The Measurement on the Decoupling Effect of Carbon Emissions in East China
——Based on the research of provincial panel data

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Abstract—**This paper uses the Tapio decoupling model to study the decoupling state of GDP and carbon dioxide emissions of "Six Provinces and One City" in East China. It uses the gray prediction model to give a short-term forecast about the GDP and carbon dioxide emissions of provinces and cities during the "13th Five-Year" Plan period. The research shows that the decoupling effect exists between the economic growth and carbon dioxide emissions in different provinces and cities of East China. The decoupling index is quite different from one region to another, among which Shanghai and Zhejiang perform best. The predictions suggest that during the "13th Five-Year", Shanghai and Zhejiang will maintain their strong decoupling state with their GDP's growing and carbon dioxide emissions' decreasing. The decoupling index of Fujian and Jiangsu is relatively lower, in the next five years, Fujian will turn into strong decoupling state with decreasing carbon dioxide emissions while carbon dioxide emissions in Jiangsu increases slightly with its average decoupling elasticity value as 0.028, and it's expected to achieve strong decoupling. The data of other provinces show their decoupling instability, and the weak decoupling will still play the dominant role during the "13th Five-Year" period.**

Keywords-East China; carbon dioxide emission; tapio decoupling; grey prediction; "13th Five-Year" plan

I. INTRODUCTION

The area of "six provinces and one city" in East China (Jiangsu, Zhejiang, Shandong, Anhui, Fujian, Jiangxi, Shanghai) is one of the best areas of regional economic development in China. Statistics show that the total economy in eastern China in 2014 accounted for 37.3% of the total national economy. The annual economic growth rate is 8.2%, which is higher than the national average of 7.4%. The total population percentage is 29.4%. The huge number of population has caused the huge consumption of resources, and finally led to the deterioration of the environment. So the researches on the decoupling status of economic and total carbon dioxide emissions in East China are particularly necessary. They have important practical significance on the national or regional economic development strategy to save energy and reduce emission.

II. LITERATURE REVIEW

Scholars at home and abroad have researched CO_2 displacement a lot. Among them, Tapio Pet (2005) studied decoupling of economic growth and transportation volume of Finland in the period of 1970-2001. Clara Inés Pardo Martínez (2009) studied decoupling relationship between carbon emissions and economic growth in Columbia and Germany, and found that there is obvious decoupling between them [3]. LU (2007) analyzed the decoupling relationship between carbon emissions of the transportation industry and economic growth in Germany, Japan, South Korea and Taiwan [4]. Mohamed (2014) used Granger causality test to analyze the relationship between variables like carbon emissions and energy use, financial development in India. The results showed that there was a causal relationship between carbon emissions and other variables [5]. Zhou Yinxiang (2016) used Tapio model, cointegration theory and Granger causality test to study the relationship between economic growth and carbon emissions of traffic transportation industry. The decoupling status between them is not obvious. In the long term, the two variables have a coupling relationship, there is a one-way causal relationship between economic growth and the emission of CO_2 [6].

III. DATA SELECTION AND MODEL BUILDING

A. Data Selection

According to the availability of data, the article selected energy consumption of coal, coke, gasoline, diesel oil, fuel oil and natural gas, and GDP panel data of six provinces and one city.

B. Tapio Decoupling Model

The Tapio decoupling effect model was developed by Tapio when he was studying the decoupling level between transport volume and the CO2 emissions in European. CO2 decoupling is the process that the relationship between economic growth and greenhouse gas emissions has been weakened and even disappeared.

$$e = \frac{\frac{\Delta CO_2}{CO_2}}{\frac{\Delta GDP}{GDP}} \qquad (1)$$

Tapio elastic analysis method uses elastic value to analyze the decoupling relationship between carbon dioxide

and economic growth. The decoupling elastic value is shown in Equation 1.

C. Measurement Model of Carbon Dioxide Emission

Carbon emission coefficient is based on Guidelines for National Greenhouse Gas Emission Inventory of IPCC. The corresponding data for all kinds of energy is shown in Table 1.

TABLE I. STANDARD COAL COEFFICIENT AND CARBON EMISSION COEFFICIENT

energy	standard coal coefficient	carbon emission coefficient
raw coal	0.7143	0.7559
coke	0.9714	0.8550
gasoline	1.4714	0.5538
diesel	1.4571	0.5921
oil	1.4286	0.6185

Equation of carbon dioxide emission:

$$CO_2 = \sum_{i=1}^{n} H_i \theta_i \delta_i \left(44/12 \right) \qquad (2)$$

CO2 is the total carbon dioxide emissions; H_i represents consumption of energy I; θ_i is the standard coal coefficient of energy I; δ_i is the carbon emission coefficient of energy I, in which 44 and 12 are the amount of carbon dioxide molecules respectively; From $\delta_i *3.67(44/12)$, we get emissions coefficient of different energy.

