ANALYSIS ON THE FACTORS THAT INFLUENCE THE UTILIZATION RATE OF RENEWABLE ENERGY IN THE FRAMEWORK OF MARXIST REPRODUCTION

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Abstract: Developing the renewable energy to replace traditional fossil energy is not only an essential part of sustainable development strategies of most countries all over the world, but also an important theoretical issue that draws the attention of the academic circle. On the basis of a Marxian reproduction scheme, the essay analyzes the inf uence of market demand, technological progress and policy promotion on the utilization rate of renewable energy and their mechanisms during the development of the renewable energy industry. A panel data set of 28 OECD countries for 34 years is constructed to examine the role of market, technology and policy on renewable energy's utilization rate. In addition, based on theoretical analysis and econometrical analysis, market, policy and technology—the three main factors will go through a thorough analysis.

Key words: utilization of renewable energy; Marxian reproduction scheme; energy policy

Introduction

The renewable energy industry is the one which can ensure national energy security and reduce greenhouse gas emissions, and the world's major industrialized countries have fully understood its importance and made the development of this industry an important part of their sustainable development strategy. However, after the rapid growth in the 1970s and 1980s, the renewable energy utilization worldwide gradually became stagnant in the 1990s and even displayed a declining trend in the 21st century, which showed that renewable energy is now in the bottleneck period (see Figure 1).

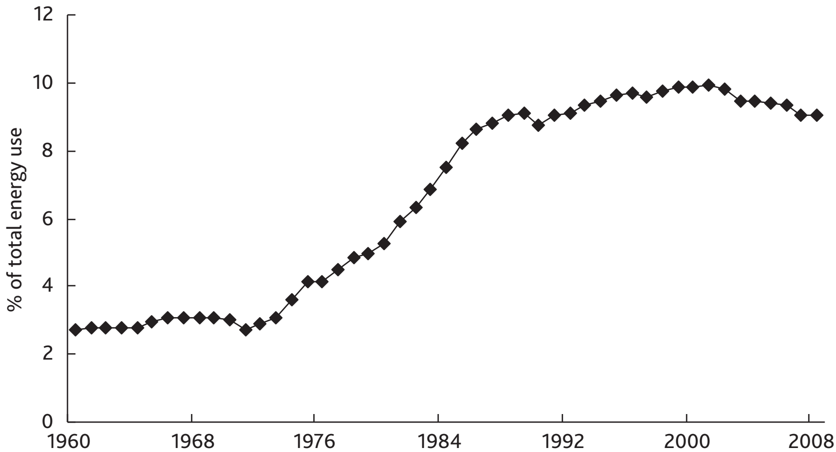

Figure 1 Worldwide Renewable Energy Utilization (1960–2008)

Source: World Bank.

Therefore, the barriers encountered in the application of renewable energy and the means to overcome these barriers have become a focus of the academic research.

A considerable part of the literature has emphasized that the pressure of competition from the market and the challenge from technology bottlenecks were the main reasons for the stagnation of new energy industries and highlighted the role of the technological advances and the experience and the learning effects in reducing the cost of new energy production and improving their competitive advantage. For example, Zimmerman (1982) measured the positive externalities of the nuclear energy industry caused by the existence of spillover benefits of technology and learning curve opportunities. Christiansson (1995) studied the new energy industry experience curve and learning curve and used historical data to estimate the experience curve of both the wind energy industry and the solar industry and also estimated the impact of introduction of new technologies on the energy industry. Popp (2001) tested the role of the application of new technologies on energy efficiency through the data of U.S. patents and the energy consumption in various industrial sectors in different periods. Tahvonen and Salo (2001) studied transformation between the renewable energy and non-renewable energy in different stages of the development of economy on the basis of the endogenous growth model. Jacobsson (2004) made a systematic study of the technical difficulties and the corresponding solutions for the transformation from the economy system dependent on fossil fuels and other non-renewable energy sources to a sustainable energy system in the case of Sweden. Owen (2006) combining the energy industry characteristics with the greenhouse gas emissions, focused on the existence of market failures and government regulations in the development of a new energy industry.

