

Urban Spatial Structure and Motorization in China

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ABSTRACT

Using data from 161 Chinese cities, this paper investigates the effects of various dimensions of urban spatial structure on the ownership and commute mode split of automobile. Results confirm the positive effects of city size on auto ownership and mode split and the negative effect of density on auto ownership. Echoing a small number of studies, this research discovers the seemingly counterintuitive effect of jobs-housing balance on the use of automobiles, probably due to the potential advantage of public transit relative to driving in dense and congested Chinese cities. Cities should emphasize public transit and maintain density in the future.

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1 INTRODUCTION

Motorization, in particular the purchase and use of private automobiles, is a worldwide phenomenon that has immense economic, environmental, and sociopolitical implications, especially in an increasingly urbanized world (Sperling and Gordon, 2009). The question of what determines motorization has attracted the attention of academics as well as the private sector and national and local governments for a long time. At the national level, the empirical literature points to rising per capita income as a primary determinant of motorization (e.g., Dargay and Gately, 1999), although government intervention on vehicle ownership and use (e.g., through vehicle and fuel prices) also matters. At the metropolitan level, congestion becomes a concern (Ingram and Liu, 1997). Aside from the idiosyncratic local transportation policies such as the provision of public transit and various demand management strategies, urban spatial structure, and more generally the built environment has concerned transportation, environmental, and urban scholars due to theoretical predictions (e.g., Boarnet and Crane, 2001) and policy interests in reducing dependence on driving, traffic congestion, and related environmental and health impacts through spatial planning of urban regions. For example, many consider urban density as a primary factor explaining the difference in the level of motorization across cities of similar income levels (e.g., Kenworthy and Laube, 1996; Ingram and Liu, 1997; Ewing and Cervero, 2001; Brownstone and Golob, 2009). Research on the behaviors of individuals and households has provided rich evidence about the linkage between private decisions on automobile ownership and use and the built environment, especially at the neighborhood scale. However, few have systematically investigated at the metropolitan level whether and how more nuanced but potentially important aspects of spatial structure, such as the relative locations of jobs versus housing and the intra-city spatial variation in density, impact motorization. Moreover, the joint

consideration of automobile ownership and use seems insufficient at the aggregate levels despite the fact that regions with similar vehicle ownership rates may have very different patterns of usage (e.g., Canada vs. Japan).

This study aims to enhance the literature by empirically investigating the relationship between urban spatial structure and the ownership and use of private automobiles in China today. Due to its rapid income growth, urbanization and motorization, China has quickly risen to the leading market of new automobiles, the biggest net importer of oil, and the largest emitter of greenhouse gas in the world. Residents in Chinese cities today are traveling longer distances, making more trips, and relying more on fossil fuel-based modes. Rapidly worsening urban traffic congestion and air pollution in China have attracted a great deal of international attention and domestic policy responses such as transit investment, auto ownership restrictions, and driving restrictions recently (e.g., Sun et al., 2014). To address the motorization challenge, it is important to rely on not just the expansion of transit infrastructure and the regulation of consumer behavior, but also well-informed urban spatial planning. This can be critical for the long-term urban sustainability and efficiency as China's cities are quickly transitioning from the socialist urban landscape (Bertaud and Renaud, 1995) to an urban space that is increasingly shaped by the labor, land, and travel markets.

Using data from 161 medium-sized and large Chinese cities, where we have sufficient data to measure urban spatial structure, we estimate the relationship between motorization and the overall spatial pattern of cities, controlling for the level of economic growth (or income) and the provision of road and transit infrastructures. Our approach illustrates the interaction between two dimensions of motorization: city-level auto ownership and automobile mode split among commuters. This study provides one of the earliest pieces of evidence on how urban spatial

structure may inhibit or stimulate auto ownership and usage at the city scale, especially in the developing world. Our findings yield important implications for urban decision makers and planners in China and similar emerging economies. The rest of the paper begins with a review of relevant literature, followed by the explanation of method and data. Then the paper presents and discusses the results of analysis. The last section offers concluding remarks together with future research priorities.

2 LITERATURE REVIEW

There is a substantial amount of research on the determinants of private automobile ownership (see reviews by De Jong et al., 2004 and Anowar et al., 2014) and perhaps an even bigger literature directly on automobile usage, often as part of the broader topic of travel demand and behavior. Traditional engineering and economic analyses of motorization emphasize socio-demographics, transportation infrastructure and level of service, and of course, the pricing of vehicles, fuels, roads, parking, etc. (e.g., Ben-Akiva and Lerman, 1985; Ortuzar and Willumsen, 2011). The past few decades have also seen an increasing amount of attention devoted to the role of the built environment or the form of land use in urban regions. Several reviews of this literature, such as Crane (2000), Guo and Chen (2007), Mokhtarian and Cao (2008), NRC (2009) and Ewing and Cervero (2010) have shown that features of the built environment (mainly at the neighborhood scale), such as the “three Ds” (density, diversity or land use mix, and design related to comfort, safety or interest of travelers) and street pattern (or connectivity), are often associated with different aspects of travel behavior including vehicle ownership, trip frequency, travel distance, mode choice, etc. A smaller number of studies have also paid attention to the mobility implications of spatial structure at the city or metropolitan scale, such as the more analyzed aspects of city size and average density (Izraeli and McCarthy, 1985; Gordon, Kumar

