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Study on the Influences of Technological Progress on China's Energy Efficiency Based on Meta Regression Analysis

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Abstract: In this paper, we use the Meta regression analysis method to carry out a quantitative research on 39 domestic articles which are about the influences of technological progress on China's energy efficiency. It is aimed at exploring the influences of differences in model design, data selection and evaluation method on empirical results. The results show that, in terms of energy efficiency measures, selecting the absolute value gets better empirical results than using the relative amount, while higher utility value will be achieved in case of relative amount of technological progress variable than in case of level value. The industrial structure with the proportion of the secondary industry as measurement increases the bounce-back effect of technological progress on energy efficiency, thus reducing the function effect of technological progress on energy efficiency. But energy price and human capital can make the results more valuable. Furthermore, whether selecting panel data or provincial data, sample data selection will not affect the empirical research results. Additionally, selecting tobit model and considering lagging factors in model design can increase the significance of results.

Keywords: *Technological Progress, Energy Efficiency, Meta Regression Analysis*

1. Introduction

In the 21st century, with the rapid growth of global economy and the quickening pace of industrialization, energy restraint is increasingly prominent, and energy efficiency is becoming a focus of economic growth and energy policies of countries [1]. Against this backdrop, many scholars, at home and abroad, have studied approaches for energy efficiency issue from the influencing factors of energy efficiency. Technological progress, among others, is the most important approach[2], and the related research literature mainly includes: Lutz (2007), in the study of renewable energy in Europe, argued technological progress, a constraint, can greatly improve energy efficiency[3];Yu Jianxun (2011) verified the role of technological progress in improving energy efficiency using the stepwise regression method based on data of industrial enterprises in 30 areas from 2004-2010[4]; Tan Zhongfu and Zhang Jinliang (2010) established a state space model of energy efficiency based on China's statistical data from 1978-2006, demonstrating the positive effect of technological progress on energy efficiency[5]; Qu Xiaoe (2009) indicated that technological progress played a significantly positive role in enhancing energy efficiency[6]; Chen Xiaoyi (2016) carried out an empirical research on the relation of technological progress to energy efficiency using ARDL model, showing that technological progress can markedly improve energy efficiency[7]. Nonetheless, Khazzom (1980) proposed technological progress could boost economic growth while improving energy efficiency as a result of the bounce-back effect of energy consumption, resulting in more energy demand, which along with the decreased cost of energy made actual energy price fall and real income increase which increased energy consumption and had a negative effect on improving energy efficiency[8]; CHEN Xiaoyi (2012) found through an empirical research that when energy efficiency was low, technological progress can improve energy efficiency, and vice versa[9]; Zhao Nan et al. researched the influences of technological progress on regional energy efficiency, and found that the positive effect of technological progress on energy efficiency was not obvious[10]; Li Jiyang (2011) found that technological progress had a negative effect on energy efficiency through an empirical study[11]; Tang Anbao and Li Xingmin (2014) found by studies that the influences of technological progress on energy efficiency was limited by its development level, and the decreased energy price can adversely affect efficiency[12]. As can be seen from the above literature, there are disagreements and disputes in the results of existing researches on whether technological progress can improve energy efficiency. In fact, the results of empirical analysis are not the same as a result of differences in estimation methods, data selection and the treatment of variables. Hence, on the basis of 39 representative and independent research articles at home and abroad, this paper conducts an empirical research on the influences of differences in model design, data selection and estimation on research results using the Meta regression analysis method. It is aimed at finding out the decisive factor of differences in the existing research results from a quantitative perspective, providing references for follow-up studies.

2. Study design:

2.1. The Meta regression analysis method:

Compared with the conventional literature review methods, Meta regression analysis (MRA) is quantitative and systematic, which can integrate the results of empirical researches with common purposes to make a periodic summary of research progress in a field [13,14]. It is not limited to qualitative descriptions and summaries, and can avoid the influences of reviewer's subjective preferences to a large extent. More importantly, it can explore deep-seated reasons for differences in previous research conclusions, namely find out moderator variable and verify the moderating effect [15, 16].

