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Car ownership and urban development in Chinese cities: A panel data analysis

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ABSTRACT

Growth in car ownership has significant impacts on the use of urban space and management of urban environments, which makes it a topic of increasing interest especially for developing countries such as China. The dynamics of and factors influencing ownership in Chinese cities need careful investigation. Using fixed effects models applied to annual panel data (1994–2012; 293 cities) this study aimed to achieve the following: 1) assess the relationships between car ownership and average annual income *per capita*, population, built-up area, road area *per capita*, urban population density, number of taxis and bus passenger volume; 2) examine the variation of these relationships across geographical regions (East, middle, and West China) and city sizes (cities with small, medium, large, and super-large populations). The results showed that car ownership was positively associated with average annual income *per capita*, built-up area, road area *per capita*, urban population density, and number of taxis at the national level. All associations, except with the number of taxis, varied significantly across geographical regions. Built-up area, road area *per capita*, and number of taxis had different associations with car ownership depending on city sizes. The findings improve the understanding of relationships between car ownership and urban environments vis-a-vis variations in income and infrastructure *per capita*, population density, and transportation alternatives. These results have important policy implications for managing cars and health problems related to cars in China.

1. Introduction

Growth in the number of cars has become a prominent feature of contemporary cities, as the accumulation of personal wealth and the demand for transport greatly encourage the ownership and use of cars. On one hand, cars provide convenience, but on the other hand, they place unprecedented pressure on energy conservation objectives, transport infrastructure, air quality, and human health (Pucher et al. 2007). Cities have been severely affected by health- and transport-related problems, many of which accompany growth in the number of cars, such as air pollution, traffic congestion, and shortage of parking space (Carty 1999; Clayton et al. 2014). Before taking measures to address these issues, it is necessary to understand the factors influencing car ownership. There have been a number of studies on the influential factors of the growth of car ownership in North America (Ogilvie et al. 2008; Potoglou and Kanaroglou 2008) and the European Union (Kain 2001; Mogridge and Eldridge 1970; Prieto and Caemmerer 2013); researchers have also begun showing interest in countries with emerging economies, which are experiencing fast growth in car numbers along with dramatic economic growth and urban expansion (Verma 2015; Wu et al. 2014).

Current understanding of car ownership growth is primarily a function of two lines of research. One line of research involves forecasting the growth of car ownership, based on aggregated time-series or cross-sectional data, to test its relationship with gross domestic product (GDP) and other income measures (Ingram and Liu 1999; Wu et al. 2014). The other line involves a growing body of research using disaggregated data to reveal other importance of indicators, particularly related to urban characteristics such as built-up area and urban population density, that may influence car ownership and use. However, these emerging studies are limited to cross-sectional data analysis or short-term time-series analysis for specific spatial areas (Guerra 2014; Schwanen and Wang 2014; Zhao 2011). A large-scale and longitudinal association between car ownership and urban development indicators, has not been established yet, except in terms of road metrics (Ingram and Liu 1999). Furthermore, this association may vary across geographical and/or urban features, such as different city sizes. This has not

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previously been examined elsewhere but could be pertinent in the context of China, given that it is a geographically large and heterogonous country, where the growth in car numbers could be similarly heterogonous in different cities and geographical locations with different development trajectories.

Using annual panel data for 1994–2012 from 293 prefecture-level cities in China, this study aims to achieve the following: (1) assess the relationship between car ownership and urban development measured in terms of increasing affluence, changes in population and the urban environment, and provision of transportation alternatives and (2) examine the variability in these relationships in different settings based on geographical locations (Eastern, middle, and Western China) and city size groups (cities with small, medium, large, and super-large populations). Accordingly, we developed three hypotheses as follows:

H1. Car ownership is co-influenced by variables related to wealth (annual income *per capita*), changes in population (total population and urbanization rate), urban environment (built-up areas, road area *per capita*, and urban population density), and transportation alternatives (buses and taxis);

H2. The influences of wealth, population, urban environment, and transportation alternatives on car ownership vary across regions;

H3. The influences of wealth, population, urban environment, and transportation alternatives on car ownership vary across city size groups.

The findings provide information on the dynamics of and factors influencing the growth in car numbers in China, and provide evidence for national policy-making and the development of local strategies to manage growth in cars. Next, we summarize the existing literature on the relationship between the growth of car ownership and urban development (Section 2) before describing the data and inferential methods employed in this study (Section 3). This is followed by the analytical results (Section 4) which are discussed according to the current stage of development of Chinese cites (Section 5). Finally, we conclude the study, discussing its limitations whilst offering recommendations for future research (Section 6).

2. Car ownership growth with urban development

Existing literature reveals that car ownership growth is closely related to socioeconomic development and urban development metrics, such as the urbanization rate. Wealth is a key connector between car ownership growth and societal development. After an international investigation of motorization and road provision using cross-sectional data, Ingram and Liu (1999) determined that gross national product (GNP) *per capita* is positively correlated with car ownership with a higher elasticity at the national level than at urban levels. Chamon et al. (2008) documented a non-linear relationship between gross domestic product (GDP) *per capita* and car ownership, stating that car ownership remained low up to a *per capita* annual income of approximately 5000 US dollars (USD) and then grew rapidly. Dargay and Gately (1999) predicted that vehicle purchases increased sharply for incomes in the range of 2000 USD to 5000 USD and, further, that car ownership is affected by urban development. Additionally, cross-country analyses revealed that urbanization rate was positively associated with the growth of car ownership, because larger urban populations were synonymous with higher incomes and stronger willingness to travel (Ingram and Liu 1997).

