Influence of economic growth and energy consumption on carbon emissions in Yangtze River Economic Belt

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Abstract. This paper investigated the influence of economic growth and energy consumption on carbon emissions by using an extended STIRPAT model with panel data in Yangtze River Economic Belt from 2000 to 2017. We applied PCA to avoid the multicollinearity of the variable. The results show that the per capita GDP, the industrial structure, the population scale, the population structure, the export scale, the investment scale, the consumption and the FDI all lead to the increase of carbon emissions. The energy intensity has an inhibitory effect on carbon emissions. The EKC hypothesis is confirmed in Yangtze River Economic Belt, but in the west part, the economic growth and carbon emissions exhibit a reversed N-shaped relationship. The three control variables which promote economic growth, respectively, the export scale has the strongest effect in promoting the carbon emissions in the whole area, the investment scale has the biggest influence in the east part, the consumption has the largest impact in the mid-west part. Finally, some suggestions are provided.

1. Introduction
Yangtze River Economic Belt is located in the central area of China, which traverses from east to west, and it includes 9 provinces and 2 municipalities directly under the Central Government, which are Shanghai, Zhejiang Province, Jiangsu Province, Anhui Province, Jiangxi Province, Hubei Province, Hunan Province, Chongqing, Sichuan Province, Yunnan Province and Guizhou Province, respectively. It has an important strategic status in the overall regional development of China. As an important area supporting the development of Chinese economy, the GDP of Yangtze River Economic Belt reached RMB 40.298524 trillion yuan, accounting for 44.76% of the total GDP of China, and it had a growth rate of 8.6%, higher than the average national level. However, in addition to the great achievement of economic development, the overall energy consumption of Yangtze River Economic Belt has also continuously increased. In 2017, the overall energy consumption of Yangtze River Economic Belt was 1.7168 billion tons of standard coal equivalent, accounting for 38.28% of total national energy consumption. Energy consumption, especially the consumption of fossil fuel, will generate massive emission of CO₂[1,2] (Ren and Zhao, 2014; Ma et al., 2019). The greenhouse gases, mainly consisting of CO₂, are increasing sharply with the continuous development of human industrial activities, which has led to continuous increase of global mean temperature, caused global climate change, resulted in more and more extreme weathers around the world, and generated huge impact on human production and development. According to the WMO Statement on the State of the Global Climate released by
World Meteorological Organization (WMO), the ten years from 2010 to 2019 were the hottest ten years in human history. In order to tackle climate change, the Chinese government has always undertaken its due responsibility and accountability as a main country, and took the initiative to enter into the Paris Agreement. In addition, China promised to reduce the carbon dioxide emission intensity per unit of GDP by 60%–65% by 2030 from the level in 2005, and reach the peak of carbon dioxide emission as soon as possible. In order to achieve this goal, China has always promoted the path to low-carbon economy and sustainable development. The population, GDP and total export and import volume of Yangtze River Economic Belt all account for more than 40% of the national level. As a developing country, China is still at the period of industrial development, while it is also committed to Paris Agreement, so the relationship between economic growth and carbon emission has become a popular research subject. Many researchers are exploring how to reach balance between economic growth and carbon emission, and realize sustainable low-carbon growth of economy. Therefore, investigation of the influence of the economic growth of Yangtze River Economic Belt on its carbon emission has realistic significance for China to realize energy conservation, emission reduction and low-carbon development, and fulfill its commitment to Paris Agreement as soon as possible.

2. Literature review

Economic activities are accompanied by a large amount of energy consumption, and the energy consumption will produce unexpected output—an enormous increase in carbon dioxide emissions, so the economic growth is interrelated with carbon emissions. Current researches about the influence of economic growth on carbon emissions mainly focus on two aspects. Firstly, some researchers tried to verify the Environmental Kuznets Curve (EKC) between carbon emissions and economic growth. Hu et al. (2013a) [3] used different methods to verify the EKCs for different types of data. When they used non-parametric model to study the time-series data of China during 1970-2008, they found that the EKC did not exist during this period, and there was a positive linear relationship between economic growth and carbon emissions. Ren and Du (2017) [4] verified the EKC of carbon emissions in Beijing-Tianjin-Hebei Region, the results show that the EKC did not exist in Beijing-Tianjin-Hebei, and the curve was of N shape. Fang et al. (2019) [5] calculated the carbon emissions EKCs in East, Central and West China, respectively, and they found that all EKCs of the three regions presented the reversed N shape. However, some other studies showed that the EKC existed. Hu et al. (2013b) [6] employed the dynamic spatial panel data model to investigate the provincial panel data of 30 provinces in China from 2001 to 2010, and found there was an EKC between economic growth and carbon emissions. Korhan et al. (2019) [7] proved the existence of EKC of carbon emissions in Chinese agriculture. By introducing renewable energy, Yao et al. (2019) [8] verified the RKC of renewable energy and the EKC of carbon emissions utilizing the data of 17 developing and developed countries as well as 6 economic and geographic areas in the world, and discussed their relation. The results show the existence of both RKC and EKC, and for each country, the inflection point of RKC was at the left of the inflection point of corresponding EKC. The reason for different results may be because different researchers may use varied data scopes, and they may come up with different conclusions during verification of EKC as a result.

