]. Paier et al.[3] used the measurement method of the patent intensity in the United States to calculate patent-intensive industries in EU countries. Jiang[4] identified six patent-intensive industries in China by constructing four patent density measurement indicators. Wang et al.[5] defined patent-intensive industries in Zhejiang province by dividing the sample period into three periods and comparing whether the patent intensity in any one period was higher than the average intensity. Therefore, the patent intensity is the main basis for defining patent-intensive industries.

Energy productivity has always been a hot topic in academic circles. Domestic and foreign scholars have also actively carried out researches on energy productivity and accumulated rich research results. In terms of the measurement of energy productivity, early scholars proposed that the intensity of the energy consumption is the most reliable single indicator for evaluating energy productivity[6-7]. With the deepening of the research, the intensity of the energy consumption cannot completely include all the connotation of energy productivity, and is gradually replaced by the total factor analysis method, which includes capital, labor, resources, environment and other multi-input factors[8]. The common measurements of total factor energy productivity include the Malmquist-Luenberger (ML)[9] and Global Malmquist-Luenberger (GML)[10] productivity indexes. The former tends to be unrecyclable and linearly unsolvable, while the latter ignores the influence of term change. Therefore, Pastor et al.[11] constructed the Biennial Malmquist (BM) productivity index but the BM productivity index does not take into account the case of undesirable outputs. It follows that, Wang et al.[12] introduced a new Biennial Malmquist-Luenberger (BML) productivity index based on the BM productivity index, combining with the undesirable outputs, to obtain relatively more accurate energy productivity results.

According to the above literature review, we found that although energy productivity has attracted a lot of attention from domestic and foreign scholars, the scientific and reasonable method utilized to accurately measure the results of energy productivity is not many. Most of the literatures still focus on regions as the research objects of energy productivity, with little attention paid to the energy productivity of patent-intensive industries. This paper will focus on the above issues and make breakthroughs from two aspects:(1) The BML productivity index was adopted to calculate the energy productivity of patent-intensive industries from 2007 to 2016. This BML model not only allows different reduction ratios of undesirable outputs to achieve more accurate measurement of energy productivity, but also solves the unsolvable problem, enabling the existence of energy productivity in all patent-intensive industries.(2) By using the new productivity decomposition method, the overall difference is decomposed into six factors, which are summarized as three effects, in order to systematically analyse the sources of energy productivity changes in patent-intensive industries.Compared with previous researches, the empirical results of this paper can better reflect the energy productivity differences in patent-intensive industries.

3. Models, methods, and data descriptions

3.1 BML productivity index model

Based on the analysis of Wang et al.[12], this paper utilized the BML productivity index to calculate the energy productivity of patent-intensive industries considering low-carbon factors. The specific model is shown as follows.

Suppose there are \( I \) patent-intensive industries, and all of them include \( N \) factor inputs \( x=(x_1,\ldots,x_N) \in R^+_N \), \( M \) desirable outputs \( y=(y_1,\ldots,y_M) \in R^+_M \) and \( S \) undesirable outputs \( b=(b_1,\ldots,b_S) \in R^+_S \).
In the \( t=1, \ldots, T \) period, the set of production possibilities of the \( i=1, \ldots, I \) industry’s factor inputs, desirable outputs and undesirable outputs is \((x'_i,y'_i,b'_i)\). If the production possibility set meets: 1) the closed set and bounded set, 2) the expected output and input can be disposed freely, 3) the zero binding axiom and the output weak disposability axiom, then the environmental production technology can be expressed as:

\[
T'(x') = \{ (y', b') : \sum_{i=1}^{I} z_i y'_i \geq y'_i, \sum_{i=1}^{I} z_i b'_i = b'_i, \sum_{i=1}^{I} z_i x'_i \leq x'_i, z_i \geq 0, i = 1, \ldots, I \} \quad (1)
\]

In equation (1), \( i \) is the patent-intensive industry referred to in the construction of environmental technology frontier, \( i' \) is the industry being evaluated, \( z_i \) is the weight corresponding to the observed value of the \( i \)-th industry, and \( z_i\geq0 \) represents the constant return to scale.

