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Short Communication

Potential cooperation in renewable energy between China and the United States of America

Wei Zhang [a], Jun Yang [a], Pengfei Sheng [b], Xuesong Li [c], Xingwu Wang [d,*]

[a] School of Economics and Business Administration, Chongqing University, 400030 Chongqing, PR China
[b] School of Economics, Henan University, 475000 Henan, PR China
[c] School of Management, Chongqing College of Electronic Engineering, 401331 Chongqing, PR China
[d] School of Engineering, Alfred University, 14802 Alfred, NY, USA

HIGHLIGHTS

- An indicator called "renewable energy cooperation index" is introduced.
- A model correlates GDP, CO_2 emission, energy price and the cooperation index.
- The cooperation can stimulate economy and reduce CO_2 emission.
- Combining US and Chinese resources will be mutually beneficial.

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ABSTRACT

China and the United States of America (US) are developing renewable energy concurrently. In this paper, we seek the opportunities for potential cooperation between these two countries based on the analysis of annual economic data. A mathematical model has been established to characterize correlations among GDP, carbon dioxide emissions, energy prices and the renewable energy cooperation index. Based on statistical analyses, such cooperation can promote economic development, reduce carbon dioxide emissions, improve the environment and realize green growth. If US monetary and technology resources and Chinese markets are combined, benefits can be mutually gained.

1. Introduction

In terms of annual energy consumption, coal utilization and carbon dioxide (CO_2) emissions, China and the United States of America (US) are currently in first and second places globally, respectively. To meet domestic energy needs, both countries heavily depend on imported oil, but with two different trajectories. For China, the amount of imported oil amounted to approximately 7% of all oil consumption in 1993, jumping to 40% in 2004 and to 60% in 2013. If this trend continues, the imported oil share may reach 66% in 2020. Recently, the Chinese government placed a cap of 61% by 2015. For the US, imported oil accounted for 49% in 1993, increasing to 65% in 2004 and decreasing to 40% in 2013 (BP, 2013; EIA). If both countries develop large-scale renewable energy profiles, reliance on imported oil can be reduced (Yao and Chang, 2014; Aslani and Wong, 2014). Furthermore, additional renewable energy production may slow the depletion of traditional energy reserves, reduce carbon dioxide (CO_2) emissions, and provide benefits to the environment. The countries should jointly develop strategic plans to enhance economic growth via renewable energy while achieving sustainability (Mezher et al., 2012). For China, the majority of its population is made of farmers who are familiar with the concept of renewable energies and are willing to consider efficient harvesting technologies (Ding et al., 2014). For the US, some of its renewable energy technologies may be readily exportable to Chinese markets (Zhu et al., 2011). With potential cooperation, China may solve some energy and environmental issues, and the US may recover its early R&D (research and development) investments in technologies (Wan and Craig, 2013; Christoffersen, 2010). In the past 10 years or so, different cooperation possibilities were explored, and a few consortia were formed (Wendt, 2008; Lieberthal and Sandalow, 2009; Lewis, 2014). Simultaneously, limited renewable energy policies were proposed, and their effectiveness was discussed (Buckman, 2011; Yin and Powers, 2010; Menz and Vachon, 2006). At present, both solar and wind technologies are currently being utilized for electrical power generation, and fuel

* Corresponding author.
E-mail address: fwangx@alfred.edu (X. Wang).

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cell technologies are being considered for automotive applications (Bosetti et al., 2012; Friebe et al., 2014; Barbir, 2005; Tuo, 2013a,b; Hwang, 2013).

