The Impact of Sino-US Clean Energy Trade Complementarity on China's Clean Energy Consumption

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Abstract. This paper analyzes the dynamic relationship between Sino--US clean energy trade complementary index and China's clean energy consumption by using autoregressive distributed lagged model (ARDL) based on the sample data from 1992 to 2017. The results show that there is a long-term cointegration relationship among Sino—US clean energy trade complementary index, China's clean energy consumption, economic growth, and energy intensity. In the long run, the complementarity of clean energy trade between China and the United States has a negative impact on the growth of China's clean energy consumption, proves that the complementary relationship between U.S. clean energy export growth and China's import growth is only reflected in theory, and there is no actual trade complementarity ,reflected in the trade between the two countries. In the long run, the increase of per capita GDP and the decrease of energy intensity will be accompanied by the increasing clean energy in China, which indicates that China is in the process of energy structure optimization, and with the economic growth, the proportion of clean energy utilization is also increasing. Besides, in the short term, the industrial structure has a positive impact on China's clean energy consumption, and clean energy consumption in the first lag stage also promotes the clean energy consumption in the current period, while other factors do not significantly contribute to clean energy consumption in China. Finally, on the basis of empirical analysis, the corresponding countermeasures and suggestions are put forward.

1 INTRODUCTION

With the change of global climate and the destruction of human living environment caused by the massive use of traditional energy, global warming and environmental pollution have become difficult problems that all countries need to deal with together, and the countries began to pay attention to the development and utilization of clean energy. As the world's second largest economy, China is facing internal and external pressure in the fields of climate and environmental improvement for its annual energy consumption and CO2 emissions are ranking first in the world. The energy consumption in China—the biggest increase among all countries in more than a decade—rose by nearly half from 2007 to 2017(BP,2018). In 2017, the energy consumption of coal and oil were top 2 of the world, which accounted for 60.4 % and 18.8 % respectively in China. Proportion of coal consumption is relatively high, and put great pressure on energy conservation and emission reduction. Based on that point, the Chinese government has pledged to accelerate the use of clean energy, which will reach to 35 % of total energy consumption in China by 2030. Compared with China, the United States is rich in clean energy resources and has advantages in both experience and technology in developing clean energy, while China has just focused on strengthening international trade cooperation and clean energy technologies in recent years.

According to the economic development of various countries, there is a correlation relationship between the economic growth and the energy consumption(Yemane, 2004; DolgpolovalI, et al,2014; Ergin& Simbarashe, 2019) . Statistically, there is a great difference in thermal efficiency among different energy resources. The thermal efficiency of natural gas is above 75%, that of oil is about 65% and coal is 40%-60%. Therefore, based onthe energy consumption structure of a country, the energy efficiency will be low if the proportion of traditional energy consumption (such as coal)is high (Meng& Zhou, 2014). As inefficient energy consumption

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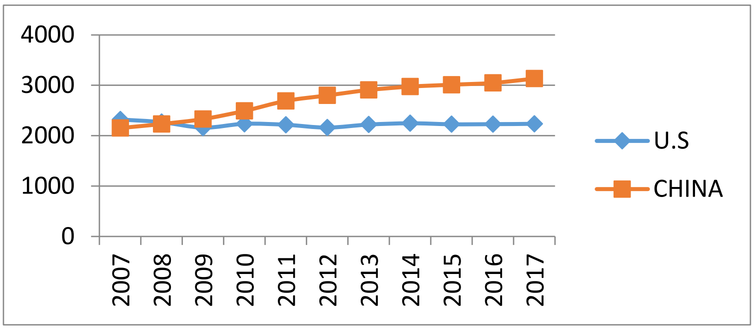

Figure 1. Annual Primary Energy Consumption in Mtoe for the US and China from 2007 to 2017.

