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# CARBON REDUCTION STRATEGIES FOR THE EXPLOSIVE TAKEOFF STAGE OF URBANIZATION IN CHINA

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**Abstract**

Focusing on 199 Chinese cities at or above prefectural level, this paper mainly explores the interaction mechanism between urbanization and carbon emissions in China from 2003 to 2016, and evaluates the benefit and cost of different carbon reduction measures. Specifically, an econometric model was established based on simultaneous equations, and estimated by the generalized method of moments (GMM). The results show that: every 1% increase in the urban percentage of population boosts the gross domestic product (GDP) by 0.332%, while elevating the carbon intensity by 0.175%; the key to resolve the contradiction between urbanization and carbon reduction lies in effective control of the economic cost of carbon reduction; the measures like promoting tertiary industry and reducing the proportion of secondary industry should be adopted cautiously; the carbon reduction cost will surge up, if the proportion of secondary industry reduces or that of clean energy rises too fast; in the future, the carbon reduction strategies should focus on the low-carbon development and the transform of economic growth mode.

*Keywords:* carbon emissions, carbon reduction, simultaneous equations, urbanization

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## 1. Introduction

Currently, more and more people are moving to large cities and adapting to the urban lifestyle. This trend of urbanization is a mixed blessing. On the one hand, the economy will pick up speed and output more values (Ahmed et al., 2017). On the other hand, the energy consumption will face a substantial growth, pushing up the total carbon emissions (Alam et al., 2016; Dietrich and Chen, 2018; Peng et al., 2018). Taking China for instance, urbanization has exerted an increasing impact on economic growth and carbon emissions. Since the 1990s, domestic and foreign scholars have paid much attention to how urbanization affects carbon emissions and economic growth, how to reduce carbon emissions in urbanization, how carbon emissions influence economic growth, and how to evaluate the economic cost of carbon reduction (Al-Mulali et al., 2015). Concerning the impact of urbanization on carbon emissions, Sun et al. (2013) analyzed the historical data of many countries, and summed up how carbon emissions are affected in different stages of urbanization: carbon emissions are both driven and curbs by urbanization; in the middle stage, urbanization mainly exhibits the driving effect, causing a rapid growth in carbon emissions. Similar conclusions were drawn by Poumanyvong and Kaneko (2010), Sadorsky (2014), suggesting that the rising carbon emissions in China is a significant long-lasting effect of urbanization.

Regarding the impact of urbanization on economic growth, Berry and Glaeser (2005) examined the situation in 95 economies, and found the significant positive correlation between urbanization and economic growth. Zhou (1982) compared the development data of 157 countries and regions,

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revealing the close correlation between urban percentage of population and per capita gross domestic product (GDP) in most countries and regions.

Relating to the carbon reduction strategy in urbanization, Parikh and Shukla (1995), Lin and Liu (2010) held that, for developing countries, the key to reducing carbon emissions in urbanization lies in controlling the growth in energy consumption; these countries should regulate the urbanization speed, and pursue low-carbon development in urbanization.

In relation to the impact of carbon reduction (i.e. controlling the pollution of bio-environment) on economic growth, Stokey (1998) pointed out that pollution control will suppress economic growth in the long run, if intellectual capital accumulates slower than tangible capital. Wu et al. (2013) investigated the carbon emissions of fossil energy consumption and economic growth in China, drawing the following conclusions: carbon reduction has a negative impact on economic growth; the rising carbon emissions are not mainly induced by economic growth.

With reference to the economic cost of carbon reduction, Zheng et al. (2012) assessed the cost and benefit of carbon reduction under different scenarios in China from 2005 to 2050, using the regional integrated climate-economy model (RICE). The cost-benefit assessment shows that: the carbon reduction in China has a high cost and low benefit, and the cost-benefit ratio is negatively correlated with the intensity of carbon reduction. In this paper, the cost analysis of carbon reduction is taken as the basis for studying, formulating and implementing the carbon reduction strategy. During strategy formulation, the carbon reduction cost mainly refers to the long-term cost of carbon reduction in urbanization, rather than the cost of a specific sector or industry.

Overall, the above studies have several common defects: Concerning the impact of urbanization on carbon emission, most scholars focused on the direct impact of urbanization on carbon emissions, failing to tackle the influence from indirect channels like economic output, secondary industry, tertiary industry, energy intensity and environmental regulation(Azam et al., 2019); Concerning the impact of urbanization on economic growth in China under the constraint of carbon reduction, most scholars highlighted the direct driving effect of urbanization on economic growth, without considering the effects of indirect paths like carbon emissions, secondary industry, tertiary industry, energy intensity and environmental regulation(Sarkodie et al. 2020).

To make up for these defects, this paper establishes an econometric model based on simultaneous equations, selects the panel data of 2003-2016 from 199 Chinese cities, and compares and analyzes the effects and economic costs of different carbon reduction measures. On this basis, the author put forward several suggestions on the carbon reduction strategies for China in the current stage of urbanization.

## 2. Background

Urbanization is an inevitable outcome of the socioeconomic development of a country or region. In a certain sense, the urban population represents the development level of that country or region. Thanks to socioeconomic development, the urban percentage of population in China has grown from 10.6% in 1949 to 59.6% at the end of 2018. Fig. 1 presents the trends of urban population and urban percentage of population in China from 1949 to 2018. As shown in Figure 1, both urban population and urban percentage of population in China have been increasing since 1949. However, the urbanization process can be clearly divided into several stages, because socioeconomic policies, urbanization plans and demographic calibers differ from period to period. American urban geographer Northam (1975) and Lu (2012) studied the development laws of cities across the globe, and summarized the trajectory of urbanization as a flattened S curve (Fig. 2). Northam's trajectory of urbanization, reflecting the population flow, industrial structure, and economic level in each stage, has been widely accepted as the law of urbanization. According to Northam, the urbanization process can be divided into three stages: gradual growth (urban percentage of population <30%), explosive takeoff (urban percentage of population between 30% and 70%), and maturity (urban percentage of population >70%). In 1996, the urban percentage of population in China grew to 30.48%, marking the start of the explosive takeoff stage.

