# A Study on the Energy Intensity from the Perspective of Structure Change and Technical Progress

——Taking China as Example

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**Abstract**

This paper created a model to study energy intensity (EI) from the perspective of industrial structure and technical progress which we call it structural effect and technical effect here. As to pierce the veil of EI, we divided the economy into two stages: industrializing stage and post-industrializing stage in this model. It is clear that: 1) in the process of industrializing, its overall EI will be unstable: rising, falling or unchanging; 2) in the process of post-industrializing, its overall EI will decrease even if the technology makes no progress; 3) when the economy structure keeps unchanged, the EI will decline if the technology continues to make progress. Finally, employing the regional date from the China Statistical Yearbook, we tested the model showing that it is workable. We also found that technical effect and structural effect have greater influence in north, west and middle areas than east coastal areas, so policy makers should invest more in inner areas to achieve higher energy efficiency.

**Key words:** Energy Intensity; Structural Effect; Technical Effect

## I. Introduction

Energy is the driving factors of economic development; this is the consensus of our human beings. As a result, we should save energy, precisely speaking, maximizing the economic efficiency of energy in order to achieve sustainable economic development.

Recently, Low Carbon Economy (LCE), which pursues high energy efficiency by systematical planning, policy making and innovation to advance energy renewable technology and reduce the emission of greenhouse

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gas (Liu, 2010), becomes one of the main stream development tendency in the $21^{th}$ century. At the same time, relevant researches about low carbon economy spring up in many aspects such as Carbon Trust, clear energy, $CO_2$ emission, technology and so on.

Energy intensity (EI), units of energy per unit of GDP (Liddle, 2012), is an important index to measure the efficiency of energy, the lower the better, and for this reason, it has become one of important branches of low carbon economy which arouses wild attention in the academic field of empirical studies. For example, Halkos et al (2011) did the empirical study about oil consumption and economic efficiency, and it indicates that advanced economies have much higher turning points compared to emerging and developing economies. Tyler et al (2012) did the empirical research on energy efficiency and Economic development in China, and it analyzes the evolution of energy intensity in Chinese economy and stressed the importance of transforming China's economic structure.

Azomahou et al. (2003) claimed that the EI is shown to decrease over the period 1971-1999 in OECD countries, indicating a significant energy-saving technical progress trend. Richard et al. (2006) studied technical progress, energy efficiency and rebound effect, and they put that it needs the technology improvement and other polices to achieve low carbon economy. They clearly claimed that technical progress helps promote the energy efficiency. Few papers have researched economic structure and technical progress systematically. Ji et al. (2011), one of few scholars that did the job, claimed technical progress and energy efficiency manifest a strong and positive relationship and the secondary industry has a negative impact on the energy efficiency which is what the consensus in this field.

Though structural change and technical progress are vital to EI, we can see that these studies focused on empirical ways but have not gone deep in the theoretical field, i.e. generally, how the technical effect and structural effect work on EI?

As a result, this paper aims at explore this mechanism through mathematical model. Moreover, we also test the model in regional data of China, which is different from other empirical studies using province-based data or national-based data.

This paper is organized as following. In the section II, we will analyze the feature of EI in every sectors and the role of technology. In the section III, mathematical model will be employed to explore how structure change and technical progress work on EI statically and dynamically. In the section IV, we will examine the model of section III using the regional data coming from the China Statistical Yearbook. Finally, we will make the conclusion of this article in the section Ⅴ.

## II.The EI of Every Sectors and the Role of Technology

The idea of this paper based on the fact that the EI of every sector are different and has its own characteristics. The EI in the tertiary sector is always lower than others and the EI of the secondary sector is always higher than others. Without any doubt, the EI will change when the structure changes.

Except the economy structure, it is wildly believed that the technology also services the EI, which we will give some brief introduction on it.

### 2.1. The EI of the primary sector

The primary industry or the primary sector of the economy is the sector of an economy making direct use of natural resources, and it includes agriculture, forestry and fishing, mining, and extraction of oil and gas.

Is the primary sector energy saving? It is hard to answer. 100 years before, definitely, it was energy saving sector, because the input was almost human capital and little physical capital especially machines. With the process of modernization, various kinds of machines were employed and new technology was applied in this sector, the output increased with more energy consumption. As a result, the EI of this section becomes complex enough to depict.

