中国经济结构变化对能源强度的非线性影响

摘要：本文基于装备资本中明显存在技术进步这一事实，定义并估计了技术进步，包括资本体现的技术进步和希克斯中性的技术进步。此外，在定义了经济结构、能源价格和能源强度等变量之后，设定了这些变量间的一个门槛协整模型。检验结果证实了它们之间存在门槛关系，估计模型表明当经济结构指标大约是 40.435%时，经济结构对能源强度有非线性的影响：在 1980-1982，1995-1997 和 2003-2008 期间，经济结构和能源价格对能源强度有正向的影响，但是在 1983-1994，1998-2002 和 2009 年，却产生负向的影响；在 1980-2009 年期间，技术进步也对能源强度产生负向的影响。这些结论提供证据表明经济结构对能源强度有非线性的影响，这暗示了中国应该经常对经济结构进行重新调整，激励技术进步以便持续减少能源强度。

关键词：经济结构，能源强度，检验，门槛协整

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The Nonlinear Effect of China's Economic StructureChange on Energy Intensity

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Abstract: This paper, based on the fact that there exists manifest technological progress embodied in equipment capital, defines and estimates technological progress(TECH) including capital embodied technological progress and Hicks-neutral technological progress. Also, we define the variables of economic structure(ES), energy price(PRICE) as well as energy intensity(EI), then specify a threshold cointegration model between them. The tests results conform there is a threshold cointegration relation among the variables, and the estimated model exposes the relation that ES has nonlinear effect on EI when ES is around 40.435%: during the periods of 1980-1982, 1995-1997 and 2003-2008, ES and PRICE produce positive effects on EI, but negative effects for the periods of 1983-1994, 1998-2002 and 2009; TECH produce negative effect on EI during 1980-2009. These conclusions provide evidences that economic structure has the nonlinear effects on energy intensity and imply China should always carry out the structure readjustment, stimulate technological progress so as to reduce the energy intensity continuously.

Keywords: Economic structure; Energy intensity; Testing; Threshold cointegration

1. Introduction

Since China initiated market reforms in 1978, its economic structure has been evolution on the way to advance. The proportion of industry in GDP (structure hereafter) had changed from 44% in 1980 to 37% in 1990, and then ascended to 42% in 1997, but it became 39% in 2002. After then, it straight climbed to 43% in 2006, and readjusted to 40% in 2009. Correspondingly, the energy consumed for each 10,000 Yuan of GDP (energy intensity hereafter) presented the similar characteristics: at the beginning of reforms, the energy intensity decreased from 13.26(it was measured by tce/10^4yuan, which is calculated at 1980 constant prices, hereinafter the same) in 1980 to 8.94 in 1990. Hence our motivation is to answer the question: can and what extend the declining of energy intensity be attributed to economic structural adjustment? With the emphasis of the reforms turned from rural to urban, China began to set up a market-oriented economy, but initial immature market economy led to blindness and inefficiency of resources allocation, and economic agents pursued development, which induced so many high-level energy consuming projects and firms, and caused the structure raise to 42% in 1997. A typical fact of China's economic was the serious deflation in 1998-2002, to get over it, stimulating economic growth policy was implemented, which caused fast growth of the high-level energy consuming industries, such as iron and steel, building materials, nonferrous metals, chemicals and so on. It was results in the increase of the structure by 2.7% in 2003-2005, but the energy intensity increased by 9.6%. Above data imply questions: does the structure of China have different effects on energy intensity in different periods? What's the technological progress rule for the energy efficiency? Answering those questions is our motivation.

The relationship between energy intensity and economic structure is a hot spot in the literatures. Maddison (1987) declare "structure change is an important factor on energy intensity, and the effect reflected by the hypothesis of structure bonus". Schäfer (2005) demonstrate that the main industry would shift from agriculture to industry, and then to services, which brings about the structures of product and energy consumption optimized, so one would expect energy intensity decreased. Wang & Yang (2006) concluded that readjusted and optimized industry structure would benefit to improve energy efficiency. Yuan et al. (2010) applied grey incidence to test the relationship between energy consumption and industry/GDP during different periods, and the result showed that the change of industry/GDP caused the energy intensity declined in 1997-2000. Fisher-Vanden et al. (2004) investigate the reasons of energy intensity's fluctuation using panel data of companies, their conclusion revealed the structure change pushed the energy intensity decreased 53%. Philip (2009) provided empirical evidence fully supporting the views of Fisher-Vanden et al. (2004).

Using Törnqvist and Sato-Vartia Index decomposition methods, Liao et al. (2007) found the contribution from structural effects on the decline of energy intensity was -6% in 1997-2002. Ma & Stern (2008) used logarithmic mean Divisia index (LMDI) techniques to decompose changes in energy intensity, and the result showed that the structural change at the industry and sector (sub-industry) level actually increase energy intensity in 1980-2003. Wu (2008) applied a shift-share analysis to decompose the change in energy intensity and found that economic structure change caused the energy intensity increased during 1995-2004 except 1998. Li & Wang (2008) used five commonly decomposition techniques to analyze China's manufacturing energy intensity and found the structure changes contributed 7.5% to the decrease of energy intensity in

1995-2000. Qi (2007) found structure change was the main factor to declining energy intensity by decomposition analysis.

