Technology Progress and Energy Efficiency: An Empirical Analysis of Shanghai Industrial Firms

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Abstract: In the tough stage of transition development, it is necessary for Shanghai industrial sector to take measures like R&D and technology import to improve energy efficiency, which also contributes to carbon emission reduction, reduction of the external dependence of energy consumption and the achievement of green development. This paper estimates energy efficiency of Shanghai industrial sector based on historical data of industrial enterprises in Shanghai and analyzes the mechanism and level of the influence of factors like R&D and technology import on energy efficiency of the industrial enterprises. The results show that the internal R&D investment of enterprises have a significant positive impact on energy efficiency of collective and private enterprises in Shanghai. Foreign investment has positive spill-over effect and leads to energy efficiency improvement for foreign-invested enterprises in Shanghai. Besides, the deeper the enterprises engage in export trade, the higher the energy intensity and the lower the energy efficiency will be, which implies that the export-oriented enterprises are more likely to produce and export energy-intensive products and suffer from energy efficiency loss. So, it is not only necessary to encourage internal R&D innovation of enterprises, but also important to implement transformation and upgrading of enterprises in the value chain of international trade.

1. Introduction
The industry sector is a major energy consumer in Shanghai. Though the proportion of GDP of the secondary industry in the overall GDP of Shanghai reduced to 30.46% in 2017 due to the industrial restructuring, the proportion of energy consumed by secondary industry in the overall energy consumption reached 56.36%. Meanwhile, Shanghai relies heavily on energy imports (Tang et al. 2005): in 2017, the consumption volume of coal, oil and power in Shanghai reached 45.78 million tons, 37.75 tons and 152.68 billion kWh, respectively, and the proportions of the import of these resources were 99.35%, 97.39%, 43.31%. Therefore, saving energy in the industry is an important way to alleviate short supply of energy and reduce energy consumption in Shanghai. To improve the energy efficiency is an effective way to reduce the soil energy consumption and emissions of greenhouse gases and discharge of pollutants. In these two decades, the energy intensity of Shanghai maintained a declining trend, from 1.09 tons of standard coal/10,000 yuan in 1998 to 0.52 tons of standard coal/10,000 yuan. To study the driving factors for improvement of energy efficiency of the industry sector in Shanghai is important for policy-making for industrial development and energy consumption in the stage of industrial restructuring in Shanghai. This study explored the factors that improved the energy efficiency of the industry in Shanghai, analyzed how and to what extent the factor of technological innovation influenced the technological progress of industrial enterprises in Shanghai.
Analysis of the energy intensity of the secondary industry and influencing factors of energy efficiency shows that the decrease of energy intensity in China derived from regional and industrial technological progress (Guang et al., 2019). Enterprises, the micro units of economic activities, can reflect the changes in the energy intensity and energy efficiency with their operational and innovative initiatives. With the unbalanced panel data of 35,371 enterprises in Shanghai included in the “China Industrial Enterprise Database” from 1998 to 2013, this study used the stochastic frontier analysis model to assess the enterprises’ energy efficiency and used the Tobit model to analyze the impact of factors including enterprises’ R&D innovation on energy efficiency. The research result shows that investment to R&D could significantly improve the energy efficiency of collective and private enterprises; the technology spillover effect of introducing foreign investments could improve the energy efficiency of foreign-funded enterprises; foreign trading enterprises that engage themselves in production and export of energy-intensive products had low energy efficiency. Section 2 built a stochastic frontier analysis model based on the Translog production function to assess the enterprise energy efficiency of the industry in Shanghai. Section 3 estimated the scores of enterprises’ energy efficiency and used the Tobit model to analyze the impact of R&D innovation on energy efficiency of enterprises with different sources of energies; Section 4 concluded this study and proposed policy-making suggestions.