Another part of the literature discusses the rise in global warming in recent years and combines the development of the new energy industry and greenhouse gas emissions together to study the critical role of the development of new energy on climate change and the impact of governmental cooperation and international cooperation on the development of the new energy industry. Representative studies include: Grubler and Messner (1998) and Sims et al. (2003) regarded the new energy industry as the primary means of controlling global warming; Jaffe et al. (2004) pointed out that market failure was the main barrier to the development of the new energy industry and discussed the necessity for the government intervention; Edenhofer and Kriegler (2005) analyzed the effect that technological change caused by the development of new energy has had on global warming and welfare, based on the MIND model; Abrell and Weigt (2008) analyzed the push effect of carbon emissions trading on the development of the renewable energy industry on the basis of computational general equilibrium model (CGE) using German data; Hoel (2008), using the Hotelling model, studied non-renewable fossil energy consumption path and discussed how the change of the path of fossil energy which may be caused by the strict monitoring of greenhouse gas emissions would affect the development of the renewable energy industry.

What is more, there is a considerable amount of literature focused more on policy recommendations and specific successful stories for the government to support the development of the new energy industry. The following are the representative ideas: Haas (2000) and Held et al. (2010) introduced the European Union's successful experience in the promotion of new energy power generation; Biswas et al. (2001) provided successful cases in rural areas of Bangladesh to promote renewable energy; Martinot et al. (2002) described a road map to build the renewable energy market in developing countries and provided some success stories; Lewis and Wiser (2005) compared the effectiveness of different policies for the development of the new energy industry in different countries; Benítez (2006) and Blanco (2009) focused on the policy recommendations about the development of the wind energy industry.

To sum up, most of the literature has focused on analyzing the technology obstacles and the marketing challenges faced by the renewable energy industry and discussed all kinds of obstacles in the development of renewable energy and also all means of policy measures that could be adopted by governments, while economic research on the factors that influence the developing speed of the renewable energy industry, and on the working mechanisms, is relatively sparse. Besides, in quite a lot of the literature, models are constructed based on the Hotelling framework of Neoclassical Resource Economics, whose core concept is very hard to understand by those readers who lack the math basis of Optimal Control Theory. Moreover, the literature has the major limitation of lacking strict econometrical analyses in their conclusions. Most of the literature relies on the statements of descriptive statistics and simple numerical tests, which leave visible deficiencies on the precision of analyses.

Therefore, based on the researches above, this article tries to use more intuitive economic analytic tools to research the factors that could influence the utilization of renewable energy and the working mechanism from an economics perspective, and then to verify the theoretical analysis by the method of Panel Data Regression.

Factors that Influence the Utilization of Renewable Energy

The Marxian reproduction scheme is one of the most important parts of Marxian economics. Nowadays some scholars also try to understand this reproduction scheme as a major source of the modern economic growth theories. In this section we use the Marxian reproduction model rather than the neoclassical economic growth model to build our theoretical model. The main difference of the Marxian model from the neoclassical model is the emphasis of the correlation between two economic sectors: production goods and consumer goods. This characteristic is not only crucial for us to understand the relationship between energy demands and economic development, but also helpful to build a model in which the renewable energy sector becomes an important basis of sustainable development. In the following part of this article, we will use the Marxian reproduction scheme as a basic tool to analyze three main factors, market, policy and technology, that impact of the utilization rate of renewable energy, and to figure out how and to what extent those factors influence the success of the renewable energy department.

Model Setup

In reality, energy can be considered not only as a production good, but also as a consumer good. In order to simplify the analysis, we emphasize energy as a production good. Hence the economy in our model consists of three sectors: the first sector produces energy good, the second produces capital goods without energy, and the third produces consumer goods. The expanded reproduction model can be written as follows.

$$\begin{cases} I: C_E^1 + \Delta C_E^1 + C_K^1 + \Delta C_K^1 + V^1 + \Delta V^1 + M^1 / X = W_E \\ II: C_E^2 + \Delta C_E^2 + C_K^2 + \Delta C_K^2 + V^2 + \Delta V^2 + M^2 / X = W_K \\ III: C_E^3 + \Delta C_E^3 + C_K^3 + \Delta C_K^3 + V^3 + \Delta V^3 + M^3 / X = W_C \end{cases} \quad (1)$$

where C stands for constant capital, and is divided into two parts, one for energy good (C_E) and the other for machine or workshop (C_K). V stands for variable capital, M for surplus value, M/X for one part of surplus value which is consumed by capitalists, and W for total value of goods. The superscript (i = 1, 2, 3) represents three sectors of the economy.