Secondly, researches on the decoupling effect between economic growth and carbon emissions have been conducted. In their research based on the extremely long time-series data of 12 European countries from 1861 to 2015, Jeyhun et al. (2019) found that economic growth and carbon emissions were relatively decoupled in the 8 countries of the United Kingdom, France, Belgium, Sweden, Finland, Germany, Italy and Norway, while it was not decoupled yet in the four countries of Austria, Denmark, the Netherlands and Switzerland [9]. With the regional industry as the research object, Liu et al. (2018) [10] analyzed the decoupling state between carbon emissions and economic growth in 8 regions in China based on different periods. According to their research, various regions presented weak decoupling during the “ninth five-year plan” period; with the fast growth of economy, all regions except for the northwest region demonstrated the expansion and connection during the “tenth five-year plan” period; while during the “twelfth five-year plan” period, due to the decline of energy intensity,
all regions except for the northwest region showed weak decoupling state once again. In addition to research on the national and regional decoupling state, many scholars also analyzed and studied the decoupling state between industrial economic growth and carbon emissions [2] (Ma et al., 2019), the decoupling state between economic growth and carbon emissions on the provincial level [11] (Xu and Zhai, 2016) or the decoupling state between the economic growth of a certain industry and carbon emissions on provincial level [12-14] (Qu and Li, 2019; Li, 2019; Lang et al., 2019). Using methods such as the decomposition and regression methods, some other researchers have conducted comprehensive analysis of the relationship between various factors and the change in carbon emissions, and these factors include economic growth, population [15,16] (Fan, 2013; Zhao et al., 2016), urbanization [17,18] (Lin et al., 2017; Muhammad et al., 2017), industrial structure [19,20] (Wu and Yan, 2014; Tao et al., 2015) and foreign trade [21,22] (Shen and Yu, 2015; Liu et al., 2019).

Among the researches on the relationship between economic growth and carbon emissions in Yangtze River Economic Belt, Huang and He (2017) [23] found that the economic scale is the primary influencing factor on the growth of carbon emissions in Yangtze River Economic Belt by using the LMDI model; Tang et al. (2019) [24] employed the STIRPAT model, and according to their research, the per capita GDP is the factor with most significant influence on the increase of carbon emissions in Yangtze River Economic Belt; Huang et al. (2019) [25] studied the decoupling state between economic growth and carbon emissions in Yangtze River Economic Belt. The results of many types of research prove that economic growth is the main influencing factor on the increase of carbon emissions in Yangtze River Economic Belt, so in this paper, the panel data will be adopted to verify whether the Environmental Kuznets Curve (EKC) of carbon dioxide emissions exists in Yangtze River Economic Belt. Furthermore, among existing literatures, economic growth is mainly measured based on single indexes, such as per capita GDP, GDP, etc. In our paper, the extended STIRPAT model will be employed to comprehensively investigate the influence of economic growth on carbon emissions from the perspectives of per capita GDP and industrial structure, with the three factors promoting economic growth—investment, export and consumption—as the control variables.

3. Methodology and data

3.1. STIRPAT model

The STIRPAT model is a random model proposed by Dietz et al., which is based on the IPAT model put forward by Ehrlich et al. in 1972. Later, York et al. further improved this model and established the scalable random environmental influence evaluation model, which has achieved broad applications in evaluation of influencing factors on carbon emissions in recent years, and its basic expression is as follows:

\[ I = aP^bA^cT^d\epsilon \]  

(1)

where, I represents the impact on the environment, P represents the population, A stands for affluence, T refers to technology, a is the constant term, b, c and d are the coefficients of P, A and T, respectively, and \( \epsilon \) is the error term.

Conduct linear transformation to Formula (1), take logarithms on both sides of equation, and transform it to the following equation:

\[ \ln I_t = \alpha + \beta_1 \ln P_t + \beta_2 \ln A_t + \beta_3 \ln T_t + \epsilon \]  

(2)

where, \( t \) represents the year.

