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Investigation of Carbon Tax Pilot in YRD Urban Agglomerations—Analysis and Application of a Novel ESER System with Carbon Tax Constraints

Guochang Fang [a,b,*], Lixin Tian [b,c], Min Fu [b], Mei Sun [b], Ruijin Du [b],Menghe Liu [a]

[a] *School of Economics, Nanjing University of Finance and Economics, Nanjing, Jiangsu, 210046, China*
[b] *Center for Energy Development and Environmental Protection, Jiangsu University, Zhenjiang, Jiangsu, 212013, China*
[c] *School of Mathematical Sciences, Nanjing Normal University, Nanjing, Jiangsu, 210046, China*

Abstract

This paper attempts to explore the dynamic behavior of energy-saving and emission-reduction (ESER) system in Yangtze River Delta (YRD) urban agglomerations, which has not yet been reported in present literature. The novel YRD urban agglomerations carbon tax attractor is achieved. A scenario study is carried out. The results show that, the ESER system in YRD urban agglomerations is superior to the average case in China, in which the impacts on economic growth are almost the same. The economic property of YRD urban agglomerations is the main cause why the ESER system of YRD urban agglomerations being superior.

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Keywords: Yangtze River Delta urban agglomerations; carbon tax; energy-saving and emission-reduction; energy intensity; economic growth.

1. Introduction

Carbon tax is a more efficient economic measure among the policy instruments of ESER system [1], which is helpful to achieve the ESER targets. Under the action of carbon tax, pollution sources could be controlled better and the final consumption of energy will be affected [2, 3]. Select some areas as a pilot before carrying out a policy across large range [4, 5]. This practice could avert some detrimental effects during the progress of implementing policy, abundant experience could be accumulated simultaneously. Carbon trading [6] and low carbon city [7] had applied on a series of pilot projects in certain areas, and

* Corresponding author. Tel.: +86 (025) 84028202; fax: +86 (025) 84028202.
E-mail address: fgchang79@163.com (G. Fang).

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summed up a lot more experience. Will carbon tax or carbon trading make a better effect in ESER system? For some districts (cities), carbon tax is better suited for the development of ESER to a certain degree. In the practice process, carbon tax is bound to have an effect on economy, employment and social welfare [8-10]; thus we need to know how much the economic areas are influenced by carbon tax, and how to cope with these conundrums. We [11] introduced a novel four-dimensional ESER dynamic evolutionary system with a series of productive results. This research, based on the previous study, is to establish a Yangtze River Delta (YRD) urban agglomerations ESER system with carbon tax constraints. The carbon tax pilot in YRD urban agglomerations and consequent influence of carbon tax are discussed.

2. **The model**

Appling commercialization management to the ESER system, rational use of government control, giving full play to the economic property of YRD urban agglomerations, establishing proper carbon tax incentives, all of these will further optimize the ESER system. In the four-dimensional ESER system [11], it is assumed that ESER, carbon emissions, economic growth and carbon tax are restrained by commercialization management, government control, the economic property of YRD urban agglomerations and carbon tax incentives respectively. The corresponding restriction conditions are assumed to be $F_1(x,y,z,w,t)$, $F_2(x,y,z,w,t)$, $F_3(x,y,z,w,t)$, $F_4(x,y,z,w,t)$.

$F_1(x,y,z,w,t)=a_5'(z-y)\cdot\left(d/1-(1+d)^{-t}\right)$ is time-dependent commercialization management, a_5' is the accommodation coefficient of commercialization management, d is effective rate of discount, t is the period, $t\in I$ ($a_5'\cdot\left(d/1-(1+d)^{-t}\right)=a_5$). $F_2(x,y,z,w,t)=-b_5y$ is time-dependent government control, b_5 is the coefficient of government control. $F_3(x,y,z,w,t)=c_5z$ is the economic property of YRD urban agglomerations. $F_4(x,y,z,w,t)=d_2z(y-x)$ is carbon tax incentives, d_2 is the incentive coefficient.

The novel ESER system with carbon tax constraints can be described by the following differential equations:

$$\begin{cases}\dot{x}=a_1x(y/M-1)-a_2y+a_3z+a_4w+a_5(z-y)\\ \dot{y}=-b_1x+b_2y(1-y/C)+b_3z(1-z/E)-b_4w-b_5y\\ \dot{z}=c_1x(x/N-1)-c_2y-c_3z-c_4w+c_5z\\ \dot{w}=d_1w(y-T)+d_2z(y-x)\end{cases}\tag{1}$$

where $x(t)$ is the time-dependent variable of ESER, $y(t)$, of carbon emissions, $z(t)$, of economic growth, $\omega(t)$, of carbon tax. $a_i,b_i,c_i,d_1,M,C,E,N,T$ are positive constants.($i=1,2,3,4$), $t\in I$, I is a given economic period (see [11]).