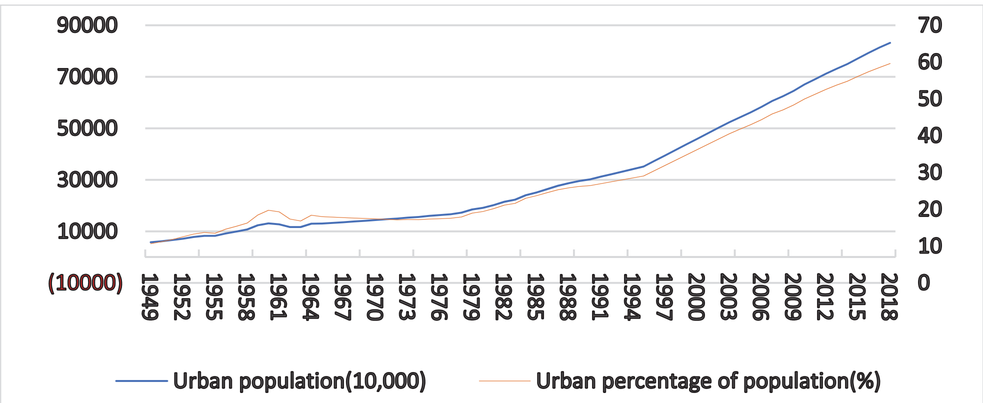


**Fig. 1.** The trends of urban population and urban percentage of population in China from 1949 to 2018

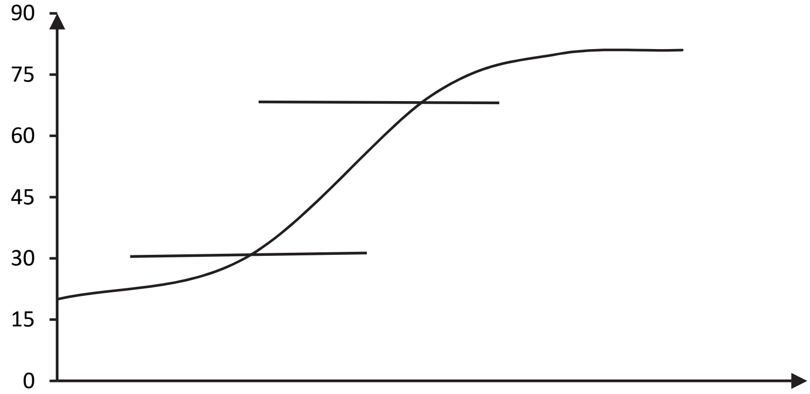


**Fig. 2.** Northam's trajectory of urbanization

Since then, China has saw a rapid growth in carbon emissions. Fig. 3 illustrates the trend of carbon emissions in China since 1996, according to the data of the World Bank (World Development Indicators; http://datatopics.worldbank.org/world-development-indicators/). As shown in Fig. 4, urbanization influences the total carbon emissions, and regulates growth rate and intensity of the emissions, from dimensions of scale, structure and technology. This paper holds that urbanization affects carbon emissions through channels like economic output, industrial structure, energy intensity and environmental regulation. According to Lin and Sun (2011), urbanization has an indirect promoting or suppressing effect on carbon emissions.

The rapid urbanization often induces a sharp increase in energy consumption and carbon emissions. If measures are taken to save energy and reduce emissions, the urbanization will slow down, and energy consumption will decline, which in turn drags down the economic output of urbanization. To sum up, there is an inherent interaction and feedback mechanism between urbanization and carbon emissions in China. The interactions between relevant factors, namely, urbanization, economic output, industrial structure (characterized by the proportions of secondary and tertiary industries), energy intensity, environmental regulation and carbon emissions, are illustrated in Fig. 5. Besides its direct impact, urbanization influences carbon emissions via indirect channels like economic output, industrial development, technical progress and environmental regulation. In return, carbon emissions directly affect urbanization by acting on economic growth and creating various negative externalities. Meanwhile, carbon emissions also have indirect impacts on urbanization via the paths of industrial development, energy utilization and environmental regulation. Therefore, a complex research system should be set up before identifying the relationship between urbanization and carbon emissions.

Based on the above considerations, this paper attempts to develop a systematic analysis model based on simultaneous equations, and apply it to evaluate the effects of different carbon reduction measures for the explosive takeoff stage of urbanization.

