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A new production function with technological innovation factor and its application to the analysis of energy-saving effect in LSD*

Qian Liao[2], Zhibin Wu[2], Jiuping Xu[1,2†]

[1] Low-carbon Technology and Economy Research Center, Sichuan University, Chengdu 610064, P. R. China
[2] Uncertainty Decision-Making Laboratory, Sichuan University, Chengdu 610064, P. R. China

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Abstract. Energy and technology draw much attention these days. Against the background of low-carbon economy, the utilization of clean energy, or green energy seems irreplaceable. It's been widely accepted that technological innovation increases energy efficiency. This paper attempts to create a new Cobb-Douglas production function and estimate the impact of technological innovation over energy saving regarding to clean energy and non-clean energy by adding technological innovation factor. We assume that technological innovation has constant growth rate. Based on the new function model, an empirical study of Leshan District (LSD) is presented and time serial data is used from 1995 $\sim$ 2009. The result of our study indicates that the performance of clean-energy-saving effect of technological innovation still has large room for improvement in LSD, which provides policy implication for decision makers.

Keywords: Cobb-Douglas production function, clean energy, technological innovation, low-carbon economy (LCE)

1 Introduction

Since the birth of Cobb-Douglas production function in 1928[5], numerous researches have addressed this issue and contributed to production function. The main merit of original production function was that it allowed for input factors to change in magnitude in response to factor price changes, rather than fixing ratios of these inputs[10], which makes this production function a good approximation for total production over time. However, one limitation of this production function is quite undesirable for later application to both macro- and micro-economy analysis, which is the two-factor input in this production function. Given its limitation regarding the two-factor input in explaining economic growth and the need to treat more than two factors, researchers seek to extend this production function to better explain the source of economic growth. CES (Solow) production function was introduced in 1961 by Arrow et al.[3]. Hogan and Manne[11] introduced a version wherein they embedded a Cobb-Douglas production function for capital and labour within a CES (Solow) function.

There have been numerous extensions of the Cobb-Douglas and CES (Solow) production functions, such as the Variable Elasticity of Substitution (VES) function introduced by Revankar[18] and the Stone-Geary (displaced Cobb-Douglas) production function. A highly generalized form incorporating several elements of these was created by Fullerton[8]. Most of these newly-formed production functions address different issues given different phases of economic and social development. For energy economist, what they interest most is the energy efficiency gains over energy consumption with technological progress over time. Intensive researches have addressed the relationship between technological innovation and energy consumption. Maria[17] used a stochastic frontier production function model to analyze the energy efficiency of Spanish industry given

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† Corresponding author. Tel.: +86 28 85418522. *E-mail address*: xujiuping@scu.edu.cn.

the severity of global warming according to the estimates of Intergovernmental Panel on Climate Change (IPCC)[13]. Horace and Robin studied the rebound effect of technological innovation towards energy efficient design[12]. Harry discussed how energy efficiency gains affected energy consumption using several production function including adjusted form of Cobb-Douglas production function and made comparison between different production functions to best explain the energy efficiency[10]. Following that, Wei[19] presented similar Cobb-Douglas production function and assumed that there are totally three primary resources required in the production of an economy as capital, labor, and energy. Most studies are for the theory that technological innovation can reduce energy consumption. Still, few hold opposite attitude towards this issue. Horace[12] cast doubt on the theory that technological innovation improves the efficiency of energy-using products and systems and leads to lower energy consumption and hence reduces environmental impacts. Yuan[4] studied energy-saving effect of technological progress based on Cobb-Douglas production function and its finding was also quite consistent with previous studies that technology reduces energy intensity.

Against the background of low-carbon development and global warming crisis, energy consumption draw unprecedented attention. One reason for the significant role of energy lies in that energy is nonrenewable. Another more important reason is that the use of energy generates pollutants to earth. The main contributor of present global warming is CO_2. Dovi et al. studied the sustainable future of cleaner energy and conclude that the global warming related to CO_2 emissions, coupled with steeply rising energy prices and the recent global financial institutional melt-down are causing massive societal concerns and give rise to increasing demand for ways to improve societal and individual energy efficiency and for ways to shift increasingly to alternative, low or non-carbon based energy systems[6]. The government of United Kingdom unprecedentedly proposed a white paper on low-carbon energy named "our energy future: creating a low carbon economy" in 2003 after the Economic Development Strategy[9]. Giving the strategic significance of energy in modern society as well as its irreplaceable role in constructing low-carbon community, this paper further classifies energy into two categories: clean energy and non-clean energy. The object of this paper is to discover the impact of technological innovation upon clean energy and compare the elasticity of technological innovation over different types of energy. Moreover, based on previous researches, this paper forms a new production function in an attempt to discover the relationship between technological innovation and clean and non-clean energy.