Moving from these general trends regarding the relationship between car ownership and socioeconomic and urban development, a growing body of research has started to explore and reveal the variation in car ownership levels seen across different territories at various stages of development. Metz (2013) found indications that the effect of income on car ownership lost significance when the spatial region of interest was highly developed in economic terms. Moreover, peak car theory suggests, usually in terms of motor vehicle distance travel *per capita*, that car use has saturated in the developed world, whilst continuing to grow in the developing world (David 2013). Pucher et al. (2007) stated that rapid growth of the urban population and urban sprawl were key to understanding the burgeoning increase in ownership of motor vehicles in India and China.

In addition to urbanization rates, researchers have examined high-resolution urban environment indicators, which can offer explanatory value in this context: certain disaggregated data analyses have shown that urban population density effects on car ownership and travel demand are context dependent. Further, Beesley and Kain (1964) stated that the number of car owners was negatively correlated with population density in American cities in 1960. Another study illustrated a causal relationship between car density and human travel behavior (Badoe and Miller 2000). Other disaggregate studies have involved detailed survey data pertaining to household attributes, neighborhood features, urban form, and transportation accessibility. For example, Chen and McKnight (2007) analyzed the effects of the built environment on the travel behavior of homemakers in New York; Boarnet and Crane (2001) investigated the impact of urban form on non-work trips in Orange County, Los Angles; Cervero and Kockelman (1997) examined the influences of transport intensity and accessibility on household travel in San Francisco; and Hong et al. (2014) investigated the influence of the built environment on transport behavior in Seattle. Going beyond developed country contexts, Zegras (2010) analyzed the relationship between the urban built environment and car ownership in Santiago de Chile, and Guerra (2014) argued that the relationship between urban built environment and car use in Mexico City was stronger than the relationship observed in American cities.

These findings encourage examination of the relationship between car ownership and urban development, which is a major driver of the growth in car numbers encapsulating a wide range of metrics such as road infrastructure and metrics quantifying built-up areas. Exploration of this relationship contributes to urban spatial management. Modern transport planning often employs land use patterns and road infrastructure as important mediums to modify travel demands and behaviors (Guerra 2014; Schwanen and Wang 2014; Zhao 2011). Additionally, large cities tend to impose high import duties, vehicle registration fees, parking fees, road taxes, and vehicle quotas to restrain car ownership, as is the case in Singapore and Hong Kong (Lam and Tam 2002). Alternative transport choices are encouraged, including public transportation, walking, and bicycling; however, the effectiveness of such alternatives in controlling the growth in car numbers is equivocal and requires continued investigation. Recently, some Chinese cities, including Beijing, Shanghai, and Guangzhou, started to control the number of cars by various means, such as the implementation of quota systems to limit private car ownership (Wang et al. 2014). There has been evidence to suggest that public transport services could serve to temper car ownership in Portland (Jun 2008), Yorkshire (Button et al. 1980), and Hong Kong (Cullinane 2002), although the magnitude of this effect differs across cities.

Surprisingly, most of our understanding of the heterogeneity of car ownership is implicitly dependent on disaggregated analyses of individual, selected cities (Chen and McKnight 2007; Zegras 2010; Zhang et al. 2014), which have been subject to changes in explanatory forces over time. By contrast, aggregated analyses are often limited to considering wealth related factors (Dargay and Gately 1999; Ingram and Liu 1999), which needs to be improved upon by incorporating alternative potential explanatory variables as identified by disaggregated analyses. Evidence from aggregate analyses covering a long time period could illuminate an overall picture of the influences of multifaceted urban characteristics on car ownership. There is also a need to examine car ownership explicitly based on the demographic and locational characteristics of cities.

3. Data and methods

3.1. Data

This study was conducted at the prefecture-city level in mainland China. Data were collected from the China City Statistical Yearbooks, and the analysis spanned 1994 to 2012, which was a period of rapid economic development and urbanization in Chinese cities with concomitant growth of car ownership. However, as data were missing for some cities for the period under consideration, the final sample is constituted by 293 of the 336 prefecture-level cities. Owing to increasing traffic congestion, some cities have issued regulation policies such as the rolling of purchases, which affected car ownership after 2010 (*e.g.*, in Beijing in 2011, Guangzhou in 2012, and Tianjin in 2013). However, these policies have little impact in analytical terms. We denoted each city as Eastern, middle, or Western in terms of geographical region (Fig. 1). For analytical purposes we also ranked all cities by their total population based on Census 2010, which provided the basis for categorizing cities into size quartiles: small city (<=2.31 million), medium-size city (>2.31–3.53 million), large city (>3.53–5.81 million), and super-large city (>5.81 million).

3.2. Variables

The car ownership rate in a given city was used as the dependent variable, representing the number of private cars (intended for private household use) owned per 1000 persons. Compared with total car ownership, car ownership rate is a better indicator of the willingness to own cars, and its usage avoids the estimation bias associated with total population size.