Historically, economic growth is affected by the availability of traditional energies. In early studies, energy elements were introduced in the Cobb–Douglas production function. In addition to capital and labor factors, energy can be considered as a third factor of production. In production, the cost of energy is usually small, whereas its effect is large (Gastaldo and Ragot, 1996; Rasche and Tatom, 1997). If energy utilization becomes more efficient, economic growth may be extended to a longer time period (Norman, 1996). If energy consumption is reduced, an economy may not grow at its original pace. If traditional energies are exhausted, economic growth may not be sustained (Ayres et al., 2013). After four decades of research, technologies to efficiently harvest renewable energies, which are naturally replenished energy sources that can be regenerated, are available. In addition to solar and wind energy, biomass, hydroelectricity, geothermal and tidal energy are also considered renewable energy. Today, some renewable energy can replace traditional energy in electricity generation, hot water/space heating and motor fuel applications (Grimaud and Rouge, 2003). Depending on the locations of such energy resources, one type of technology may be more suitable for economic growth than others (Tuo, 2013a,b; Karlstrøm and Ryghaug, 2014). For economic development, one prefers a large renewable energy proportion in the overall energy profile because it should lead to more sustainable development and more benefits to the economy (Valente, 2005; Apergis and Payne, 2010).

Thus, in the context of cooperation between China and US, it is desirable to systematically study the relationship between renewable energy and economic growth. In 2012, the Chinese annual renewable energy consumption was 226.69 million tons of oil equivalent (MTOE), including 194.79 MTOE of hydroelectricity and 31.90 MTOE of other renewable energy. Currently, renewable energies contribute approximately 8.5% of overall energy consumption, and the goal is to reach 15% by 2020. To meet this goal, China is aggressively increasing the power generation capacities for different types of renewable energies (Liu and Goldstein, 2013). In the US, the annual renewable energy consumption was 113.92 MTOE, including 63.20 MTOE of hydroelectricity and 50.72 MTOE of other renewable energy in 2012. Currently, renewable energies contribute 9% of overall energy consumption, and the goal is to reach 12% in 2020. For the electrical power generation sector, renewable energy will exceed 10% of overall energy consumption in 2015 and 20% in 2020 (Lean and Smyth, 2013).

In this paper, a mathematical model is established to correlate GDP, CO_2 emissions, energy prices and the renewable energy cooperation index. In Section 2, the research methods are described, in which a measure for cooperation is proposed. In Section 3, the results are provided based on a vector auto-regression model and its analysis. In Section 4, discussions are provided. In Section 5, conclusions and policy implications are given.

2. Methods

Cooperation between China and US on renewable energies started around 2000 and expanded around 2014.[1] Currently, such cooperation is at governmental, non-governmental and/or academic levels and may lead to green growth in the world economy. To reduce CO_2 and other greenhouse gas emissions, both China and the US need to find solutions in the power generation, transportation, manufacturing and construction sectors (Guo et al., 2010). In addition, coal and other traditional energy supplies are limited and will be exhausted in the future, which further motivates both countries to seek solutions collaboratively (Gullberg et al., 2014). The costs of R&D are relatively high, and the Chinese renewable energy industry is still in its early stages, without an effective mechanism for the deployment of renewable energy (Yuan et al., 2014; Schuman and Lin, 2012). If the R&D results in the US can be transferred to China, where the manufacturing base is being built, it may be a win-win situation for both countries (Wan and Craig, 2013).

Table 1
Stationarity test results.

	ADF		PP		KPSS	
	Level	First difference	Level	First difference	Level	First difference
CO_2	1.968	−4.328***	0.560	−3.212**	0.6695**	0.131
GDP_c	0.636	−2.633*	0.253	−2.599*	0.673**	0.069
GDP_u	−2.126	−3.030**	−1.800	−3.030**	0.660**	0.322
$RNCI_c$	−0.821	−5.110***	−0.821	−5.140***	0.341*	0.293
$RNCI_u$	−2.483	−4.488***	−2.415	−4.482***	0.245	0.188
EPRICE	−0.651	−7.173***	−0.454	−7.202***	0.480**	0.281

RNCIU analyzed by KPSS being always stable.

*** Denotes statistical significance at the 1% levels.
** Denotes statistical significance at the 5% levels.
* Denotes statistical significance at the 10% levels.

Table 2
Lag orders of the VAR model.

Lag	Log *L*	AIC	SC
0	231.5572	−18.12457	−17.88080
1	291.5794	−21.95478[a]	−19.46370[a]
2	325.3011	−21.02036	−18.94256

[a] Lag order selected by the criterion.