and Harry, 1989; Kenworthy and Laube, 1996; Schwanen, 2002; Lee, Gordon, and Richardson, 2009; Cervero and Murakami, 2010), jobs-housing balance (Cervero, 1989, 1996; Peng, 1997; Sultana, 2002; Bento et al, 2005; Wang and Chai, 2009), and various measures of spatial clustering including the dominance of city center and more generally the degree of polycentricity (Izraeli and McCarthy, 1985; Levinson, 1998; Schwanen et al., 2004; Bento et al, 2005; Ma and Banister, 2007; Modarres, 2011). Overall, these studies suggest that people in larger, less dense, more jobs-housing imbalanced, and more sprawled (thus less centralized) urban regions tend to rely more on private motor vehicles. Evidence seems stronger and more consistent for city size, density, and jobs-housing balance, although Peng (1997) stresses the nonlinear relationship between jobs-housing balance and vehicle miles traveled. While the effect of polycentric urban development (not merely centralization) on travel behavior, especially among commuters, is less clear.

Instead of providing a comprehensive review of factors influencing motorization, below we review the relevant literature noting the two broad categories of approaches to study auto ownership and usage: disaggregate studies of individual and/or household decisions and aggregate analysis of populations grouped at the zone, regional, or national levels.

Emphasizing the behavioral structure of individuals and households, disaggregate studies of auto ownership and usage dominate the literature in both quantity and depth. This stream of literature includes both relatively straightforward empirical analyses of cross-sectional or longitudinal data (e.g., Bento et al., 2005; Dargay and Hanly, 2007; Matas and Raymond, 2008; Nolan, 2010) and those (usually partially) taking into consideration the complicated interdependencies among multiple dimensions of private decisions such as auto ownership, travel (mode, frequency, distance), and residential location (e.g., Ben-Akiva and Lerman 1974;

Kitamura, 1989; De Jong 1990; Bhat and Guo, 2007; Cao et al., 2007). The major empirical findings of this literature, mostly from the U.S. and the European countries, suggest that income plays a fundamental role in auto ownership (e.g., Schimek, 1996; Bento et al., 2005; Cao et al., 2007; Dargay and Hanly, 2007; Zegras, 2010), although the positive income effect diminishes as people own more cars (Matas and Raymond, 2008; Nolan, 2010). It is also generally found that household characteristics relevant to mobility needs, such as household size, adult job participation, and number of children, contribute to auto ownership and use (e.g., Dargay and Hanly, 2007; Whelan, 2007). In addition, many studies find that the form of the built environment (mainly on the neighborhood-scale), most notably local population density, negatively affects auto ownership and usage, but only at the margin (e.g., Schimek, 1996; Cervero and Kockelman, 1997; Bento et al., 2005; Cao et al., 2007; Fang, 2008). Nevertheless, a few studies find stronger effects of density in Europe (Gim, 2012), New York City (Salon, 2009), and Chinese cities (Li et al., 2010), compared to the typical findings in the U.S. Also, some (Bento et al., 2005; Zegras, 2010) suggest that the combined effect of a range of urban built environment can have a substantial impact on auto ownership and driving.

While providing important evidence regarding the micro behavioral structure of transportation and motorization, the disaggregate approach is limited in its ability to provide aggregate projections at different locations or spatial scales (NCHRP, 2012). Transferring elasticity estimates to other locations or spatial scales is difficult because the aggregate characteristics of the city, regional, or national levels are often not considered in disaggregate analyses. For example, the built environment is usually measured at the local or neighborhood level in disaggregate analyses.¹ This necessitates aggregate studies.

There is a relatively small stream of literature on the aggregate behaviors of automobile ownership and usage, including those at the national or regional level (e.g., Romilly et al., 2001; Dargay et al., 2007; Cao and Huang, 2013) and those at the city or metropolitan level (e.g., Kenworthy and Laube, 1996; Ingram and Liu, 1997; Cervero and Murakami, 2010). Findings of these aggregate studies, such as the effects of average income and density, are overall consistent with those of the disaggregate studies, but with important additional insights. For example, Romilly et al. (2001) examine the Britain national time-series data and find that for both car ownership and use, income and bus fare elasticities are positive and motoring costs elasticity is negative, with long-run elasticities larger in absolute magnitude than short-run elasticities and car use elasticities larger than ownership elasticities. Using pooled time-series and cross-sectional data from 45 countries, Dargay et al. (2007) illustrate an S-shaped relationship between vehicle ownership and per-capita income (ownership grows faster at middle income), with the country-specific vehicle ownership saturation level negatively affected by urbanization and population density. Using a panel of regions (each containing a central metropolitan area, but usually much bigger) in China at the prefecture and above levels, Cao and Huang (2013) show that regional car ownership positively associates with a region's urbanization rate, urban built up area, level of economic development or income, per capita road area, per capita number of buses, and negatively associates with urban population density and per capita number of taxies. In addition to the strong negative correlation between urban density and auto ownership across the world suggested by Kenworthy and Laube (1996), Cervero and Murakami (2010) find significant negative relationship between urban population density and the amount of driving per capita across U.S. urban areas, an effect partially offset by the traffic-inducing effects of denser urban settings. In addition to effects of local built-environmental effects, Bento et al. (2005) suggest

that better jobs-housing balance and higher metropolitan population centrality reduce the amount and probability of driving to work in the U.S., although Ma and Banister (2007) and Modarres (2011) argue that urban decentralization and polycentricity have a more complex and less clear effect on commute pattern.

