Effects of Population Flow on Regional Carbon Emissions: Evidence From China

lei Wu (wulei18@cug.edu.cn)
China University of Geosciences https://orcid.org/0000-0001-8761-2867
Xiaoyan Jia
China University of Geosciences
Li Gao
China University of Geosciences Great Wall College
Yuanqi Zhou
China University of Geosciences

Research Article

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Posted Date: March 11th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-240712/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on July 1st, 2021. See the published version at https://doi.org/10.1007/s11356-021-15131-7.

Effects of population flow on regional carbon emissions: Evidence from China

Lei Wu [1] • Xiaoyan Jia[1] • Li Gao[1] • Yuanqi Zhou[1]

Abstract

Population flow can influence the growth of regional carbon emissions. This paper analyzes the dual transmission mechanism of population flow's impact on population structure and carbon emission. On this basis, it empirically studies the impact of population flow and other related factors on carbon emissions in China by using panel data of 30 provinces and cities in China from 2005 to 2018 with panel econometric regression and heterogeneity analysis. The results show that, i) Over all, no matter in long-term or short-term, China's population flow can reduce the growth of carbon emissions. ii) The aging of regional population and knowledge structure improvement caused by population flow helps reduce carbon emissions, while the regional urbanization caused by population flow and household miniaturization have no significant correlation with the growth of carbon emissions. iii) From the perspective of geographical heterogeneity, the northwest of "Hu Huangyong line" has poor ecological environment, low population density and low level of economic development. Population flow promotes the increase of carbon emissions, while the southeast of "Hu Huangyong line" is on the contrary. iv) The consumption level of Chinese residents, per capita GDP, energy intensity and energy consumption structure have positive effects on carbon emissions, while carbon emission intensity has negative effects. Finally, this paper puts forward relevant suggestions from the perspective of coordinating population policy and energy conservation and carbon emissions reduction policy.

Keywords:

Population flow; Population structure; Carbon emissions; Hu Huangyong line

Highlights:

- Analyze the dual transmission mechanism of population flow's impact on population structure and carbon emission.
- Empirically studies the effects of population flow and other related factors on regional carbon emissions with panel econometric regression and heterogeneity analysis.

Corresponding author:

- Lei Wu, wulei18@cug.edu.cn ;
- Li. Gao, gaoli@cug.edu.cn

The affiliation and address:

1 School of Economics and Management, China University of Geosciences, Wuhan, 430074, China

1 Introduction

Recently, global warming caused by carbon emissions growth has become the focus of academic community. Countries make great efforts to accelerate the development of low-carbon economy and achieve the goal of carbon emissions reduction. As the world's second largest economy, China has huge pressure to reduce carbon emissions. In response to this, in 2015, China promised in the Paris Agreement to strive to achieve the goal of reducing carbon emission intensity by 60% - 65% by 2030 compared with 2005. On September 2020, Chinese government announced at the UN General Assembly that China will try to achieve the carbon neutralization by 2060. Therefore, it is of great practical significance to study the relevant factors affecting carbon emissions providing theoretical and empirical support for the formulation of energy conservation and emission reduction policies.

Currently, there is plenty of research on the factors affecting carbon emissions. Among which, economic development level, population factor, technology level, urbanization, energy structure and industrial structure are considered to be the main factors driving the growth of carbon emissions (Li and Wu, 2019). On this basis, consumption, trade, employment and transportation are gradually introduced into the research on the impact of carbon emissions (Cui et al., 2020; Yang et al., 2019). It is clearly known that population is always an indispensable factor in carbon emissions related research. Given that, monitoring and analyzing the impact of human factors such as population on carbon emissions has become an important research topic (Zhu et al., 2010).

Most literatures related to the impact of population factors on carbon emissions only focus on the impact of total population on carbon emissions. For example, in the typical environmental pressure model IPAT, population size was taken as the primary factor affecting carbon emissions (Ehrlich and Holdren, 1971). Simultaneously, most scholars believe that the expansion of population size will increase carbon emissions (Albrecht et al., 2002). With the development of society and the differentiation of the internal structure of the population, many scholars have begun to pay attention to the impact of factors such as population urbanization, family size and age structure of population on carbon emissions (Tian et al., 2015). Furthermore, the United National Population Fund (UNFPA) pointed out that greenhouse gas emissions are inherently related to factors such as population growth rate, family size, age composition, urban-rural population ratio, gender and geographic distribution of the population and per capita income. And they can have a long-term impact on climate change. Besides above, population flow is an important factor affecting the change of population structure and economic growth (Duan, 2008). For instance, the large number of floating population in China is an extremely active labor factor influencing economic development (Yang and Zeng, 2014), which will also have an important impact on carbon emissions in different regions.

Population flow has changed the age structure of the population in various regions (Liu, 2017). And aging is a characteristic of the change in the age structure of the population. With the irreversible development of aging, the impact of population aging on carbon emissions is becoming more and more important. On one hand, some studies have shown that aging has played a significant role in promoting carbon emissions (Liu and Li, 2012; Menz and Welsch, 2010). On the other hand, some studies have shown that aging has a significant inhibitory effect on carbon emissions (Dalton et al., 2008; Li et al., 2011). Meanwhile, some scholars believe that the relationship between aging and carbon emissions is a significant inverted "U" shape (Yu and Kong, 2017) or a "N" curve (Yang and Yang, 2018) instead of a static and complete linear relationship. Therefore, the constraints of population flow and other factors should be considered in terms of the relationship between aging and carbon emissions.