Referring to the optimization problem of desirable and undesirable outputs handled by Chung et al.[9], we construct the following directional distance function:

\[
D(x', y', b'; g) = \max \{ \beta \mid (y', b') + \beta g \in P(x) \} \quad (2)
\]

If the direction vector is expressed as \( g=(y'-b') \), it means that, in the case of given factor inputs, the desirable outputs and the undesirable outputs of the industrial industry increase or decrease in the same proportion, and \( \beta \) is the maximum degree of desirable outputs increase and undesirable outputs decrease.

Based on the directional distance function, the BML productivity index of energy productivity of patent-intensive industries was finally obtained as:

\[
BMPI_{it}^{11} = \frac{1 + D^b \left( x', y', b'; y', -b' \right)}{1 + D^b \left( x'^t, y'^t, b'^t, y'^t, -b'^t \right)} = \left[ \frac{1 + D^b \left( x', y', b'; y', -b' \right)}{1 + D^b \left( x'^t, y'^t, b'^t, y'^t, -b'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( x', y', b'; y', -b' \right)}{1 + D^{11} \left( x'^t, y'^t, b'^t, y'^t, -b'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( x'^t, y'^t, b'^t, y'^t, -b'^t \right)}{1 + D^{11} \left( x'^t, y'^t, b'^t, y'^t, -b'^t \right)} \right] \quad (3)
\]

In equation (3), the BML productivity index can be decomposed into the product of efficiency change (EC) and technical change (TC). \( D^b \left( x', y', b'; y', -b' \right) \) and \( D^b \left( x', y', b'; y', -b' \right) \) are respectively the directional distance functions of the industrial industry in period \( t \) under the two periods (\( t \) and \( t+1 \) periods) and the period \( t \).

3.2 Energy productivity decomposition

Through the measurement method of the BML productivity index, the scientific and reliable energy productivity can be obtained, and the efficiency results can be further decomposed to realize the comprehensive investigation of energy productivity.

Assuming that the input factors of patent-intensive industries include the capital \( K \), the labor \( L \) and the energy \( E \), the desirable output is the added value \( Y \) and the undesirable output is the carbon dioxide emission \( C \), then by using the BML index, the output growth of patent-intensive industries is decomposed into:

\[
\frac{Y_{it}^{t+1}}{Y_{it}} = \left[ \frac{1 + D^b \left( L', K', E', Y', C'; Y', C' \right)}{1 + D^b \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( L', K', E', Y', C'; Y', C' \right)}{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)}{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \quad (4)
\]

Based on the decomposition of output growth, energy productivity \( EP \) is decomposed as follows:

\[
EP = \frac{Y_{it}^{t+1}/E_{it}^{t+1}}{Y_{it}/E_{it}} = \left[ \frac{1 + D^b \left( L', K', E', Y', C'; Y', C' \right)}{1 + D^b \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( L', K', E', Y', C'; Y', C' \right)}{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \times \left[ \frac{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)}{1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)} \right] \quad (\text{\textit{\textbf{EP}}})
\]

\[
1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)
\]

\[
1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)
\]

\[
1 + D^{11} \left( L'^t, K'^t, E'^t, Y'^t, C'^t, Y'^t, C'^t \right)
\]
1 + \frac{\bar{D}^{t+1}(L^{t+1}, K^{t+1}, E^{t+1}, Y^{t+1}, C^{t+1}, Y^{t+1}, C^{t+1})}{1 + \bar{D}^{t}(L^{t}, K^{t}, E^{t}, Y^{t}, C^{t}, Y^{t}, C^{t})} \times \frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}, y^{t+1}, c^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}, y^{t}, c^{t})} \times \frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}, y^{t+1}, c^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}, y^{t}, c^{t})} (5)

In equation (5), \( l = L/E, k = K/E, y = Y/E, \) and \( c = C/E. \) Therefore, EP can be decomposed into EC, TC and potential maximum energy productivity change (PEPC).