In conclusion, the existing literature on the determinants of motorization, especially related to the urban built environment seems to focus more on disaggregate analysis with the built environment measured at the neighborhood level than on aggregate analysis at the metropolitan level. Additionally, they also focus more on the developed economies than on the developing and emerging economies. For the metropolitan-level analyses, few have considered the interrelationship between automobile ownership and usage.

3 METHOD AND DATA

We use a number of linear regressions to explore the relationship between motorization and characteristics across Chinese cities. We are able to measure two important dimensions of motorization: the private automobile ownership rate and the share of commuters by private automobile in each city. It is widely known that auto ownership is one of the key determinants of travel behavior of individuals and households including choices over trip frequency, destination, chaining, and apparently mode (Bhat and Pulugurta, 1998). In this study, auto ownership is estimated using published official statistics on private automobile stock and urban population (people living in urban districts for more than six months).² Commute trips have long been a focus in urban transportation research due to its direct relation to labor productivity, contribution to peak-hour congestion, and impact on urban quality of life. We obtain city-level commute mode split data from the 2010 Urban Household Short Survey (UHSS) of 400,000 urban households in 30 provinces conducted by the Urban Household Survey Division of the Urban

Department under the National Bureau of Statistics (NBS) of China. The number of sampled households in each prefecture-and-above level city ranges from about one thousands for a small city to more than 30,000 in Beijing.³ Our city-level mode split data are estimated from the survey question on household head's commute mode in the 2010 UHSS and sample weights provided by the NBS. Detailed description of survey methodology and administration are available in NBS (2011).

To begin with, we treat auto ownership and mode split as independently determined by a range of city characteristics. We then estimate a structural equation model (SEM) allowing the simultaneous estimation of both variables, with auto ownership as a mediating variable between city characteristics and travel behavior, following the established behavioral evidence (e.g., Ben-Akiva and Lerman, 1974; Bhat, 1996).

The explanatory variables of interest are different dimensions of urban spatial structure, including city size, density, jobs-housing balance, and polycentricity. The first dimension is measured by the size of urban population (while controlling for average population density), which indicates the scale of agglomeration and spatial scope. We expect that larger cities will make trips longer, which can lead to motorization as previously found in the U.S. (e.g., Krizek, 2003) and the U.K. (e.g., Woods and Ferguson, 2014). The second dimension is the average urban population density, defined by the number of urban residents per square kilometer of urban built-up area. We expect that density will negatively affect motorization, as found by most of the disaggregate and aggregate studies reviewed in the previous section.

The third dimension measures the extent of jobs-housing separation. The literature on excess commute has employed various measures of the spatial relationship between employment and housing in urban areas, such as gravity-based accessibility (Horner, 2004; O'Kelly and

Niedzielski, 2009; O’Kelly et al., 2012), proportionally matched commuting (Yang, 2008; Layman and Horner, 2010), and segregation- or dissimilarity-type index (Horner and Marion, 2009). Similar to Bento et al.’s (2005) adaptation of the residential segregation measure (Massey and Denton, 1988), we follow Horner and Marion (2009) to use a spatial dissimilarity index (also called “Duncan and Duncan index”) defined by

$$D = 0.5 * \sum_i^n \left| \frac{p_i}{P} - \frac{e_i}{E} \right|,$$

in which i indexes urban districts (the finest scale we have), p_i is district i ’s population, P is total urban population, e_i is district i ’s number of employers (as proxy of employment due to data constraints), and E is the total number of employers in a city.⁴ D calculates the absolute difference between subarea i ’s share of urban employment and the subarea’s share of urban residential population, summed across all subareas of a city. This index is larger where employment and population are more spatially separated. We expect that jobs-housing separation, or imbalance, will likely induce more demand for faster or motorized commute, as argued in Cervero (1989), Peng (1997), and Wang and Chai (2009).

The fourth measure of urban spatial structure is polycentricity, which concerns with the variation in urban density.⁵ We follow previous studies (e.g., Lee and Gordon, 2007) to define polycentricity based on the clustering of employment instead of population since employment centers are generally more closely associated with spatial clusters of a city’s physical and human capital. We define the district with the highest density of employment as a city’s main employment center, which almost always turns out to be one of the older and geographically central districts.⁶ The default polycentricity index is calculated as

$$P1 = \sqrt{\sum_{i=1}^n (d_i * x_i)^2 / n},$$

where d_i is the ratio between district i 's straight-line distance to the main center and the furthest district's distance to the main center; and x_i is the ratio between district i 's employment and the main center's employment. PI essentially represents the average of outer districts' total employment relative to that of the center district, weighted by the distance of each outer district from the center district (relative to city size). Four alternative indices ($P2$ to $P5$) are also calculated as a means of robustness check.⁷ Gordon's "co-location hypothesis" (Gordon and Wong, 1985) argues that multiple centers of employment may both reduce average commute distance and alleviate congestion at the main center. Based on this hypothesis, we expect that a higher degree of polycentricity may have an unknown total effect on motorization – while the need for automobiles may be alleviated as workers can live closer to their jobs, the use of autos can be more attractive as city-level congestion is reduced due to polycentricity. Thus we expect polycentricity's effect on motorization to be different from that of average density.