In conclusion, the EI of this sector varies fiercely from economy to economy, which is low in the developing economies and high in the developed economies. However, in general, the EI in this sector is always lower than that in the secondary sector which I will analyze below.

### 2.2. The EI of the secondary sector

The secondary sector of the economy or industrial sector includes those economic sectors that create a finished, tangible product: production and construction. Many of these industries consume large quantities of energy and require factories and machinery to convert the raw materials into goods and products.

From the definition, we can see that it consumes plenty of energy, thus some scholars even put that the secondary sector is driven by energy input (Liu, Ang and Ong, 1992). Indeed, some industries, say electricity, oil and gas, are high energy intensive; they input raw material and output energy directly.

This sector is high energy consumption, namely, low energy efficiency or high energy intensive comparing to the primary and tertiary industry.

### 2.3. The EI of the tertiary sector

The tertiary industry or the tertiary sector of the economy or the service sector consists of the "soft" parts of the economy, i.e. activities where people offer their knowledge and time to improve productivity, performance, potential, and sustainability including the provision of services to other businesses as well as final consumers in which services may involve the transport, distribution and sale of goods from producer to a consumer, or may happen in wholesaling and retailing, or may involve the provision of a service, such as in pest control or entertainment.

We can make judgment that the energy efficiency of this sector is higher than the other two sectors. It is typically low energy consumption sector (Schipper et al. 1986). This sector characterized with human capital input, or labor intensive (Krugman and Obstfeld, 2011), which needs more labor force than other sectors. It is wildly known that the man is superior to machines in productivity for men have a higher energy conversion rate than machines, i.e. the same “fuel” input can generate more energy.

For example, the haircut house is an ordinary department of the service sector. From the observation, it often takes 3 dollars once for a man with the energy cost for about 0.2 dollar in China, if the oil price is $100 per one barrel (136Kg), we can calculate the EI in this process is about 0.1 Kg oil equivalent per unit of GDP, which is surprisingly lower than the other two sectors and the overall EI.

Haircut house is not exceptional one, and the service sector includes many departments that have the similar or even lower EI, like law consulting. Sometimes the lawyers makes huge amount of money just needing to open their mouths.

## 2.4. The role of technical progress

The technical progress plays an important role in the overall EI which we cannot neglect (Wang et al. 2009). Promoting technical innovation increases energy efficiency (Horace and Robin, 2007), i.e. the technical effect will always decrease EI. The mechanism is relevant simple because technical progress can supply more energy with lower raw materials. For example, 20 years ago, the children used incandescent lamps to do their homework in the night, but now, they use energy-efficient LED lights, which the EI has tripled or even more lowered. In conclusion, increasing the efficiency of energy and GDP is the feature and mission of promoted technology.

# III.Mathematical Model

In the previous section, we analyzed the EI of the three sectors which the tertiary sector is the lowest and the secondary sector is the highest. We also gave a brief introduction of technology. It gives us a first impression that the change of economic structure will change the EI at the same time, and the improvement of technology will also push EI down. How the overall EI change with the changing of economic structure and technical progress simultaneously?

## 3.1. Static analysis

In order to research the effect of economy structure change and technology promotion on the overall EI, this mathematic model involves dynamic process, so we must set up static model and then analyzing dynamically in terms of time t.

**Assumption 1:** the share of the primary sector, the secondary sector and the tertiary sector are $\alpha$ , $\beta$ and $\gamma$ respectively, where $\alpha$ 、 $\beta$ 、 $\gamma \in (0,1)$ and $\alpha + \beta + \gamma = 1$.

**Assumption 2:** A, B and C denote the EI of the primary sector, the secondary sector and the tertiary sector respectively, where A、B、C$\in(0, \infty)$. They are affected by the technical progress.

We can write the overall EI, $E = \frac{M\alpha A + M\beta B + M\gamma C}{M} = \alpha A + \beta B + \gamma C$ (3.1); M is output in terms of GDP. It is clear that the EI is only related to the industry structure, $\alpha$ 、 $\beta$ and $\gamma$ , and the respective EI, A, B and C.

### 3.2. Dynamic analysis

This article aims at piercing the veil of the economy structure and technology on how they work with the overall EI, so dynamic analysis, in terms of time t, is necessary. As a result, it is essential to change the assumptions a little by the following:

**Assumption 1:** the share of the primary sector, secondary sector and tertiary sector are $\alpha(t)$、$\beta(t)$、$\gamma(t)$, as before, they are positive and satisfy $\alpha(t)+\beta(t)+\gamma(t)=1$.