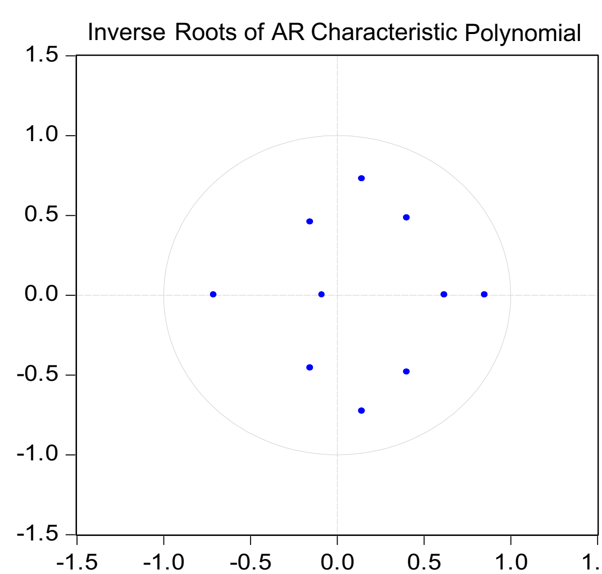

Fig. 1. Inverse roots of AR characteristic polynomial.

[1] The milestones are as follows: "The cooperation agreement of energy efficiency and renewable energy science and technology for China and the US" in 2000, the "Sino-US clean energy technology forum" in 2001, "The cooperation protocol of energy efficiency and renewable energy" in 2006, "The green partnership project framework under the ten-year cooperation of energy for China and the US and the large-scale consulting cooperation of renewable energy generation for China and the US" in 2008, "The understanding memorandum of strengthening

In terms of the impacts of renewable energy cooperation on the economy, one needs to develop an effective measure to gauge the outcome because there is no commonly agreed upon indicator in the literature. In this paper, two variables will be considered: the intra-industry trade index (IIT) and energy efficiency index (EE) (Yoshida, 2013; Egger et al., 2007; Algieri et al., 2011). IIT can measure a country's technology maturity level, such as the development and utilization of renewable energy, and is related to economy scales, economic development levels, residents' incomes, and their preferences, as follows:

$$IIT = 1 - \frac{|X - M|}{|X + M|} \quad (1)$$

where X is amount of exports of the renewable energy industry and M is the amount of imports of the industry. Both X and M values are in US dollars. IIT values are between 0 and 1. When X is

