Article

The Energy Rebound Effect for Construction Industry: Empirical Evidence from the China

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Abstract: As the largest energy consumer and carbon emitter, China has made substantial efforts to improve energy efficiency for decrease energy consumption, while the energy rebound effect determines its effectiveness. The embodied energy consumption of construction projects accounted for nearly one-sixth of the total economy's energy consumption in China. This paper is based on the logical relationship among capital input, technological progress, economic growth, and energy consumption, adapting an alternative estimation model to estimate the energy rebound effect for the construction industry in China for the first time. Empirical results in our paper reveal that the energy rebound effect for the construction industry in China is about 59.5% for the period of 1990–2014. The results indicate that the energy rebound effect does exist in China's construction industry and it presented a fluctuating declining trend. This implies that half of the energy savings by technological progress is achieved. In addition, China's government should implement proper energy pricing reforms and energy taxes to promote the sustainable development of China's construction industry.

Keywords: construction industry; energy rebound effect; sustainability; solow remainder; ridge regression

1. Introduction

As the world's largest developing country, China has increased its GDP by a multiple exceeding 80-fold since its reform and opening-up of its economy in 1978. Meanwhile, China has faced more and more emerging conflicts in terms of energy supply and demand. In 2007, China became the largest carbon emitter [1] and with a GDP of $5.8786 trillion USD in 2010, China overtook the United States, becoming the world's largest energy consumer [2]. China is on a path to rapid urbanization and industrialization. There is no doubt that the energy demand will soar in the future. Therefore, improving energy efficiency is vitally important for energy savings and CO_2 emission reduction. This problem has been a focus of both academic circles and the Chinese government and China has made substantial efforts to improve energy efficiency in the past decades.

Since 2006, plans for energy reduction have been incorporated into the national strategic plans and policies in China [3]. The 11th "Five-Year Plan" set the target of reducing energy intensity, the energy consumption per unit of GDP would be reduced by 20% from 2006 to 2010. In 2009, China's government put forward the target that CO2 emissions per GDP would drop by 40–45% of that in 2020, relative to 2005 levels. Furthermore, China's 12th "Five-Year Plan" proposed to decrease the aggregate energy intensity by 17% from 2011 to 2015. Additionally, the Chinese government promises that its carbon emissions would reach the peak in approximately 2030. To achieve these ambitious goals, all industries in China have to spare no effort to find appropriate ways in which to promote technological progress and to reduce carbon emissions [4–6].

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As the primary energy consumer in China, the embodied energy consumption of construction projects accounted for nearly one-sixth of the total economy's energy consumption in China [7] in 2007. Therefore, considering the requirement of the sustainability of development in China, the construction industry is supposed to take great responsibility for mitigating pollution. It is necessary to develop its energy-related technologies and improve its energy efficiency in the construction industry, and the China Energy Statistical Yearbook shows that the energy intensity of the Chinese construction industry has been continuously falling, from 0.623 tce/10,000 RMB in 1990 to 0.044 tce/10,000 RMB in 2014 (1990 constant price), with an obvious downward trend, indicating that construction industry energy efficiency has been improving.

In the meantime, the energy efficiency in the construction industry has been enhanced significantly. In contrast to the expected effect, the energy consumption is still increasing rather than decreasing (Figure 1), from 12.13 Mtce in 1990 to 78.23 Mtce in 2014, with a growth rate of 545%.The most important reason is the large energy demands driven by rapid economic growth, while the "rebound effect" is also an important aspect not to be neglected [8].