For simplification, the first and third sectors in Type (1) can be integrated into one large sector whose products can be used as capital goods and consumer goods as well, but those products cannot substitute for energy good in the production process. This simplification will not have a substantive effect on our conclusions. Furthermore, we can rewrite the model as follows:

$$\begin{aligned} I: C_E^1 + \Delta C_E^1 + C_K^1 + \Delta C_K^1 + V^1 + \Delta V^1 + M^1 / X = W_{EG} \\ II: C_E^2 + \Delta C_E^2 + C_K^2 + \Delta C_K^2 + V^2 + \Delta V^2 + M^2 / X = W_{FG} \end{aligned} \quad (2)$$

There are two ways to satisfy the energy demand, one is fossil energy and the other is renewable energy. We assume the fossil energy supply is non-renewable. In order to underline this characteristic of fossil energy, we set the supply function of fossil energy as follows:

$$Q_f^t = \begin{cases} \bar{q} & if \ R_f^t - \bar{q} \geq 0 \\ R_f^t & if \ R_f^t - \bar{q} < 0 \text{ or } R_f^t > 0 \\ 0 & if \ R_f^t \leq 0 \end{cases} \quad (3)$$

where Q_f^t represents the supply of fossil energy in period t. R_f^t stands for the total reserves of fossil energy in period t, and $\bar{q}$ for an exogenous fixed yield of fossil energy. Type (3) includes the assumption that fossil energy will supply a fixed yield until all reserves are exhausted. When the reserves of fossil energy become zero, the supply of fossil energy becomes zero as well.[1]

Assume $R_f^t = Q_f^t < 0$ which means that the more the fossil energy is used, the lower the reserves will be, removing the possibility of finding new reserves by exploration, that is, the total reserves of fossil energy is known in period 0.

On the other hand, the renewable energy is renewable. The reproduction process will not be restricted by the limited reserves in nature. One can produce any amount of renewable energy good by inputting enough capital goods and labor. Hence, theoretically speaking, the supply of renewable energy can always match the social demand for energy. In our model, the so-called "production of energy good" simplifies into the "production of renewable energy" and the supply of fossil energy is defined as "the gift of nature."

Assumption Setup

Our model is similar to the traditional two-division expanded reproduction model in terms of form, however the implication of our model is quite different from the traditional one. So in order to confirm this point, it is necessary for us to review the main assumptions that we set different from the traditional model.

1. The model is made up of two divisions; the first division produces the final good which can be used either as reproduction goods or as consumer goods. The second division produces the energy good which is considered as an irreplaceable material in the production process.
2. There are two ways to meet the demand for energy good: using fossil energy or renewable energy. Fossil energy and renewable energy are equivalent for consumers, so the prices of the two kinds of energy good are the same.
3. Fossil energy is non-renewable, potentially yielding a fixed amount every period. One cannot increase the potential yield of fossil energy by input capital and labor.
4. Renewable energy is renewable, that is, one can produce renewable energy goods by using constant and variable capital.
5. The supply of fossil energy cannot meet the need for energy at period 0 (before extraction begins), that is, assume the output of renewable energy is positive from period 0.[2]
6. Technical progress only happens in the second division which produces energy goods,[3] that is, the technology of the final goods division never changes in this model.

Analysis of the Model

When the supply of fossil energy cannot meet the demand for energy, the economy has to fill the energy gap by the production of renewable energy. So the demand side of energy will impact greatly the utilization of renewable energy. In order to show the influence of the demand side, we introduce economic growth in this reproduction model, following the works by Krelle (1971) and Harris (1972) who explore the way to understand Marx as a growth theorist. Using their approaches, we can conclude the quantitative relation of economic growth to energy demand which is summarized as Proposition 1.

Proposition 1: there is a positive relation between economic growth and energy demand. When the ratio C_E/C_K is constant, the growth rate of economic and energy demand are equal.