drives economic growth, it will inevitably generate large amounts of carbon emissions and cause pollution to the environment.The pollution, in turn,will dampen down economic growth(Tiba& Omri， 2017). Technological innovation plays a significant role in promoting energy efficiency both in the short and the long term(Xiongfeng, et al, 2019). As the traditional energy, like coal, is gradually replaced by clean energy, and energy technology is improved, the energy consumption structure will be optimized and the energy efficiency will be improved. It means that ifeconomic growthaccompanied by improvements in energy efficiency, it will lead to a slowdown or reduction in total energy consumption.Therefore, improving energy efficiency, changing the structure of energy consumption and reducing the intensity of energy consumption are keys to reduce CO2 emissions, which should be important means used to promote the development of China's low-carbon economy in the future (Wu&Zeng, 2013; Xiaojun ， et al, 2019). It suggests that advanced energy technologies and the increase of clean energy consumption enhance the energy efficiency. In this case, economic growth does not necessarily enlarge energy consumption. Figure 1 illustrates the annual primary energy consumption for the US and China from 2007 to 2017. Since 2007, the consumption of China has risen continuously and there is a great increase during the succeeding years. Meanwhile, the trend of America's energy declined slightly and nearly remained stable in recent years. It is clear that the growth of the US economy has not been accompanied by an increase in total energy demand, which has been driven by improvements in energy efficiency. By contrast, China's energy efficiency is still relatively low.

For a long time, there has been a huge trade deficit between the United States and China. The clean energy cooperation between the United States and China enables the United States to take advantage of its energy and technology, increase its exports of clean energy products, technologies and equipment to China, and reduce the trade deficit. In the cooperation of clean energy, if the United States can appropriately reduce the export restrictions onhigh-tech products to China, China will also moderately widen the market in the investment field, the cooperation between the two sides will surely promote win-win situation under the trade balance. For example, China has been faced with insufficient natural gas supply every winter in recent years, while the United States is the largest producer of natural gas. Therefore, increasing the trade of natural gas between China and the United States can help solve the problem of natural gas shortage in China.

In order to analyze the impact of Sino-U.S. clean energy trade cooperation on China's clean energy consumption, this paper will take Sino-U.S. clean energy trade complementary index (TCI) , China's clean energy consumption ratio (CE) , energy intensity (TEG) , per capita output (PG) and industrial structure (STRU) as the objects, construct an ARDL model, analyze the dynamic relationship among them, and try to put forward the corresponding recommendations.

2 METHODS AND DATA

2.1 Methods

In this section, we develop an econometric model to estimate the dynamic relation betweenSino—U.S. clean energy trade complementarity and China's clean energy consumption. We know that the premise of foreign trade is that the export products have comparative advantages, such as relatively rich resources, high-quality products and technology. If a country's products have a certain export competitiveness, there should be a potential cooperation with other countries. Where there is a certain trade potential, there is a potential economic effect. Trade Completeness Index (TC) in this paper measures the complementarity of clean energy trade between China and the United States. The TC between countries k and j is defined as(WTO,2017):

$TC_{ij} = 100(1 - \text{sum}(|m_{ik} - x_{ij}| / 2))$

where xij is the share of good i in global exports of country j and mik is the share of good i in all imports of country k. The index is zero when no goods are exported by one country or imported by the other and 100 when the export and import shares exactly match.

In order to reflect the influence of the Sino-U.S. clean energy trade complementarityon China's clean energy consumption, this paper adopts the proportion of clean energy consumption in total energy consumption (CE) to show the change of China's clean energy consumption.

At the same time, considering other factors in clean energy consumption, this paper introduces the per capita output (PG), industrial structure (STRU) and energy intensity (TEG) as control variables. PG is the real GDP per capita, STRU is the ratio of industrial output to GDP, and TEG is the ratio of total energy consumption to GDP. In view of the empirical strategies provided by theprior literatures (Bas and Ledezma, 2010; Bustos, 2011), the empirical framework can take thefollowing form.