As suggested by the literature, we control for important urban characteristics such as the level of economic development (urban gross domestic product, or GDP, per capita) or income (average wage) and, as evidenced in Bento et al. (2005) and Matas et al. (2009), the provision of transportation infrastructure (road area per capita, rapid rail transit network density/availability) and services (number of buses per capita). We do not include vehicle or fuel cost as the prices of both are fairly homogeneous across cities in China given unified state regulation of these markets. Table 1 provides the definition, descriptive statistics, and data sources of the variables used in this study. Restricted by the urban employment data available through China's Second National Economic Census (2008), our sample only includes 161 Chinese cities at the prefecture level and above.

TABLE 1 about here

4 RESULTS

Using ordinary least squares (OLS) regressions, we first estimate independently the influences of city characteristics on auto ownership and mode split. Results are shown in Table 2's columns (1) and (2), respectively. Column (1) suggests that urban auto ownership is significantly affected by level of economic growth ($\epsilon=.38$), city size ($\epsilon=.33$), and population density ($\epsilon=-.42$), consistent with literature findings including those of both disaggregate (income and density effects) and aggregate (all three effects) studies. Column (2) suggests that density has a negative, but insignificant effect on the mode split of automobiles among commuters, which differ from the common findings of significant density effect in western developed countries (e.g., Cervero and Murakami, 2010). The lack of sensitivity of auto usage to density may result from Chinese cities' much higher densities in general (Wang, 2010). Urban polycentricity PI negatively affects auto ownership, but this effect is statistically insignificant, likely due to the opposite effects of distance shortening and congestion alleviation. Other factors, such as jobs-housing balance D and the provision of road and bus, have little connection with auto ownership. The auto mode split among commuters is significantly affected by city size ($\epsilon=.27$), level of economic growth ($\epsilon=.52$), and per capita road provision ($\epsilon=.22$). These qualitative relationships are consistent with findings in the literature (e.g., Morigridge, 1997; Bento et al. 2005; Cervero and Murakami, 2010),⁸ reflecting the motorization challenges brought to cities by urbanization, economic growth, and infrastructure expansion.

However, results of column (2) suggest a negative relationship between auto mode split and the imbalance or separation between jobs and housing at the urban district level. The coefficient ($\epsilon=-2.30$) is not only statistically significant, but also economically substantive (the standardized coefficient is about half of those of population size and per capita GDP). Such a

result seems counterintuitive, especially from the experience of the developed country cities (e.g., Cervero, 1989; Peng, 1997; Bento et al., 2005; Cervero and Murakami, 2010). Per capita number of transit buses negatively affects the auto mode split, but the effect is not statistically significant. Both OLS regressions are free from serious outlier or heteroskedasticity problems (max VIF = 2.08; null hypothesis of the White tests not rejected).

TABLE 2 about here

As discussed previously, the simple exogenous models shown in columns (1) and (2) may be biased due to the lack of connection between ownership and mode choice decisions of urban households. That is, commuters' choice of private automobile conditions on household auto ownership, which is endogenous to many city characteristics that simultaneously affect the choice of commute mode. To address this, we first estimate a baseline model in which ownership and mode split are simultaneously estimated (results omitted here), followed by a structural equation model (SEM) allowing a mediating effect of ownership on mode split. Column (3) presents the SEM results, which show an improved model goodness of fit compared to the results of the baseline simultaneous model, with log pseudolikelihood increases from -389.034 to -382.416 and standardized root mean square residual (SRMR) reduces from .024 to .000. Both the baseline simultaneous equation system and the SEM are estimated using the quasimaximum likelihood approach (Klein and Muthén, 2007) as our data violate the normality assumption (p value=.000 in the Doornik-hansen χ^2 test).

Aside from the quantified mediating effect of auto ownership, the SEM results do not dramatically differ from the OLS results. Nevertheless, the direct effects of city size and economic growth level on auto mode split are weakened and the negative effect of per capita number of transit buses on mode split becomes statistically significant. City size has positive