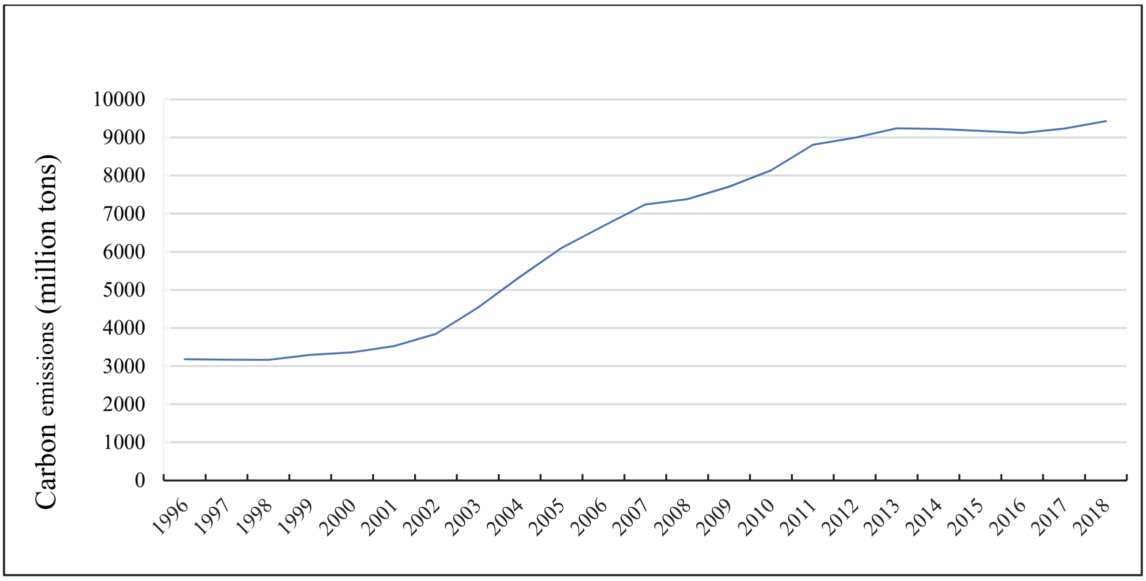


**Fig. 3.** The trend of carbon emissions in China from1996 to 2018

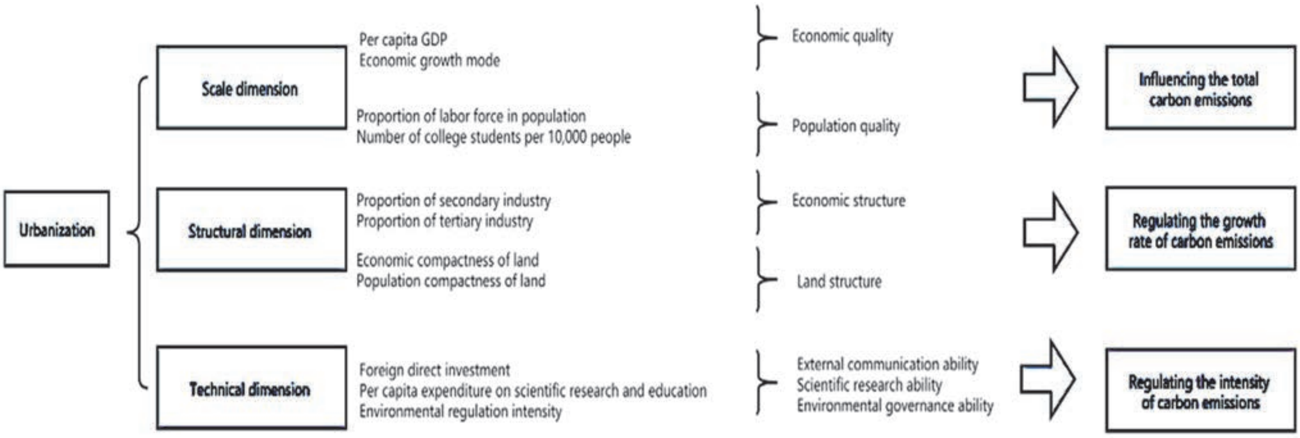


**Fig. 4.** The three dimensions that urbanization affects carbon emissions

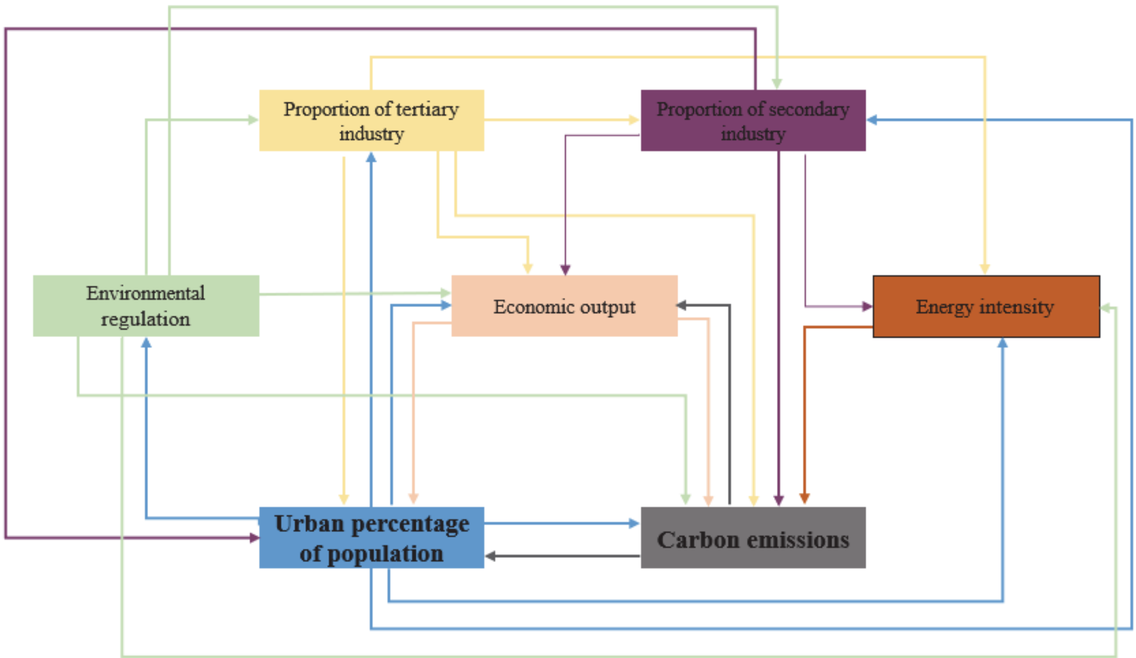


**Fig. 5.** Interactive mechanism between urbanization and carbon emissions

## 3. Methodology

### *3.1. Model construction*

As shown in Figure 5, there is an inherent interaction and feedback mechanism between urbanization, economic output, industrial structure, energy intensity, environmental regulation and carbon emissions. The internal correlations between these factors cannot be fully demonstrated by an econometric model based on a single equation. To clearly describe these influence channels, it is necessary to establish an econometric model based on simultaneous equations.

Therefore, this paper firstly constructs the functions of these factors, and then establishes an econometric model based on these functions. Firstly, the carbon emissions function was set up, referring to Grossman and Krueger's (1995) findings on carbon emissions and economic output Eq. (1):

$$\mathrm{TC} = \sum_{i=1}^{n} \mathrm{D}\frac{D_i}{D}\frac{TE_i}{D_i}\frac{TC_i}{EG_i} = F(D, S_1, S_2, S_3, PGE, PGEC) \quad (1)$$

where: i is the type of industry; $S_1$ is the proportion of the primary industry in GDP, which continues to decrease with socioeconomic development. Previous studies have shown that the primary industry accounts for less than 5% of the total energy consumption (Al-Mulali and Ozturk, 2015). Hence, the impact of the primary industry on carbon emissions is negligible. Then, the carbon emissions function can be rewritten as $\mathrm{TC} = F(D, S_2, S_3, PGE, PGEC)$. Since the urbanization in China belongs to the explosive takeoff stage, other factors affecting carbon emissions should also be considered, such as economic growth mode, energy intensity of fixed assets investment, and urban percentage of population. In the light of the above analysis and relevant literature, the carbon emissions function can be finalized as Eq. (2):

$$\mathrm{TC} = F(D, S_2, S_3, PGE, ER, DFK, LK, PGEC, CL) \quad (2)$$

Next, the economic output function was designed based on the corrected Stokey's model (Eq. 3):

$$D = K^a(HKL \times L \times TC)^{1-a} = K^a(HK \times TC)^{1-a} = G(TFK, TC) \quad (3)$$

where, HKL, L and TC are the mean knowledge of laborers, labor input and product cleanness, respectively; 0<a<1. The other factors that affect or contribute to economic output in urbanization were introduced to the function, including environmental regulation, industrial structure changes and energy intensity. Thus, the economic output function can be finalized as Eq. (4):

$$\mathrm{D} = \mathrm{G}(\mathrm{TFK}, \mathrm{LK}, \mathrm{TC}, S_2, S_3, \mathrm{PGE}, \mathrm{ER}, \mathrm{CL}) \quad (4)$$

Considering environmental regulation, the proportion of tertiary industry, economic growth mode and science and education level, the function of secondary industry structure was established, drawing on Wang Yao et al. (2017) (Eq. 5):

$$S_2 = H(S_3, ER, PUR, DFK, CL) \quad (5)$$

Considering human capital, environmental regulation, labor price, energy intensity of fixed assets investment and economic growth mode, the function of tertiary industry was built based on Wu et al. (2011) (Eq. 6):

$$S_3 = J(LK, ER, LP, DFK, PFKE, CL) \quad (6)$$

Considering external exchange ability, economic growth mode, energy intensity of fixed assets investment, industrial structure, environmental regulation, human capital, labor productivity and fixed assets investment, the technical progress function was formulated based on Feng et al. (2008) and Chen et al. (2015) (Eq. 7):

$$\mathrm{PGE} = \mathrm{K}(\mathrm{FDI}, \mathrm{PFKE}, \mathrm{DFK}, S_2, S_3, \mathrm{ER}, \mathrm{LK}, \mathrm{QL}, \mathrm{TFK}, \mathrm{CL}) \quad (7)$$

Considering per capital income, labor quality, science and education level, energy consumption and carbon intensity of energy use, the environmental regulation function was developed based on Li and Li (2015) and Gao et al. (2016) (Eq. 8):

$$\mathrm{ER} = \mathrm{Q}(\mathrm{FDI}, \mathrm{PD}, \mathrm{PE}, \mathrm{PGEC}, \mathrm{PUR}, \mathrm{TE}, \mathrm{CL}) \quad (8)$$

Considering economic growth mode, carbon intensity of energy use, energy intensity of fixed assets investment, science and education level, per capita income, labor price, industrial structure and external exchange ability, the urbanization function was derived based on Shen (2013) and, Wang and Gong (2014) (Eq. 9):

$$\mathrm{CL}=\mathrm{R}\ (\mathrm{DFK}, \mathrm{PGEC}, \mathrm{PFKE}, \mathrm{PUR}, \mathrm{PD}, \mathrm{LP}, \mathrm{ST}, \mathrm{FDI}) \quad (9)$$

The variables related to the above seven functions are explained in Table 1. PGEC represents the carbon intensity of overall energy consumption; Since the carbon emissions coefficient of fossil energy remains constant, the PGEC has a negative correlation with the proportion of clean energy consumption in total energy consumption, and thus reflects the energy structure.

