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Original Research

Exploring the Nexus of Energy Consumption Structure and CO_2 Emissions in China: Empirical Evidence Based on the Translog Production Function

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Abstract

With the rapid development of China's economy, CO_2 emissions have surged and environmental pollution has become increasingly serious, drawing broad attention domestically and overseas. To improve China's environmental quality, the Chinese government has set a series of ambitious goals to control carbon intensity and even cut total CO_2 emissions. China's energy consumption structure relies heavily on coal, which is the largest contributor to CO_2 emissions in China. However, so far research on the relationship between energy consumption structure and CO_2 emissions in China remains scarce. This paper investigates this topic for the first time and calculates the input-output and alternative elasticities and impacts the energy consumption structure on carbon emissions per capita on the basis of the translog production function as the theoretical framework. The empirical results suggest that to substitute coal with oil or gas may decrease CO_2 emissions significantly, and replacing coal with gas is the optimal choice. As such, improving China's energy structure by increasing the share of gas and decreasing the reliance on coal would cut China's CO_2 emissions remarkably and benefit China's environmental quality.

Keywords: CO_2 emissions, energy consumption structure, translog production function, China

Introduction

In China, environmental problems have become increasingly severe since the economy began to take off in the late 1970s. Under these conditions, climate change has drawn considerable attention domestically and overseas. A large amount of greenhouse gases (GHG), such as carbon dioxide (CO_2), have sped up the process of global warming. Meanwhile, plant diseases and insect pests, land desertification, the rising sea level, and other issues will occur due to global warming. Therefore, these issues will bring many threats to our human existence. According

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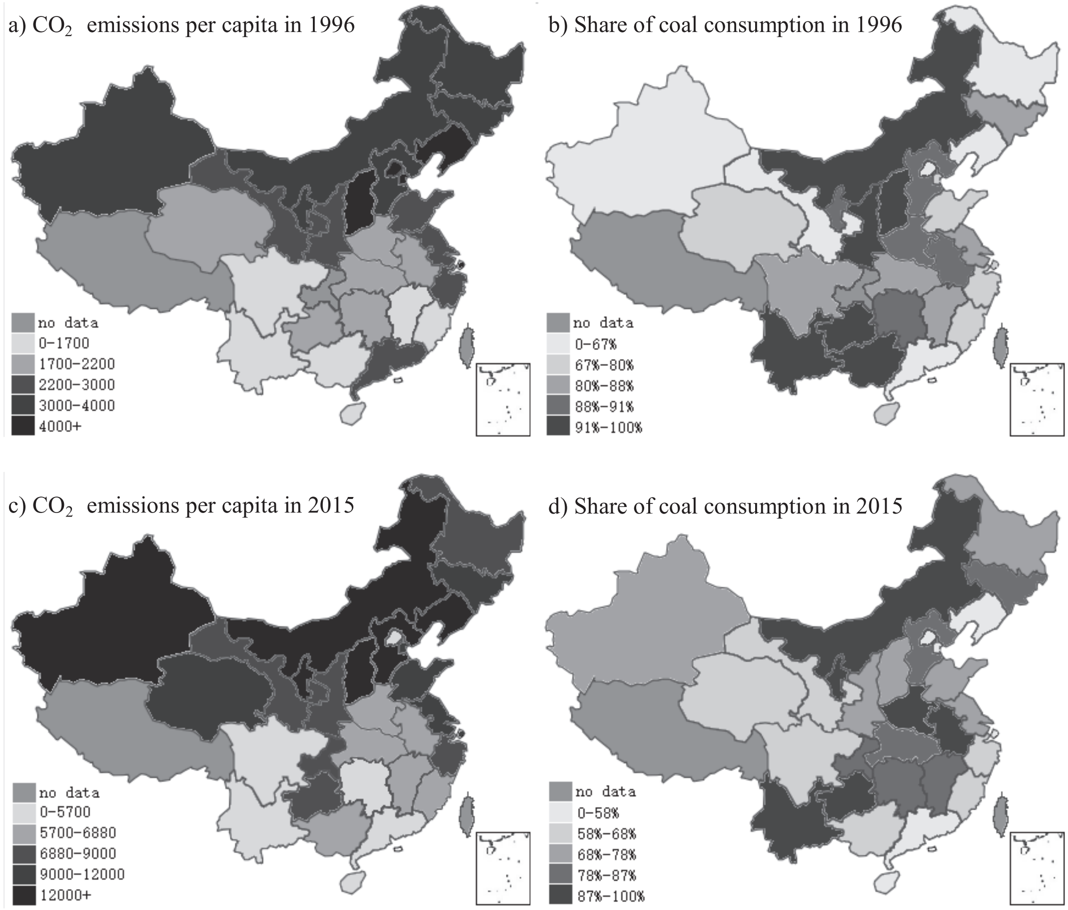

Fig. 1. Per capita CO_2 emissions (kg/person, panels a and c) and share of coal consumption in energy mix (panels b and d), 1996-2015.

to a report from the Intergovernmental Panel on Climate Change (IPCC), the consumption of fossil fuels is the main reason for the rapid increase in CO_2 emissions. To address this problem, the Chinese government is determined to set a goal to address these energy issues, which requires the intensity of carbon emissions to decrease by 40-50% by 2020, compared to the amount released in 2005. The adjustment of the energy consumption structure has a direct influence on carbon emissions. Therefore, research regarding the relationship between energy consumption structure and carbon emissions is significant.