**Assumption 2:** the EI of every sector is A(t), B(t) and C(t), where, just as described in the section II, C(t) is the lowest and B(t) is the highest.

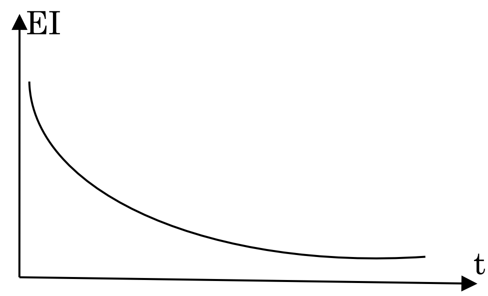
We substitute the relevant assumption to the basic model (3.1), and we can rewrite the overall energy efficiency:

$$E(t) = \alpha(t)A(t) + \beta(t)B(t) + \gamma(t)C(t) \quad (3.2)$$

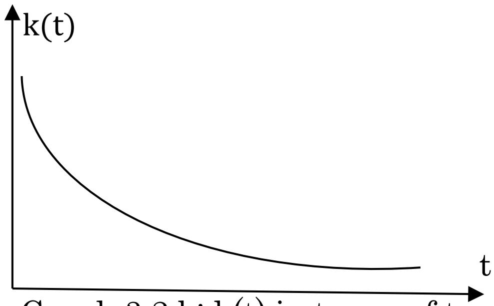
Now we differentiate E(t) with t, we can get the resulting as following:

$$\frac{\partial E(t)}{\partial t} = [1 - \alpha(t) - \beta(t)]\frac{\partial C(t)}{\partial t} + \beta(t)\frac{\partial B(t)}{\partial t} + \alpha(t)\frac{\partial A(t)}{\partial t} + [B(t) - C(t)]\frac{\partial \beta(t)}{\partial t} + [A(t) - C(t)]\frac{\partial \alpha(t)}{\partial t} \quad (3.3)$$

We assume neutral technical progress (Romer, 2006), for simplicity, we re-assume technical progress satisfies $\frac{\partial A(t)}{\partial t} = \frac{\partial B(t)}{\partial t} = \frac{\partial C(t)}{\partial t} = -k(t)$, where $k(t) > 0$, the EI is declining in every sector of economy (see Graph 3.2.a and Graph 3.2.b).



Graph 3.2.a: EI in terms of t



Graph 3.2.b: k(t) in terms of t

Substituting it to fraction (3.3), it is:

$$\frac{\partial E(t)}{\partial t} = \frac{\partial \alpha(t)}{\partial t}[A(t) - C(t)] + \frac{\partial \beta(t)}{\partial t}[B(t) - C(t)] - k(t) \quad (3.4)$$

From the fraction of (3.4), it is easy to judge that $[A(t) - C(t)]$ and

$[B(t) - C(t)]$ are positive, but determining the sign of (3.6) is still impossible for not knowing $\frac{\partial \alpha(t)}{\partial t}$ and $\frac{\partial \beta(t)}{\partial t}$. These two items, $\frac{\partial \alpha(t)}{\partial t}$ and $\frac{\partial \beta(t)}{\partial t}$, have their own characteristics in the different stages of economic development.

According to Petty-Clark's law, the change of economy structures can be regarded as three periods, the agriculture society, industrial society and the post-industrial society, so there are two stages to consider, stage Ⅰ: from agriculture society to industrial society and stage Ⅱ: from industrial society to the post-industrial society, if we want to analyze energy intensity dynamically.

### 3.2.1. Stage Ⅰ: From Agricultural Society to Industrial Society

In this stage, generally speaking, the share of primary sector is declining and the share of the tertiary sector is improving. As for the share of the secondary sector, it doesn't perform stable tendency; it may rise or fall sometimes though the GDP of this sector is increasing.

In order to analyze the tendency of the overall EI from the perspective of industrial structure and technology, we should discussion these scenarios respectively.

**Scenario 1:** the share of the primary and secondary sector is falling, which roughly meets the fact in China. In this condition, both $\frac{\partial \alpha(t)}{\partial t}$ and $\frac{\partial \beta(t)}{\partial t}$ are negative, so the sign of (3.4) is negative even if k(t)=0, no technical progress has been made.