The framework we used for modelling car ownership and urban development was based on the socioeconomic and urban characteristics of cities, including eight independent variables. Given the strong correlation between GDP *per capita* and income, average income was selected to measure the wealth of a city. Population variables included total population size and urbanization rate. Urbanization rate was calculated by the ratio of urban population to total population, reflecting the relative number and mobility of people living in cities and, therefore, contributing to the growth of car ownership (McIntosh et al. 2014). By balancing the importance of factors vis-à-vis data availability, the urban environment in this study was examined in terms of the size of the built-up area (developed area with urban facilities and services), road area *per capita*, and urban population density to assess the influences of urban expansion, improvement in road systems, and density of urban development on car ownership (Badoe and Miller 2000; Guerra 2014; Schwanen and Wang 2014; Zhao 2011). Urban population density was calculated by dividing urban population by built-up area. Regarding transportation alternatives, although subways are increasing in importance, they do not exist in every Chinese city. Chinese people frequently use public buses in their daily lives, and the government promotes their use in order to deter private cars. Thus, bus passenger volume was used to reflect a dimension of transportation alternatives (Meek et al. 2010; Moutou and Greaves 2014; Paulley et al. 2006). Further, taxis were also included as another component of transportation alternatives due to their d frequent use.

Car ownership rate and its potential influential factors across all cities, regions and city sizes in 2012 are presented (Table 1) which provides the most recent cross-sectional profile of all variables included in the models herein. The mean car ownership rate was 68 per 1000 persons in the Eastern cities, higher than 35 and 52 per 1000 persons in the middle and Western cities, respectively. Annual income *per capita* ranged from 11,216 Chinese *yuan* (CNY) to 36,350 CNY (about 1725 USD to 5592 USD), and the Eastern cities were more affluent compared to those in other regions. Residents in super-large and small cities exhibited higher average incomes compared to residents in large and medium-size cities. Cities differing in terms of their location and sizes, also exhibited differences in terms of their populations, urbanization rates, built-up area, road area, bus usage, and number of taxis, thereby implying differences in car ownership trends are a function of these different urban trajectories.

3.3. Statistical analysis

Panel data analysis methods were used to quantify the explanatory value of the above-mentioned urban characteristics on car ownership between 1994 and 2012. In order to avoid non-stationary time-series and spurious regressions, four types of unit root tests were conducted for each variable, namely the PP–Fisher chi-square test (Maddala and

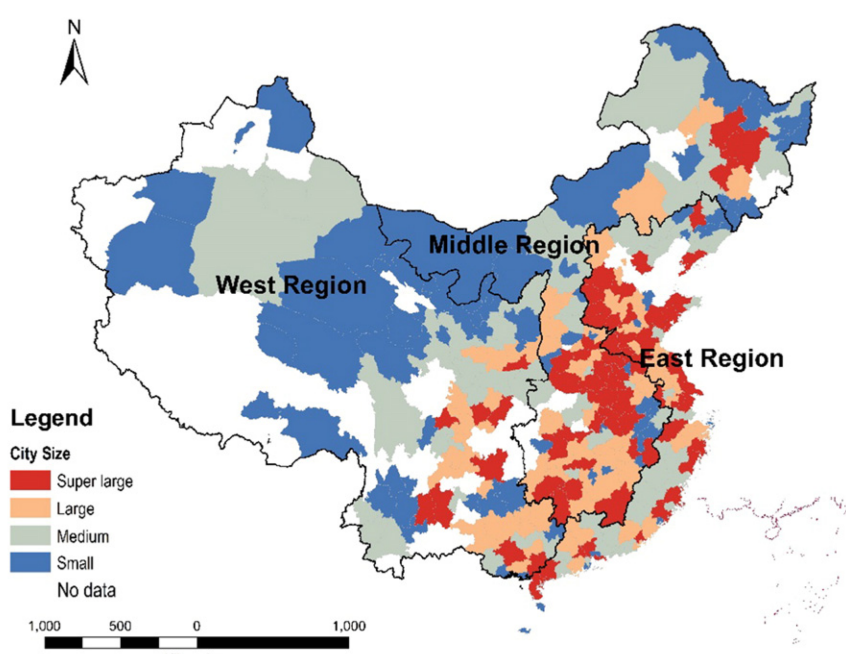

Fig. 1. Size and geography of Chinese cities.

Table 1
Descriptive statistics of car ownership and the potential influential factors in 2012.
Data sources: China Statistical Yearbook, 2013.