No matter what type of energy we use, meeting the needs of energy consumption is essential. However, there is a great difference in the amount of carbon emissions when using different types of energy to provide the same amount of energy. Moreover, the energy's form, use method, and use field will also affect the carbon emissions of energy. Hence, improving the energy consumption structure will significantly reduce carbon emissions. In recent years, secondary industry has developed at a rapid pace in China. For example, coal, as a fundamental source of energy, has been consumed at alarming amounts, which has caused a high amount of carbon emissions and a rapid deterioration of the environment. Therefore, by producing a lower amount of carbon emissions, the environment in China will be better through improving the energy consumption structure, reducing coal consumption, and decreasing the proportion of coal to total energy consumption.

Given the considerable differences in economic and social development across different regions, China's CO_2 emissions and energy consumption structure also have different characteristics across provinces[1]. As shown in Fig. 1, in both 1996 and 2015 (the beginning and ending years of our sample period), the per capita CO_2 emissions were relatively higher in the northern and northwestern provinces such as Shanxi, Hebei, Inner Mongolia, Ningxia, and Shanxi, where the ratios of coal consumption in energy mix were also higher. As such, it could be seen intuitively that China's energy consumption structure might be highly correlated with CO_2 emissions per capita.

According to different studies, the existing research can be divided into five categories. The first category discusses the impact factors of carbon emissions, where [1] broke down the impact factors of carbon emissions

[1] Currently China has 23 provinces, 4 centrally administered municipalities, and 5 autonomous regions. Because these entities are administratively equal, in this study "province" is utilized to refer to the province-level administrative entity. Tibet and Taiwan are excluded from the dataset due to lack of data.

in China from 1957 to 2000, based on the logarithmic mean divisia index method; [2-3] used the STIRPAT model to further analyze the impact factors; [2] argued that economic growth has had the most significant impact on carbon emission; [3] used this model to analyze the factors that influence carbon emissions in the process of the new-type urbanization in Henan; [4] used Malmquist's index analysis method in a paper and found that the technological progress is the main reason for the increase of carbon emissions; and [5] provided panel data analysis regarding the influencing factors of carbon emissions in eastern, central, and western China, respectively .

The second category discusses the relationship between energy consumption and carbon emissions. For instance, [6-9] analyzed the connection between energy consumption, carbon emissions, and the economic aspect and concluded that covariance existed among them; [6] discussed conditions in China and came up with some suggestions regarding a new formulation of a relevant policy; [7] used the panel data method in the study; [8] simply discussed the connection in Liaoning Province; Omri researched the relationship in MENA countries, and the evidence was provided from simultaneous equation models [9]; [10] analyzed the data of energy consumption and carbon emissions from 2000 to 2011 in Shaanxi Province using the LMDI energy-forecasting model; and [11] analyzed the impacts of Industrial energy efficiency with CO_2 emissions using data envelopment analysis (DEA).

The third category discusses the relationship between the energy consumption structure and energy intensity: [12] also discussed this issue between 1973 and 1990 in a world that had a complete decomposition model; [13] demonstrated that the improvement of energy consumption structure reduced energy intensity in China in the 1990s; and [14] researched the data between 1980 and 2006 in China and suggested decreasing the proportion of fossil fuel in energy and increasing the efficiency of energy.

The fourth category is about the relationship between energy consumption structure and the intensity of carbon emissions (measured by the ratio of carbon emissions and GDP): [15] applied econometrics methods to analyze this issue; [16] predicted the energy consumption structure for the future and provided valuable suggestions on achieving the target in the 12th Five-Year Plan based on their conclusion; and [17] used extended Kaya identity to analyze the connection during 1995 and 2010 in China.

The fifth category discusses the energy consumption structure and carbon emissions: [18] discussed the relationship between Mexico's household energy consumption structure and carbon emissions from 1996 to 2006, moreover arguing that higher gas appliance efficiency and the reduction of electricity emission factor could lead to a decrease of carbon emissions; [19] argued this issue in China based on the CGE model; and [20] analyzed the situation of 30 provinces in China between 2000 and 2011 through the SBM model, and provided valuable advice to the government. At present, a small amount of research has been done regarding the relationship between the energy consumption structure and carbon emissions and therefore this is the overall object of this paper.