This paper creates a new Cobb-Douglas production function model by adding new economic factor and analyzes its properties in Section 2. Section 3 is an empirical research of Leshan District, China, using newly formed production function. Moreover, regarding data analysis, we use time serial data and adjust data at constant price by employing GDP deflator and GDP indices. Multi-linear regression method is also employed to calculate the results. Section 5 presents policy implications according to our findings in Section 4. The last section concludes the results and addresses further work of this research.

2 A new production function and its properties

A new Cobb-Douglas production function will be formed and its properties will be discussed in this section.

2.1 A new production function

Charles Cobb and Paul Douglas presented a classic production function in 1928 when they were working on the problem of relating inputs and output at the national aggregate level, that is, Cobb-Douglas production function[5]. For production, the function is $Y = AL^{\alpha}K^{\beta}$, where $Y =$ total production (the monetary value of all goods produced in a year); $L =$labor input; $K =$capital input; $A =$ total factor productivity.

Originally, this was attempting to solve two issues: (1) to measure the changes in the amount of labor and capital which have been used to turn out this volume of goods; and (2) to determine what relationships existed between the three factors of labor, capital and product.

Over decades, the history of economic growth shows that, energy is also a good indicator of economic growth. Kraft and Kraft[14] unprecedentedly studied the relationship between energy consumption and economic growth. Mahmoud[16] analyzed the relationship between energy consumption and GDP in six oil-importing countries. Lise and Van Montfort[15] found recently that in Turkey, energy consumption and GDP are cointegrated and the direction of causality is running from GDP to energy consumption. Fatih[7] analyzed the long-run relationship between energy consumption and real gross domestic product (GDP) in Turkey taking into account the size of unrecorded economy. Saunders[10] analyzed the impact of energy efficiency gains on output(roughly, GDP) using a Cobb-Douglas production function. Wei[19] assumed there are totally three primary resources required in the production of an economy as capital K, labor L, energy E and presented a Cobb-Douglas production function included the factor energy.

Based on the previous studies, this paper presents a new Cobb-Douglas production function with five variables: output (Y), capital (K), labor (L), energy (E), and capacity of technological innovation (T). Capital, labor, energy, and technological innovation are considered as production factors combined to produce maximum output. So the production function takes the mathematical following form:

$$Y(t) = f(K(t), L(t), E(t), T(t)). \tag{1}$$

Furthermore, against the low-carbon economic background, energy is classified into two categories: clean energy and non-clean energy. Generally, the source of clean energy mainly originates from wind, solar, wave, tidal hydropower and nuclear. Non-clean energy mainly refers to coal, fuel, and other forms of traditional energy which cause environmental pollution. Consequently, the above function is adjusted as:

$$Y(t) = f(K(t), L(t), E_1(t), E_2(t), T(t)). \tag{2}$$

We assume that technological innovation is exogenous and has a constant growth rate c, and it grows exponentially

$$T(t) = Ae^{ct}. \tag{3}$$

Thus, the new production function is as follows:

$$Y(t) = Ae^{ct}K(t)^{\alpha}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2}. \tag{4}$$

In the above function, Y represents Output, thus, as a dependent variable; the independent variables are K, L, E, Ae^{ct}, which stand for capital, labor, energy and technology, respectively.

2.2 The properties of the new cobb-douglas production function and economic explanation of variables

Property 1. When $Y(t) = Ae^{ct}K(t)^{\alpha}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2}$.
The economic explanations of α, β, γ_1, γ_2 are the elasticity of output with respect to capital; the elasticity of output regarding labor; the elasticity of output with respect to clean energy and non-clean energy, respectively. and $0 < \alpha, \beta, \gamma_1, \gamma_2 < 1$.