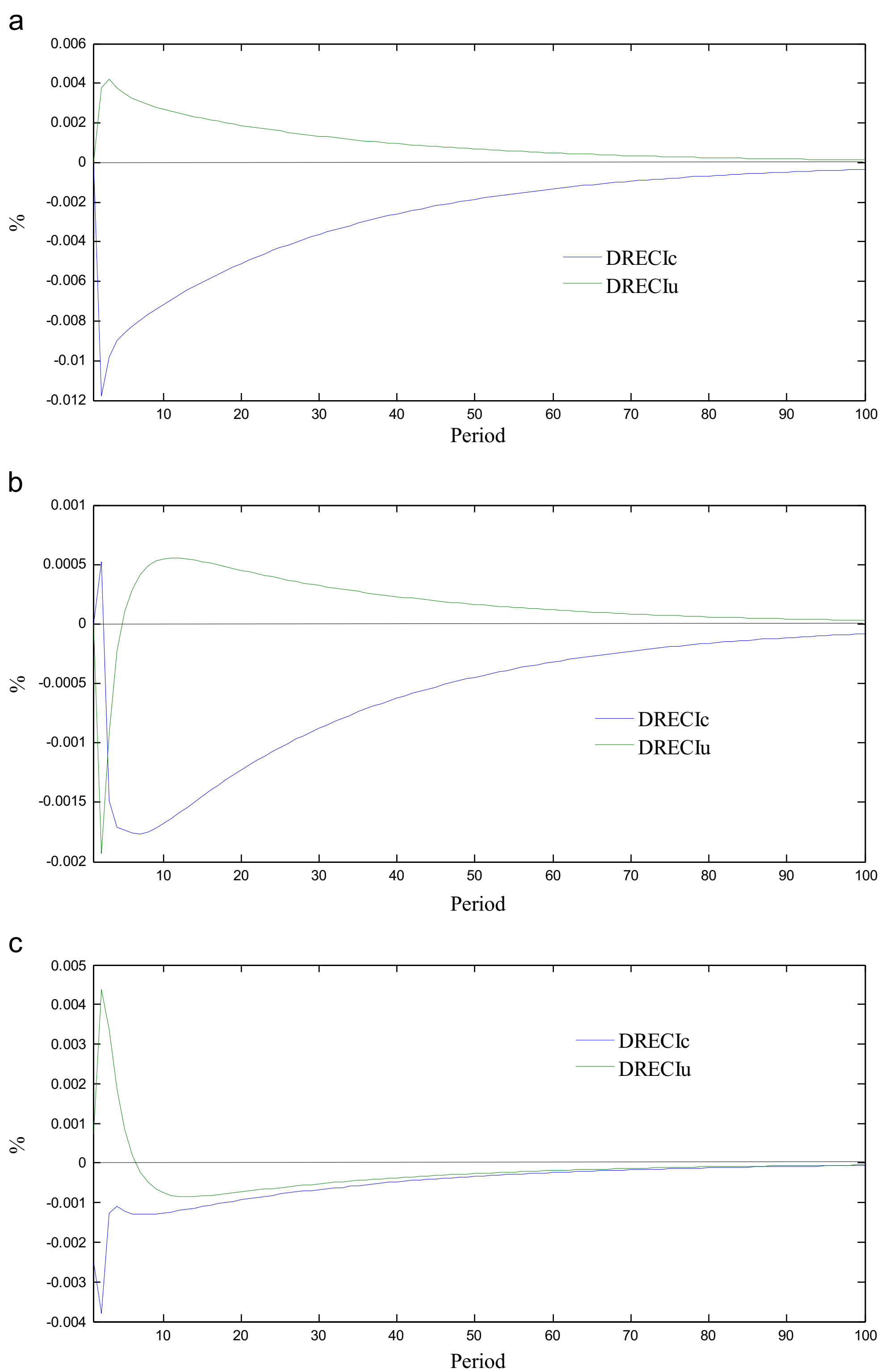

Fig. 2. Impulse responses: (a) Response of DGDPc, (b) response of DGDPu, and (c) response of DCO_2 emission. Notes: The ordinate denotes the fluctuation (%) caused by One S.D. Innovations; the abscissa denotes period of fluctuation.

close to *M*, IIT will be close to one. The greater the IIT value, the greater the economic cooperation between China and US is. For China, if the export amount (to US) equals the import amount (from US), cooperation with the US is at its highest. Identically, for the US, if the export amount (to China) equals the import amount (from China), cooperation with China is at its highest. In this study, one IIT parameter is for China, and the other for the US.

Unlike visible IIT, EE reflects potential benefits, which may not show an immediate impact at the beginning of the cooperation but will gradually display long-lasting impacts as the cooperation continues. That is, as EE increases, manufacturing costs will be reduced and the economy may be improved. In this paper, EE is defined as GDP per unit of energy consumption. One EE parameter is for China, and the other for the US.

Based on IIT and EE, an index called RECI (renewable energy cooperation index) is introduced as follows:

$$RECI = IIT \times EE$$

Thus, both short-term and long-term benefits due to cooperation are considered here. One RECI variable is for China ($RECI_c$), and the other for the US ($RECI_u$).

Vector autoregression (VAR) is a model used to reflect the linear interdependencies among multiple time series. It is more general than the univariate autoregression (AR). For each endogenous variable, there exists a unique equation showing its evolution based on its own lags and the lags of other variables. Typically, VAR requires a list of variables that may affect each other intertemporally. To establish a VAR model, in addition to $RECI_c$ and $RECI_u$, we need other variables, including GDP_c and GDP_u, overall carbon dioxide emissions (CO_2) and international energy prices (EPRICE). Such variables can be found in the literature dealing with similar issues (Yoon et al., 2011; Liu et al., 2012; Wang, 2013). The first five variables are treated as endogenous variables because they directly affect renewable energy and vice versa. The last variable, EPRICE, is treated as the exogenous variable because it directly affects the renewable energy price but is not apparently affected by the renewable energy price due to the limited utilization of renewable energy at this moment.