Population flow will promote rural residents to move into cities and towns, further gathering in central cities, which results in changes in the urban and rural demographic structure (Gao and Zhang, 2016). Carbon emissions caused by the increase of labor force and the construction of infrastructure during urbanization has gradually entered into the research field of scholars. Some scholars believe that urbanization will promote carbon emissions (Chen et al., 2020) and have a positive effect on regional carbon emissions at different levels of economic development. Some other scholars reckon that urbanization will inhibit carbon emissions (Wang and Cheng, 2020; Yuan and Sun, 2020). Especially the urbanization of high-income provinces has a stronger inhibitory effect on carbon emissions. Meanwhile, some scholars believe that the relationship between urbanization and carbon emissions presents an inverted "U" shape (Sun and Huang, 2020), which is long-term and non-linear.

Population flow will change the family structure, which is directly reflected in the fact that the family size tends to be "small" and the structure tends to be "simplified" (Shao and Wu, 2018). In some degree, family size will affect the family energy consumption to change the carbon emissions. Most scholars believe that there is a positive correlation between family size and carbon emissions (Hu et al., 2020; Zheng, 2019). The scale effect of family size will positively increase carbon emissions, while the miniaturization and simplification of family size will decrease carbon emissions. On the other hand, some scholars believe that the relationship between population size and carbon emissions presents a "U" shape (Cui et al., 2019). That is to say, when the family size expands in the initial stage, energy consumption increases, and carbon emissions increase consequently. However, when the family size reaches a certain extent, carbon emissions will decrease owing to the existence of scale effect.

Population flow also changes the knowledge structure of population in different regions (Ding et al., 2018). The change of population knowledge structure is reflected in the different education levels. Education can increase the awareness of carbon emission reduction, and it will also affect the consumption of different energy consumables, which could lead to carbon emissions reduction. Eventually, the higher educated population and the accumulation of human capital will have significant inhibitory effects on carbon emissions in the future (Li and Xu, 2020; Yang and Lu, 2019). When economy reaches a certain level, the education level of residents will increase, which could restrain the increase of carbon emissions (Tong et al., 2018).

To sum up, scholars at home and abroad have done a lot of research on the relationship between population flow and carbon emissions. However, these studies are not clear on the impact mechanism of population structure change, especially population flow on carbon emissions. Due to the differences of angles, methods and samples of research, the empirical conclusions are not the same. In spite of this, these studies also provide a solid research foundation for the follow-up research. With the rapid economic growth and social development, the scale of China's population flow continues to grow leading to continuous changes in the population structure. Therefore, it is of great theoretical significance and practical value to analyze the relationship between China's regional population flow and carbon emissions.

The main contribution of this paper is embodied in the following four aspects: firstly, it explores the factors affecting carbon emissions from the perspective of population flow rather than total population, which could enrich the study between population and carbon emissions. Secondly, from the perspective of population structure change, this paper analyzes the mechanism and path of population flow affecting carbon emissions. Thirdly, this paper comprehensively examines the relationship between different population structures and carbon emissions as much as possible, which it is different from the analysis of the relationship between a single population structure and carbon emissions by related scholars. Finally, the paper divides China into two parts: Southeast and northwest by using Hu Huangyong line, which is the geographical division line of China, to investigate the influence of the heterogeneity of geographical environment, population density and economic development on the carbon emission effect of population flow.

2 The mechanism of population movement affecting carbon emissions

2.1 The direct transmission mechanism

Population flow manifests the spatial shift of population directly. The characteristics of the shift not only manifest the changes in the number of people in different spaces but also bring about a comprehensive adjustment of the population structure in space. The changes of population age structure, urban-rural structure, family structure and knowledge structure caused by population flow mean that the social and economic activities of population will transfer or change in the process of adjustment. Since production and consumption is the most basic economic activity of population, the demographic changes brought about by population flow will directly affect the energy consumption of production and eventually affect the carbon emissions in different regions.

As for the impact of population structure changes on production, population flow directly leads to spatial changes in the number of labor forces, which in turn affects the price's changes in factor market. Meanwhile, according to the change of factor input cost, the production decision of enterprises will be adjusted. The change of production activities leads to the adjustment of energy consumption, which directly affects the carbon emissions in production activities. In short term, population outflow will lead to a decline in output, while population inflow will lead to an increase in output for population inflow areas. However, in long run, due to the adjustment of production factors, decision-making and the role of technological innovation, the impact of population flow on the output of inflow and outflow areas is uncertain So is the impact on carbon emissions in production activities.

As for the direct impact of population flow on consumption, population flow makes part or all of consumption transfer spatially, which leads to the growth of consumption in inflow area and the decline of consumption in outflow area. It is acknowledged that regional differences lead to unbalanced spatial economic development. In the field of consumption, this imbalance is manifested in different consumption levels and structures. In essence, there are diversities in the demand structure and quantity of consumer goods and services with different energy densities. Affected by the economic level, social culture, consumption habits and consumption demand, the inflow population will gradually be integrated into the local consumer groups. In outflow areas, the outflow of population also means changes in consumption levels and structure. Therefore, the change of consumption caused by population flow is not a simple transfer in space but accompanied by the time conversion, structural change, preference change and level adjustment of consumption, which directly affects the change of local energy consumption and carbon emissions.

2.2 The indirect transmission mechanism

Population flow also indirectly affects carbon emissions by influencing social, economic, and cultural activities. The main channels are as follows: firstly, it acts on carbon emissions through the impact on economic structure. The impact includes changes of industrial structure, income structure, savings structure, human capital structure, trade structure and total factor productivity. These changes will be reflected in the production and consumption of energy quantity and type of demand changes, thus affecting carbon emissions. Secondly, it acts on carbon emissions through the impact on public services. Population flow and aging demands more regional public services which provide guarantees for the public to participate in social economic, political, and cultural activities. But these guarantees must be at the expense of consuming social public products. Providing public products will also lead to a large amount of energy consumption, which leads to increasing carbon emissions. Thirdly, it acts on carbon emissions through impact on society and culture. Population is the main carrier of social culture which has regional differences. The change of population structure caused by population flow will accelerate the cultural integration and changes of different regions. Therefore, the culture determines the willingness and preferences of the residents' social and economic activities, thereby indirectly affecting carbon emissions.