In Eq. (1), integrate $\dot{y}(dy/dt)$ and $\dot{z}(dz/dt)$ with t, the energy consumption and the GDP could be deduced as the dynamic evolution formulas $y^*(t)=\varphi_1(x,ky,z,w,t)$ and $z(t)=\varphi_2(x,y,z,w,t)$. The time-dependent energy intensity during a given period can be depicted as follows:

$$U(t)=\varphi_1(x,ky,z,w,t)/\varphi_2(x,y,z,w,t)\tag{2}$$

When the coefficients of Eq. (1) are given different values, the system presented in Eq. (1) will show different dynamic behavior. During the progress of parameter identification in section 3 ($e\le 0.00021$), it is found that when the parameters of Eq. (1) are given as $a_1=0.2874$, $a_2=0.5874$, $a_3=0.1614$,

$a_4 = 0.8372,\quad a_5 = 0.0345,\quad b_1 = 0.1943,\quad b_2 = 0.3926,\quad b_3 = 0.4321,\quad b_4 = 0.0628,$ $b_5 = 0.4613,\ c_1 = 0.4948,\ c_2 = 0.3042,\ c_3 = 0.5483,\ c_4 = 0.1041,\ c_5 = 0.2368,\ d_1 = 0.3029,$ $d_2 = 0.1269\ M = 3.7426,\ C = 0.4236,\ E = 0.6857,\ N = 0.0312,\ T = 0.4198$, the initials are given [00.0000000294 0.0207 0.068 0.000274], a chaotic attractor could be observed as shown in Fig. 1. The Lyapunov exponent spectrum is shown in Fig. 2.

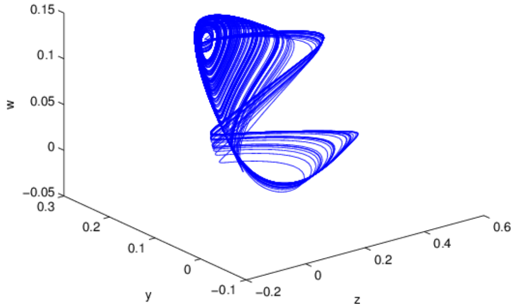

Fig.1. YRD urban agglomerations carbon tax attractor.

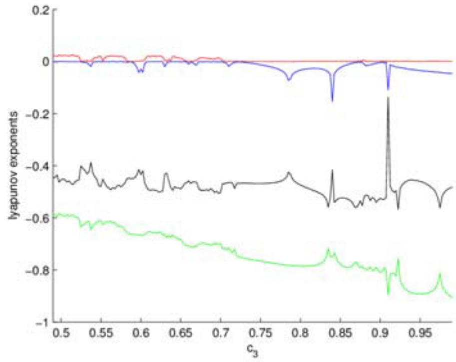

Fig.2. Lyapunov exponent spectrum.

3. Parameter identification

Calculation of ESER is mainly referred to the algorithm in reference [12]. The source data of carbon emissions and economic growth originate from Statistical Yearbook. Calculation of carbon tax is mainly referred to the algorithm in reference [11]. The data of ESER, carbon emissions, economic growth and carbon tax of YRD urban agglomerations of the years 2000 to 2013 can be shown in Table 1.

Table 1. Data of ESER, carbon emissions, economic growth and carbon tax (2000-2013, 1999 as the base).

year	x	y	z	w	year	x	y	z	w
2000	1.8126	1.0598	1.1232	1.0741	2007	4.4716	2.3144	3.3044	2.5646
2001	2.1497	1.1274	1.2444	1.1578	2008	4.9285	2.4376	3.8380	2.7341
2002	3.4816	1.2375	1.4051	1.2877	2009	4.3158	2.5451	4.1830	2.8891
2003	3.6781	1.4037	1.6642	1.4796	2010	5.2714	2.7603	4.9805	3.1706
2004	2.9517	1.6345	2.0037	1.7450	2011	5.0847	2.9062	5.8062	3.3775
2005	3.1549	1.9187	2.3810	2.0742	2012	5.3932	2.9883	6.2840	3.4729
2006	4.2483	2.0936	2.7716	2.2917	2013	5.5976	3.1180	6.8280	3.6236

Based on the Genetic Algorithm-Back Propagation (GA-BP) neural network, let crossover rate be 0.8 and mutation rate be 0.04. When the error $e \le 8.9635e-005$, the parameters of the actual system are shown in Table 2.