Units of various energy consumptions are converted to 10000 tons of standard coal (104t). With Equation 2, we get CO2 emissions of provinces in East China from 2005 to 2014. And the trends are shown in Figure 1.
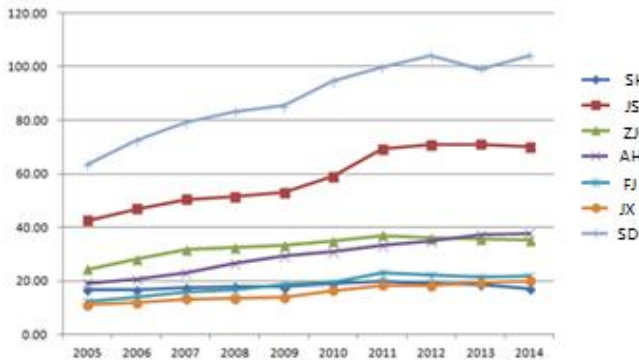

Figure 1. CO$_2$ emission of six provinces and one city during 2014 - 2005 (10 million tons)

D. Decoupling Effect and Analysis

The results of different provinces during 2005-2014 are shown in Table 2.

From the results of decoupling effect measurement in different provinces and regions emissions, we can see that the decoupling index showed a decreasing trend during 2005-2008 (except Anhui), indicating that CO2 growth rate is lower than the speed of economic development and the growth mode is changing. Economic development has

shown a good trend. The decoupling index increases and decreases with the different impact of global financial crisis in 2008. During 2011-2014, six cities showed strong decoupling state.

TABLE II. DECOUPLING RESULTS OF PROVINCES AND CITIES FROM 2005 TO 2014

index	SH	JS	ZJ	AH	FJ	JX	SD
2005—2006	w	w	st	w	w	w	w
2006—2007	w	w	w	w	w	w	w
2007—2008	w	w	w	w	w	w	w
2008—2009	s	w	w	w	w	w	w
2009—2010	w	w	w	w	w	w	w
2010—2011	w	st	w	w	w	w	w
2011—2012	s	w	s	w	s	s	w
2012—2013	s	w	s	w	s	w	s
2013—2014	s	s	s	w	w	w	w

PS: w=weak; s=strong; st=strengthen

IV. GREY PREDICTION MODEL OF DECOUPLING

A. GM (1,1) Grey Prediction Model

Grey system prediction theory is a new method to study the problem with "small sample" and "poor information".

Set X(0)={X(0)(1), X(0)(2), …, X(0)(n)} as the original sequence data, X(1)={X(1)(1), X(1)(2),…, X(1)(n)}as the first order cumulative generation sequence, in which:

$$X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i), k = 1,2,\cdots n \quad (3)$$

We name X(0)(k)+a X(1)(k)=b as the original form of the GM (1,1) model.

Z(1)={Z(1)(1), Z(1)(2), …, Z(1)(n)} are the generated sequences adjacent to X(1), in which

$$Z^{(1)}(k) = \frac{1}{2}[X^{(1)}(k) + X^{(1)}(k-1)], k = 2,3,\cdots,n$$

Describe X(0)(k)+a Z(1)(k)=b as the basic form of model. Parameter a is the development coefficient and b is the grey function.

If $\hat{a}$ =[a, b] is a parameter list, and

$$B = \begin{bmatrix} -\frac{1}{2}(Z^{(1)}(2) & 1 \\ -\frac{1}{2}(Z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -\frac{1}{2}(Z^{(1)}(n) & 1 \end{bmatrix} \quad Y = \begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ \vdots \\ X^{(0)}(n) \end{bmatrix} \quad (4)$$

Then the least square estimation of X(0)(k)+a Z(1)(k)=b must be satisfied with the following:

$$B\hat{a} = Y \Rightarrow \hat{a} = B^{-1}Y \Rightarrow \hat{a} = B^{-1}(B^{\mathrm{T}})^{-1}B^{\mathrm{T}}Y \Rightarrow \hat{a} = (B^{\mathrm{T}}B)^{-1}B^{\mathrm{T}}Y$$

The time response sequence of GM(1,1) model:

$$\hat{X}^{(0)}(t+1) = (1-e^a)[X^{(0)}(1) - \frac{b}{a}]e^{-at} \quad, \quad t = 1,2,\cdots,n$$

$$\hat{X}^{(0)}(1) = X^{(0)}(1) \qquad (5)$$

B. Grey Prediction Data Processing

In this paper, the grey prediction is made by the time series data of GDP during 2010-2014.