In order to further explore the influence of economic growth on carbon emissions, expand Variable A in Formula (2). Use the per capita GDP and industrial structure to represent the affluent degree, include investment, export and consumption which can promote economic growth into the model as control variables, and consider the comprehensive influence of various factors of economic development on carbon emissions. Based on the conclusions of existing literatures and researches, the population structure and foreign direct investment with direct influence on carbon emissions should also be included into the model. Therefore, Formula (2) can be expanded to:
\[ \ln C_t = \alpha + \beta_1 \ln P_t + \beta_2 \ln PS_t + \beta_3 \ln A_t + \beta_4 \ln IS_t + \beta_5 \ln IV_t + \beta_6 \ln OT_t + \beta_7 \ln CL_t + \beta_8 \ln FDI_t + \beta_9 \ln EI_t + \varepsilon \]  

where, \( C \) represents the volume of carbon emissions; \( P \) is the population scale, which is represented as the total population; \( PS \) is the population structure, which is represented as the proportion of the urban population in total population; \( A \) refers to the per capita GDP; \( IS \) is the industrial structure, and considering industry is the main area requiring power consumption, it is expressed by the ratio between the total output of secondary industry and GDP; \( IV \) is the investment scale, which is represented as the total fixed asset investment of society; \( OT \) is the export scale, which is expressed by the total export volume of operating unit; \( CL \) is the consumption level, which is indicated by the ratio between the total retail sales of consumer goods and GDP; \( FDI \) is foreign direct investment, which is represented by the total foreign direct investment; \( EI \) refers to the energy intensity, which reflects the technological level, and it is represented as the ratio between total energy consumption and GDP.

In order to verify the EKC of Yangtze River Economic Belt, the panel data of carbon emissions and per capita GDP are used for regression of equation:

\[ C_{it} = a_i + b_1 A_{it} + b_2 A_{it}^2 + b_3 A_{it}^3 + u_{it} \]  

where, \( C_{it} \) represents the carbon emissions of the \( i \)th province in the \( t \)th year; \( A_{it} \) is the GDP of the \( i \)th province in the \( t \)th year. According to Formula (4), it can be determined that the following several curve relations may exist between carbon emissions and economic growth:

1. If \( b_1 \neq 0 \), and \( b_2 = b_3 = 0 \), there is a linear relation between carbon emissions and economic growth.
2. If \( b_1 < 0, b_2 > 0 \), and \( b_3 = 0 \), the relationship between carbon emissions and economic growth presents the U-shape curve; on the contrary, if \( b_1 > 0, b_2 < 0 \), and \( b_3 = 0 \), then the relationship between carbon emissions and economic growth presents the reversed U-shape curve.
3. If \( b_1 > 0, b_2 < 0 \), and \( b_3 > 0 \), the relationship between carbon emissions and economic growth presents the N-shape curve; on the other hand, if \( b_1 < 0, b_2 > 0 \), and \( b_3 < 0 \), the relationship between carbon emissions and economic growth presents the reversed N-shape curve.

### 3.2. Data sources

At present, there is no direct statistical data of carbon emissions. By referring to IPCC2006 Guidelines for National Greenhouse Gas Inventories, we select 8 fossil fuels from China Energy Statistical Yearbook: coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil and natural gas. The estimated carbon dioxide emissions generated by energy consumption is used as the provincial carbon dioxide emissions, and the calculation formula is as follows:

\[ C = \sum E_j \times CF_j \times CC_j \times COF_j \times 44/12 \]  

where, \( C \) is the total carbon emissions (TC), \( j=1,2,\ldots,8 \) represents 8 types of fossil energy resources, \( E_j \) stands for the consumption of the \( j \)th energy source (T), \( CF_j \) represents the average lower heating value of the \( j \)th energy source (TJ/T), \( CC_j \) is the carbon content of the \( j \)th energy source (TC/TJ), \( COF_j \) refers to the carbon oxidation factor of the \( j \)th energy source; 44/12 represents the molecular weight ratio of carbon dioxide and carbon. The average lower heating value, carbon content and carbon oxidation factor data of various energy resources are all from Preparation Guidelines for Provincial Greenhouse List (FGBQH No.[2011]1041).

The rest variable data are obtained from the 2001-2018 China Statistical Yearbooks, China Energy Statistical Yearbook and the statistical year books of various provinces and cities.