**Table 1.** The variables making up the seven functions

| ***Variable*** | ***Name*** | ***Meaning*** |
|---|---|---|
| D | Economic output | Gross domestic product (GDP) |
| PD | Per capita income | Per capita GDP |
| QL | Labor productivity | Output per unit of labor (D/LK) |
| TC | Total carbon emissions | Product greenness |
| PUR | Science and education level | Per capita expenditure on scientific research and education |
| TE | Energy consumption | Total energy consumption |
| PE | Labor quality | The number of college students per 10,000 people |
| TFK | Total fixed assets | Fixed assets investment |
| FDI | External communication ability | Foreign direct investment |
| PGE | Energy intensity | Energy consumption per unit of GDP (TE/D), reflecting the level of energy-saving technology |
| PFKE | Energy intensity of fixed assets investment | Energy consumption per unit of fixed assets investment (TE/TFK) |
| S2 | Proportion of secondary industry | Proportion of secondary industry output to GDP |
| S3 | Proportion of tertiary industry | Proportion of tertiary industry output to GDP |
| CL | Urban percentage of population | Urban population / total population |
| LP | Labor price | Labor force / total population, which is negatively correlated with labor price |
| DFK | Economic growth mode | Fixed assets investment / GDP |
| LK | Human capital | Total labor force |
| ER | Environmental regulation intensity | Urban environmental governance investment per unit of built-up area |
| ST | Industrial structure | S2+ S3 |
| PC | Carbon intensity | Carbon emissions per unit of GDP (TC/D) |
| PGEC | Carbon intensity of energy use | Carbon emissions from energy consumption per unit of GDP (TE/D) |

Eqs. (5-9) provide the tool to measure the direct and indirect impacts of urbanization on carbon emissions, and evaluate the effect and socioeconomic cost of different carbon reduction measures. Inspired by Dinda (2004), Huo (2015), Xu and Wu (2016), an econometric model containing lagged variables was established based on simultaneous equations Eqs. (10-16):

$$\ln TC_{it} = \alpha_0 + \alpha_1 \ln D_{it} + \alpha_2 \ln S_{2it} + \alpha_3 \ln S_{3it} + \alpha_4 \ln PGE_{it} + \alpha_5 \ln ER_{it} + \alpha_6 \ln DFK_{it} + \alpha_7 \ln LK_{it} + \alpha_8 \ln CL_{it} + \alpha_9 \ln PGEC_{it} + \tau_{it} \quad (10)$$

$$\ln D_{it} = \beta_0 + \beta_1 \ln TFK_{it} + \beta_2 \ln LK_{it} + \beta_3 \ln TC_{it} + \beta_4 \ln S_{2it} + \beta_5 \ln S_{3it} + \beta_6 \ln PGE_{it} + \beta_7 \ln ER_{it} + \beta_8 \ln CL_{it} + \delta_{it} \quad (11)$$

$$\ln S_{2it} = \gamma_0 + \gamma_1 \ln S_{3it} + \gamma_2 \ln ER_{it-1} + \gamma_3 \ln PUR_{it-1} + \gamma_4 \ln PUR_{it-2} + \gamma_5 \ln DFK_{it-1} + \gamma_6 \ln CL_{it} + \xi_{it} \quad (12)$$

$$\ln S_{3it} = \varphi_0 + \varphi_1 \ln LK_{it} + \varphi_2 \ln ER_{it-1} + \varphi_3 \ln LP_{it-2} + \varphi_4 \ln DFK_{it-1} + \varphi_5 \ln PFKE_{it-1} + \varphi_6 \ln CL_{it} + \kappa_{it} \quad (13)$$

$$\ln PGE_{it} = \theta_0 + \theta_1 \ln FDI_{it} + \theta_2 \ln PFKE_{it} + \theta_3 \ln DFK_{it} + \theta_4 \ln S_{2it} + \theta_5 \ln S_{3it} + \theta_6 \ln ER_{it} + \theta_7 \ln LK_{it} + \theta_8 \ln QL_{it} + \theta_9 \ln TFK_{it} + \theta_{10} \ln CL_{it} + \eta_{it} \quad (14)$$

$$\ln ER_{it} = \lambda_0 + \lambda_1 \ln FDI_{it} + \lambda_2 \ln PD_{it} + \lambda_3 \left(\ln PD_{it}\right)^2 + \lambda_4 \ln PE_{it} + \lambda_5 \ln PGEC_{it-1} + \lambda_6 \ln PUR_{it-1} + \lambda_7 \ln TE_{it-2} + \lambda_8 \ln CL_{it} + \mu_{it} \quad (15)$$

$$\ln CL_{it} = \rho_0 + \rho_1 \ln DFK_{it} + \rho_2 \ln PGEC_{it} + \rho_3 \ln PFKE_{it-1} + \rho_4 \ln PUR_{it-1} + \rho_5 \ln PD_{it-1} + \rho_6 \ln LP_{it-1} + \rho_7 \ln LP_{it-2} + \rho_8 \ln ST_{it-2} + \rho_9 \ln FDI_{it-2} + \gamma_{it} \quad (16)$$

where: $i$ is the city number; t is year; $\tau_{it}$, $\delta_{it}$, $\xi_{it}$, $\kappa_{it}$, $\eta_{it}$, $\mu_{it}$, and $\gamma_{it}$ are the random error terms of carbon emissions function, economic output function, secondary industry structure function, tertiary industry structure function, technical progress function (measured by energy intensity), environmental regulation function and urbanization function, respectively; $\alpha_0$, $\beta_0$, $\gamma_0$, $\varphi_0$, $\theta_0$, $\lambda_0$ and $\rho_0$ are the constant terms of carbon emissions function, economic output function, secondary industry structure function, tertiary industry structure function, technical progress function (measured by energy intensity), environmental regulation function and urbanization function, respectively.

### *3.2. Analysis approach*

Before regression analysis, the variables in Eqs. (10-16) that are related to the panel data were subjected to unit root tests on stationarity, including the "common root" method of Levin–Lin–Chu (LLC) test (Levin et al., 2002), and the "individual root" methods of Fisher-augmented Dickey–Fuller test (ADF) and Fisher-Phillips–Perron (PP) test (Choi, 2001). The maximum lagged variable was selected by the Akaike information criterion (AIC). For the lack of space, the process of the unit root tests is not provided here. The test results show that the logarithmic form of the variables was stationary on the significance level of 5%, excluding the presence of unit root.

Then, the generalized method of moments (GMM) was adopted to estimate the econometric model based on simultaneous equations in a systematic manner (Arellano and Bond, 1991., Arellano and Bover, 1995., Blundell and Bond, 1998). There are many advantages of the GMM: heteroscedasticity and sequence correlation are allowed between random error terms; the exact distribution of the random perturbation terms is not required; the estimated parameters are close to actual results; the estimates are highly robust (Gao, 2009).

### *3.3. Data sources*

Since 2003, China has implemented the Scientific Outlook on Development, and attached great importance to the environmental issues arising in the course of development. More and more Chinese scholars have probed into carbon emissions and carbon reduction. Considering the research problem, policy background and data availability, this paper decides the measure the urbanization of Chinese cities based on the 2003-2016 data from 199 cities at or above prefectural level. These cities spread across the 30 provincial-level administrative regions (provinces) in China, except Taiwan, Hong Kong, Macau, and Tibet, mirroring the urbanization in different regions of China.

The data were extracted from the *China City Statistical Yearbooks*, *China Urban Construction Statistical Yearbooks*, and *China Energy Statistical Yearbooks* issued in 2003-2016. The missing data were filled up based on the statistical yearbooks and annual reports of relevant cities, or supplemented by interpolation. The collected data mainly cover the carbon emissions of each type of energy and the production and living activities in the 199 cities between 2003 and 2016. The data testing and model regression were both conducted on EViews 9.0. 199 cities can refer to the appendix

### *3.4. Calculation standard for carbon emissions in each city*

The international community has made painstaking efforts to establish a rational standard for urban carbon emissions. On December 8, 2014, the *International Standard for Determining Greenhouse Gas Emissions for Cities* was officially released in

Lima, Peru, at the 20th yearly session of the Conference of the Parties (COP) to the 1992 United Nations Framework Convention on Climate Change (UNFCCC). This *Standard* offers a unified tool for the calculation of greenhouse gas (GHG) emissions at the city level, and provides strong support to cities in the formulation of low-carbon policies. As of November 2015, more than 300 cities worldwide have adopted this *Standard*.

### *3.5. Calculation methods for carbon emissions in each city*

Referring to the *Standard*, this paper calculates the carbon emissions of the 199 cities from five aspects: energy consumption, transportation, waste treatment, industrial activities, and carbon sequestration capacity of urban green space.