The first term EC represents the degree of relative efficiency change of patent-intensive industries from period \( t \) to period \( t+1. \) If \( EC > 1, \) the efficiency change of patent-intensive industries in period \( t+1 \) is improved under the condition of constant input factors.

The second term TC is similar to EC, indicating the degree of relative technical change of patent-intensive industries from period \( t \) to period \( t+1. \) If \( TC > 1, \) the production frontier in the period \( t+1 \) is closer to the production frontier in the period \( t \) and the period \( t+1, \) and technological progress exists in patent-intensive industries.

From the homogeneity of the directional distance function, the third item PEPC can be further decomposed:

\[
\frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}; Y^{t+1}, C^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}; Y^{t}, C^{t})} = \frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}; Y^{t+1}, C^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}; Y^{t}, C^{t})} \times \frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}; Y^{t+1}, C^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}; Y^{t}, C^{t})} \times \frac{f^B(\vec{l}^{t+1}, k^{t+1}, 1, y^{t+1}, c^{t+1}; Y^{t+1}, C^{t+1})}{f^B(\vec{l}^{t}, k^{t}, 1, y^{t}, c^{t}; Y^{t}, C^{t})} (6)
\]

In equation (6), the first term KE represents the substitution effect of capital on energy. The higher the value of KE, the higher the degree of the substitution effect of capital on energy, the less energy used per unit of capital, and the higher the output and energy productivity of patent-intensive industries; otherwise, the lower the output and energy productivity of patent-intensive industries.

The second term LE represents the substitution effect of labor on energy. The higher the value of LE, the higher the degree of the substitution effect of labor on energy and the less energy used per unit of labor, which will also improve the output and energy productivity of patent-intensive industries.

The third term CE represents the change of energy structure effect. CE can lead to reductions in carbon dioxide emissions, but do not always ensure greater energy productivity. Only when total energy consumption declines more than value added does, energy productivity in patent-intensive industries is improved.

The fourth term OSE represents the output structure effect. OSE reflects the influence of the ratio change of desirable outputs and undesirable outputs of patent-intensive industries on the frontier outputs, including the frontier output change caused by the changes of direction vector and desirable outputs under other same conditions.

To sum up, EP can be decomposed into six parts: EC, TC, KE, LE, CE, and OSE. Moreover, TC and EC are collectively referred to as total factor productivity (TFP), KE and LE are collectively referred to as input substitution effect (ISE), and CE and OSE are collectively referred to as structural effect (SE).

3.3 Variable selection

This paper respectively selected the annual average number of all employees, capital stock and energy consumption as the indicators of labor input, capital input and energy input. For the output indexes, besides representing the desirable output by the added value of the industry, the CO₂ emission of the industry is also selected to represent the undesirable output index. Details are shown as follows:

1. Labor Input. The annual average number of all employees in each industry is used.

2. Capital Input. With reference to Yu et al.[13], it is represented by the capital stock of each industry calculated by the perpetual inventory method. The estimation model of the perpetual
inventory method is \( K_t = I_t + (1 - \delta_t)K_{t-1} \), where \( K_t \) and \( K_{t-1} \) represents the capital stock in \( t \) and \( t-1 \) years, respectively. It represents the new investment in the year \( t \), and \( \delta_t \) represents the depreciation rate in the year \( t \).

(3) Energy Input. The energy consumption of each industry over the years is used as the index of energy input.

(4) Desirable Output. Taking into account the availability of data from the sample observation interval, the added value of the industry was selected and deflated to the price level of 2007 according to the producer price index of each industry over the years.