Step 1: The original time series data of GDP of Jiangsu province:

X(0)={X(0)(1),   X(0)(2),…,X(0)(5)}={41.43,   49.11, 54.06,59.75,65.09}

Step 2: Put the original time series data into the Equation 3 to generate the cumulative sequence:

X(1)={X(1)(1), X(1)(2),…,X(1)(5)}={41.43, 90.54, 144.60, 204.35, 269.44}

Step 3: Calculate the mean sequence adjacent to X(1):

Z(1)={Z(1)(2),   Z(1)(3),…,Z(1)(5)}   ={65.99,   117.57, 174.48, 236.90}

Step 4: Put the data from Step1 and 3 into Equation 4 to get the matrix B and Y:

$$B = \begin{bmatrix} -65.99 & 1 \\ -117.57 & 1 \\ -174.48 & 1 \\ -236.90 & 1 \end{bmatrix} Y = \begin{bmatrix} 49.11 \\ 54.06 \\ 59.75 \\ 65.09 \end{bmatrix}$$

Step 5: Get the matrix obtained from Step4 into Equation.

$$\hat{a} = [a,b]^{\mathrm{T}} = (B^{\mathrm{T}}B)^{-1}B^{\mathrm{T}}Y = [-0.09404, 43.01584]^{\mathrm{T}}$$

Step 6: Put the relevant data into the Equation 5, and get response time series model of GM (1,1).

$$\hat{X}^{(0)}(t+1) = (1-e^a)[X^{(0)}(1) - \frac{b}{a}]e^{-at} = 44.773264\, e^{0.09404t}, t = 1,2,\cdots,n$$

$$\hat{X}^{(0)}(1) = X^{(0)}(1) = 41.43$$

Step 7: Calculate the predicted value of X(0).

$$\hat{X}^{(0)} = \{41.43, 49.19, 54.04, 59.37, 65.22, 71.65, 78.72, 86.48, 95.01, 104.37, 114.66\}$$

C. Results of Grey Prediction and Decoupling Analysis

Figure 2 is the actual GDP values and Figure 3 is the predictive GDP value. Figure 4 is the actual emissions of CO_2 and Figure 5 is the forecast value.

Table 3 shows the average decoupling status in the provinces of East China during the "13th Five-Year" planning period.
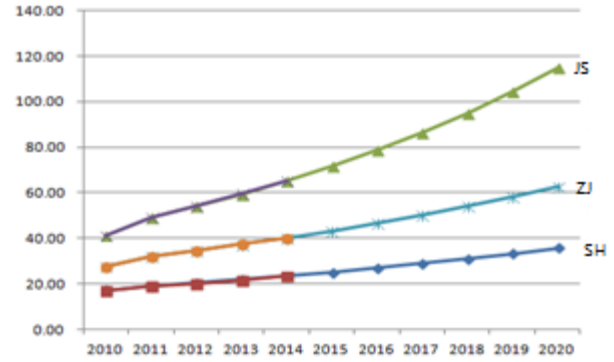

Figure 2.   Actual GDP value and predicted GDP value of Jiangsu, Zhejiang and Shanghai (100 billion Yuan)
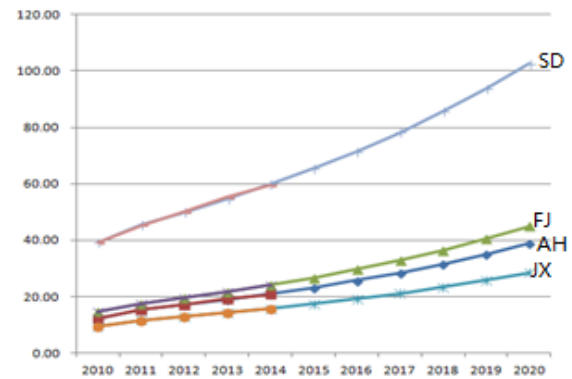

Figure 3.   Actual GDP value and predicted GDP value of Anhui, Fujian, Jiangxi and Shandong (100 billion Yuan)
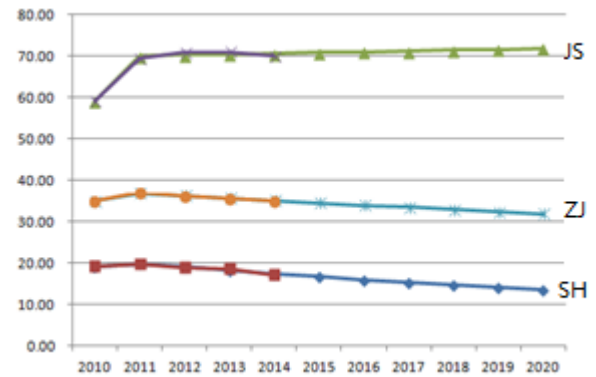