direct effects on both auto ownership and mode split, although column (3)'s results suggest that compared to auto mode split, ownership is significantly more sensitive to a change in city size ($\epsilon=.33$ for ownership vs. $.19$ for mode split). Density significantly affects ownership but not directly the mode split of private automobile, suggesting that the increase in the fixed cost of auto ownership (e.g., parking), instead of density-induced rise in the variable cost of driving (e.g., heavier congestion), is what really drives the eventual difference in travel behavior. Urban polycentricity has an insignificant negative effect on auto ownership and no direct effect on auto mode split. Even stronger than the seemingly counterintuitive OLS result, jobs-housing imbalance has no significant effect on car ownership, but a statistically and economically significant negative effect on auto mode split among commuters ($\epsilon=-2.38$, which means a standardized coefficient of -0.22 , compared to 0.27 of population size and 0.33 of per capita GDP). That is, conditioning on car ownership, one should expect fewer commuters by car in a city where jobs and housing are more separated at the level of urban districts, a finding opposite to those in developed country cities as mentioned previously. Among the control variables, economic growth level has significant positive direct effects on both car ownership and mode split with similar elasticities ($.38$ and $.42$). The provision of road area per capita positively associates with auto mode split in a statistically and economically significant way ($\epsilon=.20$). This effect is consistent with the findings of Mogridge (1997) and Bento et al. (2005), and probably reflects a bi-directional relationship including both demand-responsive road construction and induced demand of infrastructure expansion. The provision of bus per capita has an effect opposite to that of road area – it reduces commute by car with an elasticity of $.15$. This is consistent with previous findings such as Matas et al. (2009) and Redman et al. (2013). A comparison between the last two estimates (road elasticity of 0.20 vs. bus elasticity of 0.15)

suggests that Chinese cities may need to expand public transit more than proportional to the expansion of roads to curb the growth of driving.

The SEM results illustrate the mediating role played by car ownership in determining mode split. Controlling for city characteristics, the elasticity of car ownership on mode split is .26, meaning car mode split among commuters grows with ownership, but much less than proportionately. This may indicate that Chinese urban households' car purchase decisions are based on not just the need for commute, but more for other considerations such as shopping and recreational needs, and even the desire for social status. The estimated mediating effect also allows us to see the full picture of direct and indirect effects of city characteristics on the use of cars among commuters in Chinese cities. For example, roughly two-thirds of city size's total effect ($\epsilon=.274$) on car mode split among commuters is direct, with the remainder indirectly through auto ownership. Similarly, about four-fifth of per capita GDP's effect on mode split is direct, with the remainder indirectly through economic growth's effect on auto ownership. Among other urban spatial structure characteristics, our results do not suggest the simultaneous existence of significant direct and indirect effects on car use among commuters, which differs from Cervero and Kockelman's (1997) prediction that the direct and indirect effects of the built environment on driving would mutually reinforce each other. Comparing the OLS and SEM results, we find that the OLS estimates of the effects of city size and per capital GDP/income level on car use are biased upward without considering the mediating role of auto ownership, which is affected by not only city size and per capita GDP, but also population density.

Finally, we have conducted a number of robustness tests of the results using alternative polycentricity indices (*P2* through *P5*) to replace the default *P1*, using average urban worker wage instead of per capita GDP, and including the additional variable of urban rapid rail network

density or a simple dummy indicating the existence of a urban rapid rail system (there are only six cities with operational urban rapid rail in 2010 in our sample⁹). The OLS and SEM results presented in Tables 2 are quite robust to all these changes (either individually or combined) in terms of the sign, magnitude, and statistical significance of estimated coefficients. Results of the robustness tests are available upon request.

Figure 1 about here

5 DISCUSSION

Most results presented in Section 4 are consistent with our expectation and findings of previous studies, mostly from developed countries. A notable deviation is the significant negative effect of jobs-housing imbalance on the auto mode split among Chinese urban commuters. However, this seemingly counterintuitive result may not be a real surprise in the context of Chinese cities, and even broadly in many developing countries. An important difference between Chinese cities and the highly motorized western cities is the relative shares of private automobile, public transit, and non-motorized modes. While driving often dominates the mode choice among commuters in countries like the U.S. and the U.K., evidence from China's 2010 UHSS suggests that among the 161 medium-sized and large cities, more commuters use non-motorized modes (53 percent) and public transit (16 percent) than private cars (10 percent), reported in log form in Table 1. To explain the negative effect of jobs-housing imbalance on auto mode split in Chinese cities, we analyze the relationship between city characteristics and the shares of public transit and non-motorized modes among urban commuters, using the same mode split data from the 2010 UHSS.

TABLE 3 about here

Columns (1) and (2) in Table 3 present the results from regressing the mode splits of public transit and non-motorized modes on the same list of city characteristics in 161 Chinese

cities. Overall, city characteristics explain the mode split of transit (adjusted $R^2=.30$) better than that of the non-motorized modes (adjusted $R^2=.14$). As expected, we find that the provision of buses per capita positively associates with transit mode share, while the increase in road area per capita reduces transit mode share. The fact that the elasticity is large in absolute value for road provision compared to bus provision enhances our previous finding on auto mode split, suggesting a mode shift from transit to auto if cities do not expand transit service faster than road provision. While negatively affecting the non-motorized mode share, per capita GDP positively (though statistically insignificant) affect the transit mode share. This contrasts the widely recognized pattern in the developed cities, although it is understandable given China's much lower level of income. The lack of sensitivity of transit mode split to density, while different from results in western developed societies (e.g., Izraeli and McCarthy, 1985; Schwanen, 2002), may be explained in a similar way as Table 2's finding regarding the insignificant effect of density on auto mode split (i.e., densities in Chinese cities are much higher than western cities in general).