Table 2. Parameters of the actual system.

a_1	a_2	a_3	a_4	a_5	b_1	b_2	b_3	b_4	b_5	c_1
0.2874	0.5874	0.1614	0.6372	0.0345	0.0498	0.3926	0.4321	0.0628	0.4613	0.4948
c_2	c_3	c_4	c_5	d_1	d_2	M	C	E	N	T
0.3042	0.5483	0.1041	0.2368	0.3029	0.1279	3.3672	0.2352	0.6857	0.0312	0.2574

4. A scenario analysis

With the levying of carbon tax going to work gradually, each variable of the actual system will be affected. $F_3(x,y,z,w,t)$ is the economic property of YRD urban agglomerations. In order to undertake a contrastive analysis of carbon tax evolution regulations in YRD urban agglomerations and China as a whole, let $F_3(x,y,z,w,t)$ be varied, while $F_1(x,y,z,w,t)=F_2(x,y,z,w,t)=F_4(x,y,z,w,t)=0$. Fig.6 in [11] shows the energy intensity when the initial value is 15 ¥/ton-CO_2. Select the curve turning point 3 in Fig.6 (the most ideal curve) as the representative of energy intensity evolution diagram in China's ESER system with carbon tax constraints, i.e. the blue curve in Fig.3 in this paper. The green curve is the energy intensity evolution diagram of YRD urban agglomerations with carbon tax constraints; and the red curve is the energy intensity evolution diagram of 3D ESER system [12]. By observing Fig 3, it is found that the blue curve has a slighter fluctuation than the red curve. The energy intensity is always smaller than that of the red curve. The energy intensity starts with a precipitous decline after the turning point. The above analyses indicate that the 4D ESER system with carbon tax constraints is superior to the 3D ESER system

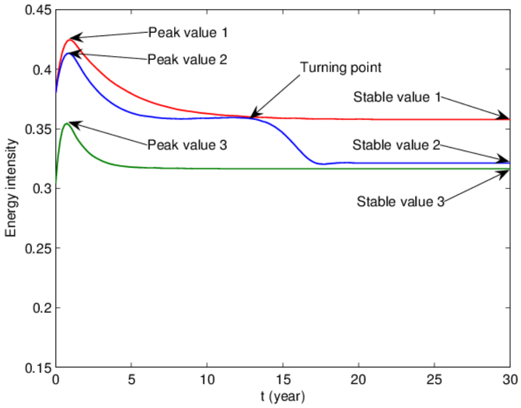

Fig.3. The comparison diagram of energy intensity.

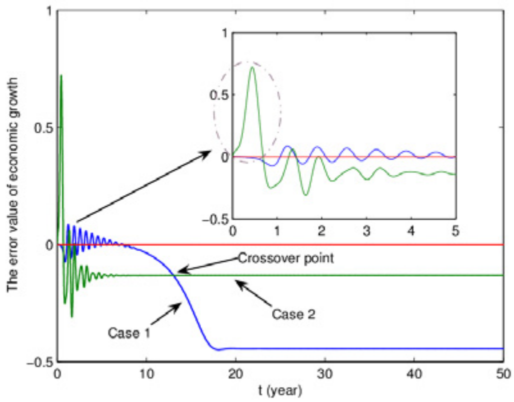

Fig.4. Error value of economic growth.

Fig.4 shows the comparison diagram of error value of economic growth under the same carbon tax rate and constraint conditions. Case 1 shows the evolution diagram of economic growth's error value when the levy amount of carbon tax is 15 ¥/ton-CO_2 in the case of China; Case 2 shows the corresponding diagram in YRD urban agglomerations' ESER system with carbon tax constraints under $F_3(x,y,z,w,t)$. From Fig.4, it can be observed that levying of carbon tax has inhibitory impact on economic growth. Both the two curves are all below the zone line (red line). There is a vast difference between the blue curve and the green one in the initial stage. In the elliptic region, the absolute value of slope in the second half is remarkably larger than that in the first half. The curve tends to be stable after a short-term fluctuation, with the fluctuation time being shorter than case 1. Between elliptic region and the crossover point, the inhibitory impact on economic growth in case 2 is bigger than that in case 1. After the crossover point, the green curve is stabilized, while the blue curve still declines. The stable value of the blue curve is much smaller than that of the green curve. The above analyses indicate that YRD urban agglomerations have shown greater resilience to carbon tax than the average case of China, which has a shorter time to reach the stable value of energy intensity and error value of economic growth; and there is smaller inhibitory impact on economic growth.

Fig.5 shows the evolution curve of energy intensity when c_5 growing. The red curve corresponds to the curve when $c_5=0.2368$. The blue curve corresponds to the curve when $c_5=0.2568$. The green curve corresponds to the curve when c_5=0.2768. It can be observed that, when c_5 becomes bigger, the peak value and stable value of energy intensity become smaller. It shows that, in the current YRD urban agglomerations' ESER system with carbon tax constraints, the economic property $F_3(x,y,z,w,t)$ is the key to the reduction of energy intensity. The more effectively $F_3(x,y,z,w,t)$ plays the role in the system, the more energy intensity declines.