It can be seen from afore-mentioned literatures, previous researches have shown that economic structure is the main influence factor on energy efficiency by using linear model or decomposition techniques. But linear model can't reveal varying influences of economic structure on energy intensity during different periods. Decomposition techniques depend on formation and decompose method of index, and it also implies a strictly assumption that all decompose factors have the same proportionate effects on energy intensity. In this sense, linear model and index decomposition approach contribute little to reveal the possible nonlinear relationship between energy intensity and economic structure. This paper, based on the data feature of economic structure and energy intensity, specifies a nonlinear threshold cointegration model, and the tests conclusions reveal the nonlinear relation between energy intensity and economic structure etc in different levels of economic structure. The estimation results indicate the economic structure etc have different effects on energy intensity in different regimes (or different periods).

The remainder of this paper is organized as follows: Section 2 briefly discuss the data feature of variables and econometric methods. Section 3 provides the empirical results, and Section 4 reviews the conclusions we draw plus outlines some of the most important policy implications.

2. Variables and model specification

In order to reveal the nonlinear relationship between energy intensity, economic structure, technological progress and energy price, this paper first gives the definitions of variables and describes their data features, then discusses model specification.

2.1 Variables and data analysis

1. Energy intensity. According to national bureau of statistic and existing literatures, energy intensity (EI hereafter) is defined by energy consumption per GDP, namely:

$$EI=NC/GDP \tag{1}$$

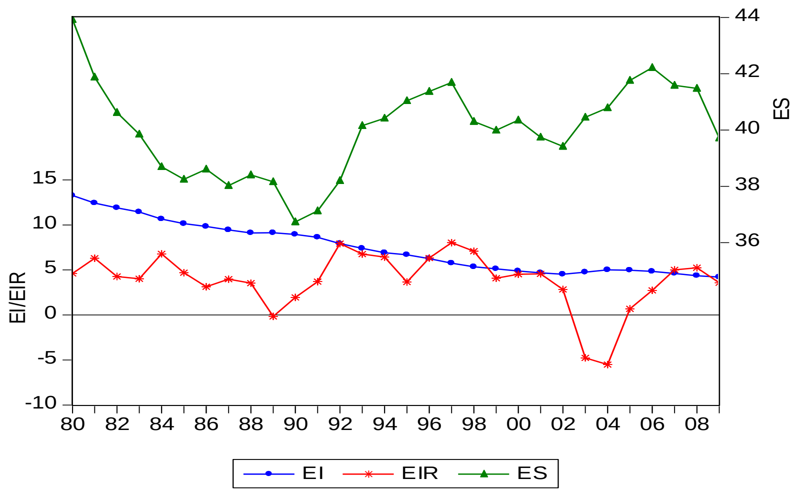
In which NC stands for energy consumption and measured by 10^4 tce, GDP for gross domestic product and measured by 10^8 Yuan (constant 1980 prices; same below except special illustrate). So EI is measured by energy consumption per 10^4 Yuan (tec/10^4 Yuan)[1].

According to formula (1), we can also define the rate of declining of energy intensity (EIR hereafter), namely:

$$EIR_t = -((EI_t / EI_{t-1}) - 1) \times 100\% \tag{2}$$

Obviously, the smaller EI means the higher energy efficiency, so EIR>0 indicates energy efficiency is improving; otherwise, EIR<0 indicates energy efficiency is decreasing. The numerical results of EI and EIR are showed by Fig.1.

Fig.1 Energy intensity and Economic structure in China, 1980-2009



As shown in Fig.1, EI is decreasing but has a latent nonlinear fluctuation in different periods; EIR shows such nonlinear fluctuation clearly, a typical example is in 2003-2005. With the development of high-level energy consuming industries (for example, iron and cement), EI was not only end its decline but increased. In 2007, under the restriction of the policy "energy conservation and emission reduction", EI declined again. In short, China's energy intensity shows significant differences in different periods. In addition, the value of EI and its fluctuation characteristic are similar to the existing researching files[2].

2. Economic structure. In the case of China, the industry consumes more than 70% of total energy, but is the largest contributor to GDP, so this paper define economic structure (ES hereafter) is:

$$ES = (GY / GDP) \times 100\% \tag{3}$$

In formula (3), GY is the industry added value (10^8 Yuan). Obviously, ES is a ratio. The calculated result is shown by the line ES in Fig.1.

