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The Impact of Population Characteristics on Transportation CO_2 Emissions – Based on Panel Data from 30 Provinces in China

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ABSTRACT

Reducing transportation CO_2 emissions and addressing population characteristic changes are two major challenges facing China, involving various requirements for sustainable economic development. This paper decomposed the population characteristics into population growth, population distribution, population quality, population living standard and age structure, by using STIRPAT model and panel data from 2000 to 2019 to explore the impact of population characteristics on China's transportation CO_2 emissions. Further, we analyzed the impact mechanism and emission effect of population aging on transportation CO_2 emissions. Results show that during 2000-2019: (1) population aging and population quality restrain the transportation CO_2 emissions, but the negative impact of population aging is indirectly produced by economic growth and transportation demand. And with the aggravation of population aging, the impact on transportation CO_2 emissions changes and presents a U-shaped. (2) Population living standard on transportation CO_2 emissions exhibits an urban - rural difference, and urban living standard was dominant in transportation CO_2 emissions. Additionally, population growth has a weakly positive effect on transportation CO_2 emissions, while population distribution has no significant effect on transportation CO_2 emissions. (3) At the regional level, the effect of population aging on transportation CO_2 emissions shows regional differences.

Keywords: Transportation CO_2 emissions; STIRPAT model; population characteristics; population aging.

1. INTRODUCTION

The transportation sector is an important area of global energy consumption and greenhouse gas (GHG) emissions. In recent years, with the development of China's economy and the increase of car ownership, China's total CO_2 emissions from transportation sector have continued to grow, which makes China face great pressure and challenges in reducing carbon dioxide emissions. According to statistics, China's transportation carbon emissions account for about 15% of the national terminal emissions, and the average growth rate of carbon emissions from 2013 to 2019 has remained above 5%. The transportation sector has become the fastest growing field of GHG emissions in China. Therefore, it is of great significance to achieve the Paris Agreement goals by exploring the factors of CO_2 emissions of transportation in China for restraining the growth of CO_2 emissions [1-2].

As the interdependence between population and transportation, related population characteristics changes have long been an important factor affecting carbon dioxide emissions from transportation sector [3-4]. Among the many population factors, China's population size and population growth have attracted the attention of scholars. However, with the common progress of China's social and economic development condition, policy system, scientific and technological progress and overall social value system, China's population shows more complex characteristics. Such as, the increasing urbanization rate, the imbalance of population structure, the overall improvement of population quality and remarkable increase of people's living standards. These population characteristics have

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changed the travel distance, travel mode and travel distribution change. In the future, how to deal with the challenge of carbon emissions caused by the growth of transportation demand and the diversification of transportation tools under the changes of demographic characteristics will become the key content of sustainable development of transportation.

From the previous studies, scholars have widely discussed the relationship between population aging and CO_2 emissions, but the results remain inconclusive [5-6]. In addition, scholars also analyzed the impact of population density and population living standard on transportation CO_2 emissions [7-8]. However, the above studies are examined the single population-related factor, few classified population factors from the perspective of demographic characteristics changes. In addition, the existing studies are based on time series data at the national scale, ignoring the impact of population aging on the development of key industries. Moreover, due to China's vast territory, eastern, central and western regions are different in many aspects.

Table. 1. Descriptive statistics of variables.

Variable	Definition	Unit
TCE	transportation CO_2 emissions	Ten thousand tons
PGDP	GDP per capita	Ten thousand yuan
TRAT	Total transport turnover	100 million ton-km
EI	Energy intensity	standard coal per yuan
URB	Urbanization rate	Percent
PI	Population intensity	Person per square
PG	Natural growth rate	Percent
PL	Adult illiteracy rate	Percent
PQ	Higher education rate	Percent
Pcu	Urban consumptive expenditure per capita	Ten thousand yuan
Pcr	Rural consumptive expenditure per capita	Ten thousand yuan
PFI	Index of population factors except population age structure	
Age14-	Share of people under 14	Percent
Age15-64	Share of people aged 15-64	Percent
Age65+	Share of people over 65	Percent

Under this circumstance, this paper aims to fill this gap by disintegrating population factors from the perspective of population characteristics to investigate the relationship between population growth, population distribution, education level, living standard, age structure and transportation CO_2 emissions. Further explored the impact of population aging on transportation CO_2 emissions at national and regional levels.