**Scenario 2:** the share of the primary falls down and that of secondary sector keeps constant. In this condition, $\frac{\partial \alpha(t)}{\partial t}$ is negative and $\frac{\partial \beta(t)}{\partial t}$ equals zero, so the sign of (3.4) is negative even if k(t) = 0. It means that the EI will decrease with time t.

**Scenario 3:** the share, the primary sector falls, exactly transfers to the secondary sector. In this condition, $[\frac{\partial \alpha(t)}{\partial t} + \frac{\partial \beta(t)}{\partial t}]$ equals to zero, thus (3.4) can be re-wrote as:

$$\frac{\partial E(t)}{\partial t} = \frac{\partial \alpha(t)}{\partial t}[A(t) - B(t)] - k(t) \quad (3.5)$$

Just as we have analyzed, the EI in the secondary sector $B(t)$ is the highest, so $A(t) - B(t) < 0$ . while $\frac{\partial \alpha(t)}{\partial t}$ is also minus. As a result, the sign of $\frac{\partial \alpha(t)}{\partial t}[A(t) - B(t)]$ in fraction (3.5) is plus. If k(t) is large enough, it can offset the negative effect of its former term, the sign of $\frac{\partial E(t)}{\partial t}$ is minus, the EI declines. If k(t) exactly offset the negative effect of its former term, $\frac{\partial E(t)}{\partial t}$ equals to zero, the EI keeps constant. If k(t) cannot offset the negative effect of its former term, the sign of $\frac{\partial E(t)}{\partial t}$ is plus, the EI increases.

**Scenario 4:** the share of the primary sector transfers to two other sectors. In this situation, $\frac{\partial \alpha(t)}{\partial t} < \frac{\partial \beta(t)}{\partial t} < 0$. If it is completely shifted to the tertiary sector, just as scenario 2, the sign of (3.4) is minus, thus the EI falls down. If it is completely shifted to the secondary sector, just as scenario 3, the sign of (3.4) can be plus if k(t) is below the offsetting level. Therefore in this scenario, the share of the primary sector transfer to the other two sectors, the EI fluctuates, going up, falling down or keeping constant.

### 3.2.2. Stage II: From Industrial Society to Post-Industrial Society

This stage mainly occurs in developed economy, like Japan and America. The share of the primary sector is low and almost keeps constant. However, the share of the secondary sector transfers to the tertiary sector.

As the situation stated above, it is reasonable to regard $\frac{\partial \alpha(t)}{\partial t}$ as zero for the change rate of α (t) is rather slow, so we can re-write equation (3.4) as:

$$\frac{\partial E(t)}{\partial t} = \frac{\partial \beta(t)}{\partial t}[B(t) - C(t)] - k(t) \quad (3.6)$$

It is evident that $[B(t) - C(t)]$ is plus and $\frac{\partial \beta(t)}{\partial t}$ is minus, so the sign of (3.6) is minus even if $k(t) = 0$, the technology makes no progress, thus the overall EI will decline with time t.

Differentiating equation (3.6) again with time t, it gets the following resulting:

$$\frac{\partial^2 E(t)}{\partial t^2} = \frac{\partial^2 \beta(t)}{\partial t^2}[B(t) - C(t)] - \frac{\partial k(t)}{\partial t} \quad (3.7)$$

Supposing that the share of the secondary sector falls in an ever slower rate in the advanced stage of post-industrializing, just like the tendency of Graph 3.2.a, thus $\frac{\partial^2 \beta(t)}{\partial t^2}$ is plus. It has been described that the sign of $\frac{\partial k(t)}{\partial t}$ is minus in the Graph 3.2.b. As a result, the sign of equation (3.7) is plus, the overall EI will decrease in a slower rate in the stage II.

If the share of the secondary falls in a constant rate, $\frac{\partial^2 \beta(t)}{\partial t^2} = 0$ , equation (3.7) can be re-wrote as:

$$\frac{\partial^2 E(t)}{\partial t^2} = -\frac{\partial k(t)}{\partial t} \quad (3.8)$$

As it is supposed that the sign of $\frac{\partial k(t)}{\partial t}$ is minus, so the sign of equation (3.8) is plus, which means the EIs in post-industrializing economies will decline in a lower rate. It is true in theoretically, but the change rate of k(t) is so slow that it creates approximately zero affect in the real world, i.e. the EI in post-industrializing economies may declining linearly when doing practical study.