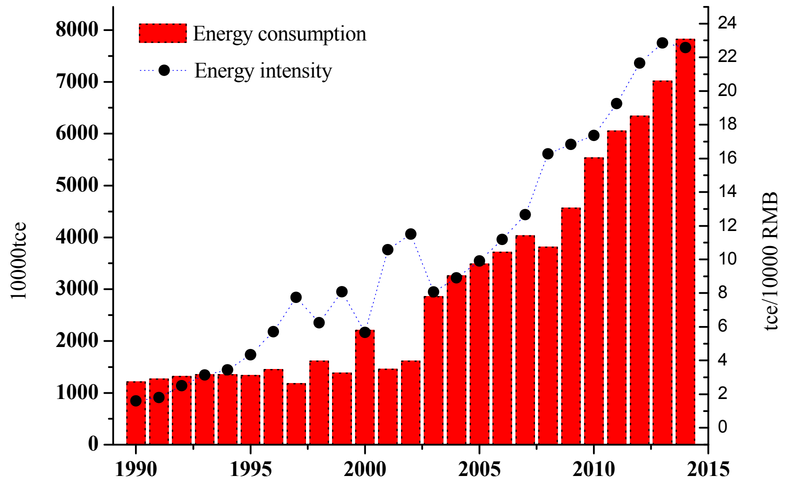

Figure 1. Energy efficiency and energy consumption in China's construction industry.

The "rebound effect" is an important issue in energy economics. Potential energy saving from improved energy efficiency can be partly, or even totally, offset by additional energy demand and consumption, caused by some economic effects, such as the substitution effect, income effect, and output effect [9]. This phenomenon is called the "energy rebound effect", which implies that, although energy efficiency enhancement induced by technological progress would reduce energy consumption, technological progress and energy efficiency enhancement can promote economic growth and, thus, generate new energy demand. Therefore, the energy saved by improved energy efficiency is partially offset by additional energy consumption. This lost part of the potential energy savings is defined as the rebound effect [10].

In fact, the development of technology in the construction industry would help improve energy efficiency and mitigate carbon emission while, at the same time, the energy price might decrease due to the accelerating technological progress, which might stimulate energy demand and offset the positive role technological progress plays in energy saving. Therefore, the energy rebound effect has to be taken into consideration to estimate the actual energy conservation achieved in the construction industry, and to avoid overestimating the effectiveness of energy efficiency improvement caused by technological progress.

Under this circumstance, the aim of this paper is to determine China's construction industry technological progress and energy rebound effect for the first time. Considering the data unavailability and non-market characteristics of energy prices in China, this paper is based on the logical relationship among capital input, technological progress, economic growth, and energy consumption, and this study adapts an alternative estimation model, employing the Solow remainder and ridge regression to estimate it.

The structure of this paper is organized as follows: Section 2 provides a literature review about the rebound effect; Section 3 presents the models and methodology; detailed discussions of empirical results are conducted in Section 4; and Section 5 provides the conclusion.

2. Literature Review

Since the earliest studies on the energy rebound effect in the estimation of energy savings [11], the energy rebound effect has received increasing attention. In China, the evolution of the rebound effect was later than in western countries. Over the past decade, there have been some studies proving that the energy rebound effect can be very significant in China [12–14].

From 2006, the studies mainly employed two types of methods to estimate the energy rebound effect in China at the macroeconomic level: the CGE (computable general equilibrium) model and the econometric approach. Based on the CGE model, Glomsrød and Wei [15] simulated the influence of an emerging market for cleaned coal on Chinese energy consumption and pollutant emission. They found that coal cleaning stimulates economic growth and reduces particle emissions, but total energy use, coal use, and CO_2 emissions increase through a rebound effect supported by the vast reserve of underemployed laborers. Zha and Zhou [16] used the CGE model to estimate the rebound effect. The authors concluded the 4% increase of energy efficiency could induce a 33% rebound, while the latter argued that, in the long term, the 5% increase of energy efficiency could generate a 178.61% backfire effect. The CGE model takes into account many related influential factors of energy efficiency in order to reflect the complexity of the economic system, such as factor substitution, income level, industrial structure, policy guidance, and technological progress. While this method conducts simulation analysis by subjectively setting the growth rate of energy efficiency, it is difficult to attain the actual rebound effect resulting from empirically-estimated energy efficiency change.