In Fig.1, ES fluctuates in the pattern of two "V" s irregularly. From 1980 to 1997, its fluctuation forms a big "V"; from 1998 to 2009, it fluctuated in the pattern of a small "V". The bottom of first "V" is at ES=36.737 (in the year of 1990); the second is at ES=39.417 (in the year of 2002). Such transformation shows the dynamic evolution of China's economic structure: at the beginning and the mid-term of the reforms, primary industry grew fast and light industries accelerate growth, but the value of industry output was relatively small, which caused the structure declined rapidly, and the value of ES decreased to the lowest in 1990 (36.737). In the late 1990s, for many high-level energy consuming projects put into operation (for example, small cement, distillery, papermaking and steel), ES increased fast. What's an effect of ES on EI in this period? In 1998-2002, China suffered a deflation which depressed energy consumption of industry production. After 2002, heavy industries grew fast, and then ES increased from 40.454 in 2003 to 42.212 in 2006. The above characteristic of ES not only ceased the decline trend of EI, but also caused it increased to 4.841 in 2006, so it formed a second fluctuation like a small "V". After 2006, the government implements a program for the emission reduction, which results in the readjustment of both economic structure and energy intensity. According to Chinese classification of industry, production and supply of energy is also belong to industrial, so formula (3) also indicates energy consumption structure, while the share of unclean energy (like coal and oil) in the final energy consumption mix account for more than 80%, so unclean energy price may aggravate the effect of ES on EI in some periods. The above analysis about the fluctuation of ES means that ES may produces nonlinear effects on EI because of ES's two "V"s fluctuation, and the transformation may take place in the interval of 36 to 41 of ES.

3. Technological progress. From the economic theory and China's fact, technological progress helps for improving energy efficient and declining energy intensity, hence how to measure technological progress and its effect on energy intensity are key questions in academic research. In the related literatures, many papers use total factor productivity (TFP) [3] to measure technological progress. However, TFP only depends on the optimized allocation of resources, and it is Hicks-neutral, which means technological progress is "not" embodied in equipment and capital, so TFP is also named un-embodied technological progress. According to the truth of China's industries, technological level and energy efficiency are improved obviously by new investment and upgrades, import and develop advanced production equipments and machines. For example, the energy intensity of steel industry declined 12.1% during 2006-2010 by energy-saving technology retrofit and using advanced energy-saving equipments. So, technological progress embodied in capital, which named embodied technological progress, may be a major component of China's technological progress. Sterner(1990) analyzed energy efficiency in the Mexican cement industry and found reduction of energy intensity was mainly due to capital embodied technical progress. Zhao(2007) found the dynamic integration of the capital accumulation and technological progress was a stylized fact in China's economic growth, so there was great technological progress in equipment capitals. The above analysis means for rapid industrialized of China, it is more accurate to measure the capital embodied and Hicks-neutral technological progress(TECH hereafter). Based on the theory and related literatures, we start by the model as follows:

$$Y = F(K,L) = F(K_e, K_s, L) = A_0 e^{\theta t} K_e^{\alpha} K_s^{\beta} L^{\gamma} \tag{4}$$

Where Y denotes the output, L is human capital, and measured by the quantity of labors and its education, K_e denotes equipment investment and K_s is building investment. Embodied technological progress presents in equipment investment K_e. Let E indicates the average technical efficiency in capital stocks, K_e can be calculated by the follow formula:

$$K_e = EK \tag{5}$$

According to Greenwood (1997), the constant of returns to scale (that is $\alpha+\beta+\gamma=1$) can be assumed, thus we can get the follow model (all variables are in the form of logarithm):

$$ln(Y/L) = lnA_0 + \theta t + \alpha ln(K_e/L) + \beta ln(K_s/L) + \varepsilon \tag{6}$$

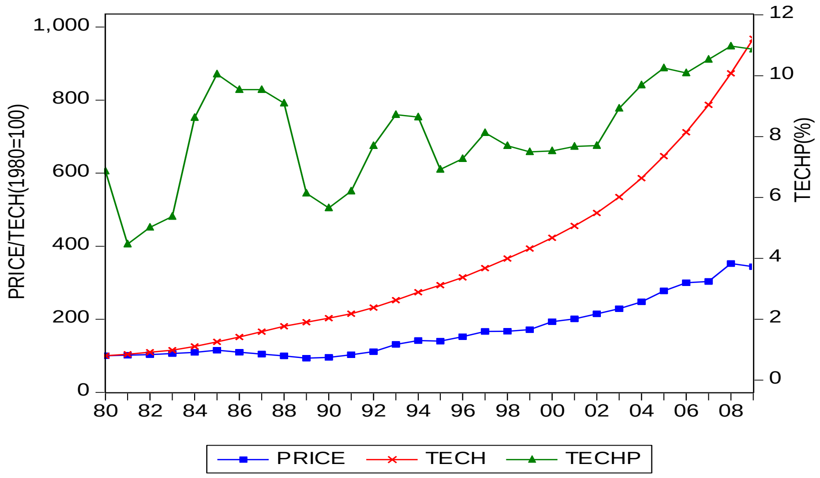
Furth more, taking (5) into model (6) and calculating its first derivative, we have:

$$\dot{y} = \theta + \alpha\dot{k}_e + \beta\dot{k}_s = \theta + \alpha(\dot{e} + \dot{k}) + \beta\dot{k}_s = (\alpha\dot{k} + \beta\dot{k}_s) + (\theta + \alpha\dot{e}) \tag{7}$$

Where $\dot{y}$, $\dot{k}_e$ and $\dot{k}_s$ denote first derivative of the variables, and means the growth rates of variables. So, $\alpha\dot{e}$ is embodied technological progress, and θ is Hicks-neutral technological progress, $\alpha\dot{k} + \beta\dot{k}_s$ is growth rate of capital stocks. Consequently, $\theta + \alpha\dot{e}$ is total technological progress including embodied and un-embodied technological progress.