Given the extent of literature, current research of carbon emissions has mainly focused on five aspects: 1) research on impact factors of carbon emissions, 2) the relationship between energy consumption and carbon emissions, 3) the relationship between the energy consumption structure and energy intensity, 4) the relationship between energy consumption structure and carbon emissions intensity, and 5) the relationship between energy consumption structure and carbon emissions [10, 14, 16, 20]. There are very few studies on the relationship between energy consumption structure and carbon emissions. Therefore, the main contributions of this paper are as follows. First, this paper is an empirical study that discusses the data of energy consumption and carbon emissions in 30 provinces in China from 1996 to 2015 based on the translog production function. Moreover, this paper provides the answer to input-output elasticity and alternative elasticity among coal, oil, and natural gas, and the relationship between the energy consumption structure and carbon emissions. Furthermore, this paper uses the GMM method, which can solve the endogeneity between variables. This paper provides a relevant basis regarding the solution of improving the energy consumption structure, which is a significant reference.

Material and Methods

Data

Energy consumption in China experienced a sharp increase from 127,175 million tons of standard coal in 1996 to 377,632 million tons of standard coal in 2015 – an approximately threefold increase. Moreover, coal, oil, and natural gas accounted for 72.5%, 20.9%, and 6.6%, respectively. As shown in Fig. 2, coal consumption showed an upward trend, while it dropped slightly after 2013; oil consumption remained stable, and natural gas consumption steadily increased.

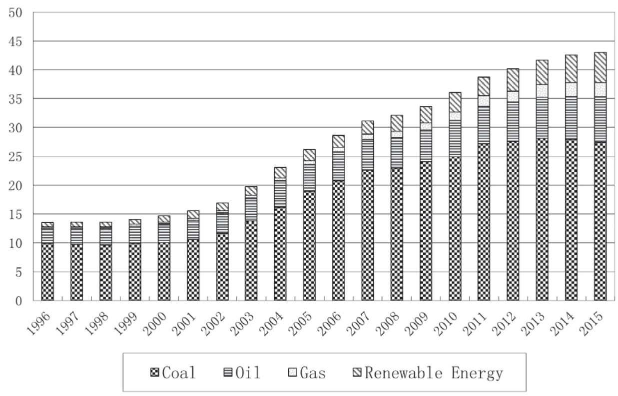

Fig. 2. Consumption of coal, oil, natural gas, and renewable energy (100 million tons equivalent coal) in China, 1996-2015.

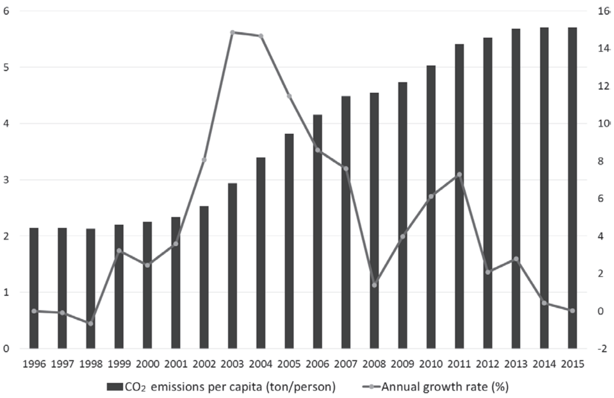

Fig. 3. Per capita CO_2 emissions (left) and corresponding annual growth rate (right), 1996-2015.

Here is the formula in "Guidelines for the calculation of carbon emissions":

$$CO_2 = \sum_j CO_{2j} = \sum_j E_j \times C_j \times N_j \times F_j \tag{1}$$

…where CO_2 is total carbon emission; CO_{2j} is the carbon emission where the amount of energy consumed is j; and E_j, C_j, N_j, and F_j are the amount of j energy consumption, carbon content, conversion of standard coal coefficient, and carbon oxidation factor. The data of N_j and F_j are taken following IPCC's (2006) guidelines, while the data for different types of energy are collected from the China energy statistical yearbook (various years). Then the estimated CO_2 emissions are divided by population to obtain per capita CO_2 emissions. Fig. 3 shows the time series of CO_2 emissions per capita and the corresponding annual growth rates from 1996 to 2015. As shown clearly in Fig. 3, during the past two decades the growth rates of per capita CO_2 emissions at first increased and then gradually decreased after the peak growth rate was reached in approximately 2003. In recent years, particularly as China's economy entered a 'new normal' with lower economic growth rate, the impetus of growth in CO_2 emissions per capita also slowed. This intuitive observation is consistent with recent studies that found a causal relationship between China's economic development and CO_2 emissions (e.g., [21-22]).

