# Research on Innovation Efficiency Loss of State-Owned Enterprises: An Empirical Analysis in China Based on DEA

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**Abstract**

The efficiency loss of state-owned enterprises has recently attracted increasing interest. In traditional view, it only emphasizes the productivity efficiency loss of state-owned enterprises, while it ignores the innovation efficiency loss. The production efficiency of state-owned enterprises has been improved by series reforms which still can't solve the problem of inefficient in china. It indicates that there are more critical factors affecting the efficiency improvement. Many qualitative studies have proved the technical innovation is the main factor affecting the efficiency of enterprises, but empirical tests are few. Therefore, in this study, we utilize Malmquist index method based on DEA model to disaggregate, evaluate and test the innovation efficiencies of state-owned enterprises and private enterprises in 5 major Chinese high-tech industries. The results show that except for aerospace vehicle manufacturing industry, the state-owned enterprises' innovation efficiencies in all the industries are significantly lower than private enterprises'. In a word, the innovation efficiency loss is the main factor which makes state-owned enterprises into survival dilemma.

Keywords: State-owned Enterprises, Innovative Efficiency, Innovation Efficiency Loss, Method of Malmquist Index; DEA model.

## 1 Introduction

It is generally known that the enterprise is the main body of technological innovation, so it needs to pay close attention to the innovation efficiency of enterprise so as to improve the whole country's capability of independent innovation in science and technology. In China, the state-owned business is served as the subject of China's national economy, whose innovation efficiency has a direct relationship with the development and operation of the whole nation's economy. For this reason, the efficiency of state-owned enterprise is always a concern for scholar. However, the studies on the efficiency of state-owned enterprise by scholars usually concentrate on the production efficiency while few of articles conduct the direct study on the innovation efficiency, another hitting-point of state-owned business performance evaluation.

Studies have confirmed that the production efficiency of state-owned enterprise is lowest among enterprises under all forms of ownership in China [1]. With respect to the reason for the inefficiency of state-owned enterprises, scholars have made the convincible theoretical explanations, such as the existence of principle-agent problem in state-owned enterprises, the policy burden and the soft budget constraint etc.[2-4] After realizing the seriousness of this issue, the Chinese Government carries out a series of reforms, such as the primary decentralization of power and transfer of profits, the subsequent property right structure adjustment, the current separation of enterprise from administration and management system and so on, which plays an active role in dealing with the low production efficiency of state-owned enterprises. The study conducted Groves study on the outcome of reform of the internal incentive mechanism of state-owned enterprises indicates that such reform measures as the contracting out system and the decentralization of power and transfer of profits and so on significantly improve the production efficiency of state-owned enterprises[5]. Sun and Tong concluded that the clear definition of property right and other institutional innovations have a positive effect on the improvement of the production efficiency of state-owned enterprises through studying such the reform measure of establishing a modern enterprise system in the state-owned enterprises in China[6]. Nevertheless, the improvement of production efficiency fails to extricate the state-owned enterprises from inefficiency, which impels us to seek for the in-depth cause. Actually, many scholars begin to turn their attention to the innovation efficiency of state-owned enterprises and plenty of empirical researches have proved that technological innovation has a significant effect on the enterprise efficiency. Seeing from the enterprise practice, innovation can bring enterprises the competitive advantages, help enterprises take the lead in accumulating experience in market and occupy much market shares to acquire favourable development space and realize economies of scale. From the perspective of consumers, the advantages of enterprise innovation lie in consumers' increasing acquaintance with the brand and the formation of preference for the brand which contribute to preventing the potential competitor from taking over the market share [7-8]. But it is only until recent years that the empirical studies concerning the relationship between the ownership of enterprise and innovation efficiency emerge [9], in which the data information is analyzed by different research techniques to find out the problem of innovation

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efficiency of state-owned enterprises. Some articles even point out that the loss of innovation efficiency is worse than that of production efficiency [1]. Since the available literature has not conducted the systematic empirical analysis on the innovation efficiency of state-owned enterprises nor made reasonable explanations of the reason for efficiency loss, it is necessary to conduct a further study on it.