Econometric approaches were also used to estimate China's economy-wide energy rebound effect. Zhou and Lin [17] used the econometric model to estimate the energy rebound effect in China at the macroeconomic level firstly, and the result showed that the energy rebound effect fluctuates from 30% to 80%. After that, most studies followed their thinking, but used various econometric approaches and data samples. For instance, Feng and Ye [18] further considered the spatial spillover effect between the regions' economic growth and estimated the energy rebound effect in China's 29 provinces from 1995 to 2011. They found that there exists significant time and spatial spillover characteristics in China's energy consumption rebound effect, and the rebound effect does not appear in all periods; it appears relatively concentrated in the eastern provinces, and less in economically underdeveloped provinces.

At present, compared with the significant studies for China's economy-wide energy rebound effect, the energy rebound effect in specific industrial sectors have received much less study. Guo and Ling [19] estimated the rebound effect in industrial sectors in China during the period of 1978–2007. The result shows that the rebound effect in the study period was roughly 46.38%. Lin and Li [20] estimated the rebound effect in China's heavy industry later on and found that the rebound effect for the heavy industry in China was about 74.3%.

The construction industry, as the main energy consumer in China, is examined in this paper and we measure the energy rebound effect of China's construction industry for the first time. This paper provides some empirical evidence on the energy rebound effect for the construction industry in China, which is the largest energy consuming country in the world. The magnitude of the rebound effect is particularly important for the design of an effective set of energy conservation policies. A large rebound effect estimation implies that efficiency policies require commensurately higher energy prices; otherwise, energy saving would not be realized due to the rebound effect, and it will be better to implement energy policies when the rebound effect is relatively small. Hence, it would be meaningful to quantitatively evaluate the magnitude of the rebound effect for the construction industry in China.

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3. Methodology

The energy rebound effect in China's construction industry is determined through the following mechanism: we assume there is a technology advancement in the construction industry. On the one hand, energy efficiency improvement promote technological progress, then it will accelerate economic growth, finally increase in energy consumption. On the other hand, energy efficiency improvement decrease in energy price, then energy demand will rise, finally increase in energy consumption.

This paper estimates the energy rebound effect in China's construction industry by comparing the energy consumption changes mainly caused by output growth after technological progress change. Therefore, the key to energy rebound effect estimation is to evaluate the potential energy savings (SE) caused by technological progress and the additional energy consumption (AE) due to output growth caused by technological change (energy efficiency improvement). In this way, we can define the energy rebound effect in China's construction industry as follows:

$$RE = \frac{AE}{SE} \times 100\% \tag{1}$$

Energy intensity is one of the most popular indicators for measuring energy efficiency of a country or industry because improvements in energy efficiency are frequently indicated by a decrease in energy intensity. It is convenient and objective to measure energy efficiency through energy consumption per GDP when energy input structure changes slightly [21]. The relationship between energy consumption and GDP can be represented as follows:

$$EI_t = \frac{E_t}{Y_t} \tag{2}$$

where Y_t is the output of China's construction industry in year t, E_t is the energy consumption of China's construction industry in year t, and EI_t represents energy consumption per GDP.

If energy efficiency is improved, energy intensity will decrease. Then, the potential energy saving (SE) in China's construction industry in year $t+1$ is as follows:

$$SE_{t+1} = Y_{t+1} \cdot (EI_t - EI_{t+1}) \tag{3}$$

Therefore, the additional energy consumption (AE) due to output growth caused by technological change in China's construction industry in year t + 1 is as follows:

$$AE_{t+1} = \sigma_{t+1} \cdot (Y_{t+1} - Y_t) \cdot EI_{t+1} \tag{4}$$

where σ_{t+1} denotes the contribution of technological progress to China's construction industry in year $t+1$.

Thus, the estimation formula of the energy rebound effect in year $t+1$ can be expressed as:

$$RE_{t+1} = \frac{AE_{t+1}}{SE_{t+1}} = \frac{\sigma_{t+1} \cdot (Y_{t+1} - Y_t) \cdot EI_{t+1}}{Y_{t+1} \cdot (EI_t - EI_{t+1})} \tag{5}$$

According to Equation (5), the key to estimating the rebound effect is to precisely estimate the contribution of technological progress to China's construction industry. Considering the data unavailability and non-market characteristics of China's energy price, this paper presents a model incorporating three input factors (capital, labor, and energy) of neoclassical product functions and Solow remainder methodology to calculate the technological progress in China's construction industry.