2. PAPER STRUCTURE

2.1 Model specification and data description

2.1.1 Model specification

In this paper, we divided P into population growth rate, population intensity, adult illiteracy rate, higher education proportion, urban consumptive expenditure per capita, rural consumptive expenditure per capita and the population share under14, people aged 15–64 and population over 65. And GDP per capita and the total transport turnover to represent A, energy intensity and urbanization rate to represent T. We also introduced the quadratic term of per capita GDP to observe the existence of the environmental Kuznets curve, because of the slow adjustments of the industrial structure, the energy structure and the related macroeconomic factors, they are not considered in this paper. The STIRPAT model is expressed as follows:

$$\begin{aligned}\ln TCE_{it} &= a + \beta_1 \ln PGDP_{it} + \beta_2 (\ln PGDP_{it})^2 \\ &+ \beta_3 TART + \beta_4 \ln P_{it} + \beta_5 \ln EI_{it} \\ &+ \beta_6 \ln URB_{it} + u_i + e_{it}\end{aligned} \quad (1)$$

Where, i denotes provinces, t denotes year. P includes all the population characteristics factors. All independent variables are in their logarithmic form.

In the regional analysis, because the time dimension is larger than the cross-sectional dimension, we adopt a linear regression model with additional panel corrected standard errors (PCSEs). This method is usually suitable for long panel data and can improve the properties of small samples by normalizing the standard error.

2.1.2 Data description

We calculated the transportation CO_2 emissions (TCE) by [9]. And we calculated the electricity CO_2 emissions factors, which facilitates the measurement of CO_2 emission from indirect transportation. All the energy consumption data were provided by the China Energy Statistical Yearbook.

The summary statistics for each variable are presented in Table 1. The panel data were balanced because each had 600 observations, collected by China Statistical Yearbook and China City Statistical Yearbook.

2.3 Empirical results

2.3.1 National analysis

Table. 2. The results of individual fixed regression model based on population characteristics.

	A	B	C	D	E	F
lnPGDP	1.7332***	1.9250***	1.7693***	1.8922 ***	1.6473***	2.2578***
	(0.2964)	(0.3047)	(0.3313)	(0.3062)	(0.3265)	(0.3642)
$(\ln PGDP)^2$	-0.1008***	-0.1205***	-0.1056***	-0.1131***	-0.1023***	-0.1605***
	(0.0335)	(0.0342)	(0.0387)	(0.0348)	(0.0401)	(0.0396)
lnTRAT	0.1455***	0.1304***	0.1470***	0.1568***	0.1251***	0.1448***
	(0.0348)	(0.0351)	(0.0354)	(0.0348)	(0.0355)	(0.0351)
lnURB	-0.8343***	-0.8478***	-0.8257***	-0.8384***	-0.6669***	-0.7852***
	(0.1651)	(0.1644)	(0.1690)	(0.1691)	(0.1798)	(0.1804)
lnEI	0.2144***	0.2247 ***	0.2151***	0.2154***	0.1879 ***	0.2212***
	(0.0577)	(0.0576)	(0.0578)	(0.0574)	(0.0582)	(0.0581)
lnPG		0.0913**				
		(0.0363)				
lnPI			0.0491			
			(0.2007)			
lnPQ				-0.0197		
				(0.0573)		
lnPL				-1.2338***		
				(0.4586)		
lnPcu					0.4143***	
					(0.1246)	
lnPcr					-0.2519***	
					(0.0863)	
lnAge0-14						-0.9188***
						(0.2805)
lnAge15-65						-3.8305***
						(0.1.130)
$\ln Age65^+$						-0.5045***
						(0.1800)
cons	-1.6774***	-2.1394***	-1.8789***	-0.2731	-2.2505***	-5.8629***
	(0.5457)	(0.5734)	(0.9888)	(0.9023)	(0.6913)	(2.2546)
Hausmann test	0.0002	0.0000	0.0326	0.0000	0.0002	0.0018
Observation	600	600	600	600	600	600
Adj-R^2	0.9376	0.9311	0.9310	0.9383	0.9387	0.9386

Note: (1) Statistical significance is indicated as follows: *P<0.10, **P<0.05, ***P<0.01. (2) Standard errors are given in parentheses.