Proof: Assume m is the rate of exploitation, α is the rate of accumulation, k is the organic composition of capital (without energy capital) and e is the ratio of energy capital to physical capital. The definition of the ratio of energy capital to physical capital is the ratio of the capital used to buy energy goods to the capital used to buy other investment goods, that is, $e = C_E/C_K$. Rewrite the Type (2) as the following equation system by using the above notation.

$$\begin{aligned} & M = mV \\ & C_K = kV \;\Rightarrow\; \Delta C_K = k\Delta V \\ & C_E = eC_K \;\Rightarrow\; \Delta C_E = e\Delta C_K \\ & \alpha M = \Delta C_E + \Delta C_K + \Delta V \end{aligned} \tag{4}$$

The first equation means surplus equal to the exploitation rate multiplied by constant capital. The second is a variation of the definition of the organic composition of capital, and the third equation does the same job to the ratio of energy capital to physical capital. The fourth equation shows us that the accumulations of surplus value have three main applications: purchasing energy goods, physical capital and labor. Plugging the first three equations into the fourth one, we can solve the growth rate of economics:

$$\Delta C_E + \Delta C_K + \Delta V = (1 + k + e \cdot k)\Delta V = \alpha M = \alpha \cdot mV \tag{5}$$

Divide by V on both sides to get the growth rate of constant capital g_V.

$$g_V \equiv \frac{\Delta V}{V} = \frac{\alpha \cdot m}{1 + k + e \cdot k} \tag{6}$$

Set $\tilde{k} \equiv k + e \cdot k$. This growth rate can be rewritten as the economic growth rate in the standard Marxian growth model:

$$g_V = \frac{\alpha m}{1 + \tilde{k}} \tag{7}$$

Using the assumption that the organic composition of capital is constant in time and the simple mathematic principle that for two time-varying variables $A(t)$ and $B(t)$, if the ratio $A(t)/B(t)$ is constant in time, then the growth rates of two variables are the same, we can easily show that:

$$g_V = g_K = g_E = g \tag{8}$$

Finally, according to Type (3), the supply function of non-renewable energy, the growth rate of the capacity of renewable energy should satisfy $g_n = g^*$ (QED).

According to Proposition 1, since the supply of fossil energy cannot increase, the capacity of renewable energy should have the same growth rate as the economic growth rate in order to meet the increase in energy demand. Hence the expansion of energy demand caused by economic growth will increase the growth rate and utilization rate of renewable energy. Just for comparison, the influence of technological progress and policy promotion is more direct. These two factors impact on the renewable industry directly. We will check the details of the renewable industry to find the variables which determine the growth rate of renewable energy capacity.

Proposition 2: The growth rate of renewable energy capacity can be expressed as follows:

$$g_n = \frac{\chi \alpha_n m_n}{1 + m_n + k_n + e_n \cdot k_n}$$

This equation shows that the growth rate is positively correlated with the accumulation rate α_n, the exploitation rate m_n and the investment efficiency χ in the renewable energy industry, negatively correlated with the organic composition of capital k_n and the ratio of energy capital to physical capital e_n.

Proof: The total value of energy goods W_{EG} can be decomposed as follows.

$$W_{EG}(t) \equiv P_E(t)Q_E(t) = P_E(t)[Q_f(t) + Q_n(t)] \tag{9}$$

where $P_E(t)$ is the price of energy good[4] in period t, $Q_E(t)$ is the total output of energy good, $Q_f(t)$ is the supply of fossil energy, and $Q_n(t)$ is the supply of renewable energy. Divide $P_E(t)$ on both sides of Type (9) to get:

$$Q_E(t) = Q_f(t) + Q_n(t) \tag{10}$$

Assume the supply function of fossil energy is Type (3), that is, for every $t \in [0, T_f]$, there exists $Q_f(t) = \bar{q} \equiv R^0_f / T_f$, where R^0_f is the total reserves of fossil energy, and T_f is the time that fossil energy is exhausted. Since the growth rate of fossil energy is defined as 0, the only way to meet the increasing demand of energy is to expand the capacity of renewable energy; hence the law of motion of renewable energy can be expressed as follows:

$$Q_n(t+1) = f[I_n(t), \chi] + Q_n(t) - \delta_n[Q_n(t) - Q_n(0)] \tag{11}$$

where δ_n is the rate of depreciation which is equal to 0 in this model for simplification. We can easily derive the growth rate of renewable energy from Type (11).