(5) Undesirable Output. Based on the benchmark calculation provided by the IPCC guidelines for national greenhouse gas emission inventories, this paper selected the eight kinds of fossil fuels (coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas) of China energy statistical yearbook to estimate the CO2 emissions \( CO_2 = \sum_{j=1}^{8} CO_{2,j} = \sum_{j=1}^{8} E_j \times NCV_j \times CEF_j \times COF_j \times \frac{44}{12} \), where \( j \) is a certain fossil fuel, \( E_j \) represents the consumption of the fossil fuel, \( NCV_j \), \( CEF_j \), and \( COF_j \) are respectively the average low calorific value of energy, carbon emission factor and carbon oxidation rate, their product is the coefficient of the carbon emission of each energy, and 44 and 12 are the chemical molecular weights of CO\(_2\) and C, respectively.

3.4 Descriptions of patent-intensive industries and data sources

The core indicator measured the patent-intensive industries is relative patent intensity. Therefore, this paper still utilizes this indicator. In order to ensure the scientific nature of the defined patent-intensive industries in terms of quality, the number of invention patents with the highest technical content among patent types is selected, and the number of effective invention patents is added on the basis that the relative patent intensity is higher than the average of the industry, which is also higher than the average of the industry. Finally, eight industries, including chemical raw materials and chemical products manufacturing, pharmaceutical manufacturing, general equipment manufacturing industry, special equipment manufacturing, transportation equipment manufacturing, electric machinery and equipment manufacturing, computer communications, and other electronic equipment manufacturing and instrumentation manufacturing, are selected as patent-intensive industries and the rest are non-patent-intensive industries.

The data of this paper mainly come from China industrial economy statistical yearbook, China energy statistical yearbook, China science and technology statistical yearbook and China statistical yearbook from 2007 to 2016. To ensure the consistency of industrial classification, this paper merged the two industries of rubber products and plastic products, integrated automobile manufacturing industry and railway, ship and aerospace industry into transportation equipment manufacturing industry, and excluded other mining, waste resources and waste materials recycling and processing industries, metal products, machinery and equipment repair industry due to the lack of data. The data of 36 industries were finally selected.

4. Differential analysis of energy productivity in patent-intensive industries

4.1 Measurement of energy productivity in patent-intensive industries

This paper used the BML productivity index to calculate the energy productivity of patent-intensive industries, non-patent-intensive industries and the whole industries from 2007 to 2016, as shown in Table 1.

| Year     | Patent-intensive industries | Non-patent-intensive industries | The whole industries |
|----------|-----------------------------|--------------------------------|---------------------|
| 2007-2008| 1.141                       | 1.150                          | 1.148               |
| 2008-2009| 1.148                       | 1.132                          | 1.136               |
In general, energy productivity is greater than 1 per year and the overall trend is on the rise, which means that China's extensive industrial development mode is changing to intensive and efficient. From 2007 to 2016, the average annual growth rate of energy productivity in patent-intensive industries is 10.3%, slightly higher than the 10.1% of non-patent-intensive industries and 10.2% of the industrial average. It can be seen that, for the patent-intensive industries, it has not fully played the low energy consumption effect, but also faces certain problems of energy conservation and emission reduction. The growth index of energy productivity of patent-intensive industries during the period rise and drop, and drop is greater than the increase of efficiency and energy productivity of the slowdown in the growth rate, which it has to do with the government to improve environmental regulation requirements in recent years, patent-intensive industry energy saving cost, not enough green production process management and other factors.

Figure 1 shows the dynamic changes of energy productivity in each industry of patent-intensive industries. As it can be seen from Figure 1, the energy productivity of each patent-intensive sub-industry fluctuates up and down around 0.9-1.3, with a large degree of fluctuation in the early stage. After 2012, the efficiency changes become smaller and more stable. In addition to the fact that the energy productivity of the transportation equipment manufacturing industry showed an upward trend from 2007 to 2016, and the energy utilization advantage continued to be prominent. Other industrial energy productivity both backwards, of which the general equipment manufacturing industry and special equipment manufacturing industry of energy productivity back even more than 10%. This shows that patent-intensive industries development in China is to pay attention to economic benefit as the guidance, the present stage can't effectively achieve "potter effect", the energy productivity of patent-intensive industries has a certain ascension space. We should actively promote the patent-intensive industries to patent advantage into the economic growth and energy utilization.
4.2 Decomposition of energy productivity in patent-intensive industries

Based on the measurement results of the BML productivity index, energy productivity is further decomposed into TFP, ISE and SE, and the percentage accumulation diagram of the contribution of energy productivity changes in patent-intensive industries is shown in Figure 2.