Proof. From Eq. (4):

$$\frac{\partial Y(t)}{\partial K} = Ae^{ct}\alpha K(t)^{\alpha-1}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2}, \qquad \frac{\partial Y(t)}{\partial L} = A\beta e^{ct}K(t)^{\alpha}L(t)^{\beta-1}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2},$$
$$\frac{\partial Y(t)}{\partial E_1} = A\gamma_1\beta e^{ct}K(t)^{\alpha}L(t)^{\beta}E_1(t)^{\gamma_1-1}E_2(t)^{\gamma_2}, \quad \frac{\partial Y(t)}{\partial E_2} = A\gamma_2\beta e^{ct}K(t)^{\alpha}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2-1}. \tag{5}$$

We get

$$\begin{aligned} Y_K(t) &= \frac{\partial Y(t)/\partial K}{Y/K} = Ae^{ct}\alpha K(t)^{\alpha-1}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2} \cdot \frac{K}{Y(t)} \\ &= \frac{Ae^{ct}\alpha K(t)^{\alpha-1}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2}}{Y(t)} = \alpha. \end{aligned} \tag{6}$$

Using the same method, we can get

$$Y_L(t) = \beta, Y_{E_1}(t) = \gamma_1, Y_{E_2}(t) = \gamma_2. \tag{7}$$

Definition 1. *Scale Elasticity refers to increasing percentage of output due to increasing of production scale. $E(x)$ denotes scale elasticity, then,*

$$E(x) = \frac{dy(t)/y(t)}{dt/t} = \frac{dy(t)}{dt} \cdot \frac{t}{y(t)}. \tag{8}$$

$E(x) >, =, < 1$ denote increasing/constant/decreasing returns to scale, respectively.

Property 2. When we have the equation $Y(t) = Ae^{ct}K(t)^{\alpha}L(t)^{\beta}E_1(t)^{\gamma_1}E_2(t)^{\gamma_2}$
The scale elasticity of Eq. (4) is $E(x) = \alpha + \beta + \gamma_1 + \gamma_2$.

Proof. From Eq. (4), we have:

$$\begin{aligned} Y_\lambda &= f((\lambda kt), \lambda L(t), \lambda E_1(t), \lambda E_2(t), T(t)) = Ae^{ct}(\lambda k)^{\alpha}(\lambda L)^{\beta}(\lambda E_1)^{\gamma_1}(\lambda E_2)^{\gamma_2} \\ &= \lambda^{\alpha+\beta+\gamma_1+\gamma_2}Ae^{ct}K^{\alpha}L^{\beta}{E_1}^{\gamma_1}{E_2}^{\gamma_2}, \end{aligned} \tag{9}$$

$$\begin{aligned} E(x) &= \frac{\mathrm{d}y_\lambda}{\mathrm{d}\lambda} \cdot \frac{\lambda}{y\lambda} = (\alpha + \beta + \gamma_1 + \gamma_2)\lambda^{\alpha+\beta+\gamma_1+\gamma_2-1}Ae^{ct}K^{\alpha}L^{\beta}{E_1}^{\gamma_1}{E_2}^{\gamma_2}\frac{\lambda}{y\lambda} \\ &= \alpha + \beta + \gamma_1 + \gamma_2. \end{aligned} \tag{10}$$

Corollary 1. *From Pro. 2, we have:*
(1) $\alpha + \beta + \gamma_1 + \gamma_2 = 1$, the economic explanation of $Y(t)$ means that this production function has constant scale elasticity;
(2) $\alpha + \beta + \gamma_1 + \gamma_2 > 1$, the economic explanation of $Y(t)$ means that this production function has increasing scale elasticity;
(3) $\alpha + \beta + \gamma_1 + \gamma_2 < 1$, the economic explanation of $Y(t)$ means that this production function has decreasing scale elasticity.

Proof. When $\alpha + \beta + \gamma_1 + \gamma_2 = 1$, we have

$$\begin{aligned} &f((\lambda kt), \lambda L(t), \lambda E_1(t), \lambda E_2(t), T(t)) = \lambda^{\alpha+\beta+\gamma_1+\gamma_2}Ae^{ct}K^{\alpha}L^{\beta}{E_1}^{\gamma_1}{E_2}^{\gamma_2} \\ &= \lambda Ae^{ct}K^{\alpha}L^{\beta}{E_1}^{\gamma_1}{E_2}^{\gamma_2} = \lambda f(Y(t)). \end{aligned} \tag{11}$$

This means that $Y(t)$ has constant scale elasticity. (2) and (3) can be proved in the same way.