The key finding in Table 3 is that jobs-housing imbalance significantly increases the transit mode share among commuters in Chinese cities, with the estimated elasticity even larger in magnitude compared to those found for the car mode share. That is, in a more jobs-housing imbalanced Chinese city, commuters actually shift away from cars to public transit. Maybe deemed impossible in the western developed cities, we consider this finding plausible in Chinese cities where income (hence value of travel time) is much lower, density is much higher (Wang, 2010), and per capita road provision is significantly less (Ng et al., 2010). In other words, even a greater extent of jobs-housing imbalance may increase average commute distance, driving may not gain a bigger advantage relative to transit because roads will be more congested due to

heavier motorized traffic and the fact that the access, egress, and waiting time cost of transit users becomes less important due to the longer main haul. In fact, our finding is consistent with the travel behavior study by Pan et al. (2009), who report that controlling for socio-demographics, longer commute distance is associated with more use of public transit instead of private cars among individuals surveyed in Shanghai. Chen and Zegras (2010) and Gómez-Gélvez and Obando (2013) have also discovered similar counterintuitive travel behavior patterns in Beijing, China and Bogotá, Colombia, respectively.¹⁰

As a side result, column (3) presents a regression of non-motorized mode split with an interaction term between per capita GDP and jobs-housing imbalance. The estimated coefficients are largely the same as those in column (2). The significant interaction effect improves the model fit and suggests that commuters in richer cities are more likely to respond to jobs-housing imbalance by reducing their use of non-motorized modes and switching towards cars or transit. This implies that the shift from non-motorized modes to car and/or transit is more likely to happen when jobs-housing imbalance increases in a richer city. The results in Table 3 are robust to alternative polycentricity indexes, to the use of wage instead of per capita GDP to measure “richness,” and to the additional controls for rail transit network density or dummy. All regressions in Table 3 are free from serious outlier or heteroskedasticity problems (max VIF = 2.15; null hypothesis of the White tests not rejected).

6 CONCLUSION

Urban passenger transportation is embedded in and fundamentally shaped by the spatial pattern of urban land use, such as city size, density, extent of polycentricity, and the relationship between employment and residential locations. City-level aggregate studies can provide important insights on how urban spatial structure affects motorization in the interacting urban

land, labor, and travel markets, thus cannot be replaced by disaggregate or economy-wide aggregate analyses.

Employing hard-to-obtain data from a large number of Chinese cities (perhaps the first time), this paper simultaneously investigates the effects of various dimensions of urban spatial structure on private automobile ownership and mode split, controlling for important economic and infrastructure characteristics. Results are robust and confirm the positive effects of city size on auto ownership and mode split, and the negative effect of density on auto ownership. Echoing a small number of recent studies in the developing world, this research discovers the seemingly counterintuitive effect of jobs-housing balance on commuters' use of automobiles, and points it to the relative advantage of public transit relative to driving in dense and congested Chinese cities. This is a major departure from the experience in the western developed countries. As one of the earliest studies on motorization in the rapidly growing Chinese cities, this study provides an important benchmark in a large emerging economy to be compared with the existing evidence in developed countries.

Well-managed motorization is crucial to the development of clean, low-carbon, and efficient cities. Our results suggest that income level and city size affect driving directly more than indirectly through auto ownership, which implies that auto ownership restrictions adopted by some large and rich Chinese cities, such as Beijing, should not be considered as the best cure for the congestion and pollution problems of rapid motorization. Besides the strategy of compact growth, Chinese cities should emphasize the development of efficient and high-quality public transit service through investment in transit systems guided by informed integrated transit-land use planning, and be cautious in the expansion of road capacity. On the other hand, the pursuit of jobs-housing balance and polycentric development in Chinese cities may not necessarily reduce

automobile ownership or use as often assumed in the low-density high-income western developed countries. This is due to jobs-housing balance and polycentricity's complicated and differentiated implications on the general costs of and need for auto and transit travel in the specific context of China.

Cities of many rapidly developing, urbanizing and motorizing countries around the world share important socio-spatial characteristics with Chinese cities. Findings of this study join a small but growing literature in the developing economy context to offer important lessons to decision makers aiming at improving urban economic and environmental efficiency through spatial planning and policy making. For example, our results suggest that it is crucial for developing cities to expand transit infrastructure and service faster than road provision to avoid the mode shift from transit to automobiles. Promoting jobs-housing balance, on the other hand, may not be as important a consideration in developing country cities compared to the developed country cities. In high-density cities of the developing world, maintaining density in future growth can be an effective way to reduce driving through discouraging car ownership.

However, constrained by data available to us, a few limitations are worth mentioning. First, the measure of density is limited to population, compared to the additional control of employment density measures in Gordon et al (1989) and Cervero and Murakami (2010). Second, the measures of jobs-housing balance and polycentricity are obtained with data at the fairly coarse resolution of urban district, with employment approximately measured by the number of employers. Third, data on urban private automobile vehicle stock are based on those of the whole administrative region of each city including city proper and surrounding rural areas. Fourth, using city-level averages (e.g., income or per capita GDP) without controlling for income distribution within city has a larger chance of producing biased results due to ecological fallacies.