For endogenous variables ($RECI_c$, $RECI_u$, GDP_c, GDP_u and CO_2), an iterative matrix equation can be given as follows:

$$\mathbf{Y}_t = \mathbf{C} + \mathbf{A}_1\mathbf{Y}_{t-1} + \ldots + \mathbf{A}_p\mathbf{Y}_{t-p} + \mathbf{H}X_t + \boldsymbol{\varepsilon}_t \tag{2}$$

where $\boldsymbol{Y_t}$ is the endogenous variable matrix (5×1) for the present or most recent year (t), $\boldsymbol{Y}_{t-1}$ is the matrix a year ago ($t-1$), $\boldsymbol{Y_{t\text{-}p}}$ is the matrix p years ago, X_t is the exogenous variable (EPRICE) for the present time (t), $\boldsymbol{\varepsilon}_t$ is the white noise matrix (5×1), C is the constant matrix (5×1), $\boldsymbol{A}_1$ is the coefficient matrix (5×5) for the previous year ($t-1$), $\boldsymbol{A_p}$ is the coefficient matrix (5×5) p years ago, and $\boldsymbol{H}$ is the weighing matrix (5×1) for the endogenous variable.

The data cover a time series between 1985 and 2012, with EE, GDP_c and GDP_u (GDP in US dollars) values from the World Bank database; IIT values from the United Nations' data base; CO_2 emission (in Megatons) values from the BP energy statistics yearbook; and International Energy Price (EPRICE, in US dollars per ton of oil equivalent) being weighted by the average price of coal, oil and natural gas globally.

(*footnote continued*)
cooperation in climate change, energy and environment for China and the US; Sino -US cooperation framework of energy and environment for ten years" in 2009, "The understanding memorandum of green partnership project implementation framework for China the US" in 2010, "The Sino-US joint statement, the cooperation memorandum of renewable energy partnership for China and the US; the cooperation protocol of setting up Sino-US clean energy research center" in 2011, "The third Sino-US energy efficiency forum" in 2012, and "The ninth meeting of energy and environment ten-year cooperation framework" in 2014.

Table 3
Total impulse response.

Response	DCO_2	$DGDP_c$	$DGDP_u$
Impulse			
$RNCI_c$	−0.05251	−0.27544	−0.06078
$RNCI_u$	−0.01843	0.10301	0.01674

Table 4
Cumulative contributions to $DGDP_c$, $DGDP_u$ and DCO_2.

	$DGDP_c$	$DGDP_u$	DCO_2
$DGDP_u$	14.07318	33.64238	26.82101
$DGDP_c$	68.95358	45.19165	47.76759
$DRECI_c$	6.15995	10.64529	6.25194
$DRECI_u$	3.96723	7.23153	4.20344
DCO_2	6.84606	3.28915	14.95602

3. Results

To ensure the validity of the VAR, the stationarity test is performed with three methods, including the ADF (Augmented Dickey–Fuller), PP (Phillips–Perron) and KPSS (Kwiatkowski–Phillips–Schmidt–Shin) methods.[2] In Table 1, the order is zero for each variable with the KPSS method. As tested by the ADF and PP methods, after the first difference operation, each variable is stable. In other words, the order of integration can be one for each of these five variables.

The lag orders of this VAR model are estimated by three inspection methods, including the Log L (Log Likelihood), AIC (Akaike Information Criterion) and SC (Schwarz Information Criterion) methods, as illustrated in Table 2. The lag order selected by both the AIC and SC methods is one, which is used in the following calculation. As illustrated in Fig. 1, the reciprocal values of the characteristic roots are all within the unit circle, indicating that VAR (1) is stable. Thus, we can analyze impulse response and variance decomposition.