2.3 Solution approach

In our paper, we assume that the production function has constant returns to scale in its four arguments, capital, labor, clean energy and non-clean energy, then

$$\alpha + \beta + \gamma_1 + \gamma_2 = 1. \tag{12}$$

From Eq. (12), we can get

$$\left(\frac{E_1}{Y}\right)^{\gamma_1}\left(\frac{E_2}{Y}\right)^{\gamma_2} \times e^{ct} \times A = \frac{Y^{1-\gamma_1-\gamma_2}}{K^{\alpha}L^{\beta}}. \tag{13}$$

Setting $\chi_1 = E_1/Y$, $\chi_2 = E_2/Y$ which indicates clean and non-clean energy consumption per output or energy intensity, respectively; setting $y_k = Y/K$ which indicates output per capital; setting $y_1 = Y/L$ which indicates output per labor. Then Eq. (13) can be rewritten as:

$$\chi_1^{\gamma_1} \times \chi_2^{\gamma_2} \times e^{ct} \times A = y_k^{\alpha}y_l^{\beta}. \tag{14}$$

Calculate the natural log of the two sides of Eq. (14), and yields:

$$\gamma_1 \ln \chi_1(t) + \gamma_2 \ln \chi_2(t) + ct + \ln A = \alpha \ln y_k(t) + \beta \ln y_l(t). \tag{15}$$

Calculate the derivative of the two sides of Eq. (15), and yields:

$$\gamma_1 \frac{\dot{\chi}_1(t)}{\chi_1(t)} + \gamma_2 \frac{\dot{\chi}_2(t)}{\chi_2(t)} = \alpha \frac{\dot{y}_k(t)}{y_k(t)} + \beta \frac{\dot{y}_l(t)}{y_l(t)} - c. \tag{16}$$

$\dot{\chi}_1(t)/\chi_1(t)$ denotes the growth rate of $\chi_1(t)$ (clean energy intensity); $\dot{\chi}_2(t)/\chi_2(t)$ denotes the growth rate of $\chi_2(t)$ (non-clean energy intensity); $\dot{y}_k(t)/y_k(t)$ denotes the growth rate of $y_k(t)$ (output per capital); $\dot{y}_l(t)/y_l(t)$ denotes the growth rate of $y_l(t)$ (output per labor); c indicates the growth rate of technological progress; a dot over a variable denotes a derivative with respect to time. Eq. (7) shows that the growth rate of energy intensity was decided by the growth rates of output per capital, output per labor and technological progress and elasticity of output. The larger is the growth rate of output per capital and output per labor, the larger is that of energy intensity; the larger is the growth rate of technological progress, the smaller is that of energy intensity. When the influence of technological progress is larger than that of output, the energy intensity will decrease.

3 Empirical research

This paper attempts to apply the new production function model to the analysis of energy-saving effect of technological innovation in Leshan District (LSD) using time serial data.

3.1 Economic features of LSD

LSD is an industry-centered economic region where industry has played an important role and contributed to the development of economy greatly over the decades. Tab. 1 shows the GDP, IAV-GDP ratio over the last 15 years in LSD. From the statistics, it is quite clear that industry has been a great influential indicator in LSD since the percentage is among the biggest compared with the other two industries and it has been steadily increased over these years, from around 20% to almost 44%. And Fig. 1 presents how GDP is structured in LSD by three industries from 1997-2009 and shows that the second industry occupies the biggest part of GDP over these years except the year 2005 and 2006. Apparently, second industry is a major economic motive. Historically speaking, second industry is in great need of energy, therefore, it consumes a large amount of energy compared with the first industry and the third industry. As we have mentioned, LSD is a traditional industry-oriented region. Energy plays a strategic part there. Against the background of low-carbon development, this paper classifies energy into two categories: clean energy and non-clean energy. The energy structure is shown in Fig. 2 from where it's clear that non-energy is the dominant type of energy in LSD, with a proportion of over 70%, while clean energy with a proportion of less than 30%. Two curves also indicate that clean-energy seems to be more and more important and it will occupy more in the future.