$$g_n(t+1) \equiv \frac{Q_n(t+1) - Q_n(t)}{Q_n(t)} = \frac{f[I_n(t), \chi]}{Q_n(t)} \tag{12}$$

where $I_n(t)$ is the investment in renewable industry, $f\,[I_n(t), \chi\,]$ is the function that translates the investment into new capacity, and χ is investment efficiency which is the parameter influenced by government policy. Assume $f\,[I_n(t), \chi] \equiv \chi I_n(t)/P_E(t)$ for further analysis. We can get the following expression from Type (12).

$$g_n = \frac{\chi \alpha_n m_n}{1 + m_n + k_n + e_n \cdot k_n} \tag{13}$$

Two facts are used to derive Type (13): the first is $I_n(t) = \alpha M_n(t)$, that is, the new investment is from surplus value. The second is

$$P_E(t) \cdot Q_n(t) \equiv W_n(t) = C_{E,n}(t) + C_{K,n}(t) + V_n(t) + M_n(t),$$

that is, the total value of renewable energy goods is equal to the sum of constant capital, variable capital and surplus value (QED).

In reality the organic composition of capital for renewable energy is always very high in the beginning. Although a high organic composition is considered as an expression of advanced technology in classical Marxian economics, the high organic composition of capital of renewable industry is the result of immature technology. Using Type (13), we can figure out the partial derivative $\partial g_n / \partial k_n < 0$ which means the high organic composition of capital leads to a slow growth rate of renewable energy capacity compared with the growth rate of energy demand. There are two ways to solve this problem.

The first is to strengthen technology to adjust the organic composition of capital to a reasonable level. For example, one can improve the labor skills and accumulate experience through the "learn by doing" effect, which decreases the organic composition of capital by increasing variable capital.

The second is to depend on support from government policy. We assume χ as the parameter that stands for investment efficiency in this model. When government uses some kinds of tax and subsidy policies to support the renewable energy industry, the investment efficiency of renewable energy will increase. The more efforts the government makes to support renewable energy, the faster the investment efficiency χ increases. The increase of investment efficiency can also fill the gap between the growth rate of renewable energy capacity and the sustainable growth rate of the economy.

Combining the above discussion with Propositions 1 and 2, we reach the following conclusions. First, economic growth leads to the growth of energy demand. When the supply of fossil energy cannot meet the demand, renewable energy should increase at a certain speed to fill the gap between supply and demand, which results in the increase of the utilization rate of renewable energy. Second, in reality the growth of the capacity of renewable energy depends on lots of factors, hence there exists the possibility that the growth rate will be slower than the growth rate required to guarantee the balance of energy supply and demand. Third, when the growth rate of the capacity of renewable energy cannot meet the current conditions, technological progress and policy support can help the renewable industry to increase the utilization rate, and to meet the conditions.

Econometrics Analysis

The theoretical model shows that the utilization rate of renewable energy is affected by three main factors. The first factor is the total energy demand. When the demand for energy increases, the utilization rate may increase as well. Technological changes are the second factor, which influences the utilization rate by decreasing the use cost of renewable energy. Last but not least, policy interventions can also encourage firms to substitute renewable energy for fossil energy. In this part, we try to use the panel data set of 28 OECD countries to test whether those factors have obvious impacts on the utilization rate of renewable energy in the real world.

The Model and Data Sources

The model to be tested is given as follows:

$$NEU = \beta0 + \beta1\ lgdp + \beta2\ IEU + \beta3\ lrds + \beta4\ PAT + \beta5\ REG + \beta6\ COE + \beta7\ OPD + \varepsilon \quad (14)$$

where:

NEU = The utilization rate of renewable energy.
lgdp = The log of gross domestic product per capita in 2000 dollars (PPP).
IEU = The degree of dependence on imported energy.
PAT = The number of patent applications to EPO.
lrds = The log of R&D budget spent on renewable energy sources.
REG = The indicator of the strength of regulation in energy industry.
COE = The carbon dioxide emissions per capita.
OPD = The spot crude oil price per barrel in Dubai market.
ε = all the other factors that might influence NEU.

First, we choose the ratio of renewable energy use to total energy use as dependent variable. It is very straightforward since we are interested in the utilization rate of renewable energy. The source for this data is the ratio of alternative and nuclear energy to total energy use reported by the *World Bank*.