Based on the above analysis and the effect of population flow, there is a common dual transmission mechanism of the impact of population flow on carbon emissions, which includes the direct and indirect transmission mechanism, as shown in Figure 1..

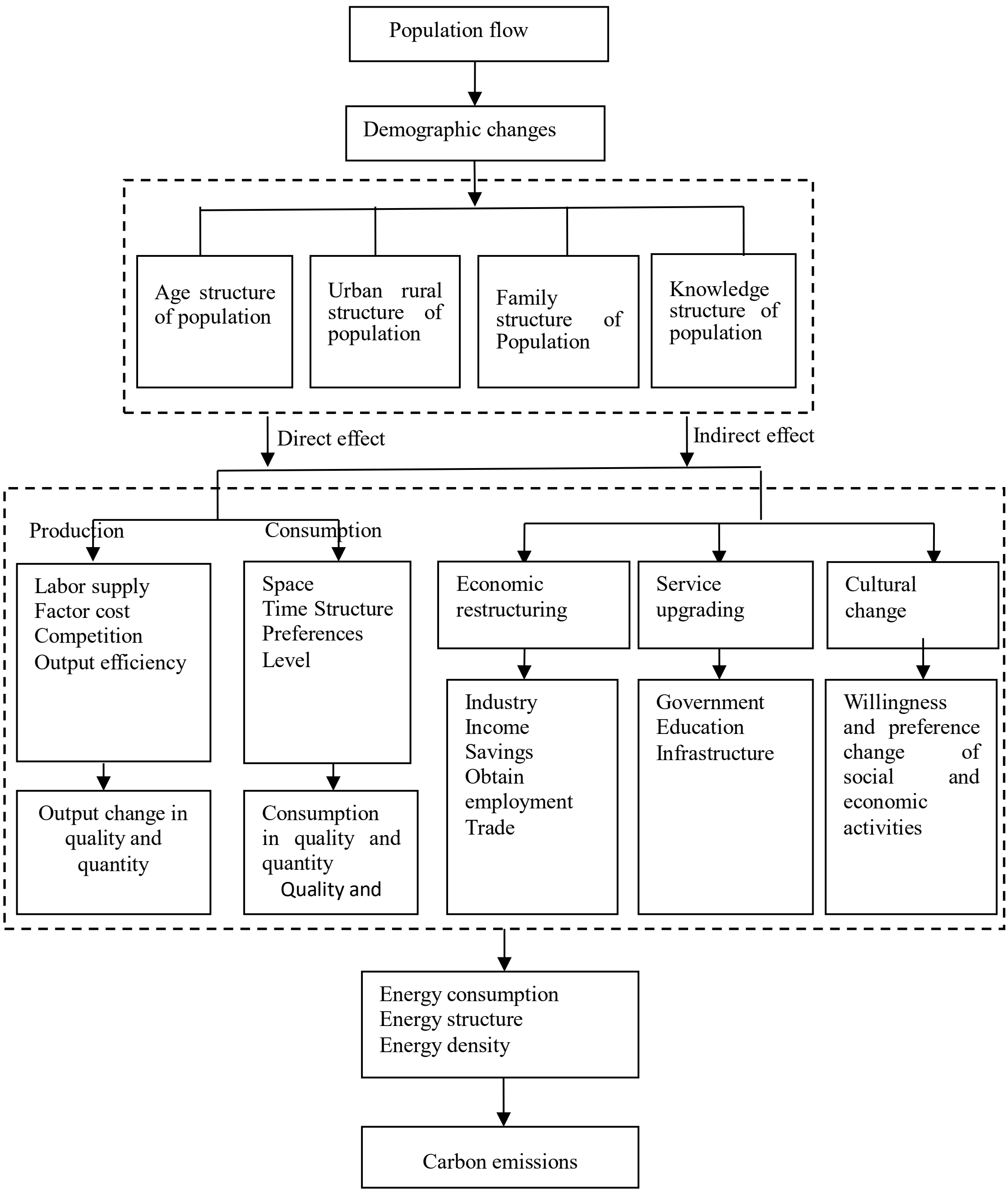

Fig. 1. Double Transmission Mechanism of Population flow on Carbon Emission

3 Methods and data

3.1 Model setting

In order to examine the impact of population flow on carbon emissions at provincial level in China, this paper uses population flow as a core explanatory variable. The basic empirical model is set as follows:

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{i,t} \tag{1}$$

Among them: *i* represents a province; *t* represents time; $\mathrm{Ln}CE_{i,t}$ represents carbon emissions; $PF_{i,t}$represents current population flow; *X* represents a control variable that affects carbon emissions; β represents the effect of an explanatory variable on the explained variable coefficient; $\mu_{i,t}$ represents time fixed effect; $\nu_{i,t}$ represents individual fixed effect; $\varepsilon_{i,t}$ represents random interference term.