Figure 1 shows the trends of per capita carbon emissions and carbon emissions intensity of Yangtze River Economic Belt during the period of 2000-2017. According to Figure 1, the carbon emissions of Yangtze River Economic Belt from 2000 to 2017 can be generally divided into three periods: in the period of 2000-2007, the per capita carbon emissions experienced fast growth from 2.6 tons per capita to 5.2 tons per capita, with annual growth of 10%, which doubled in 8 years; from 2007 to 2008, the growth slowed down a little, then the period of 2008-2011 is the second period with fast growth in
carbon emissions, but the increase speed was lower than the previous one, and the per capita carbon emissions increased from 5.2 tons per capita to 6.6 tons per capita, with annual growth of 5%; 2011-2017 is the third period, the per capita carbon emissions had gentle change during this period, which even experienced slight decline in 2014 and 2015 and bounced later, but it was basically consistent in general. The carbon emissions intensity refers to the carbon emissions for each RMB 10,000 yuan of GDP, which can reflect the technological progress and the implementation results of comprehensive energy conservation and emissions reduction measures to a certain extent. From Figure 1, it can be seen that the carbon emissions intensity presented continuous decline from 2000 to 2017, from 3.6 tons/10,000 yuan to 1.1 tons/10,000 yuan, with annual decline of 6.5%.

Figure 1. Per capita carbon emissions and carbon emissions intensity of Yangtze River Economic Belt from 2000 to 2017.

Figure 2a shows the broken line graph of the per capita carbon emissions in the 9 provinces and 2 cities of Yangtze River Economic Belt in 2000-2017. It can be seen that during the period from 2000 to 2017, the per capita carbon emissions of Shanghai was within the range of 10 tons per capita to 12 tons per capita, which was the highest among all provinces and cities of Yangtze River Economic Belt. From 2000 to 2017, the per capita carbon emissions of Jiangsu Province was generally at the rise stage, in which, the rise speed was very fast from 2000 to 2005 and slowed down in 2006-2009, but the speed increased sharply during 2009-2011, while once again slowed down in 2012, and it showed decline for the first time in 2017. For the rest provinces and cities, the change trend of per capita carbon emissions was basically consistent with overall trend of Yangtze River Economic Belt: with fast growth at first, reached peak in 2011 or 2012, and then presented gentle change or significant decline (Yunnan). In terms of absolute value, the per capita carbon emissions of Shanghai, Jiangsu, Zhejiang and Guizhou was higher than the average level of Yangtze River Economic Belt, the level of Hubei Province was close to the average level, and the per capita carbon emissions of the rest provinces and cities was lower than the average level.

Figure 2b presents the broken line graph of the carbon emissions intensity in the 9 provinces and 2 cities of Yangtze River Economic Belt in 2000-2017. According to Figure 2b, the carbon emissions intensity in all provinces and cities of Yangtze River Economic Belt presented the decline trend. From the perspective of absolute value, the carbon emissions intensity of Guizhou Province was the highest, while that of Zhejiang Province was the lowest. The carbon emissions intensity of the five provinces of Guizhou, Yunnan, Anhui, Hubei and Sichuan was higher than the average level of Yangtze River Economic Belt, and that of the rest provinces and cities was lower than the average level.

By combining Figure 2a and Figure 2b, it can be seen that Shanghai, Zhejiang and Jiangsu have relatively developed economy, they had low carbon emissions intensity, but their per capital carbon emissions was high; Jiangxi, Sichuan, Hunan, Yunnan and Chongqing have underdeveloped economy, their carbon emissions intensity was high, but their per capital carbon emissions was low; both the per
capital carbon emissions and carbon emissions intensity of Guizhou Province were higher than the average levels.

Figure 2a. Broken line graph of the per capita carbon emissions in the 9 provinces and 2 cities of Yangtze River Economic Belt in 2000-2017.

Figure 2b. Broken line graph of the carbon emissions intensity in the 9 provinces and 2 cities of Yangtze River Economic Belt in 2000-2017.
4. Regression analysis and discussion

4.1. Correlation analysis
Stata15 is used to conduct related analysis of all variables, and related coefficient matrices are listed in Table 1. According to Table 1, it can be seen the correlation coefficients between all indices are higher than 0, and the correlation coefficients between many variables are significantly correlated under the level of 1%. Further, during regression of OLS based on Formula (3), it is found that the R² value is as high as 0.9989. However, except for the per capita GDP and energy intensity, the estimated values of the coefficients of other explanatory variables are all insignificant, which indicates the existence of multicollinearity between variables.