The economic indices (GDP_c and GDP_u) and total carbon dioxide (CO_2) emissions may be affected by the renewable energy cooperation indices ($RECI_c$ and $RECI_u$). In Fig. 2(a), the vertical axis is the impulse responses of $DGDP_c$, and the horizontal axis is the lag time (year) after the initial positive impacts are applied to $DRECI_c$ and $DRECI_u$. The impact value of $DRECI_c$ or $DRECI_u$ is the respective standard deviation value in the data. As shown in Fig. 2 (a), the renewable energy cooperation index ($DRECI_u$) will cause a positive response for $DGDP_c$ because US technology and trade will help Chinese GDP. However, the $DRECI_c$ index will cause negative response for $DGDP_c$ because China's initial domestic capital in renewable energy will reduce its GDP. As the lag time approaches 100 years, both positive and negative impacts diminish. Cumulatively, the positive $DGDP_c$ response due to $DRECI_u$ is 0.10301, and the negative $DGDP_c$ response due to $DRECI_c$ is -0.27544, as tabulated in Table 3. Thus, the overall $DGDP_c$ response is slightly negative due to the large amount of Chinese capital at the beginning. That is, China needs to buy US manufacturing equipment and hire US experts to accelerate its renewable energy deployment, which does decrease Chinese GDP. Apparently, one

[2] ADF is a test for a unit root in a time series sample and is suitable for larger and more complicated sets of time series models than that for the DF (Dickey–Fuller) test. In ADF statistics, a more negative resultant value indicates stronger rejection of the hypothesis that there is a unit root at some level of confidence. The PP test is similar to ADF tests but is more comprehensive than ADF. KPSS is the only popularly used test in which the null of stationarity is tested against a non-stationary alternative.

needs to address such concerns in China. Fig. 2(b) illustrates the impulse responses of $DGDP_u$ due to $DRECI_c$ and $DRECI_u$. The renewable energy cooperation index ($DRECI_u$) may cause a negative impact on $DGDP_u$ initially but a positive impact after five years. In contrast, $DRECI_c$ may cause positive impact to $DGDP_u$ initially but a negative impact after two years. As the lag time approaches 100 years, there will be no significant impacts. Cumulatively, the $DGDP_u$ responses due to $DRECI_u$ and $DRECI_c$ are 0.01674 and −0.06078, respectively, as tabulated in Table 3. Referring to Fig. 2 (c) and Table 3, $DRECI_c$ and $DRECI_u$ will eventually reduce the total CO_2 emissions. Such an emission reduction is the main advantage of cooperation.

In Table 4, the first column is the individual contribution to $DGDP_c$ from each of five variables, calculated with 100 lag years; both $DRECI_c$ and $DRECI_u$ contribute to Chinese GDP ($DGDP_c$). Similarly, both $DRECI_c$ and $DRECI_u$ contribute to US GDP ($DGDP_u$),