3.2 Data analysis

Industry is the most important sector in LSD's economy. As we have mentioned above, industry added value occupies more than 40% of GDP in LSD and sees no sign of decreasing. And energy consumption of industry occupies more than 70% of total energy consumption in LSD, mainly in forms of coal, fuel, solar power, hydropower and natural gas. So industry is selected as an example to be studied. Annual average balance of net value of fixed assets, annual average employed persons, clean energy consumption, non-clean energy consumption, industry added value are shown in Tab. 2. Data in this table are calculated at current prices and should be changed at constant prices.

GDP deflator should be calculated at first before calculating value added at constant price.

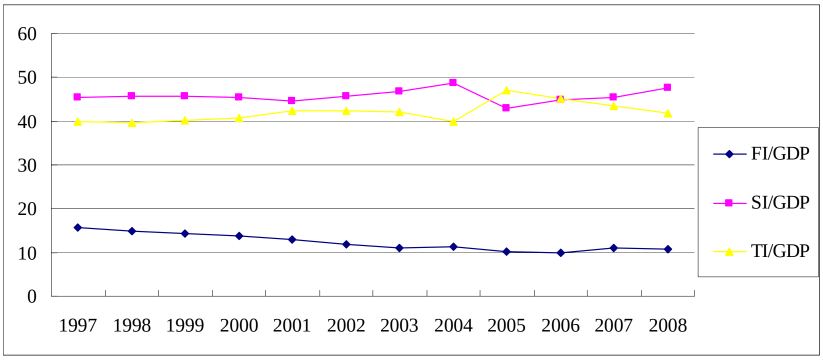

Fig. 1. GDP structure of LSD over the last 12 years
Note: FI/GDP, SI/GDP and TI/GDP stand for FI−GDP Ratio, SI−GDP Ratio and TI−GDP Ratio, respectively

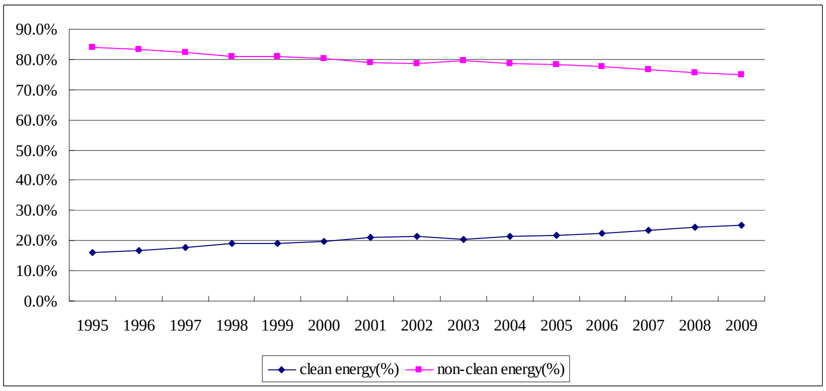

Fig. 2. Energy structure of LSD over the last 15 years

$$\text{Indices of GDP} = \frac{\text{GDP at current price}/\text{GDP deflator}}{\text{GDP of preceding year}}, \tag{17}$$

$$\text{GDP deflator} = \frac{\text{GDP at current price}/\text{indices of GDP}}{\text{GDP of preceding year}}. \tag{18}$$

GDP at current price, indices of GDP, and GDP deflator calculated according to Eq. (13) are shown in Tab. 3. Annual average balance of net value of fixed assets at constant price is calculated according to investment of fixed assets price index. Investment of fixed assets price index is also shown in Tab. 3.

$$\text{Value added at constant price} = \frac{\text{Value added at current price}}{\text{GDP deflator}}, \tag{19}$$

$$\begin{aligned}&\text{Annual average balance of net value of fixed assets at constant price}\\ &= \frac{\text{annual average balance of net value of fixed assets at current price}}{\text{investment of fixed assets price index}}.\end{aligned} \tag{20}$$

The values at constant prices calculated according to Eqs. (19) and (20) are shown in Tab. 1.