| Variable | lnc | ln1p | lnps | lna | lnis | lniv | lnot | lncs | lnfdi | lnei |
|----------|-----|------|------|-----|------|------|------|------|-------|------|
| lnc      | 1.000 |      |      |     |      |      |      |      |       |      |
| ln1p     | 0.898 | 1.000 |      |     |      |      |      |      |       |      |
| lnps     | 0.975 | 0.962 | 1.000 |     |      |      |      |      |       |      |
| lna      | 0.966 | 0.974 | 0.996 | 1.000 |      |      |      |      |       |      |
| lnis     | -0.149 | -0.508 | -0.347 | -0.355 | 1.000 |      |      |      |       |      |
| lniv     | 0.963 | 0.979 | 0.995 | 0.999 | -0.370 | 1.000 |      |      |       |      |
| lnot     | 0.996 | 0.902 | 0.974 | 0.966 | -0.165 | 0.962 | 1.000 |      |       |      |
| lncs     | 0.946 | 0.982 | 0.991 | 0.997 | -0.411 | 0.997 | 0.946 | 1.000 |       |      |
| lnfdi    | 0.974 | 0.970 | 0.996 | 0.992 | -0.357 | 0.993 | 0.976 | 0.986 | 1.000 |      |
| lnei     | -0.881 | -0.984 | -0.957 | -0.973 | 0.516 | -0.973 | -0.882 | -0.986 | -0.950 | 1.000 |

4.2. Regression analysis
There are three methods commonly used to address multicollinearity, which are ridge regression, partial least squares and PCA (principal component analysis), respectively. In ridge regression, the selection of ridge parameters involves certain subjectivity, which can cause problem. The partial least squares method is applicable to the situation with multiple dependent variables and multiple independent variables. The PCA method employs the linear combinations of multiple variables to form several principal components mutually independent from each other, and then conducts linear regression of principal components to eliminate the influence of multicollinearity. By referring to the work of Yang et al. (2018)[26], the PCA method is used in this paper to eliminate multicollinearity. In this method, standardized processing of independent variables is conducted first, and then principal component analysis is made. The results are as shown in Table 2.

| Component | Eigenvalue | Difference | Proportion | Cumulative |
|-----------|------------|------------|------------|------------|
| Comp1     | 7.94614    | 6.97574    | 0.8829     | 0.8829     |
| Comp2     | .970399    | .913661    | 0.1078     | 0.9907     |
| Comp3     | .0567384   | .0365665   | 0.0063     | 0.9970     |
| Comp4     | .0201719   | .0158572   | 0.0022     | 0.9993     |
| Comp5     | .00431465  | .00300561  | 0.0005     | 0.9998     |
| Comp6     | .00130904  | .000653198 | 0.0001     | 0.9999     |
| Comp7     | .000655839 | .000427883 | 0.0001     | 1.0000     |
| Comp8     | .000227956 | .000185826 | 0.0000     | 1.0000     |
According to Table 2, principal component 1 and principal component 2 contain 99.07% information of the original independent variables, so the first two principal components are chosen to represent the information of original independent variables.

Table 3. Principal components (eigenvectors).

| Variable | Comp1 | Comp2 | Unexplained |
|----------|-------|-------|-------------|
| zlnp     | 0.3494| -0.1031| 0.01619     |
| zlnps    | 0.3515| 0.0957 | 0.006026    |
| zlna     | 0.3527| 0.0817 | 0.001387    |
| zlnis    | -0.152| 0.929  | 0.005635    |
| zlniv    | 0.3531| 0.0657 | 0.001339    |
| zlnot    | 0.3364| 0.2901 | 0.008677    |
| zlnncs   | 0.3534| 0.0159 | 0.003759    |
| zlnfdi   | 0.3513| 0.0856 | 0.002345    |
| zlnsei   | -0.3475| 0.1199 | 0.02345     |

According to Table 3, we can obtain:

\[ \text{Fac1} = 0.3494zlnp + 0.3515zlnps + 0.3527zlna - 0.152zlnis + 0.3364zlnot + 0.3531zlnncs + 0.3513zlnfdi - 0.3475zlnsei \] (6)

\[ \text{Fac2} = -0.1031zlnp + 0.0957zlnps + 0.0817zlna + 0.9290zlnis + 0.0657zlniv + 0.2901zlnot + 0.0159zlnncs + 0.0856zlnfdi + 0.1199zlnsei \] (7)

Conduct fitted regression of the two principal components Fac1 and Fac2 and the standardized dependent variable using the ordinary least squares, and the results are listed in Table 4.