Estimation Method

Different types of fossil energy could contribute to CO_2 emissions in different ways; therefore, to replace one type of fossil energy with another may change the amount of CO_2 emissions. To capture a possible change in CO_2 emissions through the substitutions of different types of energy, the translog production function is utilized as the theoretical framework of this study. The translog production function was originally developed by [23], then it quickly become a powerful tool to analyze a firms' production structure. As summarized by [24], the biggest advantage of the translog production function is its simplicity as no priori restrictions on the substitution elasticities or returns to scale are needed.

According to the translog production function, this paper is built around the fundamental model of carbon emissions and energy consumption with non-factors. The previous results often had an impact on the latter period due to the strong inertia of carbon emissions. Therefore, the benchmark regression equation utilized in the empirical study is as follows:

$$LnE_{it} = \gamma LnE_{i,t-1} + \alpha_C LnC_t + \alpha_O LnO_t + \alpha_G LnG_{it} + \alpha_O \; LnC_t \, LnO_t + \alpha_G \; LnC_t \, LnG_t + \alpha_O \; LnO_t \, LnG_t + \alpha_C \; (LnC_t)^2 + \alpha_O \; (LnO_t)^2 + \alpha_G \; (LnG_t)^2 + \alpha_x X_t + \delta_t + \lambda_t + \varepsilon_t \tag{2}$$

…where i is the region sectional unit, i = 1,2...30; t is time; E is carbon emissions per capita; C, O, and G stand for coal, oil, and natural gas consumption, respectively; γ

Table 1. Descriptive statistics of the variables used in the empirical study.

Variable	Definition of the variable (unit)	Mean	Std. Dev	Min	Max
I	Per capita income (yuan, 2000 constant prices)	17,829.94	14,773.78	2,049.60	85,036.41
Open	Trade openness, the ratio of the sum of imports and exports to GDP	32.26	61.26	3.20	1,204.94
Second	The ratio of secondary industry's value added to GDP	0.45	0.08	0.20	0.58
RD	R&D strength, measured by the ratio of R&D expenditure to GDP	0.056	0.048	0.001	0.322
Urban	Urbanization level, measured by the ratio of non-agricultural population to total population (%)	45.18	16.78	13.86	89.60
Edu	Education level, measured by average schooling years of the people whose age is 6 or older	8.21	1.16	4.69	12.08
C	Coal consumption (kg coal equivalent/person)	1,623.47	1,444.14	132.67	10,505.72
O	Oil consumption (kg coal equivalent/person)	478.85	457.52	0.005	2,278.77
G	Gas consumption (kg coal equivalent/person)	124.70	168.39	0.05	1,388.43
E	CO2 emissions per capita (kg/person)	21,381.12	18,808.79	709.77	111,703.65

Table 2. Basic estimation results of Eq. (2).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lnC	1.261*** (0.420)	0.407 (0.575)	0.405 (0.490)	1.038** (0.478)	0.833* (0.443)	0.480 (0.437)	1.167*** (0.416)
lnO	-0.767*** (0.164)	-1.147*** (0.221)	-0.852*** (0.174)	-0.816*** (0.173)	-0.755*** (0.177)	-0.710*** (0.179)	-0.699*** (0.163)
lnG	0.521*** (0.194)	0.654*** (0.242)	0.686*** (0.208)	0.579*** (0.205)	0.354* (0.208)	0.147 (0.206)	0.445** (0.193)
lnC×lnO	0.107*** (0.022)	0.146*** (0.029)	0.113*** (0.023)	0.113*** (0.023)	0.105*** (0.024)	0.095*** (0.024)	0.099*** (0.022)
lnC×lnG	-0.056* (0.029)	-0.096*** (0.036)	-0.085*** (0.031)	-0.067** (0.031)	-0.034 (0.031)	-0.013 (0.030)	-0.043 (0.029)
lnO×lnG	-0.027** (0.013)	-0.007 (0.018)	-0.029** (0.013)	-0.025** (0.013)	-0.027* (0.014)	-0.006 (0.015)	-0.030** (0.013)
lnC^2	-0.060* (0.032)	-0.006 (0.042)	0.003 (0.037)	-0.046 (0.035)	-0.030 (0.033)	-0.018 (0.032)	-0.050 (0.032)
lnO^2	0.027*** (0.004)	0.020*** (0.005)	0.021*** (0.004)	0.029*** (0.004)	0.025*** (0.004)	0.012*** (0.005)	0.024*** (0.004)
lnG^2	0.024*** (0.006)	0.032*** (0.007)	0.033*** (0.006)	0.026*** (0.006)	0.027*** (0.006)	0.012** (0.006)	0.024*** (0.006)
lnI		0.332*** (0.106)					
Open			6.109*** (1.530)				
Second				0.457 (0.446)			
RD					-2.114*** (0.461)		
Urban						0.012*** (0.002)	
lnEdu							-0.110*** (0.026)
Constant term	1.320 (1.550)	4.192** (2.062)	3.805** (1.741)	1.993 (1.703)	3.040* (1.652)	4.850*** (1.649)	1.161 (1.534)
AR(2)	-1.13 (0.257)	-0.55 (0.584)	-1.10 (0.270)	-1.13 (0.257)	-1.05 (0.291)	-1.11 (0.265)	-0.98 (0.328)
Sargan test	144.17 (0.480)	81.82 (0.988)	115.06 (0.959)	139.25 (0.573)	103.65 (0.908)	88.94 (0.954)	129.74 (0.779)
Samples	496	496	496	496	496	496	496