In neo-classical economics, economic growth is commonly defined as growth in production (Y) in the economy, which is a function of capital (K) and labor (L).

$$Y_t = F(K_t, L_t) \tag{6}$$

where t is the time index.

This study regards energy as an input factor that combines with capital and labor to produce the output of the whole economy, or of a sector of the economy (for example, the construction industry in this paper). Based on Hicks neutral C-D production function, the production function of the three elements of China's construction industry are described as follows:

$$Y_t = A_t \cdot F(K_t, L_t, E_t) \tag{7}$$

where Y_t denotes the contributions to the total output increase of China's construction industry in year t. K_t is the capital stock of China's construction industry in year t. L_t is the labor input of China's construction industry in year t. E_t is the energy consumption of China's construction industry in year t. A is Hicks neutral technological parameter, which can be defined by: $A_t = A_0 e^{rt}$. Then, we can obtain a model incorporating the three input factors (capital, labor, and energy) of neoclassical product functions:

$$Y_t = A_0 e^{rt} \cdot K_t^{\alpha} \cdot L_t^{\beta} \cdot E_t^{\gamma} \tag{8}$$

Taking the natural logarithm of Equation (8):

$$\ln Y_t = \ln A_0 + rt + \alpha \ln K_t + \beta \ln L_t + \gamma \ln E_t \tag{9}$$

where α, β, and γ denote the output elasticities of capital, labor, and energy.

Previously, some studies used the OLS (ordinary least square) to estimate the result of Equation (9). When the predictor variables are highly correlated, ridge regression produces coefficients which predict and extrapolate better than ordinary least squares and it is a safe procedure for selecting variables. Thus, this paper employs ridge regression to estimate the result of Equation (9)

This paper uses g_Y, g_K, g_L, and g_E to represent the growth rate of output, capital, labor, and energy of the construction industry. Thus, we obtain:

$$g_Y = \alpha \cdot g_K + \beta \cdot g_L + \gamma \cdot g_E + g_A \tag{10}$$

where g_A is the Solow remainder, which represents technological progress. Thus, the technological progress rates of construction industry can be presented as follows:

$$\sigma = \frac{g_A}{g_Y} = 1 - \alpha \frac{g_K}{g_Y} - \beta \frac{g_L}{g_Y} - \gamma \frac{g_E}{g_Y} \tag{11}$$

We can obtain the contribution of technological progress to China's construction industry. Finally, based on Equation (8)–(11), and using relevant statistical data, we can calculate the energy rebound effect in China's construction industry in different years.

4. Empirical Results

4.1. Data Description

In previous related studies on China, there are few studies about the energy rebound effect in China's construction industry. Considering the development of the construction industry and the availability of data, we use a data sample over the period of 1990–2014. Details of the input-output data in Equation (8) are as follows:

Output Y : the real GDP at 1990 constant price deflated by the GDP deflator, sourced from China Statistical Yearbook and China's Construction Industry Statistical Yearbook.

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Labour input L : We use the average employment numbers at the beginning and end of each year to measure labor input. The original data is from the China Statistical Yearbook and China's Construction Industry Statistical Yearbook.

Energy input E : The energy involved in China's construction industry includes coal, oil, natural gas, and coke. The statistical yearbooks give the consumption of each energy type. In order to ensure the units are consistent and comparable, all energy types are converted into the standard coal equivalent. The aggregation is the total energy consumption in the power generation sector measured by the standard coal equivalence.

Capital stock K : The data of capital stock in each sector is unavailable in China's current statistics, but the methodology of the capital stock estimation has been well developed. There are a few studies estimating the capital stock in China's industrial sector [22,23]. This paper adopts the perpetual inventory method (PIM) to calculate the capital stock in China's construction industry. The PIM is defined as:

$$K_t = K_{t-1}(1-\delta_t) + I_t \tag{12}$$

where I_t denotes the investment in year t, K_t denotes the capital stock in year t, and δ_t is capital depreciation rate assigned (18.53%) [23]. The original data is from the China Statistical Yearbook and China's Construction Industry Statistical Yearbook.