Table 4. Regression results of the principal components.

| Source    | SS      | df | MS      | Number of obs | Number of obs | F(2,16) | Prob> F | R-squared | Adj R-squared | Root MSE |
|-----------|---------|----|---------|---------------|---------------|---------|---------|-----------|---------------|----------|
| Model     | 16.770461| 2  | 8.38523052| 18            | 18            | 584.49  | 0.000   | 0.9865    | 0.9848        | 0.11978  |
| Residual  | .229539273| 16 | .014346205|               |               |         |         |           |               |          |
| Total     | 17.0000003| 18 | .944444462|               |               |         |         |           |               |          |

| Variable | Coef.         | Std. Err. | t   | P>|t| | [95% Conf. Interval] |
|----------|---------------|-----------|-----|------|---------------------|
| Fac1     | .3356774      | .0102854  | 32.64| 0.000| [.3138733 .3574814] |
| Fac2     | .3055803      | .0299887  | 10.19| 0.000| [.2420071 .3691534] |

According to Table 4, the value of R-squared is 0.9865 and the adjusted R-squared is 0.9848 which mean high fitting degree of the function; the F value is 584.49 (P=0.000); the t values of regression coefficients have all passed the test. This indicates that the aggregate variables Fac1 and Fac2 can well explain the dependent variables, and the model has good degree of fitting. The regression model can be represented as:

\[ zlnce = 0.3357\text{Fac1} + 0.3056\text{Fac2} \] (8)

By substituting Formula (6) and Formula (7) into Formula (8), we can obtain:

\[ zlnce = 0.0858zlnp + 0.1472zlnps + 0.1434zlna + 0.2329zlnis + 0.1386zlniv + 0.2016zlnot + 0.1235zlnncs + 0.1441zlnfdi + 0.08zlnsei \] (9)

Yangtze River Economic Belt can be divided into the three parts of east, central and west parts. The east part includes Shanghai, Jiangsu and Zhejiang; the central part covers Anhui, Jiangxi, Hubei and
Hunan; the east part includes Chongqing, Sichuan, Yunnan and Guizhou. Employ the above method to conduct regression of the three parts, and the results are as follows:

The regression result of east part is:
\[
\text{zlnc}=0.1743\text{zlnp}+0.1591\text{zlnps}+0.1554\text{zlna}+0.1078\text{zlnis}+0.2403\text{zlnot}+0.0967\text{zlncs}+0.1783\text{zlnfdi}-0.0792\text{zlnei}
\] (10)

The regression result of central part is:
\[
\text{zlnc}=0.0842\text{zlnp}+0.1164\text{zlnps}+0.1209\text{zlna}+0.1253\text{zlnis}+0.1208\text{zlnot}+0.1187\text{zlncs}+0.1098\text{zlnfdi}-0.1158\text{zlnei}
\] (11)

The regression result of west part is:
\[
\text{zlnc}=-0.0548\text{zlnp}+0.1172\text{zlnps}+0.1290\text{zlna}+0.2237\text{zlnis}+0.1438\text{zlnot}+0.1203\text{zlncs}+0.1276\text{zlnfdi}-0.0997\text{zlnei}
\] (12)

Based on the unit root test of Formula (4), the carbon emissions, the per capita GDP, and the first-order series of the quadratic term and cubic term of per capita GDP are stable. The random effects model is selected based on the Hausman test. The regression results of various parts in Yangtze River Economic Belt are as follows:

| Table 5. Regression results of carbon emissions and economic growth. |
|---------------------------------------------------------------|
|                  | _cons | lna  | lna^2  | lna^3  | R^2     |
| Yangtze River Economic Belt | 1.337  | 1.308*** | -0.043*** | 0.8726  |
|                     | -13.344 | 5.815* | -0.502  | 0.015  | 0.8739  |
| East part of       | -19.064*** | 5.029*** | -0.212*** | 0.9813  |
| Yangtze River      | -14.584 | 3.751  | -0.090  | -0.004 | 0.9813  |
| Economic Belt      |        |        |         |        |         |
| Central part of    | -13.461*** | 4.368*** | -0.200*** | 0.9662  |
| Yangtze River      | -75.497 | 23.751 | -2.214  | 0.070  | 0.9587  |
| Economic Belt      |        |        |         |        |         |
| West part of       | -6.406*** | 3.012*** | -0.136*** | 0.8656  |
| Yangtze River      | 169.119*** | -53.143*** | 5.833*** | -0.211*** | 0.7689  |
| Economic Belt      |        |        |         |        |         |

Note: *, ** and *** represent significant correlation at the levels of 10%, 5% and 1%, respectively.