Considering that the production and consumption activities of the floating population may lag behind when move to a new place, this paper introduces the one-stage variable $PF_{i,t}$ on the basis of model (1) and the model (2) is constructed as follows:

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t-1} + \beta_2 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{2}$$

Considering that there may be a U-shaped curve relationship between population flow and carbon emissions, on the basis of model (1), the quadratic term of population flow is introduced to construct a model (3) as follows:

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 PF_{i,t}^2 + \beta_3 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{3}$$

Further considering that population flow will lead to changes in the age structure, urban-rural structure, family structure and knowledge structure of the population, thus affecting carbon emissions. This paper introduces the cross terms of population flow and aging, urbanization, household size and education level into the basic empirical model and obtains the specific models (4) - (7) as follows:

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 PF_{i,t}PA_{i,t} + \beta_3 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{4}$$

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 PF_{i,t}PC_{i,t} + \beta_3 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{5}$$

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 PF_{i,t}PH_{i,t} + \beta_3 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{6}$$

$$\mathrm{Ln}CE_{i,t} = \beta_0 + \beta_1 PF_{i,t} + \beta_2 PF_{i,t}PK_{i,t} + \beta_3 X_{i,t} + \mu_{i,t} + \nu_{i,t} + \varepsilon_{\mathrm{i,t}} \tag{7}$$

Among them: $PF_{i,t}PA_{i,t}$、 $PF_{i,t}PC_{i,t}$、 $PF_{i,t}PH_{i,t}$、 $PF_{i,t}PK_{i,t}$ denote the cross items of population flow and aging, urbanization, household size and education level respectively, analyzing the impact of population flow on China's provincial carbon emissions through these paths.

In order to examine whether the carbon emissions effects of geographical environment, population density and economic development level on population flow are heterogeneous, this paper applies Hu Huangyong line. Hu Huangyong line divides China into Southeast and Northwest areas. From the perspective of geographical characteristics, Southeast areas are mainly plain and hilly terrain with dense water network, which is suitable for farming; while Northwest areas are mainly snow plateau and desert area, which is suitable for grazing; from the perspective of population density and economic development level, the Southeast areas accounts for 43.18% of the national land area, gathering 93.77% of the country's population and 95.70% of GDP, while the population and economic density of

Northwest areas are extremely low; from the perspective of urbanization level, it is higher than the national average level in Southeast areas, while it is lower than the national average level in Northwest areas. "Hu Huangyong line" is not only the dividing line of China's geographical and ecological environment but also the dividing line of population concentration and economic development level. Therefore models (8) and (9) are constructed according to the "Hu Huangyong line" as follows:

$$\mathrm{Ln}CE_{wn,t} = \beta_0 + \beta_1 PF_{wn,t} + \beta_2 X_{wn,t} + \mu_{wn,t} + \nu_{wn,t} + \varepsilon_{\mathrm{wn,t}} \tag{8}$$

$$\mathrm{Ln}CE_{es,t} = \beta_0 + \beta_1 PF_{es,t} + \beta_2 X_{es,t} + \mu_{es,t} + \nu_{es,t} + \varepsilon_{\mathrm{es,t}} \tag{9}$$

Among them: *wn* represents northwest provinces; *es* represents southeast provinces; *t* represents time; Ln*CE* represents carbon emissions; *PF* represents current population flow; *X* represents control variables affecting carbon emissions; β represents coefficients of explanatory variables to explained variables; μ represents time fixed effect; v represents individual fixed effect; ε represents random interference term.

3.2 Variable selection, data source and processing

3.2.1 Variable selection

I. Explained variable

The explained variable in this paper is the annual carbon emissions of China's provinces. According to Du Limin's calculation method of carbon emissions (Du, 2010), this paper selects seven kinds of energy, including coal, coke, gasoline, kerosene, diesel, fuel oil and natural gas, multiplied the corresponding energy consumption and carbon dioxide factor, and summed to get the carbon emission data of each province. Due to the huge amount of carbon emissions in each region, there is an order of magnitude gap with other variables. We take the log of it.

II. Core explanatory variables

(1) Population flow (*PF*). The description of floating population generally depends on the statistical data of floating population. At present, there is no unified definition of floating population in academic circles. This paper defines the population flow as the difference value between permanent residents and the registered residents (Shi, 2020).

(2) Aging (*PA*). The aging of population is the most important feature of modern population transformation. At present, in most studies, aging is measured by the proportion of the elderly aged 65 and above in the total population (Li, 2019). This paper also uses this index for reference.

(3) Urbanization (*PC*). The obvious change of urban and rural population structure is reflected in urbanization. The measurement methods of urbanization generally include the proportion of population, proportion of urban land, coefficient adjustment method, etc. Considering the availability of data, in this paper, urbanization is measured by the ratio of urban population to total population (Li, 2015).

(4) Household size (*PH*). The change of family structure caused by population flow is reflected in family size. In this paper, household size is measured by the average number of each family.

(5) Knowledge structure of the population (*PK*). Some studies pointed out that education has a great dynamic effect on population flow (Meng, 1993). The population flow of school-age youth due to receiving education will also affect the knowledge structure of the population in the corresponding region. In this paper, knowledge structure of the population is measured by the proportion of junior college or above.

III. Control variables

Based on the research of other scholars, this paper selects five control variables: resident consumption (*RC*), per capita GDP (*PGDP*), energy intensity (*EI*), energy consumption structure (*EC*) and carbon emission intensity (*CI*).

Residential consumption is measured by the ratio of per capita consumption of urban residents to per capita GDP; per capita GDP is measured by the ratio of regional gross domestic product (GDP) to permanent resident population, in which GDP is converted to the constant price level based on 2005 by using the deflator index, and then took the logarithm for eliminating the effect of heteroscedasticity; energy intensity is measured by energy consumption per unit GDP; energy consumption structure is measured by the ratio of coal consumption to total energy consumption; the carbon emission intensity is measured by the carbon emission per unit GDP.

3.2.2 Data sources and descriptive statistics

The data is from 2005 to 2018 of China. Since part of the energy consumption data of Tibet cannot be obtained, the regions include 30 provinces except Tibet, Hong Kong, Macao and Taiwan. The data in 2018 of energy consumption is obtained by linear fitting, and other missing data are supplemented by interpolation method. The data mainly come from multiple bases, including: the *China Environmental Yearbook*, *the China Environmental Statistical Yearbook*, *the China energy statistical yearbook*, *the China Statistical Yearbook*, *the China Demographic Yearbook*, *EPS* database and official website of National Bureau of statistics. The data units and descriptive statistical for each variables are listed in Table 1.