	Number of cities		Car ownership rate (per 1000 persons)	Annual income *per capita* (Chinese yuan)	Total population (1000 persons)	Urbanization (%)	Built-up area (km^2)	Road area *per capita* (m^2 per person)	Urban population density (1000 persons/km^2)	Bus passenger volume (1000 person trips)	Number of taxis
China	293	Mean	52	17,711	4341	48	112	11	13	199,330	2779
		Min	7	11,216	460	23	14	1	2	530	115
		Max	407	36,350	28,850	100	1186	68	72	5,051,440	66,646
		S.D.	47	4817	3264	26	152	7	9	457,872	5172
By Region											
East	101	Mean	68	20,724	5219	49	165	13	11	320,814	4190
		Min	7	12,711	685	25	19	3	5	1840	188
		Max	407	36,350	23,030	100	1186	34	37	5,051,440	66,646
		S.D.	51	6435	3493	27	209	6	6	677,631	7799
Middle	101	Mean	35	16,404	4337	53	86	11	13	131,736	2311
		Min	11	11,698	740	23	17	4	5	4210	271
		Max	141	26,313	12,244	100	500	30	39	1,536,040	16,967
		S.D.	25	2522	2626	24	83	5	7	225,351	2910
West	91	Mean	52	16,076	3370	42	81	9	15	139,517	1724
		Min	9	11,216	460	23	14	1	2	530	115
		Max	237	27,774	28,850	99	870	68	72	1,624,000	13,979
		S.D.	55	3061	3397	25	118	8	12	297,070	2441
By size of cities											
Small	73	Mean	66	18,163	1385	39	58	10	10	71,127	1577
		Min	15	11,817	182	23	19	1	2	610	115
		Max	407	36,350	2306	99	230	26	36	735,260	7671
		S.D.	68	4805	633	28	38	5	7	111,262	1467
Medium	73	Mean	45	16,050	2918	46	68	12	14	90,142	1856
		Min	7	11,216	2318	23	14	1	5	2470	152
		Max	193	27,774	3534	97	343	68	39	734,900	7950
		S.D.	37	3329	363	19	57	9	9	123,299	1887
Large	73	Mean	40	16,668	4617	55	87	10	15	116,506	1816
		Min	9	12,295	3554	23	18	2	5	530	260
		Max	141	30,166	5814	100	326	28	72	589,860	8652
		S.D.	30	3366	614	25	59	5	10	134,405	1818
Super large	74	Mean	58	19,682	8483	53	228	12	12	521,301	6079
		Min	9	11,698	5818	23	32	3	2	7610	188
		Max	201	35,739	28,850	98	1186	32	33	5,051,440	66,646
		S.D.	44	6111	3713	27	252	6	7	814,478	9465

Wu 1999); PP–Choi test (Choi 2001); Levin, Lin, and Chu (LLC) test (Levin et al. 2002); and Im, Pesaran, and Shin (IPS) test (Im et al. 2003). The results of these tests indicated that all the variables were integrated of order one (Tamakoshi and Hamori 2014). The Johansen-Fisher test (Baltagi and Kao 2001) proved the non-existence of co-integration among sequences whilst the results of a Hausman test confirmed the appropriateness of a fixed effects model (FEM) over a random effects model (REM). Therefore, the FEM was used to estimate and explore the relationship between car ownership and the factors influencing it. By definition FEM remove the effect of time-invariant characteristics on the dependent variable. This enabled the assessment of the net effect of time-variant factors on car ownership.

A theoretical model that used all potential factors to estimate the car ownership rate can be written in natural logarithmic form as follows:

$$\begin{aligned}\ln y_{it} = {} & \alpha_i + \beta_1 \ln(Income_{it}) + \beta_2 \ln(TP_{it}) + \beta_3 \ln(Urb_{it}) \\ & + \beta_4 \ln(BUA_{it}) + \beta_5 \ln(Road_{it}) + \beta_6 \ln(UrbDen_{it}) \\ & + \beta_7 \ln(Bus_{it}) + \beta_8 \ln(Taxi_{it}) + \varepsilon_{it}, \end{aligned} \quad (1)$$

where y_{it} was the car ownership rate in city i during year t (per 1000 persons), *Income* was the average annual income *per capita* (CNY, the Chinese monetary unit), *TP* was the total population (1000 persons), *Urbanization* was the percentage of the population in urban areas (%), *BUA* was the total built-up area (km^2), *Road* was the area of roads *per capita* (m^2 per person), *UrbDen* was the urban population density (1000 persons per km^2), *Bus* was the yearly volume of bus passengers (1000 person trips), *Taxi* was the total number of taxis, α_i was a city-specific constant term in the regression model, and ε_{it} denoted the error term.

Each independent variable was first entered into a separate model. All significant variables in across these separate models were then simultaneously entered into one overarching model. Variables which became insignificant in this overarching model were then removed. Next, we employed interaction terms to test for differences in the effects of the remaining variables on car ownership across regions and city sizes. We also performed cross-validation checks to assess the model's ability to fit out-of-sample data by randomly splitting the data into five sub-samples: four used as training sets, one used for testing. The average mean absolute error (MAE) and *pseudo*-R^2 were calculated to compare the models. The variable(s) whose exclusion from the model can produce significantly higher MAE and lower *pseudo*-R^2 were dropped from the final model. All analyses were conducted in Stata (version 14; StataCorp., College Station, TX).

4. Results

The model indicated that car ownership at the national level is significantly associated with income, built-up area, road area *per capita*, urban population density, and number of taxis (Table 2). The influence of these factors further varies across regions and different city size groups (Tables 2 and 3). Following cross-validation, three factors were ruled out: total population, urbanization rate, and bus passenger volume. The findings support the notion that car ownership in Chinese cities is co-influenced by wealth, urban environment, and transportation alternatives (H1), and these influences differ across regions (H2) and city size groups (H3); however, the findings do not suggest that car ownership is affected by changes in population.

Table 2
Associations between car ownership and influential factors across all cities (1994–2012).