Finally, commute mode split is only a partial picture of the use of private automobiles (even with its obvious contribution to peak-hour congestion) – data on mileage driven and automobile use for other trip purposes are necessary to the full understanding of automobile use. Future research should not only sharpen these data, but also integrate behavior-based disaggregate data and models into the study of urban spatial structure and motorization.

¹ One exception is Bento et al. (2005), which considers many aspects of city characteristics on individual behaviors.

² The available private automobile stock data are those of the whole administrative region of each city, including city proper and surrounding areas, usually composed of rural villages and small towns. We use such data to approximate the stock of private automobiles owned by residents of the city proper, where most private automobiles are owned and used given China's significant urban-rural divide in income and vehicle ownership levels.

³ For more details about the UHSS and its relationship to China's regular Urban Household Survey, see "correcting the sampling bias of China urban household survey," funded by the Growth Research Team as part of the Knowledge for Change Programme, the World Bank, available online at <http://go.worldbank.org/Y6OX5GWCT0>.

⁴ Using the number of employers to approximate the number of jobs could lead to biased results. This is an unfortunate compromise as we are constrained by data available to us. The number of cities with available employment data at the urban district level is only 88, in which 71 are in our sample due to data availability constraint of other key variables such as average commute time. Nonetheless, it seems that the numbers of jobs and employers are highly substitutable for our purpose. Using the 88 cities where we have urban employment data at the district level, we calculate all polycentricity indices and compare them to those based on the number of employers. We find that the indices calculated based on different measures of employment are highly correlated. The minimum coefficient of correlation among the alternative indices is 0.94, with all coefficients statistically significant at the 0.00001 level. Similar results are found among the 77 cities included in our research sample.

⁵ We focus on measuring polycentricity but not the dominance of urban center, also called centralization or centrality, as adopted in Izraeli and McCarthy (1985) and Lee and Gordon (2007). This is because most Chinese cities are much more compact compared to cities in the western industrialized countries and few have significant level of low-density sprawl (Wang, 2010). It makes more sense to use employment polycentricity to characterize spatial variation across the dense urban area instead of using a center-suburb style measure.

⁶ Given the relatively small number of urban districts in each of the sample cities, we define employment centers differently from the various methods used in previous studies that identify employment centers with finer spatial units (Giuliano and Small, 1991; McDonald, 1987; McMillen and Smith, 2003). In Chinese cities, the older and geographically central districts are almost always more developed and densely utilized than districts closer to the fringe, which differs from many of the western post-industrial cities with decayed downtowns (Wang, 2010).

⁷ To capture the potential diminishing effect of distance, we use $\ln(di+1)$ and $di^{1/2}$ to replace di in $P1$ to create

$$P2 = \sqrt{\sum_{i=1}^n (\ln(di + 1) * x_i)^2 / n}$$

and

$$P3 = \sqrt{\sum_{i=1}^n (d_i * x_i^2) / n}.$$

Alternatively, we use the weighted average distance from CBD (Lee, 2007) to reflect the spatial departure of employment from a monocentric city, which results in

$$P4 = \sum_{i=1}^n \frac{e_i}{E} distance_i,$$

where $distance_i$ is the absolute straight-line distance of each district from the main center. Using di to replace $distance_i$ in $P4$, we further construct

$$P5 = \sum_{i=1}^n \frac{e_i}{E} di$$

to eliminate the impact of city size.

⁸ Except that Cervero and Murakami (2010) find only a weak effect of city size on vehicle-miles traveled.

⁹ The rail cities are Guangzhou, Nanjing, Shenzhen, Wuhan, as well as the four provincial-level cities (Beijing, Shanghai, Tianjin, and Chongqing). Shanghai and Guangzhou are dropped from our sample due to missing values in urban spatial structure variables.

¹⁰ Of course, one cannot rule out the possibility that the urban district level measure of jobs-housing imbalance is too coarse. This probably explains why jobs-housing imbalance's insignificant negative effect on the mode share of non-motorized travel, typically adopted for trips of shorter distance.

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TABLE 1: Summary of Data (obs.=161)

Variable	Definition	Mean	S.D.	Source
CAROWN	Per capita number of private automobiles owned	-3.129	0.651	a,b
SHARE_CAR	Commuter mode share by car	-2.312	0.611	c
SHARE_PT	Combined commuter mode share by bus, rail, and company bus	-1.843	0.640	c
SHARE_NM	Combined commuter mode share by walk and bicycle	-0.633	0.244	c
POP	Urban population	13.654	0.897	d
POPD	Urban population density (person/km ²)	9.197	0.293	d
D	Jobs-housing imbalance index	0.062	0.056	b, e
P1	Polycentricity index no. 1 (the default measure)	0.266	0.224	e,h,i
P2	Polycentricity index no. 2	0.203	0.172	e,h,i
P3	Polycentricity index no. 3	0.294	0.233	e,h,i
P4	Polycentricity index no. 4	6.286	3.705	e,i
P5	Polycentricity index no. 5	0.211	0.151	e,i
GDP	Per capita gross domestic product (10 ⁴ yuan/person)	10.629	0.470	b,d
WAGE	Average urban worker wage (yuan)	10.429	0.224	d
ROAD	Per capita urban road area (m ²)	2.187	0.424	b,d
BUS	Number of public buses per 10 ⁴ residents	1.753	0.531	b,d
RAIL_DEN	Density of rapid rail, measured as length (km) of rapid rail network per unit of urban built-up area (km ²)	-0.159	0.645	b,d,f
RAIL_DUM	Whether city has a rapid rail system in 2010 (YES=1, No=0)	0.062	0.242	g

Note: all variables, except RAIL_DUM, are natural-log transformed.