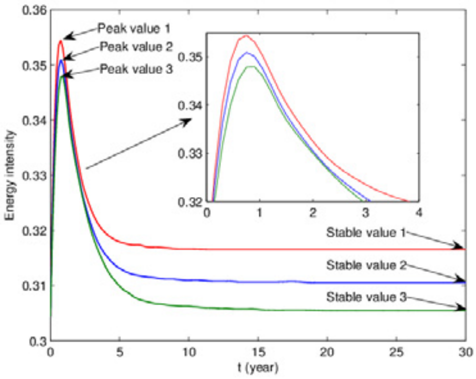

Fig.5. Energy intensity (c_5).

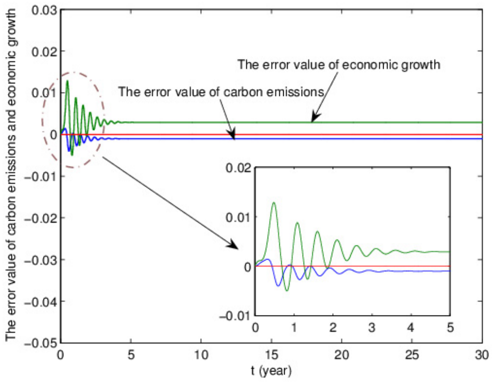

Fig.6. Error value of carbon emissions and economic growth.

Levying carbon tax into the system presented in Eq. (1), when the effect of $F_3(x,y,z,w,t)$ gets bigger, it will exert influence on $z(t)$. $z(t)$ then exerts influence on $x(t)$, $y(t)$ and $w(t)$; and reduce $U(t)$ finally. Fig.6 interprets the reason why the bigger $F_3(x,y,z,w,t)$ (c_5) makes smaller $U(t)$. It shows the error value of carbon emissions and economic growth when c_5 changing from 0.2368 to 0.2568. The blue curve is the error value of carbon emissions; the green curve is the error value of economic growth. As c_5 grows, the blue curve is lower than the red line (zone line) after a short fluctuation, with the error value of carbon emissions being negative, i.e. it has hampered the carbon emissions' growth. The green curve is higher than the red line except for a short curve below the red line in the early stage. The bigger c_5 is, the more evident the trend is, i.e. growing c_5 causes further development of the economy. In the time-dependent energy intensity formula $U(t)$, the numerator φ_1 gets small, while the denominator φ_2 gets big, and $U(t)$ gets small.

5. Conclusions

On the basis of a novel ESER system with carbon tax constraints, this paper has discussed the evolutionary behavior of YRD urban agglomerations ESER carbon tax system with multiple variable constraint. The YRD urban agglomerations carbon tax attractor is achieved. The quantitative coefficients of the actual system are obtained based on the GA-BP network. The time-dependent energy intensity calculation formula and the evolution tendency of economic growth are made as the measurements, and the differences between YRD urban agglomerations carbon tax system and China's carbon tax system are compared.

In the YRD urban agglomerations ESER system with carbon tax constraints, The economic property of YRD urban agglomerations is the mainly reason why it is superior to China's carbon tax system. The healthy and sustained development of YRD urban agglomerations' economy is the precondition of levying carbon tax in YRD urban agglomerations ESER system. The development of ESER will be promoted under combined carbon tax and the economic property of YRD urban agglomerations. Piloting carbon tax in the local area is a very good program. Carbon tax could be fanned out across the country gradually after accumulating necessary experience.

Existing literatures on carbon tax studies mainly use dynamic Computable General Equilibrium (CGE) model [13, 14], dynamic economy wide model [15], modified Cross-Entropy solution method [16], TIMES (The Integrated MARKAL-EFOM System) model [17] and so on. The research contents are multifarious, while there is little literature on carbon tax pilot. Based on the 4D ESER system with carbon tax constraints [11], this paper explores carbon tax pilot in YRD urban agglomerations, and a useful attempt of levying carbon tax in YRD urban agglomerations is made. The conclusion presents a view on the focus question of the current debate. The economic property of YRD urban agglomerations and carbon tax incentives are the key to the control of energy intensity. It is an innovation to research carbon tax pilot by dynamic method. Compared with previous researches, evolution analysis and theoretical basis in this paper are more persuasive.

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Biography

Guochang Fang is an Associate Professor in Nanjing University of Finance and Economics. His current work involves the theory and application of energy-saving and emission-reduction system, carbon tax, carbon trading, and published more than 20 academic articles in journals, which are indexed by SSCI, SCI, or EI.