2. Energy efficiency of industrial enterprises in Shanghai

2.1. Enterprise energy efficiency model
The frontier was constructed based on production technologies; the factor input level \( x = (K, L, E) \), and the output is \( Y \), where \( K \) is the capital investment, \( L \) is the labor input, and \( E \) is the energy input, \( Y \) is the enterprise’s total output. According to the study by Zhou et al. (2012), the Shephard energy distance is:
\[
D_a(K, L, E, Y) = \sup \left\{ \alpha : (L, K^\alpha, Y) \in T \right\}.
\]
Thus, the energy efficiency estimation equation of the Translog production function is:
\[
-\ln E_{it} = \beta_0 + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_T \ln T + \beta_{KL} \ln K_{it} \cdot \ln L_{it} + \beta_{KY} \ln K_{it} \cdot \ln Y_{it} + \beta_{LY} \ln L_{it} \cdot \ln Y_{it} + \beta_{TY} T \cdot \ln K_{it} + \beta_{TY} T \cdot \ln L_{it} + \frac{1}{2} \beta_{KK} \ln K_{it}^2 + \frac{1}{2} \beta_{LL} \ln L_{it}^2 + \frac{1}{2} \beta_{YY} \ln Y_{it}^2 + \frac{1}{2} \beta_{TT} T^2 + \nu_{it} - \mu_{it}
\]
where \( T \) is the time trend of technological progress, \( \nu_{it} \) is the random item that conforms to normal distribution, \( \mu_{it} = \ln D_a(K_{it}, L_{it}, E_{it}, Y_{it}) \) is non-negative term of non-efficiency. The method proposed by Kumbhakar et al. (2014) was used to assess the energy efficiency of industrial enterprises in Shanghai.

2.2. Analysis of enterprise energy efficiency
The data on industrial enterprises in Shanghai were from “China Industrial enterprise database” and “Database for General Survey on Pollutants”. The annual fixed asset investment is \( K \), the labor investment is \( L \), the total output is \( Y \), all of which are obtained by processing variables in the “China Industrial enterprise database”, and the total energy demand \( E \) came from “Database for General Survey on Pollutants”. Figure 1 shows the kernel density curve of energy efficiency of industrial enterprises in Shanghai obtained by using the stochastic frontier model, which indicates that enterprises in the high energy consumption industries have a lower chance to have high energy efficiency, and state-owned enterprises have advantages over other types of enterprises in terms of energy efficiency.
3. Analysis of influencing factors of energy efficiency of enterprises in Shanghai

3.1. Model of influencing factors of enterprise energy efficiency

On the basis of the energy efficiency estimation in Section 3, the Tobit model was used to analyze the impacts of the factors including internal driving factors, external spillover effect and the type of enterprises on the energy efficiency of industrial enterprises in Shanghai, with factors including the age of enterprises, the business scale and the financial indicators controlled. The high energy consumption enterprises belong to the six top energy consumption industries stated in “2010 National Economy and Social Development Report”. The model was set as follows:

\[ E_{\text{effscore}} = \beta_0 + \beta_1 \ln \text{age} + \beta_2 (\ln \text{age})^2 + \beta_3 \ln \text{size} + \beta_4 \text{export} + \beta_5 \ln (\text{RandD}) + \beta_6 \ln \text{liability} + \beta_7 \text{profit} + \beta_8 \text{high} + \beta_9 \text{foreign} + \eta_i + \eta_t + \epsilon \]

where \( E_{\text{effscore}} \) was the score of energy efficiency obtained by multiplying the value of energy efficiency by 100; \( \ln \text{age} \) and \( (\ln \text{age})^2 \) represent the logarithm and squared logarithm value of the age of enterprises which is obtained by adding the years of the observation and 1; \( \ln \text{size} \) is the logarithm of the total capital. Because the annual average balance of fixed assets, the total industrial output, the number of employees, and the total energy consumption were used to estimate the energy efficiency in the first stage, the total assets of the enterprise was used in this study to represent the enterprise’s business scale (Haider et al., 2019); \( \text{export} \) represents the ratio of the total export to the total sales, i.e. the ratio of total liabilities to the total assets; \( \text{profit} \) means the gross profit rate of the enterprise, i.e. the ratio of the difference between the enterprise’s net income and the operational cost to the net sales income; \( \text{high} \) is the virtual variable for enterprises that belong to the high energy consumption industries and are assigned the value of 1; \( \text{foreign} \) is the ratio of investment from Hong Kong, Macau and Taiwan to the investment from abroad; \( \eta_i \) and \( \eta_t \) represent the individual fixed effect and the time fixed effect, respectively.