In Table 2, the coefficient of per capita GDP is positive, but its squared form is negative. This finding is consistent with earlier studies. The total turnover of transportation and energy intensity exhibits a positive coefficient, while urbanization rate has a negative coefficient. They are correlated with transportation CO_2 emissions. Regression A is an elementary version that omits additional factors. Population growth, population distribution, population quality, living standard and age structure are introduced into the model step-by-step to ensure the rationality of the estimated coefficients. From regression B to D, we can see that population growth exhibits a positive coefficient, adult illiteracy rate has negative coefficient, while population distribution has no significant effect on transportation CO_2 emissions. From regression E, population living standard on transportation CO_2 emissions exhibits an urban - rural difference, and urban living standard was dominant in transportation CO_2 emissions. From regression F, the population share under 14, population shares aged 15–64 and over 65 are negatively and significantly correlated with CO_2 emissions of transportation. In Table 3, we used panel data from 2000 to 2015 for robustness testing, and the results show that our empirical results are robust.

In Table 2, population aging has a significant effect on transportation CO_2 reduction. Next, we investigated the path of carbon emission reduction effect of population aging, and provided a reasonable explanation for its influencing mechanism. According to theoretical analysis, population aging may affect CO_2 emissions in transportation sector through economic growth and

Table. 3. The robustness results of individual fixed regression model based on population characteristics.

	A	B	C	D	E	F
lnPGDP	1.6511***	2.0126***	1.7549***	1.7841 ***	1.7990***	2.2021***
	(0.3873)	(0.4009)	(0.4345)	(0.3930)	(0.4207)	(0.4920)
$(\ln PGDP)^2$	-0.0827*	-0.1205***	-0.0960*	-0.0920**	-0.1172**	-0.1526***
	(0.0437)	(0.0449)	(0.0504)	(0.0447)	(0.0529)	(0.0545)
lnTRAT	0.1261***	0.1018**	0.1304***	0.1444***	0.1100**	0.1163**
	(0.0460)	(0.0462)	(0.0467)	(0.0460)	(0.0472)	(0.0468)
lnURB	-0.9062***	-0.9445***	-0.8906***	-0.9042***	-0.8679***	-0.7192***
	(0.2262)	(0.2243)	(0.2283)	(0.2322)	(0.2362)	(0.2380)
lnEI	0.2876***	0.3081***	0.2935***	0.2795***	0.2814***	0.2833***
	(0.0672)	(0.0669)	(0.0682)	(0.0668)	(0.0682)	(0.0679)
lnPG		0.1389***				
		(0.0447)				
lnPI			0.1286			
			(0.2433)			
lnPQ				-0.0139		
				(0.0651)		
lnPL				-1.4838***		
				(0.5066)		
lnPcu					0.3860**	
					(0.1691)	
lnPcr					-0.1382	
					(0.1188)	
lnAge0-14						-1.1554***
						(0.3682)
lnAge15-65						-3.9874***
						(1.4259)
$\ln Age65^+$						-0.5295**
						(0.2298)
cons	-1.4827**	-2.3044***	-2.0247	-0.9789	-2.5354***	-6.5315**
	(0.6977)	(0.7400)	(1.2404)	(1.0856)	(0.9367)	(2.7972)
Hausmann test	0.0003	0.0000	0.0590	0.0003	0.0001	0.0050
Observation	480	480	480	480	480	480
Adj-R^2	0.9329	0.9342	0.9328	0.9340	0.9334	0.9340

Note: (1) Statistical significance is indicated as follows: *P<0.10, **P<0.05, ***P<0.01. (2) Standard errors are given in parentheses.

Table. 4. Mediating effect estimation results.