## 2 Method, variables and data dpecification

### 2.1 METHOD

#### *2.1.1 DEA*

The methods of innovation efficiency assessment mainly include the parametric method and nonparametric method. Data envelopment analysis (DEA) is a nonparametric method by employing the linear programming for measurement with multi-input and output. The simulation result of Banker verifies that DEA has better effect than parameter estimation method does [10]. Essentially, DEA is to evaluate the leading surface of efficient production based on a group of observed value with multi input and output and make the comprehensive evaluation on the effectiveness of production unit [11]. The advantage of DEA is that validity of decision-making unit is unrelated with the choice of dimension of evaluation index and the specific function relationship between inputs and outputs is not required to be confirmed, which helps avoiding making an incorrect conclusion due to the wrong functional form [12]. Thus, it can be seen that DEA enjoys the advantaged superiority in efficiency evaluation. This study adopts DEA to evaluate the innovation efficiency of enterprises.

#### *2.1.2 Malmquist index based on DEA*

Caves, Christensen and Diewert firstly put forward the theoretical index defining the total factor productivity by employing the Malmquist input and output distance function [13]. Subsequently, Fare et al. turned the theoretical index into the empirical index based on DEA and made further amendment and established the model of Malmquist index method [14].

Under the condition of constant return to scale (CRS), the Malmquist index during the period from t to t+1 can be expressed as follows：

$$M_0(x_{t+1},y_{t+1},x_t,y_t)=\left[\frac{d_0^t(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)}\times\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^{t+1}(x_t,y_t)}\right]^{\frac{1}{2}} \quad (1)$$

In the above equation, $(x_{t+1},y_{t+1})$ and $(x_t,y_t)$ respectively represent the vector quantity of input and output during the period $(t+1)$ and $t$; $d_0^t$ and $d_0^{t+1}$ respectively represent the distance function in different period by taking Technology $T^t$ during the period of $t$ as a reference.

By reference to the technology $T^t$ in the period of $t$, the Malmquist index can be expressed as follows:

$$M_0^t(x_{t+1},y_{t+1},x_t,y_t)=\frac{d_0^t(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)} \quad (2)$$

Similarly, by reference to the technology $T^{t+1}$ during the period of $(t+1)$, the Malmquist index can be represented as follows:

$$M_0^{t+1}(x_{t+1},y_{t+1},x_t,y_t)=\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^{t+1}(x_t,y_t)} \quad (3)$$

In order to avoid the possible difference caused by the randomness of period choice, Caves et al. (1982) take the geometric mean of equation (2) and (3), namely the equation (1), as the Malmquist index from $t$ to $t+1$. As the index is greater than 1, it indicates that the total factor productivity is increasing from $t$ to $t+1$.

After the above-mentioned process, the quality of Malmquist index is fine. Fare resolved it into the variability index of technology efficiency (EF) and technical change (TC) under the hypothesis of the constant return to scale and the decomposition course can be expressed as follows [14]:

$$M_0(y_{t+1},x_{t+1},y_t,x_t)= \\ =\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)}\left[\frac{d_0^t(x_{t+1},y_{t+1})}{d_0^{t+1}(x_{t+1},y_{t+1})}\times\frac{d_0^t(x_t,y_t)}{d_0^{t+1}(x_t,y_t)}\right]^{\frac{1}{2}}= \\ =EF\times TC$$

The EF can be decomposed into the pure technical efficiency (PE) and scale efficiency (SC). After adding up the limiting condition, Ray and Desli have conducted further decomposition based on the variant return to scale (VRS) [15]. Under this condition, EF can be written as follows:

$$\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)}=\frac{d_0^{t+1}(x_{t+1},y_{t+1}/VRS)}{d_0^t(x_t,y_t/VRS)} \\ \times\left[\frac{d_0^{t+1}(x_{t+1},y_{t+1}/CRS)}{d_0^{t+1}(x_{t+1},y_{t+1}/VRS)}\times\frac{d_0^t(x_t,y_t/VRS)}{d_0^t(x_t,y_t/CRS)}\right]$$

In the above equation,

$\frac{d_0^{t+1}(x_{t+1},y_{t+1}/VRS)}{d_0^t(x_t,y_t/VRS)}$ can represent the change of PE. If $PE>1$, it indicates that the pure technical efficiency has increased; conversely, if $PE<1$, it shows that the pure technical efficiency has not increased.