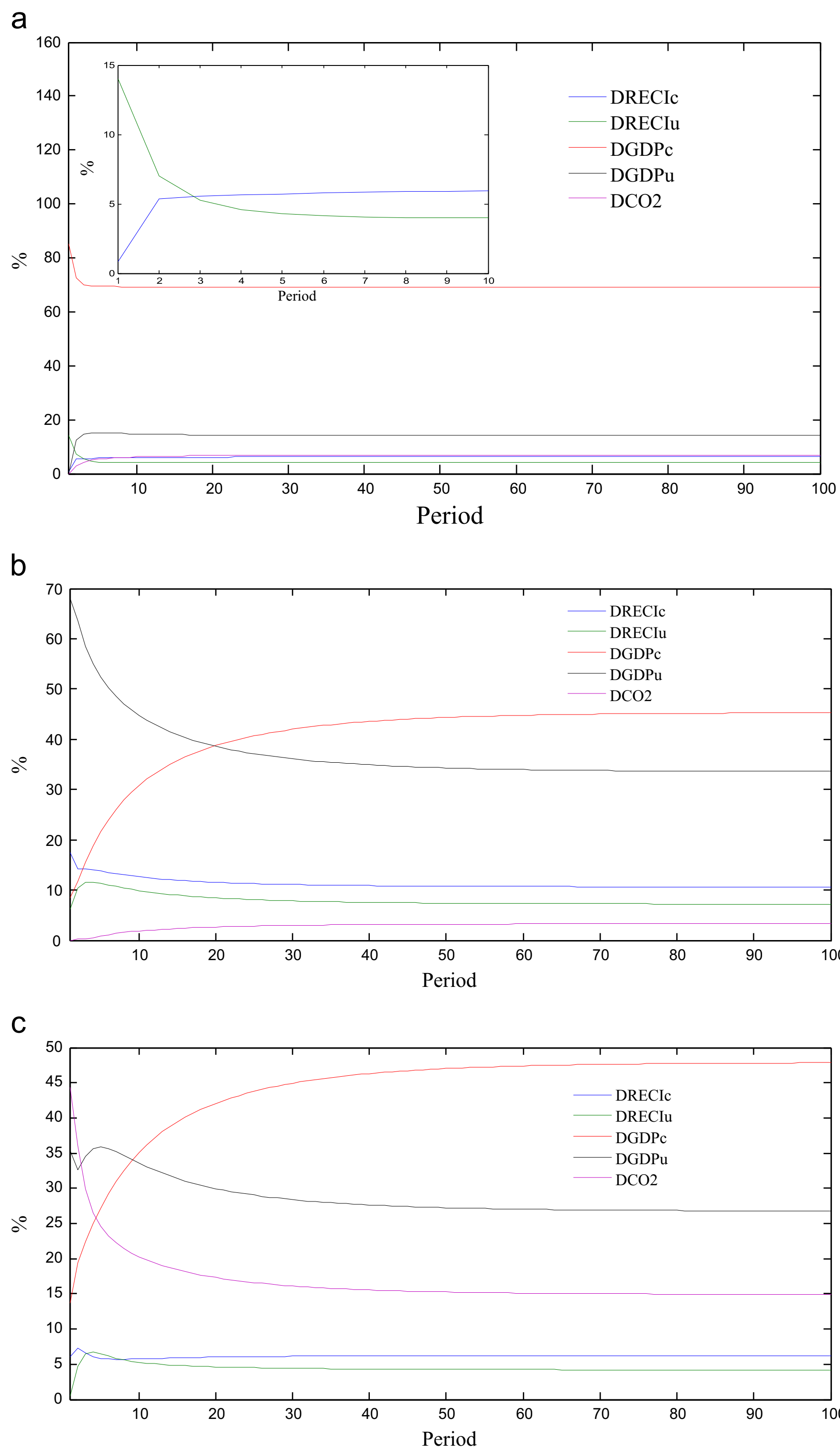

Fig. 3. Variance decomposition: (a) variance decomposition of DGDPc, (b) variance decomposition of DGDPu, and (c) variance decomposition of DCO_2. Notes: The ordinate denotes the contribution share of endogenous variable; the abscissa denotes period.

as illustrated in the second column. Furthermore, both $DRECI_c$ and $DRECI_u$ contribute to CO_2 reductions (DCO_2), as illustrated in the third column. In Fig. 3(a), the vertical axis is the individual contribution to Chinese GDP ($DGDP_c$) due to each endogenous variable, and the horizontal axis is the lag year.

As illustrated in the top portion of Fig. 3(a), initially, $DRECI_u$ contributes more to $DGDP_c$ than the Chinese index ($DRECI_c$). After a couple of years, the contributions from the cooperation indices become the same. Ultimately, $DRECI_c$ contributes more than $DRECI_u$. Thus, $DRECI_c$ will benefit $DGDP_c$ more than the US index ($DRECI_u$) cumulatively, as illustrated in Table 4. In Fig. 3(b), $DRECI_c$ contributes more to US GDP ($DGDP_u$) than $DRECI_u$. At the beginning, $DGDP_u$ is mainly affected by itself. However, 20 years later, $DGDP_c$ contributes more than $DGDP_u$. As illustrated in Fig. 3(b) and Table 4, China's economic growth may contribute to the US economy in the long run. In Table 4, $DRECI_c$ generally contributes more to DCO_2 than $DRECI_u$. In Fig. 3(c), initially, $DGDP_u$ contributes more to CO_2 emission (DCO_2) than $DGDP_c$. After 10 years, $DGDP_c$ contributes more to DCO_2 than $DGDP_u$. The reason is that the US economy has been stabilised, and the Chinese economy has been rapidly developing. In the long term, the Chinese economy (DGDPc) may contribute significantly to $DGDP_c$, $DGDP_u$ and $DCO_{2,}$ as illustrated in Table 4 and Fig. 3.