Table 1 Descriptive Statistics of Variables

Variable	Abbreviation	Mean	Std. Dev.	Min	Max
Carbon emission	Ln*CE*	9.9529	0.8418	6.9758	11.5005
Population flow	*PF*	-26.6509	576.0515	-1839.6292	1958.1107
Aging	*PA*	0.0268	0.0470	0.0047	0.2082
Urbanization	*PC*	53.5336	13.8901	26.8633	89.6066
Household size	*PH*	3.1002	0.3268	2.33	3.93
Knowledge structure of the population	*PK*	11.1864	7.0146	2.7182	48.6550
Resident consumption	*RC*	37.8996	33.2518	-180.0661	209.3243
Per capita GDP	Ln*PGDP*	10.4189	0.6419	8.5275	11.9388
Energy intensity	*EI*	1.2533	0.7205	0.3541	4.1398
Energy consumption structure	*EC*	95.0285	39.5722	1.8250	242.6667
Carbon emission intensity	*CI*	2.7738	2.2239	0.2199	11.8292

3.2.3 Data verification

In order to avoid spurious regression, it is necessary to put unit root test and co-integration test on panel data. In this paper, ADF test, LLC test, IPS test and PP test are used to test the unit root of panel data. The specific test results are listed in Table 2. Although some variables in the IPS test did not pass the significance test, combined with the other three tests, it can be considered that the variables in the previous model are stable.

Table 2 Panel Unit Root Test

Variable	ADF test	LLC test	IPS test	PP test
PF	8.4450^{***}	-6.2167^{***}	-1.7244^{**}	9.4378^{***}
PF_{t-1}	7.2295^{***}	-5.0822^{***}	-19.3283^{***}	7.9328^{***}

PF^2	14.0037***	-9.5100***	-4.0776***	6.2759***
Ln*CE*	4.7102***	-1.6755**	2.8517	2.7192***
Ln*PGDP*	2.4090***	-4.5696***	5.3771	1.4368*
EI	3.8686***	-6.1734***	3.8495	1.8620**
EC	4.0199***	-2.0922**	0.8175	1.4860*
CI	6.1060***	-1.3457*	1.8588	1.8261**
RC	5.5558***	-12.2926***	-4.3047***	83.1745***
PA	6.2324***	-19.2297***	-16.7934	64.4652***
PC	3.2817***	-16.0227***	-5.9853	2.5984***
PH	5.4646***	-3.5450***	-0.8417	3.3643***
PK	8.3184***	-3.8319***	-2.1943**	5.5630***

Note: ***, **, * denote statistical significance levels at 1%, 5%, and 10% respectively.

In this paper, Kao test, pedroni test and westerlund test are used to test the co-integration on variables in each model, so as to explain whether the regression of each model is appropriate. The specific test results are listed in Table 3. It can be found that there is a co-integration relationship between the variables of each model, which indicates that the model setting is appropriate.

Table 3 Panel Co-integration Test

Model	Kao test	Pedroni test	Westerlund test
（1）	3.4268***	10.1327***	2.2617**
（2）	3.6400***	10.9364***	4.3362***
（3）	3.3450***	10.5790***	2.9116***
（4）	3.3042***	11.4279***	4.6570***
（5）	3.5942***	10.8801***	2.9218***
（6）	3.3954***	10.8634***	2.9691***
（7）	2.5622***	10.9828***	3.3116***

Note: ***, **, * denote statistical significance levels at 1%, 5%, and 10% respectively.

4. Results and analysis

4.1 Regression results and analysis of basic model

After unit root test and co-integration test based on panel data, Hausman test is carried out to select random effect or fixed effect. The original hypothesis of Hausman test is random effect model. However, according to the test results in Table 4, the null hypothesis was rejected by all the three models at the 5% significance level，so it is reasonable to be explained by fixed effect model. The regression results of basic empirical models are listed in Table 4.

Table 4 Regression of Basic Empirical Model

Variable	（1）	（2）	（3）
PF	-0.0001305***		-0.0001481***
PF_{t-1}		-0.0001608***	
PF^2			-2.97×10^{-8}*
RC	0.0009031***	0.0010124***	0.0008888***
Ln*PGDP*	0.5769989***	0.558726***	0.5814856***
EI	0.422068***	0.4159254***	0.4208712***
EC	0.0109579***	0.0109413***	0.0108436***
CI	-0.0343593***	-0.0345389**	-0.036917**
Cons	2.42956***	2.627068**	2.402215**
R^2	0.9093	0.8899	0.9100
Hausman test	12.67**	12.60**	13.85**

Note: ***, **, * denote statistical significance levels at 1%, 5%, and 10% respectively.

In model (1), the coefficient of population flow is negative, and passes the test at the 1% significance level, which indicates that in the short term, population flow reduces carbon emissions in China. In model (2), the coefficient of population flow lagging for one period is still negative at the 1% significance level, indicating that even though the production and consumption activities lag due to population flow, it still has an inhibitory effect on carbon emissions. In model (3), the coefficient of quadratic term of population flow also negatively passes the test at 1% significance level. It indicates that in long run, population flow in China also reduces carbon emissions. The above elastic coefficients are all small, but considering the huge population base and floating population in China, the impact of population flow on the carbon emissions cannot be ignored. In conclusion, taking the nation as a whole, population flow in China is beneficial to reducing carbon emissions, but the specific reasons need further analysis.