Regressor ($n = 293$)	Coefficient (S.E.)
Annual income *per capita*	1.13^{***} (0.03)
Built-up area	0.59^{***} (0.06)
Road area *per capita*	0.35^{***} (0.04)
Urban population density	0.34^{***} (0.05)
Taxi number	0.17^{***} (0.04)

Boldfaced numbers indicate statistical significance ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

4.1. Car ownership across cities

At the national level, a 1% increase in annual income *per capita* was associated with a 1.13% ($p < 0.001$) increase in car ownership, which is greater than the proportional effects of any other variable used in this study (Table 2). The average annual income *per capita* across all cities ranged from 11,216 CNY to 36,350 CNY with a mean of 17,711 CNY (Table 1), approximately equivalent in range to 1800 USD to 5800 USD.

In terms of effects on car ownership, income therefore suggested the largest association followed by variables pertaining to the urban environment and transport alternatives. The urban environment was characterized by three metrics in this study: road area *per capita*, built-up area, and urban population density. A1% increase in built-up area resulted in a 0.59% increase in car ownership whilst the same proportional increases in road area *per capita* and urban population density resulted in a 0.35% and 0.34% increase in car ownership respectively. Further, a 1% increase in the number of taxis was associated with a 0.17% increase in car ownership ($p < 0.001$) with the volume of bus passengers excluded on the grounds of overfitting.

Both indicators of urban population, total population and urbanization, were dropped from the final models after cross-validation: overlap is possible with other included variables, for example there is high correlation between total population and the built-up area.

4.2. Car ownership across regions

All five potential influential variables that were significant above in the context of all cities continued to exert significant positive influences on car ownership in each region, with the exceptions that insignificant effects of urban population density and number of taxis were estimated for the middle region (Table 3). However, and interestingly, nuances existed among different regions in terms of the explanatory strength of some variables (Table 3). For example, the effect of annual income *per capita* on car ownership in the Western region was significantly weaker than that in the Eastern (0.36% less for each 1% increase in income) and middle regions (0.24% less for each 1% increase in income), while no significant differences were found between the Eastern and middle regions. Beyond income, the built-up area had a significantly stronger effect on car ownership in the Western region (1.07) than in the Eastern (0.58% less) and middle regions (0.79% less). The influences of urban population density were also significantly stronger in the Western (0.71%) than in the East (0.54% less) and middle regions (0.50 less). Road area *per capita* exerted a stronger effect in the East region (0.55%) than in the Western region (0.28% less). No significant differences were found in the effects of the number of taxis on car ownership in any of the three regions.

4.3. Car ownership across city size groups

All five factors that were significant above in the context of all cities continued to have significant positive effects on car ownership in the models stratified by city size, excepting the insignificant effect of the number of taxis in small cities (Table 4). However, there were slight but significant nuances across city sizes in terms of association strengths (Table 4). For example, the built-up area had a significantly stronger effect on car ownership in large cities (0.80%) than in medium cities (0.31% less). Road area *per capita* had the strongest effect in medium cities (0.81%), followed by super-large (0.36% less), large (0.50% less), and small cities (0.64% less), with the difference between super-large and

Table 3
Associations between car ownership and influential factors by region (1994–2012).

Regressor[†]	Coefficient (S.E.) East ($n = 101$)	Middle ($n = 101$)	West ($n = 91$)
Income (ref)	**1.29^{***} (0.06)**	**1.16^{***} (0.06)**	**0.92^{***} (0.06)**
Income*E	–	0.13 (0.08)	**0.36^{***} (0.08)**
Income*M	−0.13 (0.08)	–	**0.23^{**} (0.08)**
Income*W	**-0.36^{***} (0.08)**	**-0.24^{**} (0.08)**	–
BUA (ref)	**0.49^{***} (0.08)**	**0.27^{*} (0.14)**	**1.07^{***} (0.15)**
BUA*E	–	0.22 (0.16)	**-0.58^{**} (0.17)**
BUA*M	−0.22 (0.16)	–	**-0.79^{***} (0.21)**
BUA*W	**0.58^{**} (0.17)**	**0.79^{***} (0.21)**	–
Road (ref)	**0.55^{***} (0.08)**	**0.36^{***} (0.08)**	**0.27^{***} (0.06)**
Road*E	–	0.18 (0.12)	**0.28^{**} (0.10)**
Road*M	−0.18 (0.12)	–	0.10 (0.10)
Road*W	**-0.28^{**} (0.10)**	−0.10 (0.09)	–
UrbDen (ref)	**0.17^{**} (0.07)**	0.21 (0.12)	**0.71^{***} (0.14)**
UrbDen*E	–	0.04 (0.14)	**-0.54^{***} (0.15)**
UrbDen*M	−0.40 (0.14)	–	**-0.50^{**} (0.19)**
UrbDen*W	**0.54^{***} (0.15)**	**0.50^{**} (0.19)**	–
Taxi (ref)	**0.17^{**} (0.06)**	0.07 (0.10)	**0.14^{*} (0.06)**
Taxi*E	–	0.10 (0.12)	0.02 (0.09)
Taxi*M	−0.10 (0.12)	–	−0.08 (0.12)
Taxi*W	−0.02 (0.09)	0.08 (0.12)	–

Note: [†]Income: annual income *per capita*; BUA: built-up area; Road: road area *per capita*; UrbDen: urban population density; Taxi: taxi number; E: East region; M: middle region; W: West region.
Boldfaced numbers indicate statistical significance ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

Table 4
Associations between car ownership and influential factors by city size (1994–2012).