Based on the study of Stanley and Jarrell (1989), Meta regression model can be expressed as [17]:

$$Yj = \beta_0 + \sum_{k}^{K} \beta_k Z_{jk} + e_j,\ j = 1、2......N \qquad (1)$$

Where, Yj is the t value of related parameter estimator, which derives from N conclusions in empirical articles, and N is the sample size of Meta regression analysis. As the K explanatory variable in Meta regression analysis, Zjk（k=1,2……K）is the proxy variable reflecting all empirical study designs, which is used to describe differences of various studies in sample data selection, model design and estimation method. Different empirical studies fail to reach a consistent conclusion about whether technological progress can exert positive effects on energy efficiency, so estimated value of parameter indicating the effects of technological progress on energy efficiency can be positive or negative. Positive value means positive effect, and negative value means negative effect. t value corresponding to the estimated value of parameter can be also be positive or negative. In this paper, OLS estimation is used. Suppose random disturbance term ej forms a normal distribution and the estimated value of parameter $\hat{\beta}_j$ in equation (1) passes significance test, then the empirical conclusion about whether technological progress can exert positive effects on energy efficiency partly depends on the empirical study design.

2.2. Sample selection:

Based on the fundamental of Meta regression analysis, this paper conforms to the following two principles in sample selection. One is to select the domestic leading journals of economic management to ensure the authority, effectiveness and reliability of research data. The other is that sample papers have offered the t value of regression parameter concerning the influences of technological progress on energy efficiency. Upon preliminary screening and organization, there are 39 articles meeting the requirements. Information extracted from the selected articles includes authors, published journals, published time, t value of regression coefficient for proxy variable of technological progress, period of sample data, sample size, type (cross-section, time series or panel data) or level (national or provincial data, micro-data of industry or enterprise) of sample data.

This paper finally extracts 147 conclusions from 39 empirical articles based on the selection criteria of Wang Wanjun (2010), namely when there are multiple models and empirical conclusions in an article, the author argues the optimal estimated result will be selected[18]. If the author fails to show the most preferential empirical conclusion and there are few differences in symbols and significance between various estimated results, the empirical conclusion with the highest goodness of fit will be selected. If explained variables, major explanatory variables or estimation methods are substituted, different sub-sample data is employed or various variables measuring some index are included, and test method is not used to indicate the optimal estimation method, then multiple conclusions in an article will be selected [19].

2.3. Variable declaration:

2.3.1. Explained variable: Explained variable Y is the t value of parameter estimator that is about the influences of technological progress on energy efficiency extracted from the selected articles. When the influencing factor parameter of energy efficiency is estimated in the empirical research, t statistics or standard deviation corresponding to the estimated value of parameter is given. In this way, without t value in the empirical research, we can work out it according to parameter estimator and corresponding standard deviation. Therefore, if the t value cannot be calculated based on data from the article, then that article will not be selected for Meta regression analysis.

2.3.2. Explanatory variable: There is no theoretical support for how to select explanatory variables. Hence, based on the available articles, we distinguish the features of various parameters in the selected articles and divide the explanatory variables into the following five types.

(1) Measure variable of energy efficiency

Y_style is a dummy variable describing the form of energy efficiency value in the selected articles. When energy efficiency is the absolute value denoted by total factor productivity, energy consumption per unit of GDP and DEA efficiency value, let Y_style equal 1; when the growth rate of energy efficiency is presented or relative value is obtained through digital processing, let Y_style equal 0. Notably, as for energy consumption per unit of GDP, a higher "energy intensity" means a lower energy efficiency. So there is a need to unify variable symbols.

(2)Proxy variable of technological progress

Tec_form is a dummy variable describing the form of technological progress in the selected articles. Different variables are used to express technological progress in different articles, some of which selected the number of accepted patents [11], while others used total factor productivity [10]. No matter which parameter is employed, in case of relative number, let Tec_form be 1; in case of absolute number, let Tec_form be 0.