In the control variables, residents' consumption, per capita GDP, energy intensity and energy consumption structure have positive impact on carbon emissions in the three models. And they all surpass 1% significance level. It indicates that the above factors have a significant driving effect on carbon emissions, which is consistent with the actual situation in China. In recent years, China's economy continues to grow and people's living standards continue to improve, which is directly reflected in the growth of per capita GDP and the increase of household consumption. Therefore, growth of production and consumption lead to the increase of carbon emissions. Energy intensity reflects the economic efficiency of energy. The higher the energy intensity, the higher the energy consumption per unit output, therefore, the increase of energy intensity will also promote the increase of carbon emissions. Although in recent years, China has enhanced energy conservation and emission reduction, it is still difficult to shift to a green growth model due to the large proportion of energy-intensive, high polluting industries and the relatively backward technology of energy conservation and emission reduction.

In addition, the proportion of coal in China's energy consumption structure is high and the environmental pollution is serious, which is also a main reason for increasing carbon emissions. Now, China is accelerating the adjustment of energy consumption structure, promoting the development of green economy, gradually replacing traditional energy with clean energy, reducing the consumption of coal, increasing the supply of natural gas, vigorously developing hydropower resources and promoting the use of renewable energy. This work improves energy efficiency and significantly reduces carbon emissions.

In control variables, the coefficient of carbon emission intensity on carbon emissions is negative in the three models and they surpass the significance level of 1% or 5%. It indicates that the lower the carbon emission intensity is, the more the carbon emission quantity increases. This is not consistent with common sense. The decrease of carbon emission intensity means that the increase of unit GDP produces less carbon dioxide emissions (Yin et al., 2020). Since carbon emission intensity is the carbon emission per unit of GDP, considering the rapid growth of China's economy in recent decades, this empirical result seems to indicate that the growth rate of China's economy is higher than the decline rate of carbon emission intensity and China's economic development and carbon emissions have not yet decoupled.

4.2 Analysis of the impact of population structure change caused by population flow on carbon emissions

In order to further explore the impact of various demographic changes caused by population flow on carbon emissions, this paper introduces the cross terms of population flow and aging, urbanization, household size and knowledge structure of the population into the basic empirical model, and the specific regression results are shown in

Table 5.

Table 5 Regression of Different Population Structures

Variable	（4）	（5）	（6）	（7）
PF	-0.0001288***	0.0000193	-0.0002424	0.000106***
PFPA	-0.0002258*			
PFPC		-2.36×10^{-6}		
PFPH			0.0000376	
PFPK				-0.0000131***
RC	0.0009073***	0.0009428***	0.0009054***	0.001102***
LnPGDP	0.5771294***	0.5837849***	0.5789966***	0.6015039***
EI	0.4237167***	0.4365715***	0.4219315***	0.4376411***
EC	0.0109727***	0.0109745***	0.0109058***	0.0103155***
CI	-0.0345364***	-0.0365963***	-0.0340555***	-0.0290976**
Cons	2.4239***	2.3547***	2.4142***	2.2175***
R^2	0.9099	0.9099	0.9094	0.9209

Note: ***, **, * denote statistical significance levels at 1%, 5%, and 10% respectively.

As summarized in Table 5, that under different population structures, the coefficients of the control variables including residents consumption, per capita GDP, energy intensity and energy consumption structure are all positive and pass the test at the 1% significance level on carbon emissions. And the coefficients of carbon emission intensity are negative and pass the test at least at the 5% significance level on carbon emissions. The results are consistent with the basic empirical model, which indicates that the regression results of control variables are highly robust.

In model (4), the coefficient of population flow's impact on carbon emissions is negative and the cross term of population flow and aging is also negative. The two surpass significance level 1% and 10% respectively, which indicates that the aging caused by population flow inhibits the increase of carbon emissions in China. The results are consistent with the characteristics of population aging in China. In general, population aging process is accelerating in China, showing the characteristics of large amount, rapid growth, regional imbalance and aging before getting rich (Li and Zhang, 2017), while the population flow further aggravates the spatial imbalance of population aging. On one hand, from the perspective of production, the elderly people in China seldom continue to work after retirement. On the other hand, in the perspective of consumption, because China has entered the aging society when the overall economy is still underdeveloped, the income level of the elderly is generally not high. While the current old-age medical security system, old-age care service system and socialized management system have not been able to meet the requirements of the growing demand services for the elderly. Therefore, the aging of the population not only reduces the carbon emissions in the production field but also leads to the shift of the consumption structure to low carbon and energy saving, thus inhibiting the carbon emissions on the whole.

In model (5), the coefficient of the cross term between population flow and urbanization is positive, but it does not pass the significance test. This result indicates that there is no significant correlation between the increase of urbanization level caused by population flow and the growth of carbon emissions. The results are consistent with the characteristics of urbanization in China. Since the reform and opening up, population urbanization has rapidly reached 60% by 2018 in China, but the quality is not high. Population urbanization lags behind land urbanization. The reason is that Chinese urbanization is mainly manifested as urbanization of residence registration rather than real residence, that is, urbanization of population at the economic, social and cultural psychological level. Therefore, the improvement of China's urbanization level does not really reflect the role or status of population flow in the field of production and consumption. There is no significant correlation between the urbanization level and the growth of carbon emissions.

In model (6), the cross terms of population flow and household size did not pass the significance test. This result indicates that there is no significant correlation between household miniaturization caused by population flow and carbon emissions. Generally speaking, due to the scale effect of household consumption, the total energy demand of small households will exceed that of large households. Therefore, household miniaturization will increase carbon emissions. However, in China population flow not only makes the family size smaller but also makes the internal structure of the family simpler, as well as the proportion of single-person households and generational households increase (Zhou, 2016). Most of these families have simple life, low commodity and energy consumption. Therefore, there is no significant correlation between household miniaturization caused by population flow and carbon emissions.