We use Zhao's (2007) method to estimate K_e and K_s ; for L , we employ Wang's (2009) results and update it to 2009. The calculate result of $\theta + \alpha\dot{e}$ is shown by the line TECHP in Fig.2. Setting technological progress index in 1980 is 100, then we can get technological progress index (noted by TECH), which is shown in Fig.2 by the line TECH.

Fig.2 Technological progress and energy price in China, 1980-2009



We can see that the average rate of embodied technological progress is 4.644% (= $0.383\dot{e}$). It is higher than the average rate of Hicks-neutral technological progress (3.471%= θ), and accounts for 57.229% of the average rate of technological progress (8.115%) in sample periods[4]. Obviously, it is unsuitable to only use the Hicks-neutral technological progress to analysis the relationship between technological progress and energy intensity. Fig.2 also shown that the rate of technological progress (TECHP) is fluctuated drastically in 1980s, and remained stability in 1990s, after 2000, it kept increasing. The characteristic of TECHP is identical with the fluctuation of the equipment investment. In 1983-1986, the reforms of state-owned enterprises caused its equipments reconstruct, which improved the embodied technological progress. After 2000, fast growth of equipments investment promoted TECHP. In brief, China's TECH kept increasing, at the same time, as shown by the line EI in Fig.1, China's energy intensity kept decreasing. Does it mean technological progress promotes energy efficiency constantly? Does the rising of technological progress is driving energy intensity declining? This paper will answer these questions by testing results.

4. Energy price. The energy price is (PRICE hereafter) is defined as:

PRICE=EZP/GYP (8)

In which, EZP is energy complex price index by weighted average of three main energy industry's PPI (including coal, oil, and electricity), with the base year 1980, the weight is component proportion of their consumption in total energy consumption (both oil and gas use PPI of oil production). GYP is general PPI with the same base year. So, formula (8) is a relative price. The calculate result is shown by PRICE in Fig.2. If energy's PPI is higher, which means fuel cost in production is higher, in theory, PRICE can impel economic agents save energy, and energy intensity will decline. But, energy price's reforms in China undergo two stages including energy price controlled by state and by state-owned enterprises later. The PRICE in Fig.2 shows, in 1980-1993, China's energy price kept in very lower level. In 1994, China put coal price into the market (except the price of coal for generate electricity), and then PRICE increased from 111.322 in 1992 to 166.646 in 1997. In June of 1998, China's oil price reformed its form mechanism; in 1999, China raised its electricity price. These polices resulted in energy price fast increasing in 1998-2002. In 2002, PRICE was 216.873, increased by 50.228 compared with 1997's. On the contrary, energy intensity declined quickly. Does the above truth suggest high energy price benefits to improve energy efficiency? In 2003, China issued "reform program in electricity price", and in 2004 China links electricity price to coal price. At the same time, international oil price increased, which pushed China's oil price fast increased[5]. All of the above truth resulted in higher PRICE. But, ES raised and EI decreased in 2003-2004. On the other hand, there is a discordant fluctuation between energy consuming structure and its price, so the prices of coal, oil and electricity may cause different effects on EI in different periods. The above analysis suggests that China's energy price, which is dominated by state-owned energy enterprises, may have different effects on energy intensity.

2.2 Model specification

The above analysis for the data characteristic implies there maybe a nonlinear relationship between energy intensity, economic structure etc, and the effect of economic structure on energy intensity may switch from one regime to another regime at the threshold value of ES. To confirm and quantitative such possible nonlinear relationship, this paper specifies a nonlinear threshold cointegration model between the variables. Let lei_t, les_t, $ltech_t$ and $lprice_t$ denote the logarithm of EI, ES, TECH and PRICE respectively. To describe possible regime switch, this paper defines a nonlinear smooth transfer function $G(es_{t-d}, \gamma, th)$, because of ES's fluctuation in the form of two

"Vs", ES is taken to be threshold variable in the function[6], in which, d is the location parameter of regime switch, γ is the smooth parameter which determines the speed of regime switch, and th is a threshold value. Furthermore, $G(es_{t-d},\gamma,th)$ is a continuous function of threshold variable ES, and changes continuously between 0 and 1. Therefore, the threshold cointegration model amongst EI, ES etc can be specified as follows:

$$\begin{aligned} lei_t &= \beta_0+\beta_1 les_t+\beta_2 ltech_t+\beta_3 lprice_t \\ &\quad +(\lambda_0+\lambda_1 les_t+\lambda_2 ltech_t+\lambda_3 lprice_t)G(es_{t-d},\gamma,th)+u_t \end{aligned} \tag{9}$$

In model (9), the effects of variables ES etc on EI depend on the transfer function $G(es_{t-d},\gamma,th)$, when $G(\cdot)$=0 or closing to 0, the effects of the variables on EI are reflected by the first regime (described by coefficients β); when $G(\cdot)$=1 or closing to 1, the effects are reflected by the second regime (described by estimate coefficients $(\beta+\lambda)$); when 0< $G(\cdot)$ <1, the effects transfer smoothly between the two regimes, which depend on the value of $G(\cdot)$ and the effects can be described by $(\beta+\lambda\times G(\cdot))$. Especially, if all variables in model (9) follow unit root process, and the residuals is a stationary process, then model (9) is a nonlinear threshold cointegration model, which shows the long-term effects of ES etc on EI varies depending on whether ES is greater (smaller) than estimated threshold value. Based on tests results, this paper confirms that the model (9) is a threshold cointegration model, and the estimated results reveal the fact that the economic structure etc produce nonlinear effects on energy intensity.