(3) Internal control variable

Due to the multiple influencing factors of energy efficiency, when studying the influences of technological progress, we introduce dummy variables such as ics, open, esc and ep to distinguish control variables like industrial structure, openness to the outside world, energy consumption structure and energy price. If industrial structure is included in the control variable, let ics be 1, otherwise be 0; if openness to the outside world is included, let open be 1, otherwise be 0; if energy consumption structure is included, let esc be 1, otherwise be 0; if energy price is included, let ep be 1, otherwise be 0.

(4)Data characteristics variable

Panel and province are dummy variables describing characteristics of sample data in the selected articles. Panel represents the type of sample data. In case of panel data, Panel is 1; in case of cross-section data or time series data, Panel is 0. Province represents the selecting level of sample data. In case of provincial data, Province is 1; in case of industry or enterprise data, Province is 0.

(5) Model estimation features

Tobit and lag are dummy variables describing differences in estimation methods in the selected references. Tobit represents the model of estimation method. In case of Tobit model, Tobit is assigned 1, otherwise it is 0. The value of lag is 1 if Lag model considers lag effect, otherwise it is 0.

3. Empirical Study:

3.1. Results of Meta regression analysis:

This paper makes a Meta regression analysis using the Metareg method proposed by Higgins and Thompson [15].The merits of Metareg method are that permute option can be used to adjust various verifications in case of multiple concomitant variable and stata12 is employed to complete the operation, as shown in Table 2. Model (1) contains all variables in Table 1, Model (2) excludes such insignificant internal control variables as open and ecs, and Model (3) further excludes such insignificant data characteristics variables as panel and province.

Table 1: *Variables in Meta regression analysis*

Variable type	Variable	Variable declaration
Explained variable	Y	t value of parameter estimator that is about the influences of technological progress on energy efficiency
Measure variable of energy efficiency	Y_style	In case of absolute value, Y_style equals 1; in case of relative value, Y_style equals 0.
Proxy variable of technological progress	tec_form	In case of absolute amount, Tec_form is 1; in case of relative amount, Tec_form is 0.
Internal control variable	open	If openness to the outside world is included in the control variable, open is 1, otherwise it is 0.
	isc	If industrial structure is included in the control variable, ics is 1, otherwise it is 0.
	esc	If energy consumption structure is included in the control variable, esc is 1, otherwise it is 0.

3.2. Result analysis:

Meta regression analysis in Table 2 shows that:

(1) As shown in Model (1), (2) and (3), coefficient of Y_style is positive and significance test is passed, which shows that, in terms of energy efficiency measures, selecting the absolute value of total-factor energy efficiency, single-factor energy efficiency (energy consumption per unit of GDP) gets better empirical results than using the relative amount of growth rate.

(2) As shown in Model (1), (2) and (3), coefficient of Y_style is positive and significance test is passed. This means that, in the study on the influences of technological progress on energy efficiency, higher utility value will be achieved in case of relative amount of technological progress (such as logarithm value of granted patents and growth rate of total factor productivity)than in case of absolute amount.

Table 2: *Results of Meta regression analysis*

	(1)	(2)	(3)
Y_style	23.5214***	23.889***	22.3545***
	(4.43)	(5.11)	(5.08)
tec_form	-10.8851***	-11.2029***	-14.1238***
	(-3.43)	(-4.82)	(-4.53)
open	-0.1889	—	—
	(-0.12)		
isc	-6.2973*	-6.2485*	-6.2603*

	(-1.76)	(-1.71)	(-1.92)
ecs	0.1966 (0.06)	—	—
ep	8.917^{**} (2.20)	9.0491^{**} (2.34)	10.9376^{***} (3.29)
hc	2.5973 (1.73)	2.6941^{**} (2.07)	2.4425^{*} (-1.77)
panel	2.2075 (0.63)	2.336 (0.66)	—
province	5.5128 (1.31)	5.4773 (1.32)	—
tobit	11.1613^{**} (2.21)	11.43115^{***} (2.93)	13.77669^{***} (3.88)
lag	5.95242^{*} (1.42)	6.227305^{*} (1.64)	4.5386^{*} (1.66)
_cons	-3.7337 (-0.85)	-3.7914 (-0.89)	1.8224 (2.31)