4.2. Parameter Estimation

To avoid spurious regression, properties of the time series data should be tested by the unit root test. The results are presented below:

Table 1. The results of unit roots test.

Variable	ADF statistic	1% Critical value	5% Critical value	10% Critical value	Stationarity
ln Y	-2.2822	-4.3943	-3.6122	-3.2431	Non-stationary
ln K	-0.7598	-4.3943	-3.6122	-3.2431	Non-stationary
ln L	-2.9391	-4.3943	-3.6122	-3.2431	Non-stationary
ln E	-2.3286	-4.4679	-3.6450	-3.2615	Non-stationary
Δ ln Y	-4.4415	-4.4163	-3.6220	-3.2486	stationary
Δ ln K	-5.4121	-4.4163	-3.6220	-3.2486	stationary
Δ ln L	-8.6178	-4.4163	-3.6220	-3.2486	stationary
Δ ln E	-3.8258	-4.6162	-3.7105	-3.2978	stationary

Table1 indicates that although output, capital, labor, and energy are all non-stationary time series, their first difference forms are all stationary time series at the 1% significance level and all of the variables are integrated of order one.

Meanwhile, we adopt the Pearson correlation test to check whether our predictor variables are highly correlated. The results in Table 2 indicate that output, capital, labor, and energy are high correlated. Therefore, we should employ ridge regression to estimate the result of Equation (9).

Table 2. Correlation test of variables.

	Output	Capital	Labour	Energy
Output	1	0.9665	0.9574	0.9360
Capital	0.9665	1	0.9528	0.9523
Labour	0.9574	0.9528	1	0.9066
Energy	0.9360	0.9523	0.9066	1

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4.3. Estimated Result of Ridge Regression

The estimated result of ridge regression of Equation (9) is as follows:

$$\ln Y = -1.7077 + 0.6712\ln L + 0.3565\ln K + 0.4208\ln E + 0.0486t \quad (13)$$

Table 3. The result of ridge regression.

Variables	Coefficient	significance level	$R^2 = 0.951$
In L	0.6712	0.0000	
In K	0.3565	0.0000	
In E	0.4208	0.0000	
t	0.0486	0.0000	
c	-1.7077	0.0021	

The result shows that it is acceptable for the time series model that $R^2 = 0.951$. The estimated result of the ridge regression is reasonable, whereby the estimated technological progress rate will be credible. According to Equation (13), we can determine that the output elasticity of labor input of China's construction industry (0.6712) is higher than that of the energy input (0.4208) and capital input (0.3565), which indicates that China's construction industry belongs to labor-driven development, and the development of China's construction industry largely depends on labor input. As a labor-intensive industry, China's abundant labor resources provide a good impetus for the development of the construction industry, so the construction enterprises inevitably ignore the investment in technological innovation; especially, many small and medium-sized enterprises are unlikely to increase their investment in technological innovation. Although this situation has improved in recent years, the construction industry is still slightly less invested in technological innovation compared with other pillar industries. Technological progress as a lasting force in the development of the construction industry, and enterprises should be more concerned about it. Only by increasing investment in technology, speeding up technological innovation, promoting new technologies, new processes, and new materials in the industry can the construction industry shift from a labor-intensive industry to a technology-intensive industry.

Based on the above estimated results and Equations (8)–(11), using relevant statistical data, we can determine the potential energy saving and additional energy consumption, and calculate the energy rebound effect in China's construction industry from 1990 to 2014. The results are shown in Table 4 and Figure 2.

Table 4. The estimation rebound effect of energy consumption in the construction industrial sector.