$\left[\frac{d_0^{t+1}(x_{t+1},y_{t+1}/CRS)}{d_0^{t+1}(x_{t+1},y_{t+1}/VRS)}\times\frac{d_0^t(x_t,y_t/VRS)}{d_0^t(x_t,y_t/CRS)}\right]$ can indicate the scale efficiency change (SC). If $SC>1$, it shows that the scale efficiency has been improved and gradually approaches to the best scale; otherwise, it indicates that the scale efficiency has not been improved and is increasingly far away from the best scale. In short, under the condition of variable return to scale, the EF index indicating the change of technology efficiency of each decision-making unit can be decomposed into the pure technical efficiency and scale efficiency change, namely, $EF = PE \times SC$, then the Malmquist index can be expressed as follows:

$$M_0(y_{t+1}, x_{t+1}, y_t, x_t) = PE \times SC \times TC$$

Based on the above analysis, it is observed that the Malmquist index method based on DEA not only can analyze the efficiency change of DEU in different periods but also can decompose it into the rate of technical efficiency change and rate of technical progress further with the purpose of finding out the effect of respective change on the total factor productivity. The technical efficiency refers to the distance between the practical production curve of certain production unit and the forefront of technology. The closer to the forefront of technology, the efficiency is higher. Here, the forefront of technology refers to the achievable utmost output under the constant technological level. Thus, it can be found that technical efficiency and technical progress are completely different from each other for technical efficiency refers to approaching to the leading edge of technology while the technical progress refers to the outward shift of the frontier technology. The decomposition contributes a lot to getting the more detailed comprehension on the source of combine efficiency improvement and thus avoids attributing the change of efficiency to certain index and ignoring the effect of another index, having a wide range of application.

## 2.2 VARIABLES

TABLE 1. Specification of variables.

| | Variables | | Specification |
|---|---|---|---|
| Innovation input | $X_1$ | R&D personnel input intensity (RDL /E) | Number of R&D personnel / Employees |
| | $X_2$ | R&D cost input intensity (RDE/ MBI) | R&D expense of enterprises / Main business income |
| Innovation output | $Y_1$ | Number of patent application (PN/ RDL) | Number of patent application / Number of R&D personnel |
| | $Y_2$ | Innovation profit ratio (NPI/ RDE) | Sales income of new products / R&D expense of enterprises |

As there is no uniform understanding on the selection of innovation variable, this study refers to the existing literature and conducts proper extension and meanwhile takes the availability of statistical data and the practical situation of China into consideration. The selected variables (Table 1) and the relevant explanation are as follows.

(1) Innovation input variable $X_1$: R&D personnel input intensity

The innovation mainly depends on human' discovery of new knowledge and new demands and is closely related with the activity of R&D personnel. By reference to the available literature [16], this study takes the number of R&D personnel as the one of innovation input variables. However, large enterprises have lots of employees and correspondingly the research personnel is more than that of middle and small-sized enterprises, so the sole index of R&D personnel gives rise to the low comparability among enterprises. In order to avoid this problem, this research adopts the ratio between RDL and employees based on the equivalent of R&D personnel as the measurement index of innovation input variable, taking it as the R&D personnel input intensity.

(2) Innovation input variable $X_2$: R&D cost input intensity

Most available literatures take R&D expense as innovation input variable [17-18, 23]. However, the variable of R&D expense tends to involve in the following issues. Firstly, R&D expense always exists in few large and medium enterprises [19]. In 1970, the R&D expense of top 100 large enterprises in America occupies 79% of the whole nation; in 1978, the R&D expense of top 100 large enterprises in Britain accounts for 90%; in Japan, the R&D expense of large enterprises with over 1,000 million capital fund occupies 91.6%(1991). Secondly, there is the detailed record on the common standard R&D budget and the innovation input of standard R&D in large companies while the non-standard R&D expense of many small enterprises lacks embodiment. Therefore, in order to get rid of the above problems, the study selects the ratio between the R&D expense of enterprises and the main business income of enterprises as another vital innovation input variable, taking it as the R&D cost input intensity.