	First-step	Second-step		Third-step
	TCE	Economic growth	Transportation demand	TCE
lnAge3	0.2952**	0.3330***	-0.4157***	0.0851
	(0.1156)	(0.0641)	(0.1041)	(0.0893)
lnPGDP				0.8692***
				(0.0572)
lnTRAT				0.1454***
				(0.0355)
Control variables	Yes	Yes	Yes	Yes
Model selection	Fixed effects	Fixed effects	Fixed effects	Fixed effects
Obs	600	600	600	600
Adj-R^2	0.8894	0.9648	0.9399	0.9372

Note: Standard errors are shown in parentheses, and the significance is as follows:*P<0.10, **P<0.05, ***P<0.01.

transportation demand. We examined the existence of each mediation effect and established the following mediation effect model:

$$\ln TCE_{it} = \mu_i + \alpha \ln Age65^+_{it} + \theta X_{it} + \varepsilon_{it} \quad (2)$$

$$\ln Y_{it} = \mu_i + \beta \ln Age65^+_{it} + \theta X_{it} + \varepsilon_{it} \quad (3)$$

$$\ln TCE_{it} = \mu_i + \gamma \ln Age65^+_{it} + \lambda \ln Y_{it} + \theta X_{it} + \varepsilon_{it} \quad (4)$$

Where X_{it} is a group of control variables, Y_{it} is the explained variable, which including economic growth (per capita GDP) and transportation demand (total transport turnover), respectively used to test the economic growth effect and transportation development effect. Specifically, the control variables in the economic growth effect equation include total transport turnover, energy intensity, urbanization rate and population factors index. The control variables in the transportation development effect equation include per capita GDP, urbanization rate, energy intensity and population factors index. The relevant estimates are shown in Table 4.

In the first-step, the coefficient of population aging on transportation CO_2 emissions was 0.2952 at the 5% significance level. In the second-step, the coefficient of population aging on per capita GDP and total transport turnover were 0.3330 and -0.4157 at the same 1% significant level. And the coefficient of per capita GDP on CO_2 emission of transportation sector was 0.8692. The coefficient of the total transport turnover on transportation CO_2 emission was 0.1454. The results from the first and second-steps showed that the mediating effect was significant. In the third-step, the coefficient of population aging on CO_2 emissions from transportation sector was not significant. Therefore, we believed that the transmission path of population aging and CO_2 emissions from transportation was a complete indirect effect, that is, the impact of population aging on the CO_2 emissions from transportation was realized through the economic effect and the transportation demand effect.

Table. 5. The results of individual fixed regression model based on population aging.

	G	H	I
lnPFI	0.3566^{***}	0.3985^{***}	0.3696^{***}
	(0.1324)	(0.1327)	(0.1313)
lnPGDP	1.8479^{***}	2.2598^{***}	2.1059^{***}
	(0.2925)	(0.3388)	(0.3369)
$(\ln PGDP)^2$	-0.1115^{***}	-0.1534^{***}	-0.1365^{***}
	(0.0327)	(0.0372)	(0.0370)
lnTRAT	0.1401^{***}	0.1324^{***}	0.1397^{***}
	(0.03416)	(0.0352)	(0.0348)
lnURB	-0.8730^{**}	-0.9815^{***}	-1.0054^{***}
	(0.1612)	(0.1708)	(0.1688)
lnEI	0.2509^{***}	0.2763^{***}	0.2806^{***}
	(0.0571)	(0.0595)	(0.0588)
$\ln Age65^+$	0.0580	-1.7794^{**}	-19.6979^{***}
	(0.0860)	(0.7008)	(4.6641)
$(\ln Age65^+)^2$		0.9424^{***}	20.4102^{***}
		(0.3566)	(5.0236)
$(\ln Age65^+)^3$			-6.9413^{***}
			(1.7867)
cons	-2.5599^{***}	-2.5331^{***}	3.2876^{**}
	(0.6210)	(0.6388)	(1.6257)
Hausmann test	0.0000	0.0000	0.0000
Adj-R^2	0.9303	0.9389	0.9404

Note: Standard errors are given in parentheses and statistical significanceis as follows: $^{*}P<0.10$, $^{**}P<0.05$, $^{***}P<0.01$.

Based on the results in Table 2 and Table 4, we speculated that population aging may have a non-linear relationship with CO_2 emissions from the transportation sector. In order to test the hypothesis, we added regression G, H and I, and the comparison results are shown in Table 5. When other variables were fixed, there is a non-linear relationship between population aging and CO_2 emissions from the transportation sector. In regression H and I, the coefficient of $Age65^+$ and $(Age65^+)^3$ is negative, and the coefficient of $(Age65^+)^2$ is positive. The coefficients of $Age65^+$, $(Age65^+)^2$ and $(Age65^+)^3$ implied that a U-curve exists between population aging and CO_2 emissions from transportation.