3. Model Estimation and Testing

Whether model (9) is a nonlinear threshold cointegration model or not depends on testing results, we first give unit root tests for the variables involved, then test nonlinearity and determine detail form of the transfer function $G(\cdot)$, finally estimate the model and test the threshold cointegration.

3.1 unit root test for the variables

To ensure the accuracy of the conclusion, this paper uses two tests, ADF and PP respectively. The results are shown in Table 1.

Table 1 Unit Root Testing

Variable	Testing specification	ADF	PP	Conclusion
lei_t	（c,t）	-2.3728（0.3846）	-1.3774（0.8463）	I（1）
$\Delta\ lei_t$	（c,0）	-3.0342（0.044）	-2.3542（0.1632）	I（0）
les_t	（c,t）	-2.6918（0.2470）	-3.4048（0.0703）	I（1）
$\Delta\ les_t$	（c,0）	-3.5284（0.0146）	-3.5284（0.0146）	I（0）
$lprice_t$	（c,t）	-2.4357（0.3543）	-1.5205（0.7988）	I（1）
$\Delta\ lprice_t$	（c,0）	-3.6629（0.0106）	-3.7384（0.0089）	I（0）
$ltech_t$	（c,t）	0.2020（0.9967）	-0.4745（0.9790）	I（1）
$\Delta\ ltech_t$	（c,0）	-3.4767（0.0623）	-2.9275（0.0548）	I（0）

Notes: In the test specification column, the items in brackets are as follows: c indicates an intercept item, t a time trend item; for ADF and PP test statistical values, the data in brackets are the p values corresponding to statistical tests.

It can be seen from Table 1 that all variables are I(1) and their first order differences are all I(0), which further supports the conclusion.

3.2 Nonlinear test and the determination of smooth transfer function

We first give model specification testing, it includes linear versus nonlinear test (testing whether there is a nonlinear threshold), determination of smooth transfer function form and its parameters. For the purpose of testing whether there is a transformation function $G(es_{t-d},\gamma,th)$, we first determination the location parameter d. To do so, it is generally assumed that the form of $G(\cdot)$ is an exponential or a logic function, and undergo third order Taylor expansion at the original point, then put the expansion into model (9), which yields formula (10) after being reparameterized:

$$lei_t = \beta_0 + \beta x_t + (\lambda_0 + \lambda x_t)\sum_{i=1}^{3}\rho_i es_{t-d}^{i} + u_t \quad (10)$$

In formula (10)， $x_t = (les_t, ltech_t, lprice_t)'$. According to Dijk et al (2002), we estimate model (10) by ordinary least square (OLS) with different values of d, and determine final d, where the switch takes place, corresponding to the lowest AIC or maximum $\bar{R}^2$. In this paper, we choose d_{max}=6, the results are shown in Table 2. As we can see in Table 2, when d=1, -79.1451 is the lowest AIC value and 0.9772 is the maximum $\bar{R}^2$ value, so we take d=1.

Table 2 Determination of the value of d

d	0	1	2	3	4	5	6
AIC	-68.227	-79.145	-64.077	-62.323	-59.473	-57.872	-37.325
$\bar{R}^2$	0.967	0.977	0.962	0.960	0.956	0.954	0.895

Further, in order to test nonlinearity, we specify the null hypothesis (constraint) H_0: $\rho_1 = \rho_2 = \rho_3 = 0$, rejecting it means the existence of nonlinearity, the LM statistic (Teräsvirta ,1994) can be used to test the null hypothesis. However, in model (10), all variables are I(1), so LM statistic doesn’t has a classical distribution. Therefore, we have to conduct bootstrap numerical distribution of LM statistic, corresponding results are included in Table 3.

The results of Table 3 show the calculated LM^T =98.266 (testing for H_0: $\rho_1 = \rho_2 = \rho_3 = 0$), greater than LM_T^b =55.914, the critical value of 1% by bootstrap, thereby rejecting the null hypothesis and implying the presence of nonlinearity. This result provides evidence that there is a regime switch. Therefore, we need to test whether the nonlinear transfer function $G(\cdot)$ in model (9) is a logic function or an exponential function. Based on Teräsvirta et al.(2008), a sequential null hypothesis H_{01}($\rho_3 = 0$)and H_{02}($\rho_2 = 0 \mid \rho_3 = 0$) as well as H_{03}($\rho_1 = 0 \mid \rho_2 = 0, \rho_3 = 0$) have to be tested. If H_{02} is the strongest rejected, which refers that $G(\cdot)$ in model (9) is an exponential function, otherwise it would be a logic function. We again use the LM test to test the hypothesis. The corresponding results are also shown in Table 3, which obviously gives the conclusion that $G(\cdot)$ is a logic function. This result indicates that the effects of economic structure etc on energy intensity have a regime switch by a logic function, so the effects varies in different regimes (different periods) and depend on whether the value of ES is greater (smaller) than a certain value (threshold value to be determined next).