Second, GDP per capita reported by *OECD statistics* is chosen to represent the demand side of the energy market, because lots of previous researchers have found that there is a long-term stable relationship between the GDP and the consumption of energy. For example, Shafiee and Topal (2008), Smil (2008), Payne (2010) and Brown (2011) indicate this positive relationship by using international data. Shiu and Lam (2004), Zhou and Chau (2006), Yuan et al. (2007, 2008), and Zhang and Li (2007) reach similar conclusions by using Chinese data. In particular, we use the ratio of net energy import to total energy use to stand for the degree of over-demand in a country's domestic energy market, which is also reported by the *World Bank*.

Third, the number of patent applications and the R&D budget spent on renewable energy sources represent the factor of technological changes, in which the former stands for the output of R&D and the latter stands for the input of R&D. Since there may be a time-lag effect of R&D, we try to use the current and the lag value of R&D budget and patents as independent variables for the statistical analysis. Those data can be found in *IEA Energy Technology R&D Statistics*.

Furthermore, the indicators of the strength of regulation in energy industry and the carbon dioxide emissions per capita are selected to be proxies of the policy intervention factor. The indicator of the extent of regulation shows the government's ability to control the energy market, and the highest score of this index is 6, which means that the government tightly controls the price of energy good or the most powerful companies in the energy market are owned by the government, which is exactly the case in China. The lowest score of that index is 0, which means that the energy market is a perfectly competitive market in that country, one can take the United Kingdom's electricity market as an example of that case. The *OECD Stat Extract database* provides the crude data of these indicators in two markets: the electricity market and the gas market. We take the simple average of those two markets. The carbon dioxide emission per capita is selected as a proxy of the restrictive policy against the traditional fossil energy industry because the emission reduction policy and the restrictive policy against fossil energy are the same to some extent. The decrease of the carbon dioxide emission per capita can be considered as a reaction to the emission reduction policy, and also of the restrictive policy. The source of these data is the *World Bank*.

Finally, we also introduce the price of crude oil per barrel in Dubai market as a representative of the price of traditional fossil energy. These data are published by the *BP Statistical Review of World Energy*.

Result Report and Preliminary Analysis of the Results

Since data on R&D budget and patents are not available for all 34 members of OECD, we exclude six countries: Iceland, Mexico, Israel, Slovenia, Estonia and Chile. These countries' data on R&D budget is inaccessible. We cannot find even one observed value during the period from 1974 to 2007. The remaining 28 countries also have some data missing on several levels. So technically, we use an unbalanced panel data set for our linear regression. But this problem will not bother us since most statistical software can solve this automatically, including STATA which is the software we used.

Generally speaking, the main methodology of this article is very standard for panel data regressions. We use the fixed effects model to estimate the parameters at the first time. Then we switch to the random effects model. Finally, a Hausman test will be done to determine which method of model specification is optimal for our model.

In particular, we divide 28 OECD countries into four categories by average GDP per capita during 1974 to 2007.[5] We use the above methodology to estimate the value of parameters in each category and overall for the 28 countries. By doing the Hausman test one by one, we find that in all five cases there is no systematic difference between the estimated value of the parameter of the random effects model and the fixed effects model. That means the estimated value of the random effect model is robust and more effective than that of the fixed effects model. So we will choose the estimated value of random effects for the result report and analysis.

The main results of econometrics analysis can be summarized in Table 1.

Table 1 Estimated coefficients of the random effects model

	Overall	*Richest*	*Relatively Rich*	*Relatively Poor*	*Poorest*
Net Import Ratio (t − 2)	0.0039	–0.0189***	–0.0670**	–0.05117***	0.1654***
	(0.0027)	(0.0043)	(0.0326)	(0.01962)	(0.0519)
Patent (t − 1)	–0.0106	0.0025	–0.0541**	–0.3816***	0.2325***
	(0.0074)	(0.026)	(0.0265)	(0.0601)	(0.0746)
R&D Budget	–0.4043**	–2.6309***	3.6492***	–1.0578**	–0.9121***
	(0.1847)	(0.7396)	(1.0831)	(0.4589)	(0.2862)
Regulation Index	0.6892***	–6.1862***	6.7591***	–4.8482***	–2.3634***
	(0.2285)	(0.7590)	(1.4305)	(0.6506)	(0.5001)
CO_2 Emissions	–1.5938***	–2.7207***	–2.1331***	0.1079	2.9280***
	(0.1348)	(0.2341)	(0.6341)	(0.4441)	(0.4784)
GDP per capita	10.2704***	8.9349*	38.3262***	–1.6153	–20.8139***
	(0.9832)	(4.8046)	(8.1329)	(3.6324)	(4.3416)
Oil Price (t − 5)	0.0190*	–0.7527	0.1137	–0.0342	–0.01718
	(0.0106)	(0.1137)	(0.1376)	(0.07145)	(0.0698)
Constant	–73.6435***	–10.5772	–376.8952***	55.5981	189.6578***
	(10.4192)	(51.0717)	(89.7949)	(34.6495)	(37.0969)
Observations	496	181	165	168	71
Wald chi^2	224.82	262.77	107.24	156.98	158.51