From mathematical model, it reveals that 1)in the industrializing society, the overall EI has no stable tendency, falling down, keeping constant or going up; 2)in the post-industrializing society, the overall will decline with a an ever slower rate.

In addition, in the advanced stage of economic development, the share of every sector almost keeps constant, thus it is reasonable to think the change rate of every sector is zero, $\frac{\partial \alpha(t)}{\partial t} = \frac{\partial \beta(t)}{\partial t} = 0$, technical effect only and no structural effect works. As a result, equation (3.3) can be re-wrote as:

$$\frac{\partial E(t)}{\partial t} = -k(t) \quad (3.9)$$

As long as the technology makes progress, the sign of equation (3.9) is minus for $-k(t)$ is minus, thus the overall EI will decline with the time t. From the time of the Industrial Revolution, We have reasons to believe that the technology is progressing continuously, so the sign of equation (3.9) is minus. In the absent of structural effect, i.e. considering the technical effect only, it is easy to conclude that the EI decreases with technical progress.

From equation (3.9), it is obvious to see that EI will be standstill if the technology also makes no promotion. Perhaps, this is also the situation 1 million years ago, the pre-historic age of our human beings.

## IV.Empirical Study

From now on, we have demonstrated that 1) in the process of industrializing, its overall EI will be unstable: rising, falling or unchanging; 2) in the process of post-industrializing, its overall EI will decrease even if the technology makes no progress; 3) when the economy structure keeps unchanged, the EI will decline if the technology continues to make progress. But we have not test it in the real world, so in this section, we will to test this model with the regional data coming from the China Statistical Yearbook.

In this paper, we employ regional data of China, rather national-based data like Wu et al. (2007) and province-based data like Qi et al. (2010), because the economy of different areas have different characteristics. As a result, eight regions were divided according to Input-output Table (2005) as following:

| Area | Province |
| --- | --- |
| Northeast Area (A) | Heilongjiang, Jilin, Liaoning |
| Jing-Jin Area (B) | Beijing, Tianjin |
| North Coast Area (C) | Hebei, Shandong |
| East Coast Area (D) | Jiangsu, Shanghai, Zhejiang |
| South Coast Area (E) | Fujian, Guangdong, Hainan |
| Middle Area (F) | Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi |
| Northwest Area (G) | Inner Mongolia, Shanxi, Ningxia, Gansu, Qinghai, Xinjiang |
| Southwest Area (H) | Sichuan, Chongqing, Guangxi, Yunnan, Guizhou, Tibet |

### 5.1. Data

We collect the data from China Statistical Yearbook, China Statistical Yearbook on Science and Technology and China Energy Statistical Yearbook from 1999 to 2011. And then, we deal with these data in accordance with our requirement.

The aim of this empirical study is to test the model and find the characteristics of energy intensity in different regions of China. We should collect the data that can be a proper index of structural change and technical progress.

As for structural change, it is comparative easy to find; share of GDP is a perfect index, which was used by almost studies. However, it is difficult to find an index to calibrate technological progress. Some literature takes the R&D expenditure as an index to explain the technical progress. But there are still some pitfalls. For instance, the increase R&D expenditure do not necessarily causes technology promotion; reversely, technical improvement will made continuously even if R&D expenditure keeps constant or even decline in some special condition. It depends on elementary education and previous expenditure in some degree. Just as Sergio (1995) claimed: in economics, the link between R&D outlays and productivity growth[3] is one of the most difficult to observe and measure. We can just say that the R&D expenditure is positively correlated with technical progress roughly. Nevertheless, some studies use output method, patents as an index to describe technological progress. Tang et al. (2011) claimed that patents have positive relationship with technical progress. But it still challengeable; for example, the progress in the basic research areas is a powerful driving force in technological, such as the law of universal gravitation, but they are difficult to be patented.

Though input method and output method are not perfect, this paper still choose output method as an index of technical progress, because we can collect the data about patents directly in every region.

Also FDI is helpful to technical progress (Fu, et al. 2010), because in general, the foreign firms have better technology in saving energy. As a result, we also take FDI as an important index to measure technical promotion. By the way, dealing with the data, we convert the nominal FDI into real FDI.

Finally, how to calculate EI is vital in this empirical study. In this paper, we first collect the regional nominal GDP, and convert the nominal GDP into real GDP. Then find the energy consumption in every region, which is standard coal. Last, we can calculate the EI easily.