Notes: all models add the time trend variable; the number in bracket of regression coefficient is robust standard error; the number in bracket of AR and Sargan test is prob>z; *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

and α are coefficients to be estimated; X is other control variables; δ is time non-observed-effect; λ is the region non-observed-effect; and ε is random errors.

Following previous studies on CO_2 emissions in China [including 25-26], a series of control variables also have been introduced into the regression equation in order to capture the impacts of other influential factors of CO_2 emissions. The control variables utilized in this study include:

1) Per capita income (I): According to the existing research results, per capita income has significant impact on energy consumption. Therefore, GDP per capita is added in the model as per capita income and in logarithmic form.
2) Trade openness (Open): In 2009 developed countries in Europe and America put forward the "carbon tariff" policy, which showcases the contradiction between trade and the environment. Therefore, the model adds trade openness, which is expressed as the ratio of total import and export of goods and GDP.
3) Proportion of secondary industry (Second): Secondary industry uses a large amount of coal, which leads to an increase in carbon emissions. Thus, secondary industry has a significant impact on carbon emissions,

and therefore the proportion of secondary industry is added to the model.

4) R&D strength (RD): The development of technology can increase the efficiency of energy so that carbon emissions will decrease. Therefore, the model adds R&D strength, which is expressed as the ratio of R&D expenditure to GDP.
5) Urbanization level (Urban): There will be a follow-up of infrastructure construction at the same time when the urbanization level is improved. The construction of infrastructure cannot be done without a large amount of energy consumption. Meanwhile, a great difference exists between the urban and rural population in terms of energy use habits, so the urbanization level has a certain degree of influence on carbon emission intensity. This paper will build a model by selecting the ratio of non-agricultural population to the total population as the urbanization level.
6) Education level (Edu): Education level has a direct impact on energy use habits; thus, education level affects carbon emissions intensity. The average years of schooling of the provincial population is calculated as 6 years for primary school, 3 years for junior high school, 3 years for high school, and 4 years for college or above. The calculation formula is the proportion of primary education population * 6 plus proportion of junior high school education * 9 plus proportion of high school education population * 12 plus proportion of college or the above * 16.

As a summary, the descriptive statistics of all variables used in this study are presented in Table 1.

Because there might be a potential endogeneity problem in Eq. (2) due to the bilateral causality between dependent variable and explanatory variables and there would inevitably be ignored influential factors of CO_2 emissions, the Generalized Method of Moments (GMM) estimator developed by [27-28] is utilized to address the potential endogeneity problem. Because in Eq. (2) the dynamics are introduced (the first-lag term of dependent variable is used as an explanatory variable) and because the time-invariant cross-sectional factors should be accounted for, the first-difference GMM approach is utilized as the benchmark estimation method since the time-invariant fixed effects could be eliminated by taking the first-order differences of the variables.

Results and Discussion

Basic Estimation Results

The estimation results of Eq. (2) on the basis of the framework of translog production function are shown in Table 2.

Model (1) simply considers the impacts of energy consumption structure on carbon emissions, where there are no control factors. In addition, models (2-7) add per capita income, trade openness, proportion of secondary industry, R&D strength, urbanization level, and education level as complementary explanatory variables on the basis of Model (1), respectively. According to Table 2, the increase in per capita income will bring a rise in carbon emissions, and trade openness, the proportion of secondary industry, and urbanization level have the same impact on carbon emissions, while R&D strength and education level can reduce carbon emissions. The results are in line with expectations, and the coefficients of the main control variables are similar, which means that the results are reasonable and robust.

Calculating Input-Output Elasticity and Alternative Elasticity

This paper obtains input-output elasticity of coal, oil, and natural gas by deriving C_t, O_t, and G_t, respectively.