$$CE_t = (CE_t, TC_t, STRU_t, TEG_t, PG_t, \varepsilon_t) \quad (1)$$

As that time series are always non-stationary, it is effective to specify the econometric model following the process of the data generation. Results in table (2) show the dependent variable is not of integration, so the equation (1) can be represented by a structural ARDL model. The ARDL model is a standard least squares model. The ARDL model is to determine whether there is cointegration relationship between variables through the boundary test method, and to estimate the correlation Coefficient between variables on the basis of this. First proposed by Charemza&Deadman(Charemza&Deadman, 1992), then perfected and extended by Pesaran et al.(Pesaran et al, 2001). Different from the traditional co-integration test model, the ARDL model does not require the same order single integer when testing the long-term relationship among variables.Even under small samples, the estimations of ARDL model would be stable enough. The ARDL model takes the form shown as follows (2):

$$CE_t = \alpha_0 + \sum_{i=1}^{q_1} \alpha_1 CE_{t-i} + \sum_{i=0}^{q_2} \alpha_2 TC_{t-i} + \sum_{i=0}^{q_3} \alpha_3 STRU_{t-i} + \sum_{i=0}^{q_4} \alpha_4 TEG_{t-i} + \sum_{i=0}^{q_5} \alpha_5 PG_{t-i} + \varepsilon_t \quad (2)$$

Furthermore, the unit root test also imply that all the explanatory variables are not of integration higher than I (1), thus explanatory variables might be co-integrated with the dependent variable. Then, the equation (1) can fit a structural ARDL model in error-correction form as follows.

$$\Delta CE_t = \alpha_0 + \alpha_1 CE_{t-1} + \alpha_2 TC_{t-1} + \alpha_3 STRU_{t-1} + \alpha_4 TEG_{t-1} + \alpha_5 PG_{t-1} + \sum_{i=1}^{q_1} \gamma_{1i} \Delta CE_{t-i} + \sum_{i=0}^{q_2} \gamma_{2i} \Delta TC_{t-i} + \sum_{i=0}^{q_3} \gamma_{3i} \Delta STRU_{t-i} + \sum_{i=0}^{q_4} \gamma_{4i} \Delta TEG_{t-i} + \sum_{i=0}^{q_5} \gamma_{5i} \Delta PG_{t-i} + \varepsilon_t \quad (3)$$

where α_i is the long-term Correlation Coefficient of the variable, γ_i is the short-term Correlation Coefficient of the variable, q_i is the maximum lag order of the model, and $q_i$is the White noise of the normal distribution.

2.2 Data

Based on the classification of HS codes, this paper selects the representative clean energy trade products of the United States and China from 1992 to 2017 as the research sample, including Solar Energy, wind energy, biomass energy, water energy, natural gas, nuclear power, and selected both import and export data from the UN comtrade Database. Other data involved in the study, such as China's GDP per capita, industrial structure, and clean energy consumption, are collectedfrom China Energy Statistical Yearbook and China National Bureau of Statistics.

Among them, the per capita real GDP (PG) is calculated by the China's real GDP (which is adjusted by price deflator as the base year of 1978) divided by China's total population at the end of the year; The value of Energy consumption intensity (TEG) is calculated by dividing the total energy consumptionby the real GDP. Table 1 shows the descriptive data of the values above after natural logarithm. Figure 2 shows the trend of CE and TC. It can be seen that CE has been rising steadily since 1992, but clearly there is still room to achieve the goal of 35% of total consumption by 2030; At the same time, TC has been in a high position for many years, which shows that there is a strong complementarity in clean energy trade between China and America in theory. However, the dynamic relationship between TC and CE needs to be further tested by the ARDL model.

Table 1. Descriptive Statistics.

	LNCE	LNPG	LNSTRU	LNTC	LNTEG
Mean	2.388465	-0.346857	3.669433	4.087292	0.928757
Maximum	3.034953	0.655577	3.738473	4.278937	1.389892
Minimum	1.916923	-1.455002	3.511376	3.728934	0.520496
Std. Dev.	0.320811	0.658869	0.062195	0.136925	0.223413

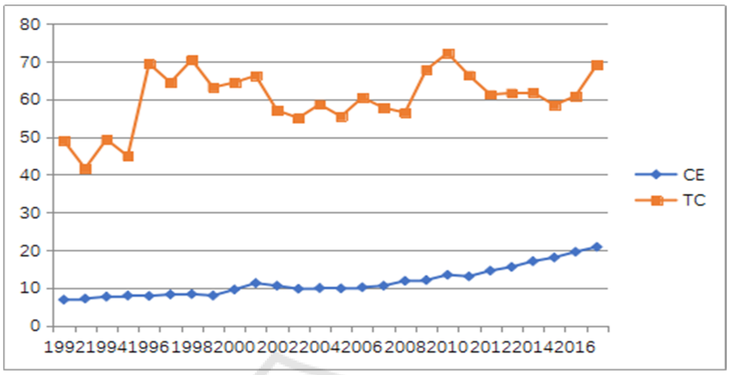

Figure 2. General Trends for CE and TC (1992-2017).