*(1) Calculation of carbon emissions from energy consumption*

Currently, *China City Statistical Yearbooks*, the most authoritative data sources on Chinese cities, only record the consumption of three types of energies: electricity, fuel gas and liquefied petroleum gas (LPG). However, the energy structure in Chinese cities is much more diversified.

Here, the carbon emissions from energy consumption in each city is calculated, drawing on Li (2016) conversion method for urban energy consumption, which assumes that the proportions of the three types of energies are the same on the city level and the provincial level.

For each city, the conversion coefficient for energy consumption in the host province (i.e. the city-level conversion coefficient for energy consumption) in 2003-2016 was calculated based on provincial energy consumption (Eq. 17):

$$CEI_{it} = \frac{PE_{it} + PG_{it} + PL_{it}}{PEE_{it}} \tag{17}$$

where: t is the year; $CEI_{it}$ is the conversion coefficient for energy consumption of the i-th city; $PE_{it}$, $PG_{it}$, $PL_{it}$ and $PEE_{it}$ are the electricity consumption, fuel gas consumption, LPG consumption and total energy consumption of the i-th province, respectively.

Next, the total energy consumption of each city was computed based on the city-level conversion coefficient (Eq. 18):

$$CCE_{it} = \frac{CE_{it} + CG_{it} + CL_{it}}{CEI_{it}} \tag{18}$$

where, t is the year; $CE_{it}$, $CG_{it}$, $CL_{it}$ and $CCE_{it}$ are the electricity consumption, fuel gas consumption, LPG consumption and total energy consumption of the i-th city, respectively.

The data involved in formulas (17) and (18) were extracted from the *China Energy Statistical Yearbooks* and *China City Statistical Yearbooks* issued in 2003-2016. For convenience, the consumption of all types of energies was measured by kilograms of standard coal. The conversion factors were looked up in the appendix "Reference Standard Coal Conversion Coefficients of Various Types of Energies" of *China Energy Statistical Yearbooks*.

Referring to Chen (2009), the carbon emission coefficient was set to 2.7163kg per kg of standard coal. Hence, the carbon emissions from energy consumption in each city can be computed by Eq. (19):

$$TCE_{it} = CCE_{it} \times 2.7163 \tag{19}$$

*(2) Calculation of carbon emissions from transportation*

Urban transportation is a large emitter of carbon dioxide. In the *China Energy Statistical Yearbooks*, the provincial transportation land is considered a terminal of energy consumption. Therefore, the carbon emissions from transportation in each city were calculated based on urban land use (Eqs. 20-21):

$$CTE_{it} = \frac{PT_{it}}{PTL_{it}} \times CTL_{it} \tag{20}$$

$$TCT_{it} = CTE_{it} \times 2.7163 \tag{21}$$

where: t is the year; $CTE_{it}$ and $TCT_{it}$ are the energy consumption and carbon emissions of transportation in the i-th city, respectively; $PT_{it}$ and $PTL_{it}$ are the energy consumption and transportation land area of the host province of the i-th city, respectively; $CTL_{it}$ is the transportation land area of the i-th city.

The data involved in formulas (20) and (21) were extracted from the *China Energy Statistical Yearbooks* and *China Urban Construction Statistical Yearbooks* issued in 2003-2016. The measuring unit of energy consumption and carbon emission coefficient were the same as Subsection 3.5 (1).

*(3) Calculation of carbon emissions from waste treatment*

Referring to Zheng et al. (2016), the carbon emissions, mainly the carbon dioxide generated in waste incineration, from waste treatment in each city was calculated by Eq. (22):

$$WC_{it} = \sum_{it} (IW_{it} \times CCW_{it} \times FCF_{it} \times E_{it} \times 2.7163) \tag{22}$$

where: t is the year; $WC_{it}$ is the amount of carbon dioxide emitted by waste incineration; i is the type of waste (i.e. solid waste, domestic waste, and sludge); $IW_{it}$ is the incineration amount of type i waste (wt/y); $CCW_{it}$ is the carbon content of type i waste; $FCF_{it}$ is the content of carbon-containing mineral of type i waste; $E_{it}$ is the combustion efficiency of type i waste.

The emissions coefficients were set to the values recommended by provincial guides: $CCW_{it}$=20%, $FCF_{it}$=39% and $E_{it}$=95%. The carbon emission coefficient was the same as Subsection 3.5 (1).

*(4) Calculation of carbon emissions from industrial activities*

Similar to those from transportation, the carbon emissions from industrial activities were calculated based on urban land use and energy consumption of provincial industrial land. Considering the varied industrial levels among the cities, the industrial level coefficient, i.e. the urban industrial output / provincial industrial output, was introduced to the Eq. (23):

$$TCI_{it} = \frac{PI_{it}}{PIL_{it}} \times \frac{CI_{it}}{CIV_{it}} \times CIL_{it} \times 2.7163 \tag{23}$$

where: t is the year; $TCI_{it}$ is the carbon emissions from industrial activities in the i-th city; $PI_{it}$ is the energy consumption of industrial activities in the host province of the i-th city; $CIL_{it}$ and $PIL_{it}$ are the industrial land areas of the i-th city and in the host province of the i-th city, respectively; $CI_{it}$ and $CIV_{it}$ are the industrial outputs of the i-th city and the host province of the i-th city, respectively.

The data involved in formula (23) were extracted from the *China City Statistical Yearbooks*, *China Urban Construction Statistical Yearbooks*, and *China Energy Statistical Yearbooks* issued in 2003-2016. The measuring unit of energy consumption and carbon emission coefficient were the same as Subsection 3.5 (1).

*(5) Carbon sequestration capacity of urban green space*

According to Yang (2003), the carbon sequestration of urban green space was computed by Eq. (24):

$$GC_{it} = GA_{it} \times l \times m \times 12 \times 365 \tag{24}$$

where: $GC_{it}$ is the carbon sequestration capacity of urban green space; $GA_{it}$ is the area of urban green space in the i-th city ($m^2$); $l$ is the leaf area index (the proportion of the total leaf area per unit land area (14.3888); $m$ is the carbon dioxide absorption per unit leaf area (g/( $m^2$·h)) (6.2006); 12(h) is the daily photosynthetic time; 365(d) is the number of days of the year.

The data involved in formula (24) were extracted from the *China City Statistical Yearbooks*, and *China Urban Construction Statistical Yearbooks* issued in 2003-2016. To sum up, the total carbon emissions in the 199 cities can be obtained as Eq. (25):

$$TC_{it} = CCE_{it} + TCT_{it} + WC_{it} + TCI_{it} - GC_{it} \tag{25}$$

The consumption of all types of energies in each city was converted into kilograms of standard coal, using the conversion coefficients listed in the appendix "Reference Standard Coal Conversion Coefficients of Various Types of Energies" of *China Energy Statistical Yearbooks*.

## 4. Empirical analysis

The empirical analysis was performed in three steps: the impacts of urbanization on carbon emissions and economic output were examined via direct and indirect channels; eight carbon reduction measures were selected and discussed based on the estimation results; the influences of the eight measures on urbanization were investigated in turn.

### *4.1. Influence channels*

The GMM results (Table 2) of the proposed econometric model were obtained based on the research data, and used to derive the effects of urbanization on carbon emissions and economic output via different channels (Table 3).

According to the calculation results of Table 2, according to the respective assumptions, the results of Table 3 and Table 4 are obtained.

Table 3 shows how urbanization affects carbon emissions via each channel, when CL increases by one unit. Obviously, ER is the only channel through which urbanization negatively affects carbon emissions, i.e. channel ER is conducive to carbon reduction. By contrast, urbanization promotes carbon emissions via channels D, $S_2$, $S_3$, PGE and TC. The promoting effect is relatively weak via channel $S_3$. Table 3 also shows how urbanization affects economic output via each channel, when CL increases by one unit. It can be seen that urbanization has a negative impact on economic output via channels PGE and ER, and mainly promotes economic output via channels D, $S_2$, $S_3$ and TC.