Data sources: a. China Statistical Yearbook for Regional Economy; b. 2010 Population Census of the People's Republic of China; c. 2010 Urban Household Short Survey by the China Bureau of Statistics; d. China City Statistical Yearbook 2011; e. The Second National Economic Census (2008); f. China Statistical Yearbook of the Tertiary Industry; g. China Urban Construction Statistical Yearbook 2010; h. Administrative Divisions of China, 2009; i. map.baidu.com (used for measuring the distances between the subcenters to the center of each city).

TABLE 2: OLS and SEM Estimates (sample size: 161 cities)

	(1) OLS		(2) OLS		(3) SEM	
	CAROWN		SHARE_CAR		CAROWN	SHARE_CAR
POP	0.3320*** (0.0676)		0.2742*** (0.0638)		POP 0.3320*** (0.0517)	0.1862*** (0.0629)
POPD	-0.4226** (0.1946)		-0.0523 (0.1835)		POPD -0.4226** (0.1975)	0.0597 (0.1870)
D	0.3161 (0.9063)		-2.2973*** (0.8547)		D 0.3161 (0.7984)	-2.3811*** (0.8671)
P1	-0.3015 (0.2028)		-0.0800 (0.1912)		P1 -0.3015 (0.1904)	-0.0001 (0.1934)
GDP	0.3750*** (0.1183)		0.5223*** (0.1116)		GDP 0.3750*** (0.1186)	0.4229*** (0.1212)
ROAD	0.0433 (0.1294)		0.2164* (0.1220)		ROAD 0.0433 (0.1379)	0.2049* (0.1078)
BUS	0.0270 (0.1027)		-0.1463 (0.0969)		BUS 0.0270 (0.0970)	-0.1535* (0.0791)
					CAROWN	0.2649*** (0.0734)
Constant	-7.8431*** (1.9177)		-11.1793*** (1.8086)		Constant -7.8431*** (1.7937)	-9.1013*** (1.8799)
Prob.>F	.0000		.0000		Log pseudolikelihood	-382.4161
Adj. R ²	.3339		.3270		SRMR	.000

Standard errors in parentheses

* p < .10, ** p < .05, *** p < .01

TABLE 3: Public Transit and Non-Motorized Mode Share Estimates (sample size: 161 cities)

	(1)	(2)	(3)
	SHARE_PT	SHARE_NM	SHARE_NM
POP	0.1012 (0.0684)	-0.0367 (0.0287)	-0.0264 (0.0289)
POPD	-0.2410 (0.1969)	0.0220 (0.0827)	0.0196 (0.0818)
D	2.7093*** (0.9169)	-0.3061 (0.3851)	-0.3068 (0.3810)
P1	-0.3391 (0.2051)	0.0852 (0.0862)	0.0715 (0.0855)
GDP	0.1681 (0.1197)	-0.2008*** (0.0503)	-0.2296*** (0.0517)
ROAD	-0.4817*** (0.1309)	-0.0271 (0.0550)	-0.0257 (0.0544)
BUS	0.4011*** (0.1039)	0.0563 (0.0437)	0.0606 (0.0432)
GDP*D	---	---	-1.5533** (0.7509)
Constant	-2.5228 (1.9401)	1.7565** (0.8148)	1.9472** (0.8114)
Prob.>F	.0000	.0001	.0000
Adj. R ²	.2961	.1444	.1624

Standard errors in parentheses

* p < .10, ** p < .05, *** p < .01

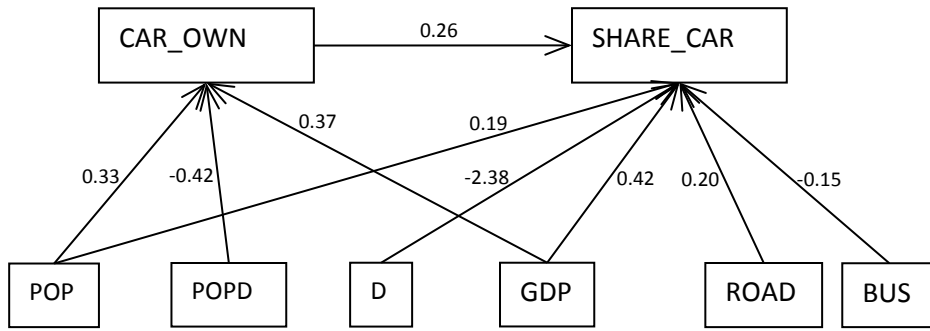


FIGURE 1: Significant Effects Estimated in the SEM Model.