Table 3 Model specification tests

Null hypothesis	LM^T	LM_T^b （1%的临界值）	p-value
H_0： $\rho_1=\rho_2=\rho_3=0$	98.266	55.914	0
H_{01}： $\rho_3=0$	0.564	26.098	0.956
H_{02}： $\rho_2=0\mid\rho_3=0$	7.237	22.003	0.187
H_{03}： $\rho_1=0\mid\rho_2=0,\rho_3=0$	71.432	19.534	0

Notes: LM^T indicates the value of LM statistic with sample values; LM_T^b indicates the critical value of 1% by bootstrap; the last column (p-value) is based on bootstrap method, in which the number of iterations is 1000.

3.3 Threshold cointegration test

Up to now, the results obtained have shown that the long-term relationship between economic structure etc and energy intensity is nonlinear with the logic function transformation. Whether such relationship is a threshold cointegration relationship or not depends on the residuals. Denoting the residuals of the model (9) as $\hat{u}_t$, if $\hat{u}_t$ ~I(0), then model (9) is the threshold cointegration model. Choi and Saikkonen (2008) proposed a threshold cointegration test, the null hypothesis is H_0： $\hat{u}_t \to I(0)$. The test statistic is:

$$C_{NLS}^{b,i}=b^{-2}\hat{\omega}_{i,u}^{-2}\sum_{t=i}^{i+b-1}(\sum_{j=i}^{t}\hat{u}_j)^2\Rightarrow\int_0^1 W^2(s)ds \qquad (11)$$

Where subscript NLS means model (9) is estimated by NLS, $\hat{\omega}_{i,u}^{-2}$ is the consistent estimate of the long-term variance ω_u^2 of $\hat{u}_t$, b is the sample size of the partial residuals selected, i is the starting point of the partial residual, and $W(s)$ is standard Brownian motion. For different b and i and H, we can calculate the maximization of the $C_{NLS}^{b,i}$:

$$C_{NLS}^{b,i;\max}=\max(C_{NLS}^{b,i_1},\cdots,C_{NLS}^{b,i_H}) \qquad (12)$$

Where H is the minimized number of subresiduals-based tests, which should guarantee the whole sample is be used to calculate $C_{NLS}^{b,i}$. The detail calculates method can refer to Choi and Saikkonen (2008). Moreover, in order to calculate the critical value of the limiting distribution in (11), based on Wang & Ouyang (2008), we designed and conducted a Monte Carlo simulation, the results of it are included in Table 4.

Obviously, the calculation value of $C_{NLS}^{b,i;\max}$ statistic is 0.4999, lower than 2.491, the critical value of 5% of its limiting distribution. Hence we accept the null hypothesis $\hat{u}_t \to I(0)$, that is, the estimated model (9) is the threshold cointegration model.

Table 4 The results of statistical tests of threshold cointegration

Statistic	Estimated value	Critical value of 5%	p-value	Conclusion
$C_{NLS}^{b,i;\max}$	0.4999	2.491	0.974	H_0

Notes: The number of iterations is 1000.

3.4 The estimation of the threshold cointegration

In order to estimate model (9), we need to determinate the threshold value th, so we sort the sample data of es and choose its mid 80% for possible threshold values. We estimate model (9) by NLS for every possible threshold value, and iterate this process until the smallest residual sum of squares (RSS) is obtained. Finally the estimated threshold value is 40.435, so the final form of the nonlinear smooth transfer function is:

$$\hat{G} = \{1 + \exp[-496(es_{t-1} - 40.435)]\}^{-1} \tag{13}$$

As we have known, ES fluctuates in the form of "Vs" in sample period, which caused nonlinear effects of ES on EI, and the transformation may take place in the interval of 36 to 41 of ES. Formula (13), especially the estimated threshold value (th =40.4) is not only confirms the nonlinear effects of ES on EI, but also gives the transform function and its level. It is one of conclusions in this paper.

Take equation (13) and previous estimated parameters $\hat{\beta}$ and $\hat{\lambda}$ (as initial values) into model (9), then we apply Newton iteration to model (9), the final estimation is as follows (in the brackets are t statistical values):