In general, when CL increases by 1 unit, urbanization affects carbon emissions (TC), economic output (D) and carbon intensity (PC) through different channels, pushing up TC by 1.278 units, D by 0.674 unit and PC by 0.604 unit. $S_2$ is the most important indirect channel through which urbanization affects TC and PC. Hence, the growing urban percentage of population can greatly improve TC and PC, an evidence of the huge pressure on carbon reduction in the explosive takeoff stage of urbanization. As a result, the core strategy of carbon reduction is to resolve the conflict between urbanization and carbon reduction.

**Table 1.** The variables making up the seven functions

| *Variable* | *Name* | *Meaning* |
|---|---|---|
| D | Economic output | Gross domestic product (GDP) |
| PD | Per capita income | Per capita GDP |
| QL | Labor productivity | Output per unit of labor (D/LK) |

| | | |
|---|---|---|
| TC | Total carbon emissions | Product greenness |
| PUR | Science and education level | Per capita expenditure on scientific research and education |
| TE | Energy consumption | Total energy consumption |
| PE | Labor quality | The number of college students per 10,000 people |
| TFK | Total fixed assets | Fixed assets investment |
| FDI | External communication ability | Foreign direct investment |
| PGE | Energy intensity | Energy consumption per unit of GDP (TE/D), reflecting the level of energy-saving technology |
| PFKE | Energy intensity of fixed assets investment | Energy consumption per unit of fixed assets investment (TE/TFK) |
| S2 | Proportion of secondary industry | Proportion of secondary industry output to GDP |
| S3 | Proportion of tertiary industry | Proportion of tertiary industry output to GDP |
| CL | Urban percentage of population | Urban population / total population |
| LP | Labor price | Labor force / total population, which is negatively correlated with labor price |
| DFK | Economic growth mode | Fixed assets investment / GDP |
| LK | Human capital | Total labor force |
| ER | Environmental regulation intensity | Urban environmental governance investment per unit of built-up area |
| ST | Industrial structure | S2+ S3 |
| PC | Carbon intensity | Carbon emissions per unit of GDP (TC/D) |
| PGEC | Carbon intensity of energy use | Carbon emissions from energy consumption per unit of GDP (TE/D) |

**Table 2.** GMM results of our model

| ***Variables*** | ***Equation 10 lnTC*** | ***Equation 11 lnD*** | ***Equation 12 lnS₂*** | ***Equation 13 lnS₃*** | ***Equation 14 lnPGE*** | ***Equation 15 lnER*** | ***Equation 16 lnCL*** |
|---|---|---|---|---|---|---|---|
| $lnS_3$ | 0.527$^{***}$ | 0.248$^{***}$ | -0.327$^{***}$ | | -0.111$^{***}$ | | |
| | (0.000) | (0.000) | (0.000) | | (0.001) | | |
| lnLP (-1) | | | | | | | -0.381$^{***}$ |
| | | | | | | | (0.000) |
| lnPE | | | | | | 1.013$^{**}$ | |
| | | | | | | (0.007) | |
| lnPGE | 0.432$^{***}$ | -0.224$^{***}$ | | | | | |
| | (0.000) | (0.000) | | | | | |
| lnDFK | 0.355$^{***}$ | | | | 0.720$^{***}$ | | 0.136$^{**}$ |
| | (0.000) | | | | (0.000) | | (0.018) |
| lnPD (-1) | | | | | | | 0.315$^{***}$ |
| | | | | | | | (0.001) |
| lnPUR (-1) | | | -0.032$^{***}$ | | | 0.421$^{***}$ | 0.168$^{***}$ |
| | | | (0.009) | | | (0.000) | (0.000) |
| lnPGEC (-1) | | | | | | -0.602$^{***}$ | |
| | | | | | | (0.002) | |
| $lnS_2$ | 0.400$^{***}$ | 0.266$^{***}$ | | | 0.612$^{**}$ | | |
| | (0.000) | (0.000) | | | (0.039) | | |
| lnTC | | 0.319$^{***}$ | | | | | |
| | | (0.000) | | | | | |
| lnTE (-2) | | | | | | 0.103$^{**}$ | |
| | | | | | | (0.017) | |
| lnPFKE (-1) | | | | 0.500$^{**}$ | | | 0.037 |
| | | | | (0.041) | | | (0.000) |
| lnFDI | | | | | -0.021$^{**}$ | -0.338$^{***}$ | |
| | | | | | (0.006) | (0.000) | |
| lnST (-2) | | | | | | | 0.492$^{***}$ |
| | | | | | | | (0.000) |
| lnLP (-2) | | | | -0.219$^{***}$ | | | -0.337$^{**}$ |
| | | | | (0.004) | | | (0.043) |
| lnLK | -0.150$^{***}$ | 0.511$^{***}$ | | 0.136$^{***}$ | -0.280$^{***}$ | | |
| | (0.007) | (0.000) | | (0.000) | (0.000) | | |
| lnFDI (-2) | | | | | | | 0.037$^{***}$ |
| | | | | | | | (0.002) |
| lnPFKE | | | | | 0.891$^{***}$ | | |
| | | | | | (0.000) | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| lnPGEC | -0.032*** | | | | | | -0.019*** |
| | (0.000) | | | | | | (0.008) |
| lnQL | | | | | -0.280*** | | |
| | | | | | (0.000) | | |
| lnER (-1) | | | -0.062*** | 0.095*** | | | |
| | | | (0.000) | (0.000) | | | |
| lnPD | | | | | | 2.543** | |
| | | | | | | (0.016) | |
| lnPUR (-2) | | | -0.135*** | | | | |
| | | | (0.000) | | | | |
| lnDFK (-1) | | | 0.113*** | -0.913** | | | |
| | | | (0.002) | (0.049) | | | |
| $(\ln PD)^2$ | | | | | | -0.153*** | |
| | | | | | | (0.002) | |
| lnTFK | | 0.160*** | | | 0.280*** | | |
| | | (0.000) | | | (0.000) | | |
| lnER | -0.021*** | -0.035*** | | | -0.034** | | |
| | (0.000) | (0.000) | | | (0.023) | | |
| lnD | 0.950*** | | | | | | |
| | (0.000) | | | | | | |
| lnCL | 0.450** | 0.332*** | 0.520** | 0.140*** | 0.175** | 0.145** | |
| | (0.036) | (0.000) | (0.045) | (0.000) | (0.045) | (0.008) | |
| $R^2$ | 0.749 | 0.952 | 0.834 | 0.723 | 0.999 | 0.526 | 0.566 |
| Durbin Watson (DW) statistic | 1.704 | 1.942 | 1.745 | 1.646 | 2.032 | 1.851 | 1.768 |

*Note: *, ** and *** mean significance at the levels of 10%, 5% and 1%, respectively. The constant terms of each equation pass the 1% significance test. The values in parenthesis are the standard errors*

**Table 3.** The effects of urbanization on carbon emissions and economic output via different channels (CL increases by 1 unit)

| ***Channels affecting TC*** | ***Variation in TC*** | ***Channels affecting D*** | ***Variation in D*** | ***Variation in PC*** |
|---|---|---|---|---|
| Channel D | +0.315 | Direct channel (D) | +0.332 | -0.017 |
| Channel $S_2$ | +0.409 | Channel $S_2$ | +0.177 | +0.232 |
| Channel $S_3$ | +0.074 | Channel $S_3$ | +0.041 | +0.032 |
| Channel PGE | +0.038 | Channel PGE | -0.015 | +0.053 |
| Channel ER | -0.008 | Channel ER | -0.006 | -0.003 |
| Direct channel (TC) | +0.450 | Channel TC | +0.144 | +0.306 |
| All channels | +1.278 | All channels | +0.674 | +0.604 |

*Note: Signs "+" and "-" stand for increase and decrease, respectively*

### *4.2. Carbon reduction measures*

Sorting out the estimation results in Table 2, the author obtained how urbanization affects carbon emissions, economic output and carbon intensity via the channels of the eight key variables in our model (Table 4). Taking PC as the dependent variable, CL, $S_2$, $S_3$, PGE, PFKE, LK, DFK and PGEC were treated as independent variables. Through the regression analysis on our panel data, the author confirmed the long-term cointegration relationship between each independent variable and the dependent variable, and verified the goodness of fit of the regression equation.