It can be seen from Figure 2 that the contribution degrees of TFP, ISE, and SE are significantly different. The contribution of TFP to energy productivity of patent-intensive industries fluctuated greatly in different periods, but showed positive contribution in most periods, and finally made the largest contribution to the change of energy productivity in 2015-2016. However, the symbol of ISE is positive, which makes a greater contribution to energy productivity. In 2010-2011, the contribution of
ISE to energy productivity reached 73.215%. These indicate that adjusting the proportion of labor, capital and other factors can optimize the marginal production of energy input to release the huge productivity. ISE has a promoting effect on growth of energy productivity but not the contribution outstanding of historical SE, reflecting the development of patent-intensive industries with high efficiency and energy saving has more advantages than other industries and there is an obvious bonus structure phenomenon. Therefore, how to play the role of SE to improve energy productivity of the patent-intensive industries can be paid more attention.

4.3 Sources of variation in energy productivity by industries

In order to further reveal the source of the difference in energy productivity, this paper calculated and decomposed the average energy productivity of eight industries in the patent-intensive industry during 2007-2016, and the results are shown in Table 2.

| Industries                              | TFP   | ISE   | SE    | EC | TC | KE | LE | CE | OSE | EP  | Rank |
|-----------------------------------------|-------|-------|-------|----|----|----|----|----|-----|-----|------|
| Chemical and chemical                   | 0.999 | 1.000 | 1.000 | 1.001 | 1.000 | 1.101 | 1.102 | 3  |
| Pharmaceutical                          | 0.990 | 1.004 | 1.001 | 1.010 | 1.005 | 1.118 | 1.130 | 2  |
| General equipment                       | 0.989 | 1.005 | 0.987 | 1.060 | 0.997 | 1.059 | 1.095 | 7  |
| Special equipment                       | 0.996 | 1.006 | 0.989 | 1.068 | 0.995 | 1.078 | 1.132 | 1  |
| Transportation equipment                | 0.991 | 1.007 | 1.000 | 1.027 | 0.991 | 1.082 | 1.098 | 4  |
| Electrical machinery and equipment      | 0.957 | 1.017 | 0.988 | 1.106 | 0.999 | 1.014 | 1.097 | 5  |
| Computer and communications             | 0.975 | 1.021 | 1.000 | 1.076 | 0.975 | 1.045 | 1.075 | 8  |
| Other electronic equipment and instrumentation | 0.967 | 1.021 | 1.000 | 1.059 | 0.995 | 1.064 | 1.096 | 6  |
| Patent-intensive industries             | 0.983 | 1.010 | 0.996 | 1.051 | 0.994 | 1.070 | 1.103 | -  |

From 2007 to 2016, the average growth rates of TC, LE, and OSE showed an upward trend, which shows that the technical change of patent-intensive industries, the substitution effect of labor on energy and the output structure effect have made positive contributions to the growth of energy productivity, with the contribution rate from high to low being 67.086% of OSE, 48.832% of LE, and 9.823% of TC. The contributions of EC, KE, and CE is negative, which are -16.198%, -4.259% and -5.283% respectively. During this period, the energy productivity of all the eight patent-intensive industries was improved, but due to the different driving factors of energy productivity, the extent of energy productivity improvement also showed the heterogeneity of the industry.