3.3 Results and discussion

The energy-saving effects of technological innovation of industry in LSD are calculated as below. Calculate natural log of the sides of Eq. (3), and yields

$$\ln Y = \ln A + ct + \alpha \ln K + \beta \ln L + \gamma_1 \ln E_1 + \gamma_2 \ln E_2. \tag{21}$$

According to Eq. (4), yields

$$\beta = 1 - \alpha - \gamma_1 - \gamma_2. \tag{22}$$

Table 1. Industry added value, GDP and IAV-GDP Ratio (calculated at current prices)

Year	IAV	GDP	IAV-GDP Ratio
1995	45658	200043	0.228240928
1996	49673	228346	0.217533918
1997	76347	252746	0.302070062
1998	89316	274378	0.325521726
1999	89787	288765	0.310934497
2000	104040	315339	0.329930646
2001	113878	345432	0.329668357
2002	123967	387449	0.319956949
2003	171637	449637	0.381723479
2004	218970	545735	0.401238696
2005	224508	636986	0.352453586
2006	260314	756564	0.344073998
2007	358904	925282	0.387886071
2008	462645	1135137	0.407567545
2009	594489	1376365	0.431926912

Note: IAV is the abbreviation for Industry Added Value[1, 2].

Table 2. Annual average balance of net value of fixed assets, annual average employed persons, energy consumption, industry added value (calculated at current prices)

Year	AFA (10,000 RMB)	AEP	EC(tce)	IAV (10,000 RMB)
1995	93583	48734	305822	45658
1996	132986	50739	333698	49673
1997	79835	52891	361964	76347
1998	113314	55208	393618	89316
1999	103743	54780	433147.5	89787
2000	155341	62450	473008.5	104040
2001	145023	59617	500876.4	113878
2002	165903	65532	550177.58	123967
2003	206573	67634	633988.17	156886
2004	238987	68890	764029	165079
2005	283646	72037	891780.4	202804
2006	401423	75290	1018335	254454
2007	476667	77036	1188062.09	331271
2008	581622	79284	1392813.10	408765
2009	741152	81861	1618495	594489

Note: AFA is the abbreviation for Annual average balance of net value of fixed assets; AEP is the abbreviation for Annual average employed persons; EC is the abbreviation for Energy consumption[1, 2].

According to Eqs. (21) $\sim$ (22), yields

$$\ln Y - \ln L = \ln A + ct + \alpha(\ln K - \ln L) + \gamma_1(\ln E_1 - \ln L) + \gamma_2(\ln E_2 - \ln L). \tag{23}$$

Eq. (23) is a linear regression model. The variables needed in parameters estimation are calculated as shown in Tab. 2. The parameters are estimated by SPSS 16.0. And the results of coefficients and related tests are shown in Tabs. 6 $\sim$ 7. The linear regress equation is shown as follows.

$$\ln Y - \ln L = 1.613 + 0.018t + 0.270(\ln K - \ln L) + 0.067(\ln E_1 - \ln L) + 0.202(\ln E_2 - \ln L). \tag{24}$$

That adjusted R square 1.000 and Sig.F change 0.000 show that the regression model is good and independent variables explain dependent variable very well. t-Tests show that t, $\ln K - \ln L$ and $\ln E_1 - \ln L$, $\ln E_2 - \ln L$ have significant effect on $\ln Y - \ln L$.

That is $c = 0.018, \alpha = 0.270, \beta = 1 - \alpha - \gamma_1 - \gamma_2 = 0.443, \gamma_1 = 0.067, \gamma_2 = 0.202$, α indicates that Y will increase 0.270% when K increases 1%; $\beta = 0.443$ indicates that Y will increase 0.443% when L increases 1%; $\gamma_1 = 0.067$ indicates that Y will increase 0.067% when E_1 increases 1%; $\gamma_2 = 0.202$ indicates that Y will increase 0.202% when E_2 increases 1%; $c = 0.018$ indicates that the growth rate of technological progress is 1.8%.

According to Eqs. (20), (3) and (5), yields:

$$Y = 5.017842197 e^{0.018t} K^{0.27} L^{0.443} E_1^{0.067} E_2^{0.202}, \tag{25}$$

$$0.067 \times \frac{\dot{\chi}_1(t)}{\chi_1(t)} + 0.202 \times \gamma_2 \frac{\dot{\chi}_2(t)}{\chi_2(t)} = 0.27 \times \frac{\dot{y}_k(t)}{y_k(t)} + 0.443 \frac{\dot{y}_l(t)}{y_l(t)} + 0.018. \tag{26}$$

Because the growth rate of technological progress is 0.018, in average technological progress leads to economic growth respectively. Then energy-saving effect of technological innovation is calculated.