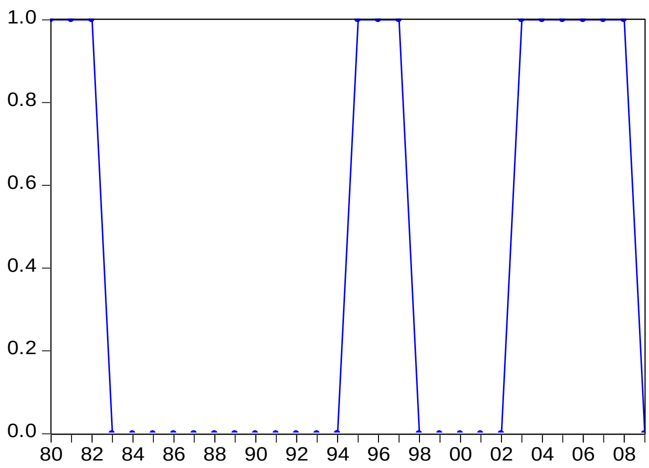
$$\begin{aligned} lei_t &= 6.199 - 0.047 les_t - 0.483 ltech_t - 0.282 lprice_t \\ &\qquad\quad (-3.255) \quad (-215.389) \quad (-40.532) \\ &\quad + [-4.248 + 0.333 les_t - 0.502 ltech_t + 1.164 lprice_t]\{1 + \exp[-496(es_{t-1} - 40.435)]\}^{-1} + \hat{u}_t \\ &\qquad\quad (1.942) \quad (-68.533) \quad (51.410) \end{aligned} \tag{14}$$

We know from the results of the threshold cointegration tests (Table 4) that equation (14) is the long-term threshold cointegration relationship among energy intensity and economic structure etc in China, this is the main conclusion of this paper. Equation (14) indicates that economic structure, technological progress and energy price have different effects on energy intensity in two regimes. In the first regime ($G(\cdot)$ is or be closing to 0, corresponding the years of 1983-1994, 1998-2002 and 2009), the long-term partial effect of economic structure on energy intensity is

-0.047, that is to say, in these periods, economic structure produces negative effect on energy efficiency, which suggests there is “structure bonus” on energy efficiency. Also, technological progress and energy price have negative effects on energy intensity. In the second regime ($G(\cdot)$ is 1 or be closing to 1, corresponds the years of 1980-1982, 1995-1997 and 2003-2008), economic structure has positive effect on energy intensity, and its value is 0.286 (=0.333-0.047). That is to say, holding constant of technological progress and energy price, if the economic structure goes up by 1%, it would cause energy intensity going up by 0.286%. In this regime, in addition, energy price also has positive effect on energy intensity. Obviously, the estimated result (14) suggests that the technological progress always has negative effect on EI, which implies that the declining energy intensity is mainly attributed to the raising technological level. In a word, the estimated result (14) is a nonlinear threshold cointegration model and indicates there is nonlinear relationship among energy intensity, economic structure, technological progress, and energy price. This relationship has an important implication: to reduce the energy intensity continuously, China should insist on adjusting the economic structure and raising the level of technological.

Furthermore, we can investigate the estimated logic transform function $G(\cdot)$. It is showed by Fig.3, which divides the long-term relationship into different regimes. Fig.3 shows that the transform function quickly switch between 0 and 1, the estimate γ (=496) indicates that the effects switch quickly, while d=1 means the change of economic structure results in energy intensity changes rapidly. For example, in 2003 the value of ES is 40.454, increased by 2.631%, which stimulates the energy intensity rising by 5.501% in 2004; in 2007 the value of ES is 41.584, decreased by 1.488%, which results in the reduction of the energy intensity by 5.231% in 2008. The above typical data is logical consistent to the estimated results.

Fig.3 Transform function G（•）



The estimated threshold value (ES=40.435), as shown in Fig.1, is located in the bottom of the fluctuation of economic structure, that is to say, the effect of ES on EI switches at ES is 40.435. When ES is smaller than 40.435, the estimated value of the transfer function $G(\cdot)$ is 0 or approximates to 0 for the years 1983-1994, 1998-2002 and 2009. In these periods, the effect of ES on EI is mainly described by the first regime (the value is $\hat{\beta}_2$=-0.047). In 1983-1992, China implemented some polices including recovering agricultural production, promoting the third and the light industry development, which induced relative lower annual averages ES (= 38.553), smaller than 40.435, such ES is helpful to depressing EI. For example, in 1990, China launched a rectification which caused the lowest economic growth (only 3.8%), many projects were compacted or paused, and the ES declined to 36.737. This rectification made economic structure "lighter", consequently caused energy intensity's reduction. Another typical year is 2009, under the subprime lending crisis and the policies of "energy conservation and emission reduction", Chinese economic structure readjusts download to 39.717 quickly. This adjustment transformed the effects of ES on EI from 0.286 in 2008 to -0.047 in 2009. Above typical truth suggested the policies of "energy conservation and emission reduction" had achieved initial success. It also indicates that the formula (14) not only reveals the different effects of ES on EI, but also accurately reflects the typical facts during sample periods.

When the estimated $G(\cdot)$ is 1 or approximates 1 for the years 1980-1982, 1995-1997, 2003-2008, ES is obviously higher than 40.435, and the effect of ES on EI is mainly described by the second regime (the value is $\hat{\beta}_2 + \hat{\gamma}_2$=0. 286). In 1980-1982, agriculture growth depressed the EI. In 1995-1997, China suffered the inflation for 4 years which pushed up the ES from 40.4 in 1994 to 41.7 in 1997. Such higher inflation reinforced the high-level energy consuming structure. In 2003-2008, China turned into a new construction stage owing to the massive urban infrastructure, which again reinforced the high-level energy consuming structure. In 2004, the ES reached to 40.787, and was higher than the threshold value 40.4. As shown in Fig.1, the readjustment pushed the energy intensity up 0.286% while ES up 1%. In a word, the high-level energy consuming structure, which formed in late 1990s and worsens around 2004, produces positive effect on EI.