Year	Energy intensity	Technological progress rate	Energy saving	Additional energy	Rebound effect
1991	0.5545	0.8052	156.0163	150.5684	0.9651
1992	0.3992	0.9452	512.2584	382.6393	0.7470
1993	0.3185	1.1045	342.0157	329.5394	0.9635
1994	0.2899	-2.4441	133.0758	-296.0447	-2.2246
1995	0.2304	0.6163	344.6090	161.9491	0.4700
1996	0.1750	0.1142	459.4034	49.7369	0.1083
1997	0.1292	1.3687	417.6998	149.2697	0.3574
1998	0.1602	-0.6546	-312.1460	-98.1042	0.3143
1999	0.1238	1.4094	405.7651	190.3836	0.4692
2000	0.1766	-1.4731	-659.4685	-349.8184	0.5305
2001	0.0946	1.2773	1259.9333	345.9651	0.2746

2002	0.0869	0.4167	142.0545	114.6299	0.8069
2003	0.1239	-0.7919	-853.4746	-447.0334	0.5238
2004	0.1123	0.4110	336.4223	274.0283	0.8145
2005	0.1009	0.3035	394.0194	169.3402	0.4298
2006	0.0894	0.4196	477.1838	262.7476	0.5506
2007	0.079	0.4179	531.8150	313.1245	0.5888
2008	0.0615	0.7484	1087.2555	505.6225	0.4650
2009	0.0594	0.2080	158.2707	182.5224	1.1532
2010	0.0576	0.0809	170.6105	89.5840	0.5251
2011	0.0520	0.6696	658.8062	710.9083	1.0791
2012	0.0462	0.1238	792.6985	118.6211	0.1496
2013	0.0438	0.1516	389.5254	153.5622	0.3942
2014	0.0443	-0.5188	-90.8422	-375.4856	4.1334

5. Discussion

The empirical results show that the energy rebound effect indeed exists in China's construction industry. The energy rebound effect is also shown to vary from 10% to 96% and to fluctuate during different periods. This paper discusses these findings further here.

From Table 4, it is shown that the impact of technological progress on energy intensity and energy savings is a dynamic change process. In 1994, 1998, 2000, 2003, and 2014, the value of five years of construction industry energy savings was negative. Excluding these five special years, we can see that the trend of energy rebound effect of China's construction industry is downward, but very tortuous (Figure 2). This is related to the development background of China's construction industry in different years. From 1991 to 2014, the average energy rebound effect of China's construction industry was 59.5%, and compared to the results of other studies on the rebound effect of Western countries' sectors [24,25] the results are relatively small. While considering the current situation of China's national economic development, China's construction industry is still in an extensive development stage. Meanwhile the results are similar to those previous studies regarding the energy rebound effect, so the estimated results are credible.

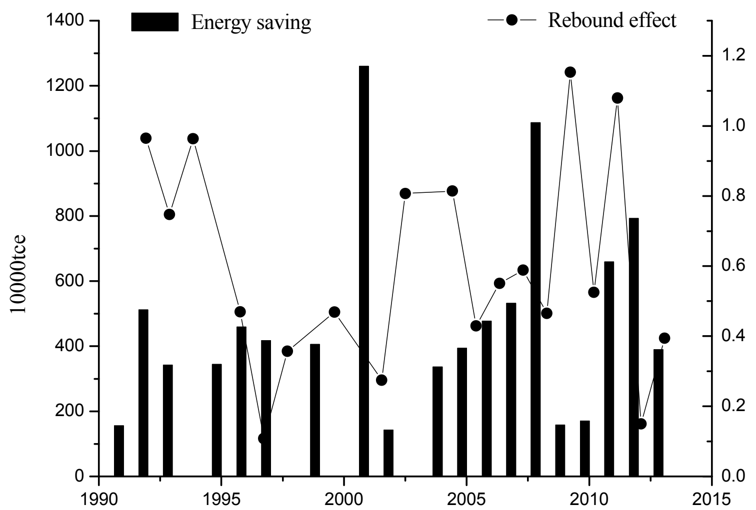

Figure 2. The fluctuation of the energy rebound effect in the construction industry (1990–2014).