(3) Innovation output variable $Y_1$: Number of patent application

The number of patent application is always employed as an important variable to measure the innovation output [20]. As the innovation is connected with the activities of R&D personnel, this study adopts the number of application patent per person as the measurement variable of output, namely, it can be expressed by the ratio between the number of application patent and the full-time equivalent of R&D personnel.

(4) Innovation output variable $Y_2$: Innovation profit ratio

The patent can reflect a part of information on innovation activity indirectly and is an existence form of innovative product. Although the patent stands for the birth of new technology, it does not mean that this kind of technology can bring about economic benefit and have the economic value. Therefore, many studies take the sales of new products as the output variable [21]. By reference to the available literatures, this research holds that only the sale of new products can not measure the profit conversion rate of the R&D expense input. The measurement index of innovation profit ratio can be expressed by the ratio between the sale income of new products and the R&D internal expense.

## 2.3 DATA SOURCES

The previous scholars tend to take private enterprise as the reference system during studying the efficiency loss of state-owned enterprises [22]. Likewise, this study takes the private enterprises as comparison. In order to acquire completely abundant data on the above variable, we select the data of state-owned and private enterprises in the following five categories of industries to conduct the corresponding empirical study according to China High-tech Industry Data Book from 2000 and 2011, namely, traditional Chinese medicine manufacturing, aerospace vehicle manufacturing, electronic and communication device manufacturing, computer and office equipment manufacturing and medical facility and instrument manufacturing.

## 3 Data analysis

In the measuring process, the study employs the data envelopment analysis software DEAP2.1 to calculate the innovation efficiency. The result of empirical analysis is as follows:

TABLE 2. Average value of innovation efficiency in five industries

| Industry | Industry code | Average value | |
|---|---|---|---|
| | | State-owned enterprises | Private enterprises |
| Pharmaceutical manufacturing | 1 | 0.739 | 1.311 |
| Electronic and communication equipment manufacturing | 2 | 0.780 | 1.425 |
| Computer and office equipment manufacturing | 3 | 0.756 | 1.440 |
| Medical equipment and instrumentation manufacturing | 4 | 0.723 | 1.346 |
| Aerospace vehicle manufacturing | 5 | 1.181 | 1.382 |

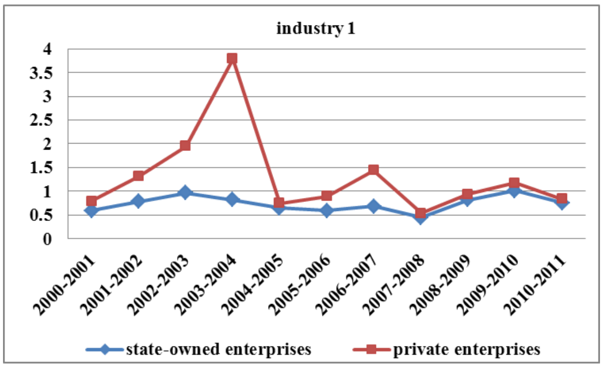


FIGURE 1. Innovation efficiency comparison of industry 1

Table 2 indicates the result of the total average innovation efficiency in five industries concerning advanced technology from 2000 to 2011. From Table 2, it can be found that the innovation efficiency of state-owned enterprises is obviously lower than that of private enterprises for each kind of industry. In order to make a detailed comparison of innovation efficiency between state-owned and private enterprises in five categories of industries, we draw the figure 1 to 5.