Notes: Standard errors in parentheses. * refers to 10%, ** refers to 5% and *** refers to 1% level of statistical significance.

Two variables which stand for the demand side of energy market, GDP per capita and the degree of dependence on imported energy, are predicted to have a positive relationship to the utilization rate of renewable energy. The sign of coefficients is consistent with the prediction in the overall 28 countries' regression, but there is a big difference in the statistical significance of those coefficients. It is interesting to note that we find a statistically significant negative relationship between the degree of dependence on imported energy and the utilization rate of renewable energy in the regression by using the data of the richest, relatively rich and relatively poor groups. The negative relationship between GDP and the utilization rate of renewable energy can also be found by doing regression using the poorest group data.

It is hard to figure out the statistically positive relationship between the technology factors and the utilization rate of renewable energy as predicted in the theoretical model. For Patent, a positive relationship can be found only in the case of the poorest group. The positive relationship between the renewable energy utilization and government R&D budget is found only in the relatively rich group. On the other hand, there is a quite obvious negative correlation between R&D budget and renewable energy use in most of the cases, which is very puzzling; we try to explain this result in the next section.

For policy intervention, we predict the negative relationship between renewable energy uses and carbon dioxide emissions theoretically and find it proved in the econometrics model; only the poorest group is an exception. We do not pay attention to the degree of government regulation in the simple supply-demand framework. In empirical research, the correlation is also ambiguous. We find a negative correlation in most of the cases. A positive relationship can only be found in the relatively rich group.

Finally, oil price is weakly statistically significant only in the overall group, and the sign of coefficients is positive which is consistent with the fact that renewable energy is a substitute for fossil energy.

Conclusion and Further Analysis of the Results

Our research shows that there are three factors that may affect the utilization rate of renewable energy; namely, market, technology and policy. Changes in these factors directly influence the supply and demand side of the energy market, thereby affecting the efficiency of the renewable energy. As we can see in Table 1 the estimates of the six indicators set to represent the three factors are all significant in at least one of the five cases, which suggests that the impact mechanism of the three factors that we had expected did exist under a certain condition which is related with the economic development level. Therefore, we will move one step further to analyze the impact of the three factors on the renewable energy use in different stages of economic development and to find out which factor will play the most important role.

The Impact of Market Factor

The market factor includes both market demand and traditional energy prices. Econometric results show that the expansion of market demand does have an impact on the renewable energy utilization rate. But the direction of the impact is ambiguous, econometrics results show a positive effect in some cases, and negative in others, because the economic development levels of countries are different. Generally speaking, for the economies or countries whose economic development level is not high enough, demand expansion will tend to have a negative impact on the renewable energy use, which may be due to the supply and demand pattern of the country—depending mainly on fossil energy from increased imports and production expansion. Conversely, countries with higher levels of economic development are more likely to balance energy supply and demand by expanding renewable energy production and thus demand expansion in those countries has a positive impact on renewable energy utilization rate.

Theoretically, when the degree of the tension due to the imbalance of domestic energy increases and a country's degree of dependence on foreign energy increases, the government will have a stronger motivation to support the development of the renewable energy industry to cope with their dependence on the imports of energy, or to ensure their national energy security, which should have a positive effect on the development of renewable energy. However, evidence shows that this phenomenon can only be found in the group of seven poorest countries.

When the prices of traditional energy increases, we find that the economy will make some response to this market signal with a 4–5-year time lag, which may be due to the time lag of the decisions made by the individuals who need a certain period to make clear whether the fluctuation of the prices is temporary or permanent. The individuals will begin to substitute renewable energy for fossil energy only when they believe that the price change is a permanent one.