Input-output elasticity of coal:

$$\eta_C = \frac{dY_t / Y_t}{dC_t / C_t} = \frac{dLnY_t}{dLnC_t} = \alpha_C + \alpha_{CO} LnO_t + \alpha_{CG} LnG_t + 2\alpha_{CC} LnC_t \tag{3}$$

Input-output elasticity of oil:

$$\eta_O = \frac{dY_t / Y_t}{dO_t / O_t} = \frac{dLnY_t}{dLnO_t} = \alpha_O + \alpha_{CO} LnC_t + \alpha_{OG} LnG_t + 2\alpha_{OO} LnO_t \tag{4}$$

Input-output elasticity of natural gas:

$$\eta_G = \frac{dY_t / Y_t}{dG_t / G_t} = \frac{dLnY_t}{dLnG_t} = \alpha_G + \alpha_{CG} LnC_t + \alpha_{OG} LnO_t + 2\alpha_{GG} LnG_t \tag{5}$$

Then, alternative elasticity of energy can be obtained.

Alternative elasticity between coal and oil:

$$\sigma_{CO} = \frac{\mathrm{d}\left(\frac{C}{O}\right)}{\frac{C}{O}} \left[\frac{d\left(\frac{MP_O}{MP_C}\right)}{\frac{MP_O}{MP_C}} \right]^{-1} = \frac{d\left(\frac{C}{O}\right)}{d\left(\frac{MP_O}{MP_C}\right)} \frac{\frac{MP_O}{MP_C}}{\frac{C}{O}} ; \; \left(\frac{MP_O}{MP_C} = \frac{\eta_O}{\eta_C}\frac{C}{O}\right) \tag{6}$$

$$\sigma_{CO} = \left[1 + \frac{-\alpha_{CO} + \frac{\eta_C}{\eta_O} \cdot \alpha_{OO}}{-\eta_C + \eta_O} \right]^{-1} \tag{7}$$

Alternative elasticity between coal and natural gas:

$$\sigma_{CG} = \left[1 + \frac{-\alpha_{CG} + \frac{\eta_C}{\eta_G} \cdot \alpha_{GG}}{-\eta_C + \eta_G} \right]^{-1} \tag{8}$$

Table 3. Input-output elasticity of coal, oil, and natural gas.

	η_C	η_O	η_G
1996	0.857	0.163	0.148
1997	0.872	0.165	0.145
1998	0.874	0.164	0.147
1999	0.869	0.165	0.151
2000	0.868	0.165	0.155
2001	0.859	0.168	0.157
2002	0.853	0.180	0.153
2003	0.835	0.199	0.148
2004	0.824	0.219	0.143
2005	0.798	0.232	0.141
2006	0.783	0.239	0.144
2007	0.768	0.245	0.148
2008	0.759	0.243	0.154
2009	0.752	0.246	0.155
2010	0.752	0.252	0.158
2011	0.734	0.257	0.163
2012	0.732	0.258	0.166
2013	0.728	0.258	0.170
2014	0.728	0.256	0.173
2015	0.736	0.256	0.175
average	0.799	0.216	0.155

Table 4. Alternative elasticity of coal, oil, and natural gas.

	σ_{CO}	σ_{CG}	σ_{OG}
1996	1.056	1.374	-0.385
1997	1.055	1.375	-0.592
1998	1.058	1.371	-0.459
1999	1.055	1.365	-0.353
2000	1.054	1.359	-0.255
2001	1.049	1.359	-0.264
2002	1.035	1.367	-0.949
2003	1.011	1.381	-7.222
2004	0.993	1.394	5.820
2005	0.977	1.405	3.656
2006	0.968	1.405	3.278
2007	0.960	1.405	3.124
2008	0.959	1.399	3.574
2009	0.955	1.400	3.397
2010	0.951	1.396	3.207
2011	0.942	1.398	3.157
2012	0.941	1.395	3.251
2013	0.939	1.393	3.452
2014	0.941	1.389	3.880
2015	0.943	1.384	4.074
average	0.992	1.386	1.669

Alternative elasticity between oil and natural gas:

$$\sigma_{OG} = \left[1 + \frac{-\alpha_{OG} + \frac{\eta_O}{\eta_G} \cdot \alpha_{GG}}{-\eta_O + \eta_G} \right]^{-1} \quad (9)$$

This paper obtained the data reported in Table 3 about energy input-output elasticity and Table 4 about energy alternative elasticity by putting the regression results into the above equations. According to the input-output elasticity in Table 3, it is obvious that the average input-output elasticities of coal, oil, and natural gas are 0.799, 0.216, and 0.155, respectively, and the input-output elasticity of the three types of energy fluctuates around the average. This proves that coal consumption has the most obvious effect on carbon emissions, followed by oil and, finally, natural gas. Additionally, it also proves that change energy consumption structure can decrease carbon emissions. According to the results in Table 4, the alternative elasticity of coal and oil, and coal and natural gas are basically stable, which stabilizes at approximately 0.992 and 1.386, respectively, while the alternative elasticity of oil and natural gas changes from negative to positive and increases by more than one. Furthermore, the alternative elasticity of coal and natural gas, and oil and natural gas is more than one at last, which proves that these two alternative ways can be implemented. The alternative elasticity of oil and natural gas is less than one, which proves that oil is not a suitable replacement for coal. This phenomenon occurs because the input-output elasticity of coal has decreased, while the input-output elasticity of oil has increased.