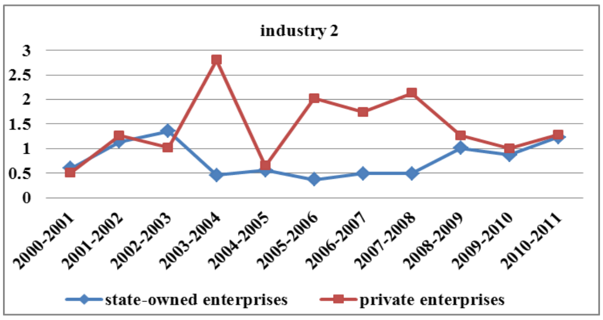


FIGURE 2. Innovation efficiency comparison of industry 2

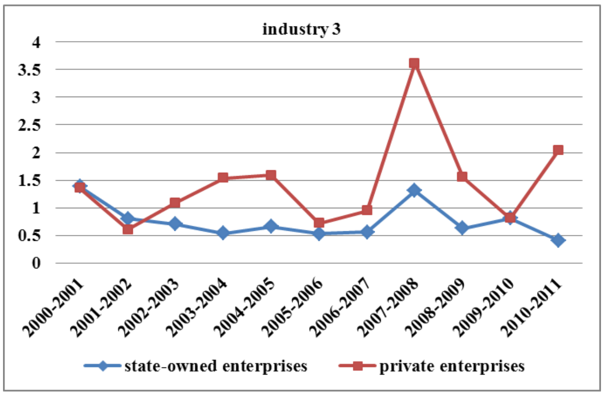


FIGURE 3. Innovation efficiency comparison of industry 3

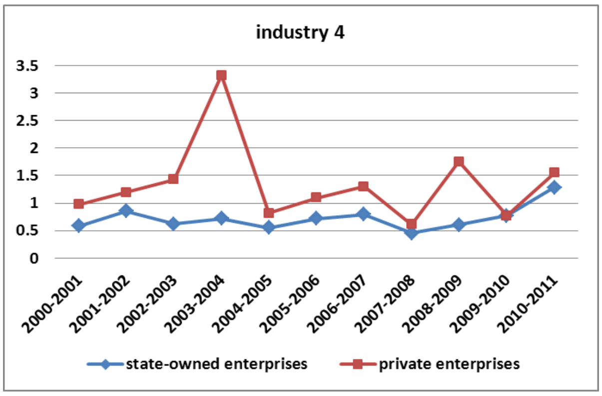


FIGURE 4. Innovation efficiency comparison of industry 4

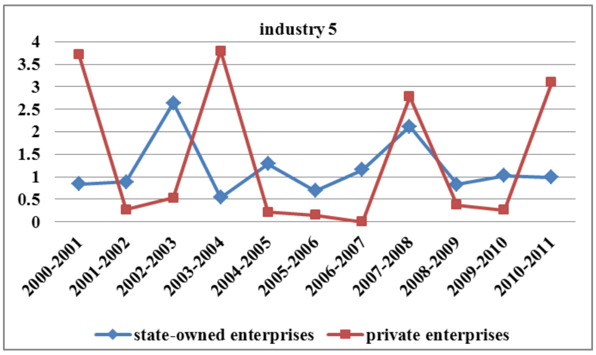


FIGURE 5. Innovation efficiency comparison of industry 5

From Figure 1 to 5, it is clear that apart from exceptional year, in traditional Chinese medicine manufacturing, electronic and communication device manufacturing, computer and office equipment manufacturing and medical facility and instrument manufacturing, the innovation efficiency of state-owned enterprises is lower than that of private enterprises and efficiency loss exists in state-owned enterprises. It can not reach some conclusion through the comparison of innovation efficiency among years in aerospace vehicle manufacturing, so it needs to rely on the average innovation efficiency, from which it can be found that the innovation efficiency of state-owned enterprises is lower than that of private enterprises. It may be because that the relative equilibrium of state-owned and private enterprises in aerospace vehicle manufacturing is different from that in other four categories. Almost all the aerospace vehicle manufacturing involves in state-owned enterprises while the number of private enterprises and employees is relatively less. For example, the number of employees of state-owned enterprises concerning aerospace vehicle manufacturing is 452,968 while private enterprises 3,563, the employees of state-owned enterprises is 127.13 times than that of private enterprises in 2010; even in 2007, with the smallest difference, the number of state-owned enterprises is 278, 971 while the private enterprises 22,447, the employees of state-owned enterprises are 12.43 times than that of private enterprises. The corresponding input of R&D personnel amount and R&D expense between state-owned enterprises and private enterprises differs a lot. Due to the control of the state, the development of private enterprises is relatively weaker in aerospace vehicle manufacturing. Therefore, no clear conclusion can be reached due to the poor comparability of innovation between state-owned and private enterprises.