Regressor[†]	Coefficient (S.E.) Small ($n = 73$)	Medium ($n = 73$)	Large ($n = 73$)	Mega ($n = 74$)
Income (ref)	**1.07^{***} (0.07)**	**1.14^{***}(0.07)**	**1.06^{***} (0.06)**	**1.06^{***} (0.08)**
Income*S	–	−0.07 (0.09)	0.02 (0.10)	0.02 (0.10)
Income*M	0.07 (0.09)	–	0.08 (0.09)	0.08 (0.10)
Income*L	−0.02 (0.10)	−0.08 (0.09)	–	0.00 (0.10)
Income*SL	−0.02 (0.10)	−0.08 (0.10)	−0.00 (0.10)	–
BUA (ref)	**0.66^{**}(0.20)**	**0.50^{**}(0.15)**	**0.80^{***}(0.10)**	**0.57^{***}(0.12)**
BUA*S	–	0.16(0.25)	−0.14(0.23)	0.09(0.24)
BUA*M	−0.16(0.25)	–	**-0.31^{*}(0.18)**	−0.08(0.20)
BUA*L	0.14(0.23)	**0.31^{*}(0.18)**	–	0.23(0.16)
BUA*SL	−0.09(0.23)	0.08(0.20)	−0.23(0.16)	–
Road (ref)	**0.17^{*}(0.08)**	**0.81^{***}(0.12)**	**0.31^{***}(0.06)**	**0.45^{***}(0.11)**
Road*S	–	**-0.64^{***}(0.14)**	−0.14(0.10)	**-0.28^{*}(0.13)**
Road*M	**0.64^{***}(0.14)**	–	**0.50^{***}(0.13)**	**0.36^{*}(0.16)**
Road*L	0.14(0.10)	**-0.50^{***}(0.13)**	–	−0.14(0.12)
Road*SL	**0.28^{*}(0.13)**	**-0.36^{*}(0.16)**	0.14(0.12)	–
UrbDen (ref)	**0.47^{*}(0.19)**	**0.33^{*}(0.14)**	**0.24^{**}(0.08)**	**0.37^{***}(0.11)**
UrbDen*S	–	0.13(0.24)	0.23(0.20)	0.10(0.22)
UrbDen*M	−0.13(0.24)	–	0.09(0.16)	−0.04(0.18)
UrbDen*L	0.23(0.20)	−0.09(0.16)	–	−0.14(0.13)
UrbDen*SL	−0.09(0.22)	0.04(0.18)	0.14(0.13)	–
Taxi (ref)	0.04(0.10)	**0.22^{**}(0.08)**	**0.22^{**}(0.08)**	**0.14^{*}(0.07)**
Taxi*S	–	**-0.27^{*}(0.13)**	**-0.27^{*}(0.13)**	−0.19(0.12)
Taxi*M	**0.27^{*}(0.13)**	–	0.00(0.11)	0.08(0.11)
Taxi*L	**0.27^{*}(0.13)**	−0.00(0.11)	–	0.08(0.10)
Taxi*SL	0.19(0.12)	−0.08(0.11)	−0.08(0.10)	–

Note: [†]Income: annual income *per capita*; BUA: built-up area; Road: road area *per capita*; UrbDen: urban population density; Taxi: taxi number; S: small cities; M: medium cities; L: large cities; SL: Super-large cities.
Boldfaced numbers indicate statistical significance ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

large cities not of statistical significance. The number of taxis had equally strong effects in medium and large cities compared to a lesser effect in small cities. No significant differences were found in the effects of annual income *per capita* and urban population density on car ownership cities of different sizes.

5. Discussion

Car ownership has become an important issue in China with the rise of car use. Wu et al. (2014) used GDP *per capita* to quantify and understand car ownership in China using member countries of the Organization for Economic Cooperation and Development (OECD) as a comparator. Li et al. (2010) modeled car ownership using cross-sectional data for 36 major Chinese cities, with a focus on urban form. Zhang et al. (2014) examined the links between household car trips and the urban environment, particularly neighborhood characteristics in Zhongshan, Guangdong, China. This research has expanded upon previous studies such as these by employing a panel data set (spanning 19 years for nearly all prefectural cities in China-293 out of 297) to better understand the spatial and temporal dynamics between car ownership and urban characteristics influencing it.

Since the late 1990s, China has been rapidly urbanizing. From 1990 to 2013, the urban population increased from 302 million to 731 million, while China's urban footprint, as indicated by the urban built-up areas, expanded from 13,148 km^2 to 47,855 km^2 (China Statistical Bureau 2014). The soaring development of Chinese cities during this period was paralleled by an increase in car ownership, which rose from 0.17 million in 1984 to 88.4 in 2012 (China Statistical Bureau 2014). As the country with the fastest growing vehicle fleet, China surpassed the United States to become the world's largest market for cars in 2009 (China Daily 2010). If this trend continues, it is estimated that by 2030, about 30% of total carbon emissions would be from the transportation sector (Li and Zhang 2014), which would further deleteriously affect air quality metrics (He et al. 2011). Therefore, understanding the dynamics of and factors influencing the growth of car ownership has important policy implications for managing cars/transportation and health problems related to cars in China.