Table 3. GDP deflator and investment of fixed assets price index

Year	GDP (10,000 RMB)	Indices of GDP	GDP deflator	Investment of fixed assets price index
1995	200043	110.8		
1996	228346	110.1	1.207554359	104.0
1997	252746	110.2	1.168339088	101.7
1998	274378	109.1	1.6289821	99.80
1999	288765	107.6	1.02549225	99.60
2000	315339	108.4	1.007404	101.1
2001	345432	108.3	1.011478	100.4
2002	387449	109.1	1.028081	100.2
2003	449637	110.0	1.055006	102.2
2004	545735	110.1	1.102383	105.6
2005	636986	110.4	1.057253	101.6
2006	756564	111.1	1.069059	101.5
2007	925282	113.0	1.082306	101.6
2008	1135137	109.6	1.119344	101.8
2009	1376365	113.4	1.0819905	104.0

Table 4. Annual average balance of net value of fixed assets and industry added value (calculated at constant price of 1995)

Year	AFA (10,000 RMB)	IAV (10,000 RMB)
1995	93583	45658
1996	127871.1538	41135.20821
1997	78500.49164	65346.61111
1998	113541.0822	54829.33176
1999	104159.6386	87555.0254
2000	153650.8408	103275.3493
2001	144445.2191	112585.7409
2002	165571.8563	120580.9659
2003	202126.2231	148706.2633
2004	226313.447	149747.4108
2005	279179.1339	191821.6359
2006	395490.6404	238016.798
2007	458774.7834	306078.8723
2008	534088.1543	405693.8707
2009	712817.435	549440.4044

Table 5. Production function analysis

t	$\ln E_1$	$\ln E_2$	$\ln Y$	$\ln L$	$\ln K$
1	10.69286598	12.34367232	10.71790341	10.78773591	11.19545958
2	10.85452559	12.45439405	10.88380341	10.83411321	11.34075958
3	11.03144516	12.56140201	11.04970341	10.87872419	11.48605958
4	11.22103504	12.66456053	11.21560341	10.92170709	11.63135958
5	11.33488568	12.78489586	11.38150341	10.96318445	11.77665958
6	11.49522864	12.89407022	11.54740341	11.00326536	11.92195958
7	11.67791974	12.99682793	11.71330341	11.04204742	12.06725958
8	11.81113763	13.1121184	11.87920341	11.07961826	12.21255958
9	11.88727159	13.24260372	12.04510341	11.11605686	12.35785958
10	12.04465378	13.35158986	12.21100341	11.15143466	12.50315958
11	12.18695667	13.46431635	12.37690341	11.18581649	12.64845958
12	12.33320766	13.57571413	12.54280341	11.21926138	12.79375958
13	12.49598273	13.68184378	12.70870341	11.25182317	12.93905958
14	12.66101982	13.78647936	12.87460341	11.28355119	13.08435958
15	12.80032253	13.89893482	13.04050341	11.31449068	13.22965958

$$(e^{0.018t} - 1) \times 100\% = 1.018162976\%.$$

And technological progress will increase the growth rate of output per capital and growth rate of output per labor 1.018162976%.

Then, it yields:

$$0.067 \times \frac{\dot{\chi}_1(t)}{\chi_1(t)} + 0.202 \times \frac{\dot{\chi}_2(t)}{\chi_2(t)} = 0.270 \times 0.01018 + 0.443 \times 0.01018 - 0.018. \tag{27}$$

The part $0.270 \times 0.01018162976 + 0.443 \times 0.01018162976$ indicates that technological innovation progress will promote the economic growth and increase energy intensity, and the part (-0.018) indicates that technological progress will decrease energy intensity. According to Eq. (27), $0.067 \times \frac{\dot{\chi}_1(t)}{\chi_1(t)} + 0.202 \times \frac{\dot{\chi}_2(t)}{\chi_2(t)} = -0.97345\%$.