After comparing the innovation efficiency of five industries, this thesis analyzes the average innovation efficiency of state-owned and private enterprises in order to conduct further explanations.

TABLE 3. Average innovation efficiency comparison of all industries between state-owned enterprises and private enterprises.

| Period | Innovation efficiency of state-owned enterprises | | | | | Innovation efficiency of private enterprises | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EF | TC | PE | SC | TFP | EF | TC | PE | SC | TFP |
| 2000-2001 | 0.735 | 1.080 | 0.860 | 0.871 | 0.800 | 1.162 | 1.133 | 0.929 | 1.200 | 1.472 |
| 2001-2002 | 1.155 | 0.808 | 1.045 | 1.103 | 0.893 | 1.280 | 0.679 | 1.090 | 1.641 | 0.928 |
| 2002-2003 | 1.423 | 0.861 | 1.130 | 1.196 | 1.256 | 1.536 | 0.981 | 1.180 | 1.201 | 1.203 |
| 2003-2004 | 0.301 | 2.047 | 0.200 | 1.585 | 0.615 | 1.201 | 2.603 | 2.798 | 0.849 | 3.048 |
| 2004-2005 | 0.537 | 1.394 | 0.480 | 1.114 | 0.741 | 0.579 | 1.580 | 0.791 | 0.772 | 0.803 |
| 2005-2006 | 0.590 | 0.976 | 0.615 | 0.994 | 0.579 | 0.835 | 1.379 | 1.047 | 0.808 | 0.976 |
| 2006-2007 | 0.730 | 1.035 | 0.741 | 1.109 | 0.737 | 1.482 | 0.718 | 1.082 | 1.288 | 1.085 |
| 2007-2008 | 0.965 | 0.973 | 1.049 | 0.889 | 0.964 | 2.089 | 0.876 | 1.361 | 1.431 | 1.934 |
| 2008-2009 | 0.774 | 1.055 | 0.896 | 0.892 | 0.778 | 1.022 | 1.114 | 1.752 | 0.726 | 1.176 |
| 2009-2010 | 2.149 | 0.422 | 1.717 | 1.460 | 0.899 | 1.647 | 0.523 | 1.550 | 1.037 | 0.803 |
| 2010-2011 | 0.281 | 3.225 | 0.409 | 0.774 | 0.933 | 0.720 | 2.912 | 0.880 | 0.761 | 1.761 |

TABLE 4. Innovation efficiency value of state-owned enterprises and private enterprises.

| | State-owned enterprises | | | | | Private enterprises | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EF | TC | PE | SC | TFP | EF | TC | PE | SC | TFP |
| Min | 0.281 | 0.432 | 0.222 | 0.823 | 0.552 | 0.511 | 0.530 | 0.757 | 0.668 | 0.910 |
| Max | 2.021 | 3.155 | 1.788 | 1.395 | 0.920 | 1.925 | 3.143 | 1.940 | 1.557 | 2.862 |
| Mean | 0.775 | 1.265 | 0.770 | 1.060 | 0.750 | 1.277 | 1.346 | 1.233 | 1.557 | 1.380 |