3.2. Result analysis

Table 1 presents the result of analysis of influencing factors of energy efficiency and energy intensity of industrial enterprises in Shanghai. As the table shows, R&D investment had no significant impact on the enterprise’s energy efficiency, indicating that the internal driving factors had no significant impact on energy efficiency of industrial enterprises in Shanghai. As for the type of enterprises, expert-dominated enterprises had lower energy efficiency, and high energy consumption enterprises had lower energy efficiency than those that belong to low energy consumption industries. In terms of the nature of enterprises, the export took up an average of 30.95% of the total sales of foreign-funded enterprises, while the corresponding proportions of state-owned enterprises, collective and private enterprises and other enterprises were 5.85%, 7.28%, 5.63%, indicating that foreign-funded enterprises relied much more on exports. Foreign trading enterprises had lower energy efficiency and the increase of foreign
shares decreased the energy efficiency, which suggests that foreign-invested industrial enterprises in Shanghai prefer export of intermediate products that have low energy efficiency.

Models (4)-(6) in Table 1 made comparison by taking the logarithm of energy intensity as the independent variables. As the table shows, R&D investment and the proportion of foreign investment had no significant impacts on the energy intensity, indicating that the internal driving factors and external spillover factors did not lead to significant improvement of the energy production rate. The analysis result of the impact of the type of enterprises on the energy intensity is consistent with the before-mentioned analysis on energy efficiency. On the one hand, enterprises with higher shares of exports had higher energy intensities, indicating that enterprises engaged in production of intermediate products and exports in international trade are energy intensive; on the other hand, industrial enterprises that belong to high energy consumption industries have significantly higher energy intensity than other enterprises.

| Table 1. Firm Energy Efficiency Influential Factors Analysis in Shanghai |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                  | (1)              | (2)              | (3)              | (4)              | (5)              | (6)              |
|                  | Energy Efficiency | Energy Efficiency | Energy Efficiency | Energy Intensity | Energy Intensity | Energy Intensity |
| Export Share     | -0.163**         | -0.162**         | -0.255***        | 0.0591*          | 0.0586*          | 0.0612**         |
|                  | (-2.16)          | (-2.16)          | (-3.20)          | (1.95)           | (1.94)           | (2.06)           |
| R&D              | 0.0136           | 0.0151           | 0.00533          | -0.00442         | -0.00477         | -0.00332         |
|                  | (0.85)           | (0.94)           | (0.33)           | (-1.00)          | (-1.08)          | (-0.76)          |
| Energy-intensive | -0.285***        | -0.288***        | 0.993***         | 0.992***         |                  |                  |
|                  | (-4.01)          | (-4.05)          | (21.73)          | (21.71)          |                  |                  |
| FDI Share        | -0.324***        | -0.326***        | -0.306***        | -0.00119         | -0.00867         | 0.0084           |
|                  | (-2.94)          | (-2.97)          | (-2.77)          | (-0.04)          | (-0.29)          | (0.28)           |
| Constant         | 52.45***         | 52.25***         | 51.14***         | -8.447***        | -8.430***        | -6.942***        |
|                  | (236.29)         | (268.71)         | (163.25)         | (-80.13)         | (-81.63)         | (-33.97)         |
| Control Variables| Yes              | Yes              | Yes              | Yes              | Yes              | Yes              |
| N                | 146335           | 146335           | 146335           | 146335           | 146335           | 146335           |
| t statistics in parentheses, * p<0.1, ** p<0.05, *** p<0.01 |

4. Conclusions and suggestions

Analysis of enterprise energy efficiency and efficiency intensity shows that the impacts of foreign investment on the energy efficiency of industrial enterprises in Shanghai were manifested in two ways: the technology spillover effect improved the energy efficiency and driving enterprises to energy-intensive production decreased energy efficiency. For state-owned enterprises, collective and private enterprises, the proportion of foreign investment was low, and the negative impact of foreign investment in driving enterprises to production and export of energy-intensive products is larger than the positive impact of such investment in the technology spillover effect. For foreign-funded enterprises, the proportion of foreign investment was high, and the improvement of energy efficiency by the technology spillover effect played a dominating role. Moreover, industrial enterprises that belonged to the high energy consumption industries had lower energy efficiency and higher energy intensity than those in the low energy consumption industries.

Given the analysis results of historical data on energy efficiency of industrial enterprises in Shanghai, in this critical stage of industrial restructuring and energy consumption transformation, Shanghai should increase investment into R&D innovation and improve energy use efficiency; meanwhile, they should improve the position of Shanghai-based foreign-trading enterprises in the value chain of international trading, shifting from production and export of energy-intensive products to production and exports of capital- and technology-intensive products.
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