4.3. Analysis of regression results

According to the regression results, the population factor can promote the increase of carbon emissions in Yangtze River Economic Belt, which is represented by the positive coefficients of both population scale and population structure. Horizontally, the population scale has the biggest effect on the increase of carbon emissions in the east part of Yangtze River Economic Belt, followed by the central part, but it has negative influence on the carbon emissions in the west part. The population structure has the most significant influence on the east part of Yangtze River Economic Belt, followed by the west part. For every 1% increase of urban population ratio, the carbon emissions of east part, west part and central part increase by 0.1591%, 0.1172% and 0.1164%, respectively. The east part of
Yangtze River Economic Belt has developed economy, which has attracted many residents to settle here, and it also has high urbanization rate of population. As a result, the carbon emissions increased due to the number of residents is higher than the emissions reduction caused by intensive development mode, so the population factor will promote the increase of carbon emissions in the east part. The west part of Yangtze River Economic Belt is economically backward, which has suffered from population loss. During the observation period, the overall population of this part experience year-on-year decline for 6 years, so the population scale has negative influence on carbon emissions.

Economic growth is the primary factor that promotes the increase of carbon emissions, and the influence of per capita GDP on carbon emissions is significantly positive in various parts of Yangtze River Economic Belt. According to Table 5, in the east and central parts of Yangtze River Economic Belt, the regression coefficients of the linear term and quadratic term of the per capita GDP and the carbon emissions are significant with great goodness of fit; after adding the cubic term, the regression is not significant, but it satisfies $b_1 > 0, b_2 < 0,$ and $b_3 = 0$. This indicates that the relationship between the economic growth and carbon emissions presents the reversed U-shape curve in the east and central parts of Yangtze River Economic Belt, the positive effect of economic growth on carbon emissions will not exist all the time, and after the economy has developed a certain level, the carbon emissions will decline with the economic growth. For the west part of Yangtze River Economic Belt, the regressions of the linear term, quadratic term and cubic term of the per capita GDP are all significant, and $b_1 < 0, b_2 > 0, b_3 < 0$, which indicates that the relationship between the economic growth and carbon emissions presents the reversed N-shape curve in the west part of Yangtze River Economic Belt. The industrial structure is the main factor that causes increase of carbon emissions in various parts of Yangtze River Economic Belt. In this paper, the industrial structure is represented by the ratio between the output of secondary industry and GDP, because the secondary industry is the main consumer of energy. According to researches, in Yangtze River Economic Belt, the carbon emissions from secondary industry is significantly higher than that generated by other industries [27](Cao and Zeng, 2019), so the secondary industry is the main reason that affects carbon emissions, which has an elasticity coefficient of 0.2329%. The influence of industrial structure in the west part is higher than that in the central and east parts, and the elasticity coefficients of the west, central and east parts of Yangtze River Economic Belt are 0.2237%, 0.1253% and 0.1038%, respectively. This is mainly because the west part experienced fast economic growth during the sample period, the increase of per capita GDP was more than 10%, which was higher than that of the central and east parts, and the continuous fast economic growth and extensive growth form resulted in significant increase of carbon dioxide emissions.

The control variables of investment scale, export scale and consumption level all have positive effect on the increase of carbon emissions in various parts of Yangtze River Economic Belt. Among them, the export scale has the biggest positive effect, and for every 1% growth in export scale, the carbon emissions of Yangtze River Economic Belt increases by 0.2016%. The export processing zones in Yangtze River Economic Belt mainly consist of companies of labor-intensive industry, while the technology-intensive industry only exists in the coastal area in the east part of Yangtze River Economic Belt, but it mainly involvs the electronic information industry, with less high-tech industry. At present, the export commodities have high homogeneity, which are mainly from the labor-intensive industry, with low added value and high energy consumption, and there are less high-tech products. The increase of export commodities will promote the growth of carbon emissions within the area. The influence of investment scale in the east part is bigger than that in the central and west parts, and the elasticity coefficients of the east, central and west parts of Yangtze River Economic Belt are 0.2403%, 0.1208% and 0.1438%, respectively. This is mainly because the Yangtze River Delta Integration program has promoted the infrastructure construction in the east part, the fast development of urbanization has promoted real estate development, and massive carbon dioxide has been generated during the investment and construction of fixed assets. The influence of consumption level in the east part is smaller than that in the central and west parts. This could be because the public awareness of low carbon is enhanced with the economic growth, and the consumers prefer low-carbon green.
products. However, with the development of new retail mode, the carbon emissions caused by the waste from take-out food and express packages has increased remarkably, so generally speaking, the consumption level is still one of the main factors that cause increase of carbon emissions.