3 RESULTS AND DISCUSSION

3.1 Result of Unit Root Test

In this paper, the variables above are tested by the Augmented dickey-fuller test statistics. The test results are shown in Table 2. It can be seen from Table 2 that the variable LNPG is stationary and the variables LNCE, LNSTRU, LNTC and LNTEG are non-stationary, but they are stationary after the first-order difference. Therefore, the variables used in this paper do not exceed I(1), and the cointegration relationship among variables can be further analyzed by using ARDL model.

Table 2. Unit Root Tests.

Variables		Augmented Dickey-Fuller
LNCE	Level	0.512
	First Difference	-4.582***
LNPG	Level	-2.164（drift）**
	First Difference	
LNSTRU	Level	0.502
	First Difference	-3.812***
LNTC	Level	-2.672*
	First Difference	-7.162***
LNTEG	Level	-1.063
	First Difference	-1.771（drift）**

3.2 Cointegration Analysis

In this paper, the ARDL model is tested by eviews10, and the cointegration relationship between variables is tested by calculating the value of the corresponding F-statistic. The lag order is determined by AIC and SC information criterion. The cointegration test results are shown in Table 3. Referring to the research of Pesaran,et al.[13], Table 3 illustrates the F-statistic values of I (0) and I (1) processes at the significance levels of 1%, 5% and 10% respectively through ARDL-Bounds Test. The test results show that when CE is the explained variable, there is a cointegration relationship among variables at the significance level of 1%. The optimal model is determined as ARDL (2,0,2,2,2). The estimations of ARDL model are shown in Table 3, and conditional error correction regressionand the coefficient of long-term equilibrium are shown in Table 4.

From Table 4, it can be found that in the long term, the impact coefficient of LNTC on LNCE is -0.652176 at the significant level of 10%. It indicates that Sino--US clean energy trade complementarity has negative impact on the growth of China's clean energy consumption, which is not conducive to the optimization of China energy consumption structure. This proves that although China's clean energy imports and U.S. clean energy exports have formed a synchronous growth trend, there is rare relationship between the growth of China's import of clean energy and theUS'clean energy export.In other words, the growth of China's clean energy imports is not driven by the growth of clean energy exports of the United States. By comparing Figure 3 and Figure 4, it can be seen that the overall China's clean energy import shows an upward trend, and the import of clean energy has accelerate since 2010; however, after 2011, the trend of clean energy export of China is opposite to the overall clean energy export of the United States. The total export of the United States has steadily increased, while the export to China has begun to slow down. This shows that the growth of U.S. clean energy export and that of China's clean energy import are not complementary, which is not reflected in the trade between the two countries. From table 4, the coefficient of LNTEG is also significantly negative(-1.835918). It shows that the change of energy intensity and the change of the proportion of clean energy consumption are reverse. To some extent, it is related to China's strengthening pollution control, limiting CO2 emissionsand increasing the use of clean energy. As a result, while the energy consumption per unit GDP decrease, the proportion of clean energy increase. The coefficient of LNPG is significantly positive(1.5614.6), that is, the increase of per capita GDP is in direct proportion to the growth of clean energy consumption. Furthermore, it shows that with China's economic growth, the use of clean energy is also increasing, and the energy consumption structure is constantly optimized.

Table 3. ARDL Estimation (dependent variable LNCE).