In model (7), the cross term of population flow and population knowledge structure is negative, which pass the test at the 1% significance level, indicating that the improvement of population knowledge structure caused by population flow in China inhibits carbon emissions in China. According to the data of "China floating population development report (2016)", in recent years, the floating population with higher education is increasing. The proportion of the floating population with the purpose of development and learning and training is increasing, especially in the new generation of young floating population. Highly educated population is more likely to accept the idea of energy conservation and emission reduction and put it into action, thus reducing carbon emissions.

4.3 Heterogeneity regression based on Hu Huanyong line

Geographical location, population density and level of economic development all limit or affect population flow and then affect the carbon emissions of region. The specific regression results are shown in Table 6.

Table 6 Heterogeneous Regression Results Based on 'Hu Huanyong line' Grouping

Variable	"Hu Huangyong line"	
	(8)	(9)
PF	0.00114***	-0.00012***
RC	0.00022	0.00033**
Ln*PGDP*	0.79247***	0.55613***
EI	0.36572***	0.59029***
EC	0.00621***	0.01043***
CI	0.02954	-0.10009***
Cons	-0.29121	2.44787***
R^2	0.9737	0.9401

Note: ***, **, * denote statistical significance levels at 1%, 5%, and 10% respectively

In the models (8) and (9), except a few variables are not significant, most control variables have highly similar impact on carbon emissions as the basic model, and they all surpass significance level 1% without obvious regional heterogeneity, which indicates that the regression results of control variables are still highly robust.

Comparing the results of model (8) and (9), the impact coefficient of population flow on carbon emissions is positive in the group of provinces located in the northwest of Hu Huangyong line, while it is negative in the group of provinces located in the southeast of Hu Huangyong line and all of them surpass 1% significance level.

The result shows that, the regression results show that, in the region with poor ecological environment, sparse population and relatively backward economic development, population flow leads to the increase of carbon emissions; in the region with good ecological environment, suitable climate, convenient transportation and developed economy, population flow leads to the decrease of carbon emissions. The reason is obvious. In order to overcome the vast and harsh natural environment, people in Northwest areas of China need to consume more energy in infrastructure construction, transportation security and life quality improvement. And the inflow of population will increase carbon emissions to a large extent. On the contrary, in Southeast areas, the climate is suitable for living and production, the dense population and developed economy make the scale effect and intensive effect exist simultaneously and improve the energy utilization efficiency, thus restraining the growth of carbon emissions. When observe the direction of population flow in China, eastward and southward migration and concentration to core cities are the main characteristics. In 2018, 7 of the 10 provinces in eastern China are net population inflow areas and the net inflow population in southern provinces was 1.685 million. This phenomenon fully demonstrates that geographical and economic factors play an important role in the population flow; at the same time, it also shows that even though there is an increase in carbon emissions caused by population inflow in Northwest China, the population flow in China leads to a decrease in carbon emissions as a whole because the population mainly flows into Southeast China.

5 Conclusion, discussion and policy implications

5.1 Conclusion and discussion

The population flow can directly bring about the change of regional population structure and lead to the spatial transfer of production and consumption, thus affecting the growth of regional carbon emissions. The change of population structure will also indirectly affect the growth of regional carbon emissions through the adjustment of social, economic and cultural activities. Based on the analysis of the dual transmission mechanism of the effect of population flow on carbon emissions through influencing population structure, this paper empirically analyzes the impact of population flow and other related factors on carbon emission by panel econometric model and heterogeneity analysis, using China's provincial panel data.

The main finding reveals that, firstly, for China as a whole, whether in the long run or in the short run, population mobility can reduce the growth of carbon emissions. Even considering the impact of production and consumption lag caused by population mobility, population mobility also has a positive effect on carbon emission reduction. Secondly, the aging and the knowledge structure improvement of population caused by population flow help to reduce carbon emissions, but the urbanization and household miniaturization caused by population flow have no significant correlation with the growth of carbon emissions. Thirdly, the results of group regression based on “Hu Huangyong line” show that the heterogeneity of geographical environment, population density and economic development have a certain impact on the carbon emission effect of population flow. In areas with good ecological environment, dense population and developed economy, population flow reduces carbon emissions, while in areas with poor ecological environment, sparse population and backward economy, population flow increases carbon emissions. Fourthly, level of residents consumption, per capita GDP, energy intensity and energy consumption structure in China have positive effects on carbon emissions, while carbon emission intensity has negative effects on carbon emissions. Due to the continuous growth of China's economy, increase of per capita GDP and energy intensity become the main factors to promote the increase of carbon emissions.

However, there are still some limitations in this paper, the most important one is that it does not consider the spatial correlation and dependence caused by population flow among regions. So it is an important direction to incorporate spatial correlation into future research on carbon emissions in the empirical test of population flow effect.

5.2 Policy implications

Based on the major findings from this paper, to coordinate population policy with energy conservation and emission reduction policy, following policy implications are drawn:

First, the government needs to improve the management, service and integration of the floating population. Through scientific and efficient management, population flows to areas with good environment and developed economy; strengthen the supply of fairness and efficient basic public services, thus to realize the full coverage of regional population, and reduce the waste of resources caused by the lack of public services; deepen the reform of urban management system and social policy, and make full use of modern technical means to achieve dynamic, convenient and sustainable development The intelligent service mode not only promotes the harmonious integration of the floating population, but also effectively reduces the service cost and carbon emissions.

Second, the aging service system needs to be improved, and aging industry needs to be developed vigorously with the goal of low-carbon environmental protection and green health. It is necessary to actively implement the 2019 "China's medium and long term plan for actively coping with population aging" to improve the elderly care and health service system, as well as to establish a comfortable social environment for the elderly. It is necessary to accelerate the development of the elderly service industry with low-carbon environmental protection and green health as the main goal to drive the development of low-carbon economy combining the characteristics of the elderly industry such as high comprehensiveness, long industrial chain, high relevance and wide range of fields. Furthermore, it is essential to allocate labor resources reasonably, to guide labor flow to the elderly service industry and to provide diversified services for the elderly.