The Impact of Technology Factor

As we have mentioned above, the impact of technology factor on renewable energy use is not significant in the majority of the groups, which is confusing. Of the two indicators, R&D spending and patent number, the performance of R&D spending is more puzzling since, in most cases, the coefficient of this variable is significantly negative, which means the increase in renewable energy R&D budget may lead to the decline in the renewable energy use. We propose two explanations for this puzzling finding which is clearly contrary to people's intuition.

First of all, let us consider an explanation from the perspective of econometric models. The regression model we used can only prove that there is a correlation between two variables, but fails to prove a causal relationship between those two. Technically, we can only say that there exists a negative correlation between these two variables, but we are not sure whether the increase of the renewable energy R&D budget would result in the decrease of renewable energy use, or whether the government's decision to expand the scale of renewable energy R&D budget is a response to the decrease of the renewable energy utilization rate.

Second, another explanation comes from economics intuition. Let us consider the rational response of a person that owns an endowment of fossil energy resources to the increase of R&D budget. When he or she gets the information that the government will expand investment in renewable energy R&D, they will rationally expect that as a substitute for fossil energy, renewable energy production costs in the future will be reduced, which means that for him (or her) the future market competition will inevitably be intensified and profits will inevitably be affected. Hence, his (or her) rational reaction to this change would be to reduce the fossil energy prices appropriately in order to sell the stock of fossil energy as soon as possible. Therefore, the increase in R&D spending on renewable energy may lead to the decline of the utilization rate of renewable energy, which can be considered as an example of the popular so-called "Green Paradox" theories.

Although there are some reasonable hypotheses to explain the anomalous impact of the technology factor on the renewable energy use, whether the technological progress can play a substantial role in promoting the renewable energy utilization rate or not needs further study.

The Impact of Policy Factor

The regression results of both the overall data and most groups show that the government's policy is the most important factor for the development of renewable energy nowadays. It is interesting to note that we find that the same policy will have different effects for the countries among different groups. This finding means that the optimal policy for the countries with different economic development level is different. Some people's meat may be others' poison.

The carbon emission reduction policy, for example, is a good case for the conclusion above. Based on theoretical models, we predict that there exists a reverse relationship between COE and new energy utilization which is proved to be true in the overall data regression. However, we get different results for the group regressions. Specifically, we get a significantly positive coefficient for the group data from the seven poorest countries, a coefficient that is not significant for the poorer countries, and a significantly negative coefficient for the group data from the rich countries. The result above reminds us that carbon reduction policies may be effective only for the countries with higher levels of economic development. The policy may have little effect for the development of the renewable energy industry if the country's economic level cannot meet certain requirements.

The effects of the policies of industrial regulation also depend significantly on a country's level of economic development. Theoretically, the government's regulation of the energy industry plays dual roles. On the one hand, the government's strong control over the energy industry may help the government to implement the long-term plans of promoting renewable energy industries, which can improve the renewable energy utilization. On the other hand, the government-controlled energy monopoly may have less impact on the development of renewable energy technologies and less promoting efficiency than the private sectors because of the lack of the market-oriented incentive mechanism, which may restrict the development of the new energy industry. Empirical results show that the policy of deregulating the renewable energy industry for countries with lower levels of economic development will help to improve energy utilization.

Notes

1. For the purpose of this article, this simple exploitation path is enough; using a more complicated path, for example, the classic Hotelling path, will not change the main conclusions. The key of our analysis is that fossil energy is non-renewable.

2. Since we have assumed that the total reserve of non-renewable energy is known at period 0, this assumption can be easily satisfied by changing the life span of fossil energy.
3. According to the assumption that the supply of fossil energy is "the gift of nature," technical advance actually only happens in the renewable energy sector in this article.
4. Assume the final good as universal equivalent, whose value is equal to its price by definition. The price of energy good is defined as the exchange value of energy good in final good terms.
5. The seven richest countries are the Netherlands, Demark, Canada, Norway, Switzerland, United States and Luxembourg. The category of relatively rich countries includes Japan, France, Germany, Belgium, Australia, Austria and Sweden. Greece, Spain, Ireland, New Zealand, Finland, the United Kingdom and Italy belong to the category of relatively poor countries in OECD. The seven poorest countries are Portugal, Turkey, Poland, Korea, Slovakia, Hungary and the Czech Republic.

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