From the perspective of technological level, FDI can promote the increase of carbon emissions, while energy intensity can inhibit the growth of carbon emissions. FDI can bring in advanced technology and advanced productivity, which can reduce the carbon emissions. However, if attention has not been paid to the quality of program during introduction of foreign businesses and investment, the area that has obtained FDI could become the “pollution haven”, thus promoting the increase of carbon emissions\[28\] (Ran and Ren, 2019). The energy intensity represents the energy consumption of unit GDP, and its value reflects the comprehensive effects related to technological level, such as the upgrade of industrial structure, the development of emerging industry and the development of new energy. The development of emissions reduction technology can effectively reduce the demand for fossil energy source, so as to effectively inhibit the increase of carbon emissions. Among various areas, FDI has the biggest influence on the east part of Yangtze River Economic Area, and its elasticity coefficient is 0.1783%. The Yangtze River Delta Area has outstanding geographic position and prosperous economy, with great conditions to introduce foreign businesses and investment, and it has attracted massive investment. However, in addition to bringing in advanced technology, foreign investment has also caused increase of carbon emissions due to energy consumption in production. Energy intensity has the biggest influence on the central part of Yangtze River Economic Area, and its elasticity coefficient is -0.1158%. The east part has high technological level, and there is limited space for energy intensity to decline; the central part is experiencing fast technological progress, and the energy consumption per unit output shows fast decline; the west part does not present significant technological advancement, and the energy consumption per unit output is still at a high level.

In general, except for energy intensity which has inhibition effect on carbon emissions, the population scale, population structure, per capita GDP, industrial structure, fixed investment, export scale, consumption capacity and FDI all promote carbon emissions.

5. Conclusions and suggestions

5.1. Conclusions
In this paper, we analyze the change in carbon emissions of Yangtze River Economic Belt from 2000 to 2017 from the three aspects of population, economy and energy intensity, focus on discussion of the relationship between economic growth and change in carbon emissions, and draw the following conclusions:

Firstly, the population scale promotes the increase of carbon emissions in the central and east parts of Yangtze River Economic Belt, while inhibits its growth in the west part; the population structure promotes the increase of carbon emissions in Yangtze River Economic Belt, with the biggest influence on the east part.

Secondly, economic growth is the primary factor that affects the increase of carbon emissions in Yangtze River Economic Belt. In the central and east parts of Yangtze River Economic Belt, the relationship between carbon emissions and per capita GDP presents the reversed U-shape curve; in the west part, the relationship between carbon emissions and per capita GDP presents the reversed N-shape curve. The industrial structure has significant impact on carbon emissions, and for every 1% decline of the proportion of the output of second industry in gross output, the carbon emissions of Yangtze River Economic Belt decreases by 0.2329%; the influence of industrial structure in the west part is more significant than that in the central and east parts.

Thirdly, among the three control variables which can promote economic growth, the export scale has the strongest effect in promoting the increase of carbon emissions in Yangtze River Economic Belt, the investment scale has the most significant influence in the east part of Yangtze River Economic Belt, and the consumption level has bigger impact in the central and west parts of Yangtze River Economic Belt.
Finally, FDI can promote the increase of carbon emissions in Yangtze River Economic Belt, its influence in the east part is bigger than that in the central and west parts; the energy intensity can effectively inhibit the growth of carbon emissions, and its impact in the central and west parts is more significant than that in the east part.

5.2. Suggestions
Based on the above conclusion, in order to reach the peak in carbon emissions by 2030, we propose the following countermeasures and suggestions to promote the green and low-carbon development of Yangtze River Economic Belt:

(1) Intensify the promotion of low-carbon concept, and improve the public awareness of low-carbon development. Urbanization development is a trend of current economic development. In addition to improving the urbanization rate of population, efforts should also be made to promote the low-carbon concept, improve the public awareness of low-carbon growth, achieve overall low-carbon lifestyle, fully carry out the intensive effects of urbanization, optimize resource allocation and realize low-carbon lifestyle in cities.

(2) Accelerate the transformation and upgrade of industrial structure, and optimize the export structure. Based on the optimization of industrial structure, increase the proportions of tertiary industry and high-tech industry, eliminate the industry with backward production capacities and high energy consumption, and effectively reduce carbon emissions. Export is the main power to promote economic growth, and measures should be taken to optimize the export structure, transform the labor-intensive industry to technology-intensive industry, increase the added value of product, and reduce the energy consumption and carbon emissions.

(3) Increase the technological level, and improve the quality of foreign investment projects. Strive to develop the energy conservation and emissions reduction technology, enhance the development of clean energy, drive the new energy industry, promote the healthy development of ecological chain, reduce energy consumption and realize emissions reduction. In the meantime, efforts should also be made to increase the quality of FDI program, and introduce environmentally friendly projects with low power consumption, high productivity and clean technology.

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