Third, to promote the development of low-carbon economy, it is necessary to strengthen the interaction between population structure and industrial structure. On one hand, speeding up the optimization of population structure will promote the transfer of rural surplus labor force to cities and towns. In order to provide a large number of high-quality human capitals for the upgrading of industrial structure, it is important to strengthen the reform of education system and to accelerate the improvement of population knowledge level and knowledge structure. On the other hand, optimizing the industrial structure contributes to accelerating the transformation of high-tech industries. Giving priority to the development of modern service industries with low energy consumption such as eco-cultural tourism, modern finance, science and technology services, information services and e-commerce is beneficial to meet the needs of high-quality development of the population.

Fourth, accelerate the new urbanization and achieve the goal realizing the social and economic role transformation of the transferred population. For urbanization, it is essential to promote the reform of household registration, rural land property rights and social security system and to solve problems of employment, education, housing, pension and education. What's more, it is necessary to realize not only the transformation of population, identity and occupation but also the transformation of thinking, knowledge and behavior mode, so as to adapt to the development mode of low energy consumption, low emission and low pollution in modern cities and towns.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research was jointly supported by the Open Funds of Regional Innovation Capabilities Monitoring and Analysis Soft Science Research Base of Hubei Province (Grant No. HBQY2021z05) and the Soft Science Research Projects of Hubei Science and Technology Support Plan (Grant No. 2017ADC138).

Authors' contributions

Lei Wu: conceptualisation, methodology, formal analysis, writing—original draft, writing—review and editing.

Xiaoyan Jia: methodology, formal analysis, writing—original draft.

Li Gao: conceptualization, writing—review and editing.

Yuanqi Zhou: writing—original draft.

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Figures

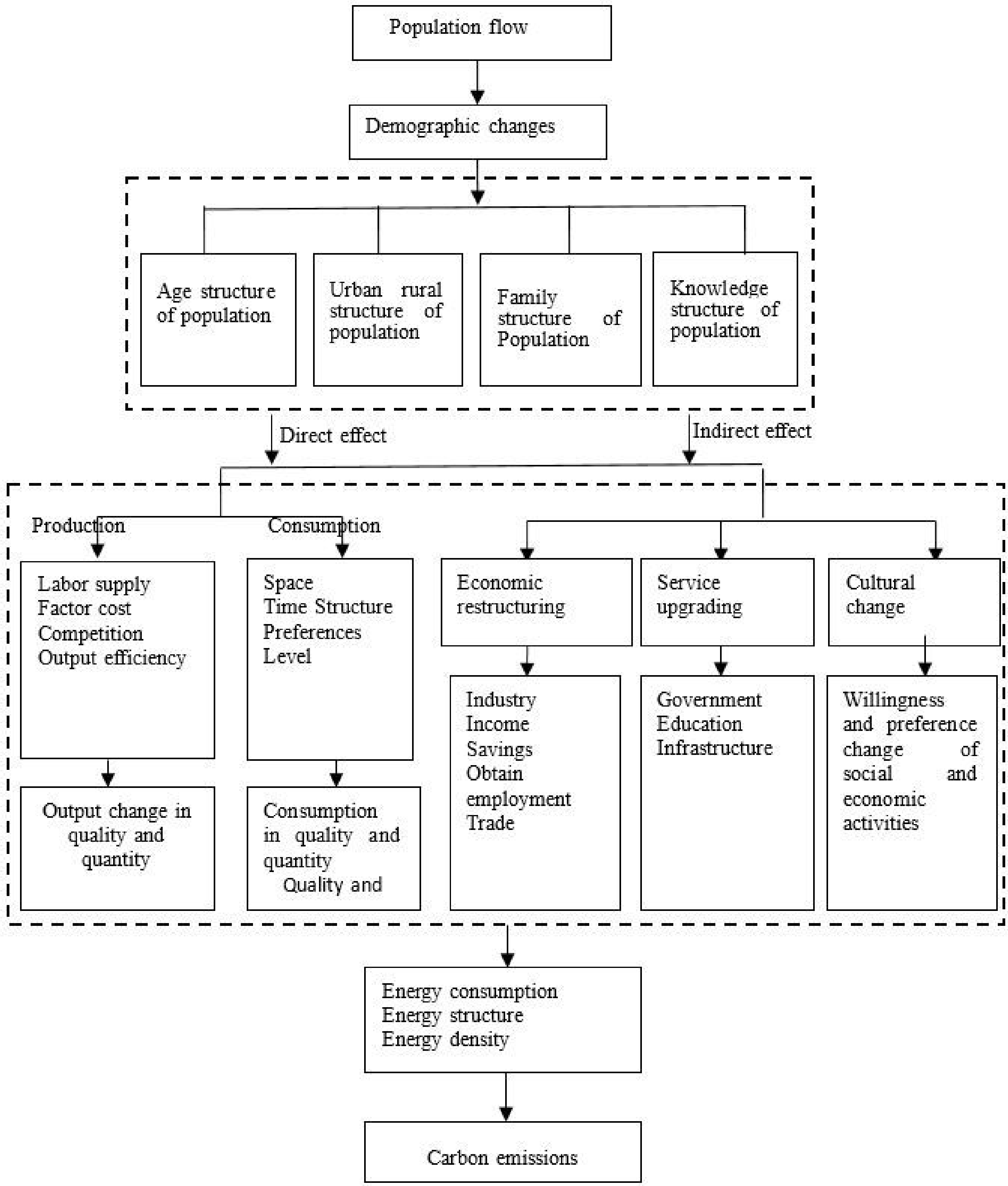

Figure 1

Double Transmission Mechanism of Population flow on Carbon Emission