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[3] Generally speaking, productivity growth has the same meaning with technical progress (see Romer 2006).

### 5.2. Econometric Model

We have successfully found the indexes, the following work is to create econometric models to test the mathematical model analyzed above. Eviews 6.0 will be applied in this paper. Using a single model to simulate these 8 regions is difficult for different regions have their own features, so we must apply to difficult model in different regions. By the way, we found that FDI and patents is incompatible in a single function, so we have to separate them and different functions.

First, we used function ei=c+se+log(pa), where ei means energy intensity, c means the constant, se means the share of tertiary sector, log(pa) means patents. The result shows that only Northeast Area is applicable by:

$$ei = 7.94 - 0.06*se - 0.44*\log(pa)$$
$$(7.01)\ (-2.39)\quad(-8.76)\qquad AR= 0.87$$

It shows that in Northeast Area both the technical effect and structural effect negatively related with energy intensity, i.e. increase the share of tertiary sector and create more patents are helpful in decrease energy intensity.

Then, we used function ei=c+in+log(pa), where ei means energy intensity, c means the constant, in means the share of secondary sector, log(pa) means patents. The result shows that region C, D, E, F and G are applicable by:

| Area | function | AR |
|---|---|---|
| North Coast Area (C) | ei = - 0.16 + 0.05*in - 0.13*log(pa) | 0.79 |
| East Coast Area (D) | ei = - 0.39 + 0.015*in - 0.04*log(pa) | 0.91 |
| South Coast Area (E) | ei = 0.53 + 0.01*in - 0.05*log(pa) | 0.62 |
| Middle Area (F) | ei = 2.18 + 0.02*in - 0. 20*log(pa) | 0.81 |
| Northwest Area (G) | ei = 2.7 + 0.02*in - 0.25*log(pa) | 0.68 |

We can see that in region C, D, E, F and G structural effect and technical work on energy intensity. That is share of secondary sector positively related to EI and the patents negatively related to EI.

What is more, we can compare that in East Coast Area and South Coast Area, the economy developed for many years and reached a relatively high level, so decrease the share of the secondary sector, increase the share of tertiary sector and technological progress have little effect to EI. However, in other 3 regions, structural effect and technical effect have greater effect in EI, so in order to decrease the overall EI of China, structural upgrading and research expenditure should focus on the north and middle areas.

We also added FDI into the model in the model ei=c+in+log(fdi) where ei means energy intensity, c means the constant, in means the share of secondary sector, log(fdi) means FDI. The result shows that only region C, D and G satisfy this model by:

| Area | function | AR |
|---|---|---|
| North Coast Area (C) | ei = 1.83 + 0.06*in - 0.44*log(fdi) | 0.59 |
| East Coast Area (D) | ei = 0.4 + 0.027*in - 0.01*log(fdi) | 0.92 |
| Northwest Area (G) | ei = - 0.24 + 0.07*in - 0.43*log(fdi) | 0.78 |

It is evident that structural effect and technical effect of are workable in these regions. Both increase in FDI and decrease in the share of the secondary sector are good for declining the energy intensity. We can also get the same result that the east areas have a comparatively lower potential in promoting energy efficiency than inner land areas. Therefore invest in the inner land and upgrading their economic structures is helpful in prompting the energy efficiency.

From the empirical study we can see: on one hand the model works well, which means the mathematical model is proper. While on the other hand, through these practical models, we found that technical effect and structural effect have greater influence in north, west and middle areas than east coastal areas.

## Ⅴ.Conclusion

This paper created a mathematical model to study energy intensity (EI) from the perspective of industrial structure and technical progress which we call it structural effect and technical effect here. As to pierce the veil of EI, we divided the economy into two stages according to the Law of Petty-Clark: industrializing stage and post-industrializing stage in this model. It is clear that: 1) in the process of industrializing, its overall EI will be unstable: rising, falling or unchanging; 2) in the process of post-industrializing, its overall EI will decrease even if the technology makes no progress; 3) when the economy structure keeps unchanged, the EI will decline if the technology continues to make progress.

Finally, employing the regional date from the China Statistical Yearbook, we tested the model showing that it is workable. We also found that technical effect and structural effect have greater influence in north areas, west and middle areas than east coastal areas, so policy makers should know more technological investment and higher service share in tertiary industry in the inner areas will cause better effect in decreasing the energy intensity and increasing energy efficiency.

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