That means technological progress decrease energy intensity of industry in LSD by 0.97345% every year at average. The parameter of clean energy-saving effect is much smaller than that of non-clean energy-saving

Table 6. Variables needed in parameters estimation

t	$\ln E_1 - \ln L$	$\ln E_2 - \ln L$	$\ln Y - \ln L$	$\ln K - \ln L$
1	1.405130068	2.05593641	1.430167502	1.607723673
2	1.520412383	2.120280844	1.549690202	1.706646373
3	1.652720971	2.182677815	1.670979219	1.80733539
4	1.799327944	2.242853433	1.793896314	1.909652485
5	1.871701234	2.32171141	1.918318961	2.013475132
6	1.991963279	2.390804856	2.044138047	2.118694218
7	2.135872322	2.454780509	2.171255987	2.225212158
8	2.231519367	2.532500145	2.299585151	2.332941322
9	2.271214733	2.626546869	2.329046553	2.431802724
10	2.393219118	2.700155201	2.359568751	2.461724922
11	2.501140179	2.791086915	2.391086915	2.562643086
12	2.613946286	2.856452754	2.423542033	2.674498204
13	2.744159553	2.930020607	2.556880236	2.777236407
14	2.877468628	3.002928166	2.591052216	2.800808387
15	2.985831843	3.084444132	2.626012724	2.915168895

Table 7. R square test

R	R square	Adjusted R square	R square change	F change	Sig. F change
1.000	1.000	1.000	1.000	1.414E5	.000

Table 8. Coefficients and t-test

	Unstandardized coefficients	t	Sig.
(Constant)	1.613	38.257	.000
t	.018	1.450	.075
$\ln KL$	.270	3.990	.002
$\ln E_1 L$	.067	2.805	.007
$\ln E_2 L$	.202	4.876	.010

effect, in other words, the impact of technology over clean energy is much smaller than that of non-clean energy, which is quite undesirable.

From the above statistics, it's easy to draw the conclusion that technological innovation places a little impact over clean energy intensity in LSD. One explanation is that the use of clean energy is still not very popular in the second industry or the whole economic chain, meanwhile, non-clean energy seems more responsive to technological innovation. We can also explain this in another way, that is there's still much room for improvement in LSD with regard to this issue. Specifically speaking, clean energy effect of technological innovation is also not desirable. Like other regions in China, non-clean energy plays a major role in industry development or economic development. And in LSD, clean energy is under further exploitation and utilization.

4 Policy implication

For a long time, being a traditional industry-oriented area, LSD, suffers a great deal of energy consumption and environmental issue, which negatively influences the development of regional economy there over the long run. This is against the new theme of developing low-carbon economy and harmonious society. This paper analyzes clean energy-saving and non-clean energy-saving effect of technological innovation by employing a new production function, through this analysis, it can be concluded that the development of technological innovation can exert great influence on energy-saving, thus serving the low-carbon development of this area and transformation of traditional mode of economic development. Policy-makers and law-makers are strongly recommended to participate in the encouragement of relevant policies with regard to clean energy and green energy or energy-saving areas. Besides, more investment in technological innovation are crucial since it can decrease the energy intensity in real world as our findings indicate. Therefore, government is also suggested to take initiatives to enhance technological innovation and reach the goal of developing low-carbon economy in terms of policy-making.

5 Conclusion

This paper provides a macroeconomic approach to develop the relationship between energy and technological innovation. Specifically, capital, labor and clean energy and non-clean energy are considered as the elements of economic growth, and a new Cobb-douglas production function is formed and applied. Besides, this paper discusses the properties of the newly formed production function. We assume that the production function has constant returns to scale. It's proved that technological innovation will decrease energy intensity, which is consistent with previous studies[10]. The empirical study of LSD proves this statement. Besides, this paper uses statistical method to test the efficiency of the model. It calculates that the coefficient of technological innovation towards energy-saving in LSD, which means when technological innovation is progressed by one unit, energy intensity decreases by 1.01 percent. Furthermore, we discuss the effect of technological innovation over clean energy and non-clean energy there so that local government can come up with timely regulations and policies in terms of clean energy utilization and non-clean energy efficiency. Results indicate currently the impact of technological innovation over clean energy is smaller that of non-clean energy. It should be noted that in this paper no comparison research and forecast is made. The parameter of each type of energy can not be calculated accurately due to the limitation of the production function. The elasticity and rebound effect of energy-saving effect are not addressed either. Therefore, our future work is to further this research by forecasting the future energy structure and optimizing this structure.

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