2.3.2 Regional analysis

In regional level, population aging shows differences in CO_2 emissions from the transportation sector. From the data in Table 6, every 1% increase in $Age65^+$ in central region increases the transportation CO_2 emissions by 0.6539%, and every 1% increase in $Age65^+$ in western region increases the transportation CO_2 emissions by 0.2760%.

Table. 6. The results of the linear regression model with attached PCSE model.

	The eastern region	The central region	The western region
lnPFI	-0.7228^{***}	-1.4585^{***}	-1.4816^{***}
	(0.1377)	(0.3144)	(0.2540)
lnPGDP	5.9645^{***}	0.9882	2.5649^{***}
	(1.1902)	(1.1063)	(0.6564)
$(\ln PGDP)^2$	-0.6724^{***}	-0.0621	-0.2293^{***}
	(0.1390)	(0.1279)	(0.0778)
lnTRAT	0.6087^{***}	0.4097^{***}	0.6095^{***}
	(0.0553)	(0.0794)	(0.0558)
lnEI	-0.8759^{***}	0.1080^{**}	-0.1681^{***}
	(0.1820)	(0.0526)	(0.0732)
lnURB	-0.7392^{***}	-0.5097^{**}	-2.4631^{***}
	(0.2845)	(0.2453)	(0.3033)
$\ln Age65^+$	0.0378	0.6539^{***}	0.2760^{**}
	(0.1823)	(0.1832)	(0.1435)
cons	-9.7885^{***}	0.6617	0.6617
	(2.5120)	(1.5809)	(1.5809)
Observation	220	160	220
Adj-R^2	0.6961	0.8448	0.8448

Note: Standard errors are given in parentheses and statistical significanceis as follows: $^{*}P<0.10$, $^{**}P<0.05$, $^{***}P<0.01$.

2.4 Discussion

First, the population quality reduces China's transportation CO_2 emissions. A reasonable explanation is that the education level reduces CO_2 emissions by improving national environmental protection awareness. Through education, the awareness of environmental crisis has been deeply rooted in the hearts of the public, inspiring the public's sense of responsibility and participation, and making environmental awareness a habit.

Secondly, the effect of living standards on CO_2 emissions from transportation shows urban-rural differences, and urban living standard was dominant in transportation CO_2 emissions. First, economic development and resident income level are the main drivers of CO_2 emissions of per capita transportation. Second, the consumptive level of urban residents is much higher than that of rural residents, and the income gap between urban and rural areas leads to the consumption difference. In addition, [10] found that CO_2 emissions of transportation from private transport from the richest decile represent more than 10% of the total CO_2 emissions.

Thirdly, population aging is currently negatively correlated with China's transportation CO_2 emissions. This negative effect is through the combined effects of economic growth and the transportation demand, but this negative correlation is not stable. Regression I showed a U-shaped nonlinear relationship between population aging and CO_2 emission from transportation. In the early stage, the aging caused by declining fertility and increased life expectancy has led to a relative decline in the labor force and the disappearance of the demographic dividend. As people get older, they need new modes of travel, especially those that can replace driving. Trains and buses can often be used as substitutes for private cars, but even in Japan, which is famous for its extensive and efficient public transportation, such services are far from being popularized. Especially in rural areas, where the age of the population even exceeds the average level, while the traditional public transportation is scarce. Therefore, in a deeply aging society, filling the travel gap of the elderly is an important way to reduce CO_2 emissions.

Finally, the impact of population aging on China's transport CO_2 emissions exhibits regional difference. These differences may not only depend on the different degrees of aging, but be related to the level of economic development and social security system in different regions. In eastern region, the improved transportation infrastructure can meet the travel needs of different ages. So that the population in eastern has no significant on CO_2 emission from transportation. The central region is an important source of labor in the eastern coastal areas of China. Aging has the most serious impact on transportation CO_2 emissions due to the massive loss of labor and the problems in transportation. In the western region, the aging level is at the preliminary stage, but grows fast, the contradiction between the rapid increase of population aging and the backward transportation system makes the relationship between the population aging and the transportation CO_2 emission should be paid more attention.

2.5 Reference

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