Since 2006, China's government has launched a policy named as "energy conservation and emission reduction", this policy set up an "energy conservation and emission reduction" target for local governments and large-scale enterprises. The implement of the policy halted the upward trend of EI, and directly caused EI changed from 4.841 in 2006 to 4.598 in 2007, and then to 4.357 in 2008. The above fact shows that "energy conservation and emission reduction" has taken effect on energy intensity. However, ES also had positive effects on EI in 2006-2008, which means the policy didn't have obvious effect on the structure. But in 2009, the effect of ES on EI turned to negative, which means that adjusting the structure is a long term strategic to reduce energy intensity continuously

Based on (14), the technological progress, produces obviously negative effect on energy intensity in whole sample periods. After 2002(in the second regime), owing to the renewal fixed assets, a large number of new equipments, especially a number of energy-saving equipments put into action, China's technology level rapidly increased, which caused the negative effect of TECH on EI(-0.985), which is about twice than it in the first regime. This result suggests that rising technical progress continually is an efficient tool to improving energy efficiency.

Comparing to existing literatures, the results of this paper reveal nonlinear effects of economic structure on energy intensity in sample periods in the case of China, which also differ from the results of Fisher-Vanden et al. (2004) and Wu (2008). Also the relationship (14) is different from the result of Lin et al (2010).These is the main contribution of the paper to the literatures.

To sum up, the formula (14) is the long-run relationship among ES, TECH, and PRICE on EI in China, which indicate that ES, PRICE have negative effects on EI in the periods of 1983-1994, 1998-2002 and 2009, but positive effects in the periods of 1980-1982, 1995-1997 and 2003-2008, and TECH produced negative effects on EI in all sample periods. This is the main conclusion of the paper.

4. Conclusions

In this paper, we estimated technological progress including capital embodied technological progress and Hicks-neutral technological progress, and specified a threshold cointegration model for Chinese economic structure, technological progress, energy price, as well as energy intensity, testing and estimation results conformed there was a threshold cointegration relation among the variables. The main findings are as follows:

(1) This paper estimates technology progress including capital embodied technological progress and Hicks-neutral technological progress exactly. Moreover, the estimated result (14) confirms that the estimated technological progress depressed the energy intensity.

(2) The long-term relationship among economic structure, technology progress, energy price and energy intensity in China is the nonlinear threshold cointegration described by (14), that is to say, the long-term effects of economic structure, technology progress, energy price on energy intensity display nonlinear transition which depend on whether the economic structure is greater (smaller) than the estimated threshold value (40.435%). In the periods of 1983-1994, 1998-2002 and 2009, the effect of economic structure on energy intensity was -0.047; in the periods of 1980-1982, 1995-1997 and 2003-2008, the effect was 0.286. This conclusion revealed the nonlinear effects of economic structure on energy intensity.

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[1] All data of this paper are obtained from various issues of China Statistical Yearbook, China Energy Statistical Yearbook and China compendium of statistics 1949-2008. We use the period from 1980 to 2009.

[2] The choice of the base year affects the values of EI, but the data characteristics of EI similar for different basic years. We analyses the EI uses year 1980 and 2000 as the base years, and found the values of EI were very similar (in natural logarithms), and it had little influence to the result of this paper. The reader can refer to Liao H., Fan Y., Wei Y.M., "What induced China's energy intensity to fluctuate: 1997-2006?"; Ma C.B., Stern D. I., "China's changing energy intensity trend: A decomposition analysis"; Wang J. S. & He C.F., "Technological Progress, Structural Change and China's Energy Efficiency", China Population, Resources and Environment, Vol. 7,no.2,(July 2009),pp. 44-49.

[3] TFP, which can be measured by Solow residual method, DEA method, SFA model and so on，has great influence on energy intensity. The reader can refer to Shi D. Wu L.X., Fu X.X., Wu B., "Studying on the difference and its causes on the energy efficiencies of different areas in China", Management World, no.2, 2008, pp. 35-43; Wu L.X., "The Fluctuations of China's Energy Efficiency: Theoretical Explains, Numerical Simulations and Policy Experiments", Economic Research Journal, no.5,(May 2009),pp. 130-142.

[4] We note the reader that it is the rate of technological progress and its index, so it is significant different from the effect technological advances on economic growth.

[5] From 2003, international oil price increased by a large margin, the oil future price of WIT increased from about $30 in the beginning of 2003 to $140 in July of 2008. Accordingly, the average oil PPI of China was 115.733 in 2003-2008.

[6] In this paper, the threshold variable es_{t-d} contains time trend, which implies the transition function tends to decrease or increase monotonically as the sample size grows, so we first get rid of this trend, the methodology refers to Choi I., Saikkonen P., "Testing linearity in cointegrating smooth transition regressions", *Econometrics Journal*, vol. 7, no.2 (Dec 2004), pp. 341–365.