Impact of Energy Consumption Structure on Carbon Emissions

According to the definition, the comprehensive coefficient of carbon emissions, δ, has a relationship with energy i that accounts for the total energy shared and the carbon emission coefficient of energy i. It can be expressed as follows:

$$\delta = \sum w_i \delta_i \quad (10)$$

Thus, the carbon emission coefficient decreases by δ_i% when the energy consumption of i is reduced by

Table 5. Alternative elasticity of coal and oil, with 1% reduction in the use of coal.

	Δδ	ΔE	ΔC
1996	-0.042%	-5.946	-0.002
1997	-0.041%	-5.519	-0.002
1998	-0.043%	-5.345	-0.002
1999	-0.041%	-5.379	-0.002
2000	-0.040%	-5.276	-0.001
2001	-0.037%	-5.606	-0.001
2002	-0.026%	-6.187	-0.001
2003	-0.009%	-7.631	0.000
2004	0.005%	-8.925	0.000
2005	0.017%	-10.985	0.001
2006	0.024%	-12.122	0.002
2007	0.030%	-13.292	0.003
2008	0.030%	-13.455	0.003
2009	0.034%	-14.089	0.003
2010	0.037%	-14.182	0.004
2011	0.043%	-15.628	0.005
2012	0.044%	-15.614	0.005
2013	0.045%	-15.775	0.005
2014	0.044%	-15.334	0.005
2015	0.042%	-14.514	0.004

Table 6. Alternative elasticity of coal and natural gas, with a 1% reduction in the use of coal.

	Δδ	ΔE	ΔC
1996	-0.279%	-7.847	-0.015
1997	-0.280%	-7.616	-0.014
1998	-0.277%	-7.480	-0.014
1999	-0.273%	-7.598	-0.014
2000	-0.268%	-7.609	-0.014
2001	-0.268%	-7.923	-0.014
2002	-0.274%	-8.640	-0.016
2003	-0.285%	-10.243	-0.020
2004	-0.294%	-11.866	-0.024
2005	-0.303%	-13.806	-0.028
2006	-0.303%	-14.995	-0.031
2007	-0.302%	-16.131	-0.033
2008	-0.298%	-16.172	-0.033
2009	-0.299%	-16.786	-0.034
2010	-0.295%	-17.152	-0.034
2011	-0.297%	-18.348	-0.037
2012	-0.295%	-18.352	-0.037
2013	-0.293%	-18.428	-0.037
2014	-0.290%	-17.989	-0.036
2015	-0.287%	-17.414	-0.034

1%. The usage of energy i is reduced while the amount of energy j is increased, which can meet the energy needs. The alternative elasticity of energy i and energy j is σ_{ij}, and the consumption share of energy j will rise by σ_{ij}%. Thus, we can obtain the change of the coefficient of carbon emissions Δδ, the equation of the total energy consumption change ΔE, and carbon emissions ΔC.

$$\Delta\delta = \left(\delta_i - \sigma_j \times \delta_i\right)\% \tag{11}$$

$$\Delta E = e_j \times \sigma_j \% - e_i \times 1\% \tag{12}$$

$$\Delta C = -E \quad \times \Delta\delta \times \Delta E \tag{13}$$

…where I and j are the type of energy, e is energy use, and EF is the carbon emissions of standard coal.

Coal and Oil

Assuming a 1% reduction in the use of coal, the estimation results are depicted in Table 5 below.

Coal and Natural Gas

Assuming a 1% reduction in the use of coal, the estimation results are shown in Table 6.

Oil and Natural Gas

Finally, assuming a 1% reduction in the use of oil, the corresponding estimation results are reported in Table 7.

From the perspective of the change of the comprehensive coefficient of carbon emissions, "coal and oil" changes from negative to positive, "coal and natural gas" is still negative, and "oil and natural gas" changes from positive to negative. The negative carbon emissions coefficient indicates that this type of substitution is helpful in reducing carbon emissions. The positive carbon emissions coefficient indicates that the alternative will increase carbon emissions. The change of the comprehensive coefficient of carbon emissions of coal and oil changes from negative to positive because the coal reduces its impact on carbon emissions with the technological development. The change of alternative elasticity of oil and natural gas is the reason why the oil and natural gas comprehensive coefficient of carbon

Table 7. Alternative elasticity of oil and natural gas, with a 1% reduction in the use of oil.