By definition, moving beyond cross-sectional data to panel data substantially increases the data available for estimating the demand for cars and makes it possible to exploit time-series information for quantifying and understanding temporalities in car use. Panel data permits more accurate inferences of model parameters and provides greater capacity for capturing the complexity of the influences on car ownership than cross-sectional data alone (Baltagi 2015). However, the city-level variables in our model were aggregated by the Statistical Bureau of each city based on surveys of sampled households with a wide range of demographic and socioeconomic characteristics; thus, these variables should be used and interpreted with caution (Walker and Catrambone 1993). For example, use of average annual income *per capita* may potentially incur aggregation bias or ecological fallacy problems due to considerable heterogeneity in individuals' income levels within cities. More information related to the tested hypotheses is provided and discussed below.

At the national level, wealth or income is a major factor influencing growth of car ownership in China. In 2012, there were 277 (out of 293) cities where the average level of annual income *per capita* ranged from 2000 to 5000 USD, and there has been a sharp rise in vehicle purchases worldwide by people in this salary range (Dargay and Gately 1999). Therefore, a large proportion of Chinese cities are at an accelerating stage of car growth driven by increases in income; however, experiences from developed countries have shown that, as people became more affluent, income-driven growth in car ownership eventually slows down or even plateaus beyond a critical level of *per capita* income (Metz 2013).

In addition, urban spatial development contributes significantly to growth in the number of cars. There have been substantial investments in urban construction, with 16.3 billion CNY spent on urban infrastructure in 2013, which is about 16 times the investments in 1995 (Ministry of Construction of P. R. China 2014), as shown by Fig. 2. The urban spatial environment, including dramatic urban sprawl, has enabled and generated higher vehicular mobility. The built-up area in China expanded from 13,148 km^2 to 47,855 km^2 from 1995 to 2013, with 5810 km^2 of roads built during this period. Given the rapid economic development of China, previous research has only used GDP or income *per capita* to explore the factors that affect car ownership in China (Huang 2011; Wu et al. 2014). In contrast, this study showed that car ownership growth in China was a function of annual income *per capita*, built-up area, road area *per capita* and urban population density.

Intuitively, car ownership and public transportation systems may complement each other. Therefore, two alternative transportation modes, buses and taxis, were examined in this study. However, bus passenger volume was excluded due to overfitting issues. A positive effect of the number of taxis on the growth of car ownership may imply that taxis are more likely to be a complementary mode of transportation rather than a replacement, especially in contemporary China where taxi services are provided in a convenient and relatively cheap manner. A positive relationship is likely to exist between annual income *per capita* and demand for taxi services, possibly to the extent that taxis could proxy for income to some extent.

The relationship between car ownership and influential factors should be closely examined by region and city size. Indeed, our findings show that the degree of influence of these factors is very context specific. In the Western region, the built-up urban area had the largest proportional effect on car ownership (1.07% increase in car ownership for 1% increase in built up area), followed by income (0.92% for 1%). Urban population density presented no significant relationship with car ownership in cities in the middle region, although this relationship was significant at the national level.

These findings support the notion that car ownership may differ across cities in different geographical regions (Komornicki 2003). China is a large country with significant regional disparities, and is generally divided into Eastern, middle, and Western regions (Fig. 1) for the purposes of geographical research and policy-making, demarcated according to historical, natural, and socioeconomic phenomena. From east to west, the landscape roughly shifts from the coastal to inland mountainous areas with regional development stages from high to low, which account for the various lifestyles (Dunford and Liu 2015; Yang et al. 2015). With differences in economic development levels, people in cities in these different regions may have different propensities for owning cars. From 1994 to 2012, the number of private cars

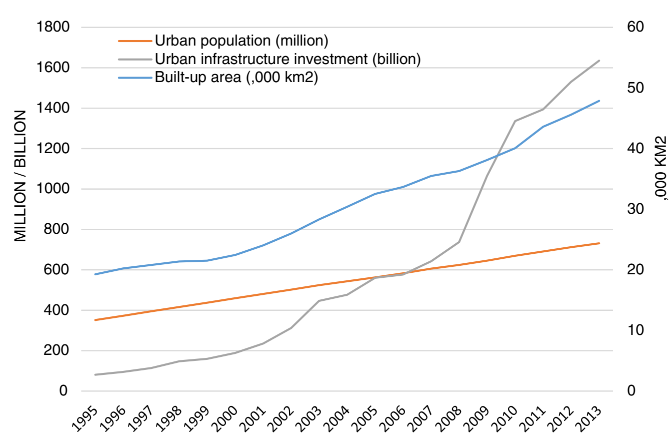

Fig. 2. Growth of urban population, urban infrastructure investments, and urban built-up areas.
Data sources: China Statistical Yearbook, 2014; China City Construction Statistical Yearbook, 2014.

increased 45, 36, and 44 times, respectively, in the Eastern, middle, and Western regions (Fig. 3). In 2012, most private cars were in the Eastern cities (58%), and only 17% were in the Western cities. Therefore, geographical location is pertinent to understanding car ownership in Chinese cities.