4. Discussion

As illustrated in Table 3 and Fig. 2(a), the response of Chinese GDP ($DGDP_c$) due to the US renewable energy cooperation index ($DRECI_u$) is because US technology and resources will help the Chinese economy. Referring to Fig. 2(b), the initial response of US GDP ($DGDP_u$) due to the Chinese renewable energy cooperation index ($DRECI_c$) is positive because US will gain access to Chinese markets. However, the long-term response of $DGDP_u$ due to $DRECI_c$ is negative if the cooperation only stays at the initial level. Thus, it will be crucial to provide other impulses or stimulus after several years. Referring to Fig. 2(b), the initial response of $DGDP_u$ due to $DRECI_u$ is negative because US monetary resources will be allocated to China. However, as illustrated in Fig. 2(b) and Table 3, the long-term and cumulative responses will be positive, and such long-term benefits may encourage the US to further develop cooperation with China. As illustrated in Table 3 and Fig. 2(a), the response of $DGDP_c$ due to $DRECI_c$ is negative because China will use its own monetary resources to establish renewable energy manufacturing facilities. Based on this model, the benefits are not large enough to counteract the substitutive cost in China. Thus, it will be important to explore other forms of impulses or stimulus so that the economic benefits to China are more visible.

As illustrated in Table 3 and Fig. 2(c), the total CO_2 emissions (DCO_2) due to $DRECI_c$ are reduced, which may motivate China to develop renewable energy for environmental reasons alone. In Fig. 2(c), the total CO_2 emission (DCO_2) due to $DRECI_u$ increases for the first seven years, which is caused by accelerating usage of traditional energy resources as China initially builds more manufacturing facilities. After seven years, DCO_2 is decreased cumulatively as more renewable energy resources replace traditional energy sources, as illustrated in Table 3 and Fig. 2(c). As far as sustainability is concerned, both countries should focus on the renewable energy industry. If economic growth can be sustained, profitability can be gained. It is mutually beneficial to explore Chinese renewable energy markets and to utilize US technologies and management systems. Referring to Table 4, $DRECI_c$ contributes approximately 6.2% to $DGDP_c$ (second column), and $DRECI_u$ contributes approximately 7.2% to $DGDP_u$ (third column). Currently, we are focusing on the effects of the investments in an ongoing study.

5. Conclusions and policy implications

Based on the above analysis, renewable energy cooperation between China and the US may stimulate economic development and reduce carbon dioxide emissions. As the world's first and second leaders in economies, the countries share a common interest in continuous economic growth while protecting the environment. Therefore, it is crucial to further improve the bilateral trade cooperation in renewable energy products.

To encourage investment in renewable energy, both countries should develop joint policies. If needed, such policies should be reviewed and revised every 3–8 years to continuously stimulate the economy, as illustrated in Figs. 2 and 3. Furthermore, China and the US should seek renewable energy cooperation with other countries and encourage international banking systems to increase investments in renewable energy.

As illustrated in Table 4 and Fig. 3, the impact of renewable energy cooperation on the economy is approximately 10% or less. To develop policies for sustainable economic growth, both countries need to explore various types of renewable energy cooperation, including industrial cooperation, which is directly related to technology transfers. At the present time, the most important policy is related to intellectual properties in renewable energy. China and the US should mutually develop intellectual property protection mechanisms via legal and administrative means. For example, both countries can mutually encourage cross-licenses and royalty distributions. The concept of cross-licenses is well understood in the US, when two companies have complementary technologies protected by patents. Such a concept should be introduced and promoted in China. Royalty payments are a normal business practice in the US and can be introduced and enforced in China, when regular and formal protections are guaranteed. Among all renewable energy technologies, biomass cooperation may be the first technology to be considered because China has a long tradition of utilizing this energy form and the US has developed different types of advanced systems. Moreover, electrical power grid modernization is another potential area for cooperation. Ninety percent of the Chinese population will be consuming electricity, and the US has developed computer and information technologies to effectively manage the grid system.

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