	Δδ	ΔE	ΔC
1996	0.807%	-2.142	0.012
1997	0.928%	-2.352	0.015
1998	0.850%	-2.365	0.014
1999	0.788%	-2.478	0.013
2000	0.731%	-2.610	0.013
2001	0.737%	-2.654	0.013
2002	1.136%	-3.058	0.024
2003	4.789%	-5.579	0.182
2004	-2.808%	-1.170	-0.022
2005	-1.547%	-1.834	-0.019
2006	-1.327%	-1.908	-0.017
2007	-1.237%	-1.778	-0.015
2008	-1.499%	-1.110	-0.011
2009	-1.396%	-1.102	-0.010
2010	-1.286%	-1.268	-0.011
2011	-1.256%	-0.698	-0.006
2012	-1.311%	-0.374	-0.003
2013	-1.428%	0.375	0.004
2014	-1.677%	1.399	0.016
2015	-1.791%	1.656	0.020

emission changes from positive to negative. Although the number is positive or negative, the value of the carbon emissions coefficient remains small. This means that the overall energy consumption structure will not change substantially in a short period. This situation may be due to technical costs, energy storage, current national conditions, and other reasons.

First, China's energy development technology is relatively backward in terms of technology and cost. It is difficult to use such clean energies as solar, wind, geothermal, and tidal. Second, where storage is concerned, China's coal reserves are abundant while oil, natural gas, and other resources are less so, and coal resources are relatively cheap compared to other resources. Finally, China's national conditions also determine the higher amount of coal use. At present, heavy industry is still the pillar of China's economic development. Regarding other energy use, the technology is weak, so there will remain much demand for the basic energy of coal. The above reasons suggest that in a short period of time, China's energy consumption structure will experience a significant change. From the total amount of energy consumption change, the three alternative methods have generally reduced total energy consumption. However, the energy consumption change of oil and natural gas was positive after the year 2013. The sharp increase of oil consumption led to this phenomenon. It can be seen from the data that the use of oil or natural gas as a replacement for coal has a similar effect on total energy consumption. Regarding the amount of carbon emissions, using natural gas instead of coal is the only way to reduce carbon emissions. Using oil instead of coal is not a suitable solution for China due to the technology involved. The technology of coal has developed rapidly, which can reduce carbon emissions, while the carbon emissions of oil are still in a state of continuous increase. Moreover, using natural gas instead of oil will increase total energy consumption, which will lead to an increase in carbon emissions.

Therefore, China can use natural gas instead of coal to reduce carbon emissions and improve current environmental problems.

Conclusions

This paper is based on the analysis of the carbon emission intensity and energy consumption structure of 30 provinces in China, and the following conclusions can be drawn:

1) According to the results of input-output elasticity, it can be clearly seen that coal has the most negative impact on the environment. Oil takes second place, and natural gas' carbon emissions are the weakest solution. However, in this case, the three-fossil energy consumption of coal is the largest. This has led to an increase in carbon emissions and makes it more difficult to reduce carbon emissions.
2) According to the results of the alternatives among coal, oil, and natural gas, using natural gas instead of coal is the only way to reduce carbon emissions. However, with the use of technological development, other solutions will be possible.

Based on the above conclusions, this paper puts forward the following suggestions:

1) Change the structure of energy consumption, using oil to replace coal. When the most serious impact on the carbon emissions of coal consumption accounted for the largest percentage of total energy consumption reduction, carbon emissions will be reduced.
2) Increase development intensity and improve energy efficiency. To improve energy efficiency and meet energy needs, energy carbon emissions will be reduced. This will reduce total energy consumption and total carbon emissions. Meanwhile, increasing the intensity of development will make the energy to play its prospective effect. On the development of natural gas application technology perspective, this can make the natural gas become a theoretically clean energy.
3) The government introduced policies to regulate the energy consumption structure. The newly revised "Air pollution prevention law" in 2015 required the adjustment of the energy consumption structure and the optimization of the use of coal. The government should also introduce a more detailed policy and

establish better structure adjustment objectives of energy consumption so that the energy consumption structure supervision will be successfully implemented.

Finally, although this study makes a contribution to the empirics of the relationship between energy mix and CO_2 emissions in China, there are still some limitations in this research. For instance, due to data limit, the impacts of prices of different types of energy on the substitution effects could not be specifically determined. Moreover, the input-output elasticity and alternative elasticity may change when the energy structure has changed sufficiently. Therefore, the threshold effect could be further investigated if the data of a longer time span were available. In this regard, more complex and delicate methods could be used to explore the long-run and real-time nexus of energy mix and CO_2 emissions, which are possible future research directions.

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