Variable	Coefficient	Std.Error	t-Statistic	Prob.*
LNCE(-1)	0.146732	0.227824	0.644059	0.534
LNCE(-2)	-0.365591	0.228609	-1.599199	0.1409
LNPG	1.903133	0.778937	2.443244	0.0347
LNSTRU	0.22887	0.828776	0.276154	0.7881
LNSTRU(-1)	0.050416	1.030798	0.048909	0.962
LNSTRU(-2)	-1.305904	0.740789	-1.762855	0.1084
LNTC	-0.251401	0.133551	-1.882435	0.0892
LNTC(-1)	-0.291565	0.149303	-1.95284	0.0794
LNTC(-2)	-0.251944	0.138546	-1.818491	0.099
LNTEG	-2.262761	0.863481	-2.620512	0.0256
LNTEG(-1)	1.714517	1.181713	1.450874	0.1774
LNTEG(-2)	-1.689481	0.825431	-2.046787	0.0679
C	14.77916	4.031182	3.666209	0.0043
@TREND	-0.167481	0.075814	-2.209114	0.0516
S.E. of regression	0.045135	Akaike info criterion		-3.06714
Sum squared resid	0.020371	Schwarz criterion		-2.379942
ARDL-BoundsTest	Value	Signif.	I(0)	I(1)
F-statistic	5.787697	10%	3.03	4.06
		5%	3.47	4.57
		1%	4.4	5.72

Table 4. Long-term relationship coefficient of ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNPG	1.561406	0.652661	2.392370	0.0378
LNSTRU	-0.842278	0.577513	-1.458457	0.1754
LNTC	-0.652176	0.294462	-2.214809	0.0511
LNTEG	-1.835918	0.667798	-2.749212	0.0205

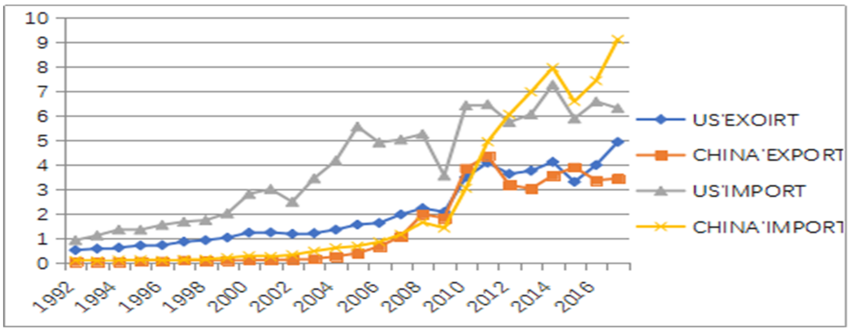

Figure 3. Clean energy imports and exports for US and China (1992-2017).

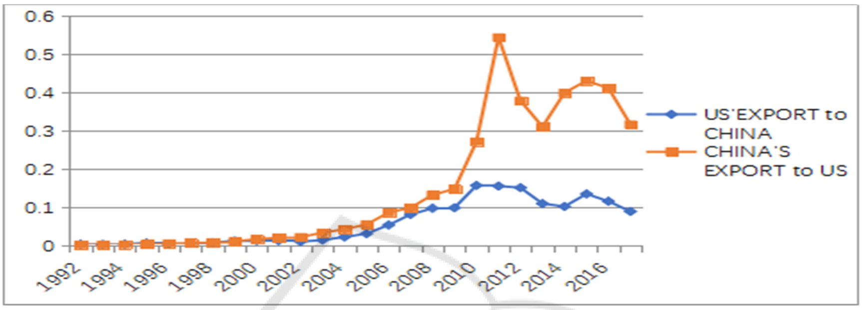

Figure 4. General Trends for bilateral trades between US and China (1992-2017).