Figure 4.   Actual and predicted CO_2 emission values of Jiangsu, Zhejiang and Shanghai (million tons)
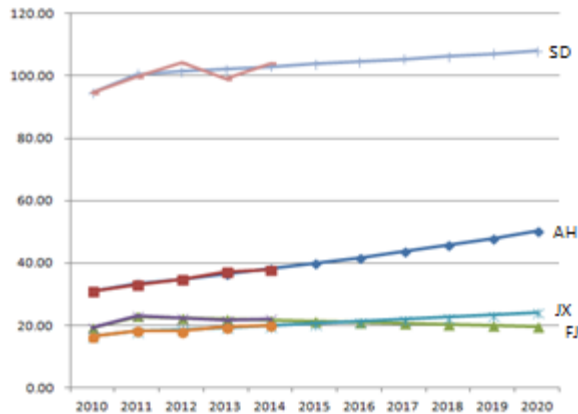
Figure 5.   Actual and predicted CO2 emission values of Anhui, Fujian, Jiangxi and Shandong (million tons)

TABLE III.   AVERAGE DECOUPLING STATUSES IN EAST CHINA DURING "13TH FIVE-YEAR"

index	$\triangle CO_2 / CO_2$	$\triangle GDP/GDP$	E	state
SH	-0.0425	0.0726	-0.58579	S
JS	0.0028	0.0986	0.028346	W
ZJ	-0.0162	0.0763	-0.21189	S
AH	0.0463	0.1077	0.429793	W
FJ	-0.0169	0.1095	-0.15457	S
JX	0.0325	0.1035	0.314391	W
SD	0.0079	0.0942	0.083589	W

PS: w=weak; s=strong; st=strengthen

From Figure 2 and Figure 3, we can see that the economy will continue to grow in various provinces and cities in "13th Five-Year" planning period. CO2 emissions of Shanghai, Zhejiang show a significant downward trend in Figure 4 and Figure 5, while CO2 emissions of other provinces have increased significantly. Table 3 shows that the decoupling elasticity value is negative in Shanghai, Zhejiang and Fujian, showing strong decoupling state. The average decoupling elasticity value is 0.028 in Jiangsu. Jiangsu has average decoupling elasticity value of 0.028. The province can rely on science and technology and talent advantages to strengthen technological innovation. There is a greater possibility of strong decoupling state of Jiangsu. Decoupling elastic values of Anhui, Jiangxi, Shandong is relatively large compared to other provinces, and they may also remain in a weak decoupling state.

V.   CONCLUSIONS AND RECOMMENDATIONS

There is a decoupling effect between economic growth and CO2 emissions in the provinces of East China, and there is a big difference between different regions. In the consecutive years of 2011-2014, Shanghai, Zhejiang and Jiangsu maintain strong decoupling status and the prediction results show that they will continue during the "13th Five-Year" period. Fujian and Jiangsu are in the status of strong decoupling during 2011-2013 and 2013-2014. The results show that Fujian will change into a strong decoupling state. The result of the Jiangsu forecast is weak decoupling; the decoupling elasticity value is low. The weak decoupling status of other provinces will continue during "13th Five-Year".

Based on these studies, we give out following recommendations:

(1) Adjust the industrial structure and promote the development of low energy consuming industries. The important way to adjust industrial structure is to change the extensive economic development to intensive economic development. Economy cannot develop with the cost of resources and environmental damage. The key to improve the efficiency of energy is to reduce CO2 emission.

(2) Adjust energy consumption structure. The rapid development of China's economy is mainly dependent on the consumption of coal, oil, natural gas and other non-renewable energy sources, which has caused tremendous pressure on energy and the environment. We can strengthen technological innovation, absorb foreign advanced experience, and develop new energy market to promote the industrialization development with clean energy, to achieve real decoupling state of economic growth and CO2.

(3) Strengthen government functions. The government can issue the relevant energy-saving emission reduction targets. According to the performance of the enterprise, it gives appropriate adjustment of taxation, credit, financial subsidies and other aspects of the subsidies. For enterprises engaged in energy saving research and development, the government can give more conveniences to enterprise's research and development. At the same time, the government should cooperate with the relevant laws and regulations on energy saving and emission reduction, and put the production of enterprises into the cage of the system.

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