As shown in Table 4, when $S_2$ increases by a unit (i.e. the industrial level improves by a unit), TC, D and PC will grow by 0.784, 0.341 and 0.446 unit, respectively. According to the results of equations (12) and (13) in Table 2, when CL increases by a unit in the current period, $S_2$ and $S_3$ will grow by 0.520 and 0.140 unit, respectively, in this period; when $S_3$ increases by a unit in the current period, $S_2$ will decrease by 0.327 unit in this period. Therefore, in the explosive takeoff stage, urbanization has a greater promoting effect on $S_2$ than on $S_3$, that is, urbanization will further promote industrial level. The results of equation (16) show that, industrial structure ST lagging by 2 periods has a direct impact of 0.492 on urbanization, i.e. improving the latter by 0.492 unit.

The above analysis demonstrates the interaction between urbanization, industrialization and industrial structure, as well as the great promoting effect of industrialization on carbon emissions and carbon intensity. Therefore, there are huge contradiction between urbanization and carbon reduction. According to the results of equation (11) in Table 2, the economic cost of carbon reduction through slowing down urbanization is GDP recession. In essence, the contradiction between urbanization and carbon reduction is the difficulty in achieving the win-win for economic growth and carbon reduction.

To resolve the contradiction, it is highly necessary to compare the effect and economic cost of different carbon reduction measures, and find a low-cost, high-benefit measure. Once implemented, such a measure will effectively lower the overall economic cost of carbon reduction, leading to the win-win for economic growth and carbon reduction in the explosive takeoff stage of urbanization.

It can also be seen from Table 4 that, when PGE decreases by a unit, carbon intensity drops by 0.305 unit and economic output grows by 0.086 unit. This means reducing energy intensity can promote economic growth, and effectively reduce carbon intensity, achieving the win-win for carbon reduction and economic growth.

When PFKE drops by a unit, the economic output rises by 0.077 unit, while carbon emissions and carbon intensity decline by 0.195 and 0.272 unit, respectively; when DFK drops by a unit, the economic output falls by 0.141 unit, while carbon emissions and carbon intensity are weakened by 0.688 and 0.547 unit, respectively. Therefore, it is also possible to achieve the win-win for carbon reduction and economic growth by reducing the energy intensity of fixed assets investment and changing the economic growth mode.

Lin (2013) pointed out that, the Chinese economy still has the potential to grow at an average annual rate of 7-8% in the next two decades; To realize carbon reduction target, China must shift from investment-driven economy to consumption-driven economy, and transform extensive energy use into low-carbon intensive energy use, at an inevitable yet affordable slowdown of economic growth. Therefore, two core measures were suggested to realizing the carbon reduction target: the growth of fixed assets investment in high-energy industries should be controlled strictly, and the economic growth should be driven by consumption rather than investment.

When LK increases by a unit, the economic output and carbon intensity grow by 0.530 and 0.095 unit, respectively, indicating that the accumulation of human capital has a much greater promoting effect on economic output than on carbon intensity. Thus, human capital is basically a feasible measure to reduce carbon emissions. PGEC contributes slightly to carbon emissions, economic output and carbon intensity, respectively 0.056, 0.023 and 0.033. This is because China's energy structure is still dominated by coal and oil. Besides, 0.319 unit of GDP is sacrificed to reduce carbon emissions by one unit, revealing the high economic cost of carbon reduction. It can be derived that optimizing energy structure is not an economically affordable measure for carbon reduction, and clean energy development cannot serve as the core measure for carbon reduction.

Furthermore, environmental regulation, as a policy measure for environmental governance, was not listed as a separate entry. However, it can be deduced from Table 4 that: when environmental regulation increases by a unit, carbon emissions and economic output drop by 0.020 and 0.025 unit, respectively. Similar to adjusting the energy structure, environmental regulation only serves as an auxiliary measure for carbon reduction. Of course, environmental regulation is a fundamental guarantee for the low-carbon transformation of the society in the long run.

**Table 4.** Comprehensive impacts of 8 key variables on TC, D and PC

| ***Scenarios*** | ***TC variation in the current period*** | ***D variation in the current period*** | ***PC variation in the current period*** |
|---|---|---|---|
| CL increases by 1 unit in the current period. | +1.278 | +0.674 | +0.604 |
| $S_2$ increases by 1 unit in the current period | +0.787 | +0.341 | +0.446 |
| $S_3$ increases by 1 unit in the current period | +0.481 | +0.314 | +0.167 |
| PGE increases by 1 unit in the current period | +0.219 | -0.086 | +0.305 |
| PFKE increases by 1 unit in the current period | +0.195 | -0.077 | +0.272 |
| LK increases by 1 unit in the current period | +0.625 | +0.530 | +0.095 |
| DFK increases by 1 unit in the current period | +0.688 | +0.141 | +0.547 |
| PGEC increases by 1 unit in the current period | -0.056 | -0.023 | -0.033 |

Note: Signs "+" and "-" stand for increase and decrease, respectively

According to Petit-Clark theorem, the secondary industry should take up a small proportion in an optimal industrial structure. As shown in Table 4, when $S_2$ decreases by one unit, the economic output falls by 0.341 unit; every unit of decline in carbon intensity requires 0.61 unit of economic cost. Thus, reducing the proportion of secondary industry cannot be taken as a key measure to achieve China's carbon reduction target. In the long run, however, the contradiction between urbanization and carbon reduction can be resolved by promoting the low-carbon transformation of the secondary industry and advancing the tertiary industry.

### *4.3 Impacts of carbon reduction on urbanization*

According to the results of equation (16) in Table 2, urbanization is mainly driven by the decline in LP (i.e. growth in labor price; the coefficients lagged one period and two periods are 0.381 and 0.337, respectively), the growth in PD (the coefficient lagged one period is 0.315), and the rise in ST (the coefficient lagged two periods is 0.492). The most fundamental driving force comes from the ST, for the rising ST can stimulate economic output and push up the PD. Therefore, the urbanization will slow down and lose impetus if the proportion of secondary industry is cut down.

Meanwhile, the decline in PFKE (the coefficient lagged one period is -0.037), PGEC (the coefficient in the current period is -0.019) and DFK (the coefficient in the current period is -0.136) has a slight suppression on urbanization, i.e. a limited negative impact on urbanization. In addition, two more carbon reduction measures, namely, $S_3$ and LK, have positive impacts on urbanization via channels ST and PD, respectively. The direct impact coefficient of $S_3$ on urbanization is 0.140. In summary, the eight carbon reduction measures have little negative impact on urbanization, as long as the increment of $S_3$ is not offset by the decrement of $S_2$.

### *4.4. Carbon reduction effects in urbanization*

This subsection mainly verifies the actual effects of the above eight carbon reduction measures. The benefits and costs of these measures were compared, laying the basis for formulating carbon reduction strategies. The authors measured the contribution of each key variable to carbon reduction in the 199 cities during 2003-2016, as well as the economic cost incurred by the variable in carbon reduction. The measured data are listed in Table 5.