After the long-term relationship coefficient of the cointegration equation is estimated, error correction model (ECM) regression based on ARDL model can be further established toanalyze the dynamic relationship between the short-term fluctuation of independent variables and dependent variable . The results are shown in table 5. The coefficients of D(LNCE(-1)) and D(LNSTRU(-1)) are significantly positive, indicating that clean energy consumption and the industrial structure in the first lag stage have a positive impact on the increase of the clean energy consumption in the current period. D(LNTC) coefficient is significantly negative, while D(LNTC(-1)) coefficient is significantly positive, which indicates that although Sino--US clean energy trade complementary index is unfavorable to the increase of China's clean energy consumption in the current period, it has a positive effect in the first lag stage. The coefficient of D(LNTEG) is significantly negative, while the coefficient of D(LNTEG(-1)) is significantly positive. Generally speaking, the impact of Sino--US clean energy trade complementary index and energy intensity on China's clean energy consumption in the short term is limited.The coefficient of the error correction term CointEq(-1) is significantly negative at the significance level of 1%, which conforms to the negative feedback mechanism, that is, when the short-term change is out of the long-term equilibrium level, it can be adjusted to the long-term equilibrium state through the error correction model.

Table 5. ECM regression.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	14.77916	2.324173	6.358890	0.0001
@TREND	-0.167481	0.026788	-6.252120	0.0001
D(LNCE(-1))	0.365591	0.158065	2.312908	0.0433
D(LNSTRU)	0.228870	0.550510	0.415741	0.6864
D(LNSTRU(-1))	1.305904	0.563589	2.317122	0.0430
D(LNTEG)	-2.262761	0.474407	-4.769662	0.0008
D(LNTEG(-1))	1.689481	0.514627	3.282920	0.0082
D(LNTC)	-0.251401	0.087067	-2.887450	0.0162
D(LNTC(-1))	0.251944	0.096313	2.615903	0.0258
CointEq(-1)*	-1.218858	0.191492	-6.365051	0.0001

4 CONCLUSION AND SUGGESTION

Based on the annual data from 1992 to 2017, this paper studies the relationship between Sino—U.S. clean energy trade complementarity and China's clean energy consumption. The results show that there is a long-term co-integration relationship among Sino—US clean energy trade complementary index, China's clean energy consumption, economic growth, and energy intensity. In the long run, the complementarity of clean energy trade between China and the United States has a negative impact on the growth of China's clean energy consumption, which is not conducive to the optimization of energy consumption structure. This proves that the complementary relationship between U.S. clean energy export growth and China's import growth is only reflected in theory, and there is no actual trade complementarity, which is not reflected in the trade between the two countries. In the long run, the increase of per capita GDP and the decrease of energy intensity will both boost clean energy consumption and optimize the energy consumption structurein China. Besides, in the short term, the industrial structure has a positive impact onclean energy consumption, and clean energy consumption in the first lag stage also promotes the consumption of clean energy in the current period, while other factors do not significantly contribute to clean energy consumption in China.

In recent years, China has formulated policies to save energy and reduce emissions, and to increase the proportion of clean energy. At present, China should speed up the adjustment of industrial structure, the development and application of clean energy technology, and improve the awareness of energy conservation of enterprises and residents. From the perspective of clean energy development goals and policy guidance of China and the United States, both China and the United States attach importance to the clean energyconsumption. The United States has advancedexperience and technology in clean energy, and it needs to expand new markets, while China is just in the early stage of development and has great market demand. Obviously, bilateral trade cooperation is beneficial to both countries. Theoretically, there is a strong complementarity, and there is a large space for win-win cooperation in practice. At present, China and the United States should reach a consensuson the intellectual property system and related legal system as soon as possible. In terms of patent application and protection, it is necessary to jointly establish transparent management measures and valid examination system to ensure the standardization of application and examination, strengthen cooperation and communication between China and the United States, so as to crack down on cross-border intellectual property violations and crimes, and maintain the bilateral trade order. In the process of specific implementation, the United States should gradually reduce the technical restriction, and China should also accelerate the liberalization of market access. Only in this way will be benifit to the clean energy trade cooperation which is caused by different division of labor in the industrial chain, that is, the high-end products of the United States enter the Chinese market, while the medium and low-end products of China enter the American market. We should improve the mechanism of capital access and exit, ensure the legalization and transparency of capital investment, and protect the legitimate rights and interests of enterprises. In addition, we should establish an effective bilateral communication and coordination mechanism, actively listen to the opinions involved in trade divergence of enterprises, and strengthen bilateral communication and consultation when formulating relevant trade policies, so that we can solve the problems existing in Sino--US cooperation in a timely manner, and promote win-win cooperation between the two sides.

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