Note: (1), ** and *** are significant at significance levels of 0.1, 0.05 and 0.01 respectively. (2)Between the brackets lies the t-statistics of significance test of variables, F represents F-statistics of significance test of equation, R^2 is goodness of fit, N is sample size, and cons is constant term.*

(3) There are multiple influencing factors of energy efficiency, and results show that introducing such control variables as industrial structure, openness to the outside world, energy consumption structure and energy price exerts different effects on the research result of technological progress. Industrial structure (ics) is negative in Model (1), (2) and (3), which indicates that a larger proportion of secondary industry cannot help technological progress improve energy efficiency. Given the high energy consumption of the secondary industry, a larger proportion will generate greater energy demands while boosting economic growth, resulting in a bounce-back effect that is not conducive to improving energy efficiency. Energy price (ep) is positive in Model (1), (2) and (3), which shows that the rising energy price offsets more demands generated by technological progress, hence reducing the bounce-back effect and improving energy efficiency. Human capital (hc) is positive in Model (1), (2) and (3), which demonstrates that, in case of a greater capital, the positive effect of technological progress on "reducing energy consumption and improving energy efficiency" will surpass the positive impacts of bounce-back effect on "expanding energy consumption and reducing energy efficiency". In the above models, open and esc fail to pass the significance test, which illustrates that whether openness to the outside world or energy consumption structure is included in control variable or not has few effects on playing the role of technological progress in improving energy efficiency.

(4) In terms of data characteristics, panel is to describe whether panel data is selected in the study. Both Model (1) and (1) fail to pass the significance test, which means that selecting panel data exerts few effects on playing the role of technological progress in improving energy efficiency. While province is to describe whether provincial data is selected in the study. Both Model (1) and (1) fail to pass the significance test, which shows that selecting provincial data exerts few effects on playing the role of technological progress in improving energy efficiency.

(5) In terms of model estimation features, tobit and lag have positive coefficient and pass the significance test. Thus it can be seen that selecting tobit model and considering lagging factors in model design can increase the significance of results. It also shows that model estimation selection often contributes to large differences in results.

4. Conclusions:

As an influencing factor of energy efficiency, technological progress cannot be ignored. But the bounce-back effect makes direction and result of such influence relatively complex. There have been debates on whether technological progress is bound to improve energy efficiency. Actually, differences in empirical research results can partly be attributed to differences in sample selection, model design and estimation method. Unlike the conventional methods of literature review, this paper employs Meta regression analysis method to quantitatively and systematically organize 147 empirical results extracted from 39 articles, and analyzes the specific characteristics of available articles one by one. Conclusions are drawn as follows:

First, the explained variable and explanatory variables measuring technological progress defined in the study may have some effects on estimation results. In terms of energy efficiency measures, selecting the absolute value of total-factor energy efficiency, single-factor energy efficiency (energy consumption per unit of GDP) gets better empirical results than using the relative amount of growth rate. In contrast, higher utility value will be achieved in case of relative amount of technological progress variable (such as logarithm value of granted patents and growth rate of total factor productivity) than in case of level value (such as the amount of granted patents and accumulation index of total factor productivity).

Second, in the study on the influences of technological progress on energy efficiency, introducing such control variables as industrial structure, openness to the outside world, energy consumption structure and energy price exerts different effects on the research result of technological progress. The industrial structure with the proportion of the secondary industry as measurement increases the bounce-back effect of technological progress on energy efficiency, thus reducing the function effect of technological progress on energy efficiency. But energy price and human capital can make the results more valuable. Openness to the outside world and the energy construction structure exert few effects on playing the role of technological progress in improving energy efficiency.

Third, whether selecting panel data or provincial data, sample data selection will not affect the empirical research results.

Fourth, different estimation methods will affect the empirical research results. Compared with other estimation methods, tobit model can make technological progress play a greater role in improving energy efficiency. And the same goes for considering lagging factors in model design.

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