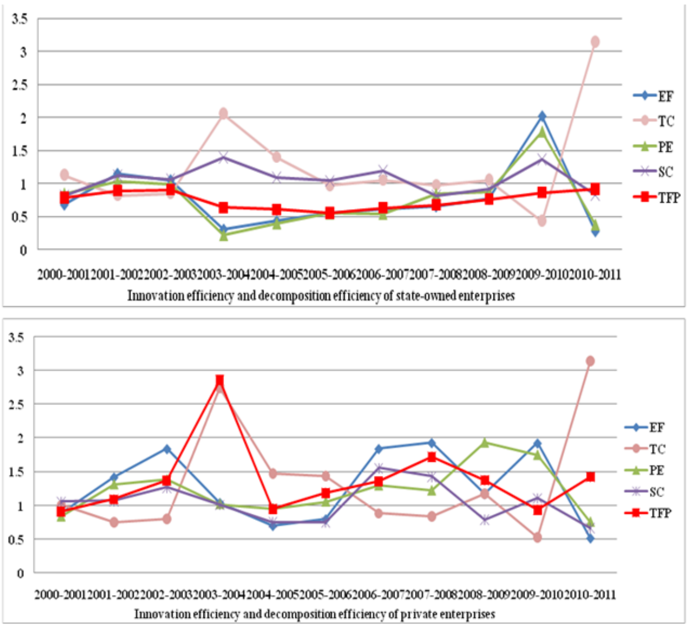


FIGURE 6. Innovation efficiency and decomposition efficiency comparison between state-owned enterprises and private enterprises

By comparing the innovation efficiency and decomposition efficiency between state-owned and private enterprises in Figure 6, it can be clear that certain distance between state-owned and private enterprise exists in both the innovation efficiency and decomposition efficiency. The efficiency value can be achieved through further organization as in Table 4. The average value of pure technical efficiency (PE) of state-owned enterprises is 0.770 while the private enterprises 1.233; the average value of EF of state-owned enterprises is 0.775 while the private enterprises 1.277, so there is great difference. Although the state-owned and private enterprises rarely differ in technological changes (TC), the great difference in technical efficiency leads to the big gap in the average value of innovation efficiency (TFP), the state-owned enterprises 0.750 and the private enterprises 1.380. In order to reflect the distance more clearly, the comparison of annual TFP between state-owned and private enterprises will be conducted as Figure 7.

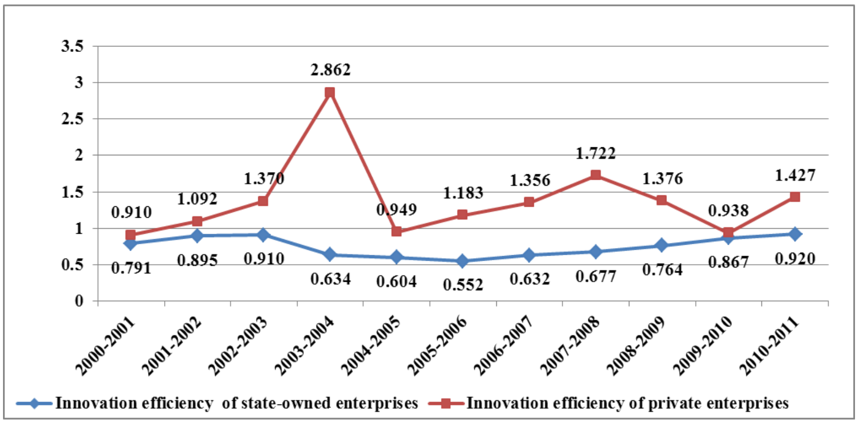


FIGURE 7. Innovation efficiency comparison between state-owned enterprises and private enterprises.

From Figure 7, it is clear that great difference between state-owned and private enterprises exists in all years other than the period from 2000 to 2001 and from 2009 to 2010. It definitely shows that the innovation efficiency of state-owned enterprises is indeed lower than that of private enterprises.

In conclusion, it can be found that the innovation efficiency of state-owned enterprises is indeed lower than that of private enterprises by both the comparison among industries and the comprehensive comparison and the loss of innovation efficiency exists in the state-owned enterprises and should be not ignored.

## 4 Conclusions

The technical innovation plays an increasingly important role in the promotion of enterprise competitiveness and the sustainable economic development. The efficiency of state-owned enterprises is always the public concern. Since the reform and opening-up policy is implemented in China, the production efficiency of state-owned enterprises has been improved to some extent through a series of effective measures while the state-owned enterprises is still confronted with the plight of low efficiency. According to the comparison of innovation efficiency between state-owned and private enterprises in China from 2000 to 2011, it can be clear that the existing loss of innovation efficiency is the major reason for the constant low efficiency of the state-owned enterprises after reform. The government should lay great emphasis on the innovation efficiency of state-owned enterprises in the subsequent reform of state-owned enterprises and strives to establish a market environment beneficial for technical innovation for enterprises.

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