Factors influencing car ownership exhibit different relationships of different strengths in cities of different sizes. Cities with different population sizes normally have different development trajectories (Turok and Mykhnenko 2007). Fig. 4 illustrates different car ownership growth trends in Chinese cities. In general, although all cities in China have grown over the past 30 years, populous cities have developed relatively fast. Cities including provincial capitals with populations of 5–10 million, particularly Beijing, Shanghai, and Guangzhou, are regional centers of China and have become magnets for human and financial capital. This has gradually connected these cities to global markets (Yang et al. 2013), while others have remained disconnected from the globalization process and seem less attractive to people and investment. This indicates that there are different urban characteristics of cities with different sizes, and there are differences in how these characteristics serve to determine car ownership. As our findings show, road area *per capita* had significantly different associations with car ownership among small, medium-size, and super-large cities. The effect of the built-up area was largest for large cities (0.8% at $p < 0.001$ level), which is significantly higher than that for medium-size cities (0.3% at $p < 0.05$ level). In 2012, 57% of the private cars were concentrated in super-large cities, while small and medium-size cities only accommodated 9% and 13% of cars, respectively (Fig. 4). Therefore, there is more pressure on car-related urban management in super-large cities.

6. Conclusions

With increasing affluence, urban development, and negative impacts of car usage such as air pollution and shortage of parking space, exploring the factors influencing the growth in car ownership is of strategic importance in contemporary China. Overall, the growth of car ownership has been driven by income and urban environment metrics over the past two decades. More importantly, this study clearly conveys a message that the relationship between car ownership and its influential factors varies across regions and city sizes. Compared with previous studies that mostly focused on income or GDP indicators (Huang 2011; Wu et al. 2014), this study expands along multiple dimensions (*i.e.*, spatial, and temporal) to examine the effects of both socioeconomic and physical metrics of urban development that could potentially affect car ownership. The findings suggest that use of only income or GDP *per capita* is insufficient to understand the growth of car ownership, which turns out to be determined by a combination of financial and urban physical environment variables.

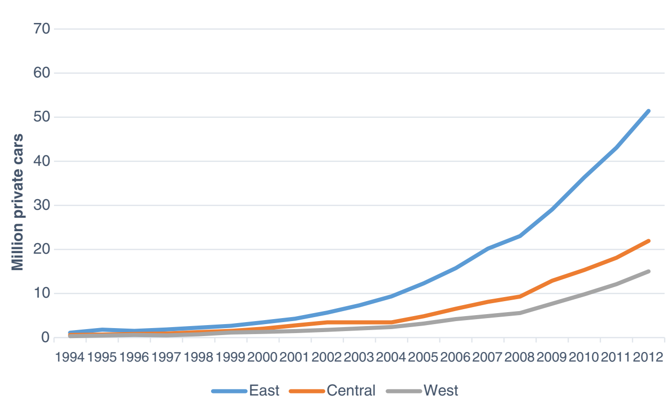

Fig. 3. Growth of private cars in China by region.
Data sources: China City Statistical Yearbooks, 1995–2013.

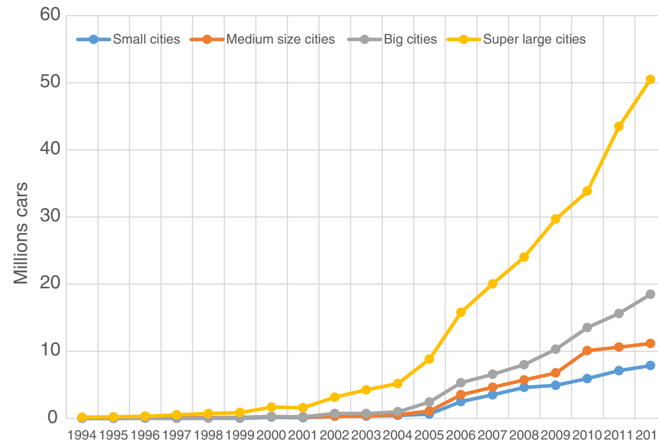

Fig. 4. Growth of private cars in China by city size.
Data sources: China City Statistical Yearbooks, 1995–2013.

Our findings have important implications for urban planning and spatial management. Urban planners should manage the relationship between growth in car ownership and urban spatial development in a systematic way. Besides wealth, physical metrics have important influences on the growth of car ownership. Therefore, urban planners should carefully heed the relationship between growth in car ownership and urban spatial development, operationalized in terms of the urban built-up area, road area *per capita*, and urban population density. Judicious planning would be beneficial in the context of effective management of automotive transportation and health problems related to cars in China. Furthermore, due to the variation of the above-mentioned relationships across regions and city size groups (Tables 3 and 4), planning and management should be tailored for different contexts as per our findings.

This study is not without limitations. First, it is difficult to measure urban trajectories *per se*. This study uses geographical location and population size as proxies thereof, similar to the approach taken by many urban scholars. The study could be improved if more urban characteristics were explored, such as urban form. Second, some relevant factors that are not available on a large scale and were thus not included in our study include subways. Third, variables aggregated for city level analysis are a potential source of bias due to large variances within resident populations; therefore, individual-level data would be useful to quantify and account for this accordingly. Fourth, the total population in Census 2010 was selected as a criterion to classify cities, and this classification was used across the entire 19-year study period, but an argument could be made for employing a time-variant classification. Lastly, the nuances of Chinese institutional management among different cities and effects of associated policy interventions were not considered in this study. For example, due to increasingly severe traffic congestion, some cities have implemented regulation policies such as raffling a certain number of permissions to purchase cars (*e.g.*, in Beijing in 2011, Guangzhou in 2012, and Tianjin in 2013) and requiring special permissions to drive cars. The extent to which such policies have affected car use patterns and car ownership is one avenue for future research.

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