Considering carbon reduction benefit, the measures that contribute the most to carbon reduction in 2003-2016 include: reducing $S_2$, lowering PGE, slashing PFKE and increasing PGEC. Thanks to the eight key indices, the carbon intensity in 2015 is 8.37% lower than that in 2003.

**Table 5.** The contribution and economic cost of each key variable to carbon reduction (%)

| *Variables* | *Annual mean variation* | *Annual mean variation of TC* | *Annual mean variation of D* | *Annual mean variation of PC* |
|---|---|---|---|---|
| CL | +0.130 | +0.166 | +0.088 | +0.079 |
| $S_2$ | -0.051 | -0.040 | -0.017 | -0.023 |
| $S_3$ | +0.070 | +0.034 | +0.022 | +0.012 |
| PGE | -1.500 | -0.329 | +0.129 | -0.458 |
| PFKE | -1.571 | -0.307 | +0.121 | -0.428 |
| LK | +0.066 | +0.041 | +0.035 | +0.006 |
| DFK | +0.046 | +0.032 | +0.007 | +0.025 |
| PGEC | +1.500 | -0.084 | -0.035 | -0.050 |

*Note: The variables were from the same sources as before; the annual mean variation of each variable was obtained through calculation; the annual mean variations of TC, D and PC were computed based on the corresponding coefficients in Table 4; signs "+" and "-" stand for increase and decrease, respectively*

Regarding carbon reduction cost, the measures of reducing $S_2$ and increasing PGEC come at the cost of a 0.05% slowdown of GDP growth rate. For every 1% of carbon reduction, the two measures need to reduce the annual GDP growth rate by 0.42% and 0.41%, respectively. By annual economic cost, the two carbon reduction measures can be ranked as: optimizing energy structure (reducing annual GDP growth rate by 0.035%) and lowering the proportion of secondary industry (reducing annual GDP growth rate by 0.017%).

During 2003-2016, the measure of increasing the ratio of fixed assets investment in GDP needs to slow down the annual GDP growth rate by 0.392% to reduce carbon emissions by 1%; the measure of reducing the energy intensity of fixed assets investment needs to slow down the annual GDP growth rate by 0.394% to reduce every 1% of carbon emissions. In general, the carbon reduction costs are mostly positive, indicating a high economic cost of the carbon reduction measures.

In particular, the two measures of reducing the proportion of secondary industry and optimizing the energy structure feature a high cost and a low benefit, and should be utilized cautiously in the decision-making of carbon reduction strategies.

## 5. Conclusions

The previous analysis on carbon reduction effects reveal that the studied measures will push up the economic cost of carbon reduction. Therefore, the key to carbon reduction in future urbanization is to develop a low-cost, high benefit carbon reduction strategy.

### *5.1. Measures to reduce PFKE*

China is currently in the middle and late stages of industrialization. The traditional high-energy industry should be transformed into a modern, low-energy and intensive model. Therefore, China has the potential to further reduce the energy intensity of fixed assets investment, during the urbanization process, and must lower PFKE by formulating and implementing strict standards for energy intensity of fixed assets investment. The government should also roll out supportive policies to modern service industry, and encourage the fixed assets investment into high and new tech industry and the tertiary industry, aiming to control the reduction in energy intensity of fixed assets investment within a scientific and effective range.

### *5.2. Measures to lower PGE*

Firstly, the primary choices for carbon reduction include increasing LK, QL and $S_3$. The two measures of improving human capital and enhancing labor productivity mainly rely on education investment and technical innovation, which agrees with the national strategy of innovation-driven economy. Hence, these two measures are effective means to ease carbon intensity.

Secondly, despite their suppressing effects on carbon intensity, increasing LK, QL and $S_3$ cannot be relied upon in the short term. After all, the Chinese economy depends heavily on fixed assets investment and secondary industry growth, and is increasingly dependent on urbanization.

Thirdly, as mentioned in the text, PFKE is the most critical factor for the decline of PGE, which is consistent with the call for reducing the proportion of secondary industry and promoting energy saving inside that industry.

Finally, energy intensity, a key attribute of energy structure, has a great impact on carbon intensity. The carbon intensity can be greatly weakened by increasing the proportion of clean energy and improving the clean energy techniques. The FDI also speeds up the decline of PGE, but the direct impact is weak. Hence, it cannot serve as the main measure of carbon reduction.

All in all, in the explosive takeoff stage of urbanization, China should pursue the transition to low-carbon economy through key measures like changing economic growth mode, optimizing industrial structure, making more use of clean energy, and improving clean energy techniques. In addition, environmental regulation can also reduce carbon intensity to a certain extent, laying the legal basis for reducing carbon emissions.

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## Appendix

The 199 cities are as follows: Beijing, Tianjin, Shenyang, Dalian, Shanghai, Nanjing, Wuxi, Suzhou, Hangzhou, Ningbo, Xiamen, Qingdao, Wuhan, Guangzhou, Zhuhai, Foshan, Dongguan, Shijiazhuang, Qinhuangdao, Baoding, Cangzhou, Taiyuan, Hohhot, Anshan, Panjin, Changchun, Jilin, Harbin, Daqing, Xuzhou, Changzhou, Nantong, Yangzhou, Zhenjiang, Wenzhou, Jiaxing, Shaoxing, Zhoushan, Hefei, Wuhu, Fuzhou, Quanzhou, Nanchang, Jinan, Dongying, Yantai, Weihai, Zhengzhou, Changsha, Shantou, Huizhou, Nanning, Haikou, Chongqing, Chengdu, Guiyang, Kunming, Xi'an, Lanzhou, Urumqi, Karamay, Tangshan, Handan, Xingtai, Zhangjiakou, Chengde, Langfang, Hengshui, Datong, Changzhi, Shuozhou, Baotou, Wuhai, Chifeng, Tongliao, Fushun, Benxi, Dandong, Jinzhou, Fuxin, Liaoyang, Tieling, Huludao, Siping, Liaoyuan, Tonghua, Baishan, Songyuan, Baicheng, Qiqihar, Jixi, Hegang, Shuangyashan, Yichun, Jiamusi, Qitaihe, Mudanjiang, Heihe, Lianyungang, Huai'an, Yancheng, Suqian, Taizhou, Huzhou, Jinhua, Luzhou, Taizhou, Bengbu, Huainan, Ma'anshan, Huaibei, Tongling, Anqing, Huangshan, Luzhou, Fuyang, Suzhou, Lu'an, Putian, Sanming, Zhangzhou, Nanping, Longyan, Pingxiang, Xinyu, Weifang, Jining, Tai'an, Rizhao, Laiwu, Linyi, Dezhou, Liaocheng, Kaifeng, Luoyang, Pingdingshan, Anyang, Xinxiang, Puyang, Xuchang, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Huangshi, Shiyan, Yichang, Ezhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Zhuzhou, Xiangtan, Hengyang, Shaoyang, Yueyang, Changde, Zhangjiajie, Luzhou, Yongzhou, Loudi, Huaihua, Zhaoqing, Meizhou, Qingyuan, Chaozhou, Liuzhou, Sanya, Zigong, Panzhihua, Luzhou, Deyang, Mianyang, Guangyuan, Suining, Leshan, Nanchong, Yibin, Guang'an, Liupanshui, Zunyi, Qujing, Tongchuan, Baoji, Xianyang, Weinan, Hanzhong, Yanan, Yulin, Jiayuguan, Jinchang , Baiyin, Tianshui, Xining, Yinchuan, Shizuishan, and Wuzhong.

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