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From 1991 to 1999, the average energy rebound effect of China's construction industry was 58%. The energy rebound effect from 96.5% down to about 30%, shows that there is an obvious downward trend. From 2000 to 2009, the average energy rebound effect of China's construction industry was 63.5%, which was slightly higher than that of the 1990s. This can be attributed to the government starting to implement the commercialization of housing in 1998, and the construction industry, which is closely related to real estate, also saw rapid development. China's construction industry developed rapidly during 2000–2009. In this period, the gross output value of China's construction industry rose from 1249.76 billion RMB to 7680.77 billion RMB. The rapid development of the construction industry has brought significant amounts of energy demand, prompting technological progress to save energy less than the energy needed for the growth of construction industry. After 2009, the average energy rebound effect was 53.7%. With the development of the construction industry becoming stable, the output growth of the construction industry tends to be stable. In this period, the rebound effect is obviously decreased, and the energy saving effect brought by technological progress is more obvious.

In addition, the energy rebound effect of the construction industry is greater than, or close to, 100% in 1991, 1993, 2009, and 2011. In these years, China's government increased its economic input and stimulated economic growth, promoting the new energy consumption to a level greater than the savings in energy consumption. Especially in 2009 and 2011, there is a backfire effect.

Through the empirical results, it is shown that the energy rebound effect indeed exists in China's construction industry, and in different periods there are different fluctuations. Overall, the energy intensity of China's construction industry presented a declining trend. For special years, in 1994, 1998, 2000, 2003, and 2014, a total of five years of the construction industry energy savings was negative. In 1998, 2000, 2003, and 2014, there was a slight increase in the intensity of energy, but in this study, this does not mean that technological progress cannot reduce the energy intensity of the construction industry. The construction industry is closely related to the development of China's national economy, real estate, and other industries. There are many times where micro-control of real estate in China's economic development process has occurred, and the development of the construction industry has also changed several times. For this reason, the energy intensity of the construction industry may rise in some years, resulting in negative energy savings.

On the whole, compared with the developed countries, the rebound effect of China's construction industry is slightly higher, but the overall energy rebound effect is less than 100%. This indicates that the technological progress of China's construction industry promotes the increase of energy efficiency, and the energy rebound effect presents a circuitously downward trend. The overall technological progress of the construction industry played a significant role in energy saving and low-carbon development.

6. Conclusions

In this paper, we determined the energy rebound effect and contribution by technological progress and in China's construction industry for the first time. Considering the data unavailability and non-market characteristics of China's energy price, this paper presents an alternative estimation model incorporating three input factors (capital, labor, and energy) of neoclassical product functions and Solow remainder methodology to calculate the energy rebound effect in China's construction industry over the period of 1990–2014.

Firstly, the results showed that the energy rebound effect indeed exists in China's construction industry. The average energy rebound effect of China's construction industry is 59.5% for the study period, and the energy rebound effect presented a fluctuating declining trend, indicating that approximately half of the potential energy saving by technological progress is achieved. The technological progress of the construction industry played a significant role in energy conservation. In addition, due to political and economic turbulence, energy efficiency was not enhanced in some special years, presenting an ineffective energy-saving state.

In addition, the results of ridge regression indicate that China's construction industry belongs to labor–driven development, and the development of China's construction industry largely depends on labor input. This reveals that the investment of technological innovation in the construction industry is insufficient. Only by increasing investment in technology, speeding up technological innovation, promoting new technologies, new processes, and new materials in the industry, can the construction industry reduce carbon emissions and energy consumption.

Finally, there is the evident energy rebound effect in China's construction industry. This means that policies, especially a reasonable control on the energy consumption adjustment, should be taken as supplementary to technological progress. The related research demonstrates that it is our low energy pricing that leads to the high energy consumption of China [26–28]. The lower energy prices under government intervention cannot truly reflect the supply-demand relation of the energy market and the external environment brought by energy use. On the one hand, it reduces the driving force for enterprises' energy conservation; on the other hand, it also reduces the alternative effect of the other input factors on energy, resulting from changes of the energy's relative price. Therefore, China should not only promote technological progress, but should also have appropriate energy prices, taxation, and other macro-control means to create the maximum energy efficiency brought by technological progress, and to promote the sustainable development of China's construction industry.

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