Three of the eight patent-intensive industries saw energy productivity growth of more than 10%, including chemical materials manufacturing, pharmaceutical manufacturing and specialized equipment manufacturing, among which specialized equipment manufacturing ranked first with a growth rate of 13.2%. The energy productivity growth sources of these three industries are OSE, which confirms the conclusion that SE is the main reason to improve the energy productivity of patent-intensive industries. However, CE is the opposite. In addition to CE of the second pharmaceutical manufacturing produce positive contribution to energy productivity, CE of other industries cannot effectively promote the energy productivity, which shows that currently there is a big problem for energy structure of patent-intensive industries, and environmental regulation failed to bring positive change of industrial development. Therefore, patent-intensive industries should be more efforts to optimize the energy structure. TFP includes EC and TC. The improvement of energy productivity in patent-intensive
industries mainly benefits from TC, while EC damages energy productivity in a certain sense. This may be because, on the one hand, the reform of the energy field in the patent-intensive industries lags behind the energy and resource reform in the traditional manufacturing industry, and the scale effect of EC has not been really played out. On the other hand, there are strong technical barriers between patent-intensive industries, which distort the reasonable allocation structure of energy elements and hinder the improvement of energy productivity. The ranks of efficiency of computer and communication manufacturing and instrumentation manufacturing are 8 and 6 respectively, but TC improved the most, 2.1%, mainly because in recent years, computer and communication manufacturing and instrumentation manufacturing enhance the consciousness of innovation, introduce advanced production equipment and advanced management experience, and constantly improve the enthusiasm of digestion, absorption and independent technology research and development ability. Therefore, the cumulative effect of TC is most pronounced. It is once again illustrated that in terms of TFP, it is necessary to focus on improving EC of patent-intensive industries, so as to realize the two-wheel drive of EC and TC of all links from energy input to desirable and undesirable outputs at an early date on the growth of energy productivity. From the perspective of ISE, the substitution effect of industrial capital on energy (37.5%) hindered the growth of energy productivity, and the substitution effect of capital on energy in pharmaceutical manufacturing alone is positive, with an average annual growth rate of 0.01% and a contribution rate of 0.787%. By contrast, the substitution effect of labor on energy is much larger than the substitution effect of capital on energy. The top three are respectively the electrical machinery manufacture, computer and communication manufacturing, and special equipment manufacturing, which illustrates that for the three industries, the labor is rich, the labor-intensive degree is high, the promotion effect of energy productivity driven by the substitution effect of labor on energy is remarkable.

5. Conclusions and suggestions
Patent-intensive industry is an important force for China's industrial optimization and upgrading, which is of great significance to the implementation of the patent power strategy and innovation-driven development strategy. Using the BML productivity index, this paper evaluated and compared the energy productivity trends of the patent-intensive industries, non-patent-intensive industries, and the whole industry from 2007 to 2016, and explored the different sources of energy productivity in patent-intensive industries through multiple decomposition. The obtained conclusions are as follows.

(1) From the perspective of the changing trend of energy productivity, the energy productivity of patent-intensive industries presents an overall upward trend, slightly higher than that of non-patent-intensive industries and overall industries, and there is still much room for improvement in energy productivity of most patent-intensive industries.

(2) From the perspective of the contribution of energy productivity, SE, ISE and TFP are in order from high to low. Further analysis shows that the sources of energy productivity growth in different industries are also different, and TC, LE and OSE are the main sources of energy productivity growth in most industries.

Based on the above conclusions, the following countermeasures and suggestions are proposed:

(1) In view of the slowdown in the growth rate of energy productivity in patent-intensive industries in recent years, we should further strengthen the supervision of patent-intensive industries, formulate measures to restrain energy conservation and emission reduction, and improve the level of energy utilization of industries in the future. There is much room for improvement of energy productivity in the industries such as instrument and meter manufacturing, general equipment manufacturing and computer communication manufacturing. The future should focus on energy consumption and pollution emissions from these industries.

(2) SE contributes the most to the energy productivity of patent-intensive industries. Therefore, green development of patent-intensive industries should be encouraged to improve environmental friendliness, especially to optimize the output structure. At the same time, it is also necessary to
effectively promote TC and LE, and strive to play its due role in improving energy productivity of patent-intensive industries.

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