Revisiting car dependency: a worldwide analysis of car travel in global metropolitan areas

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Abstract

This article aims to contribute to the understanding of car dependency of cities, a line of inquiry which emerged in the late 1980s. First, we update possibly outdated insights based on more recent data. Second, we highlight methodological limitations of this type of research, which will help determine the relevance of typical findings in the broader debate on urban sustainability. For our analysis, we base ourselves on the Mobility in Cities Database which includes properties of urban form and mobility of 56 metropolitan areas worldwide. Using OLS modelling, we found that density, public transport supply and demand, car ownership, fuel price and level of congestion are important predictors of car use. However, although these variables are significantly associated with car travel in metropolitan areas, they do explain variance to a limited extent only, partly since such variables do not cover underlying personal attributes such as age, income, attitudes, or residential self-selection. This puts the findings and the implications of earlier comparative analysis of car dependency of metropolitan areas into perspective and questions the tendency of urban planning policies to view urban density as a silver bullet solution.

***Keywords*: Car dependency; Global metropolitan areas; Urban planning policies; Density**

1. Introduction

At the time of writing, city based approaches to car dependency, as introduced by Newman and Kenworthy (1989), have become more relevant than ever, given intense ongoing debates on both global and local negative effects of car traffic, which include climate change, air pollution, road safety, and congestion. While the early literature on car dependency was inspired by scarcity of fossil fuel during the oil crises, we substantiate the importance of our present update to the threat of climate change (Ivanaj et al., 2017). Especially private transport is one of the sectors that have been blamed for their significant contribution to global warming (Saleem et al., 2018; Moriarty and Honnery, 2013). The International Energy Agency (IEA, 2018) reported that the transport sector accounts for a quarter of global CO_2 emissions, of which 74% is caused by the ever-growing subsector of road transport.

When looking at daily travel, the private car has become the primary choice almost everywhere in the developed world (Macket, 2002; Buehler et al., 2017; Metz, 2013). Studies on the level of car use around the world demonstrate the unique position of the car in citizens' regular travel patterns. Buehler et al. (2017) found that on average, almost half of trips in German, Swiss and Austrian cities and 86% in the American cities are made by private car. In the UK, two-thirds of all weekly trips, which equals three-quarters of the distance travelled by an average citizen, are made by car (Jones, 2011). In the Global South too, the growth rate of car use has been significant (Dimitrou & Gakenheimer, 2011). The

International Monetary Fund (IMF, 2005) predicted a car ownership rate of 267 per 1000 inhabitants in China by 2030, which is 17 times higher than in 2002. This is in line with the historical trends of fast-growing car ownership rates and the consequent domination of automobiles in North America in the 1950's and in Western Europe in the 1960's and 1970's.

Being economic centres and representing concentrations of population (Nieuwenhuijsen, 2020), it is logical that the lion's share of global car use is related to cities. Transport plays a critical role in urban economies by moving people and freight between numerous origins and destinations. Cities are not only home to half of the world population, but their populations are constantly increasing (United Nations, 2014). GEA (2012) estimated that 60%-80% of global energy is consumed in cities. According to UITP (2015), on average 44% of urban daily trips in the sample of cities monitored by this organization are made by car. No other transport mode can compete with these figures. However, this average number conceals a wide variety of modal shares across cities. For instance, Vienna, Prague and Casablanca show shares as low as 27%, 25% and 15% respectively, while other cities, such as Chicago, Sydney and Abu Dhabi, represent shares as high as 81%, 73% and 72% respectively. Besides, some cities show a decreasing trajectory of car use in the last years, such as Tokyo, Geneva and Brussels, although such a slowdown is usually not yet visible when considering wider metropolitan areas. When comparing groups of cities that differ in terms of car use, it is quite clear that they also vary with respect to urban form, socio-economic characteristics and public transport availability, all of which might play a role in their respective levels of car use.

Considering the ubiquity of car travel and its externalities, car use received a lot of attention in the literature (Liu and Shen, 2011, Ewing and Cervero, 2010, Chee and Fernandez, 2013, Kotval-K and Vonjovic, 2015). Often, the object of such studies are individuals or households, whereas research that takes cities as the unit of analysis is less common (e.g., Newman & Kennworthy, 2006; Kenworthy & Laube, 1999). Although the studies that do so provided valuable results, it is not clear to what extent their results still hold, given that the data used were collected in the former century. Also, there has been some debate about the validity and the interpretation of the results, particularly when it comes to converting them into policy recommendations (Mindali et al., 2004; Gordon & Richardson, 1997).

Therefore, with the current study we would like to contribute to the literature about car dependency of cities in two ways. First, we will do an exploratory analysis based on a range of updated variables that are assumed to explain car dependency, and their variance among cities around the world. A global comparison makes it possible to develop an overarching view of how variables collected at the level of the city could affect urban, and consequently global car traffic (McIntosh et al., 2014). Second, we want to engage in the debate about the meaning of the results, given the important constraints of doing research in which cities are considered the unit of analysis, rather than human individuals. We will take a closer look at the key conclusions and recommendations of previous research and explore their accordance with the outcomes of our study.

With respect to the first research goal, our contribution will not only consist of updating the research, but also of expanding it by including a larger group of non-western cities, drawing attention to the importance of car dependency of less-studied regions. We will base our analysis of car use on data from 56 global cities that are part of the Mobility in Cities Database (UITP, 2015). To our knowledge, this database has never been used for any sort of similar research. By identifying the most influential variables that explain car use, and modelling them more accurately, cities may be supported in fighting externalities related to strong car dominance such as road accidents, pollution or congestion.

Based on the above considerations, we propose the following research question: Can the findings and policy recommendations of the early literature on car dependency of cities be confirmed, based on an updated and expanded dataset?

After having conducted the intended exploratory analysis, we will place the significance of the results in a broader perspective. The remainder of this paper is structured as follows. In the next section, the relevant literature is reviewed. In section 3, we outline the properties of the data used and present the methods applied. Section 4 contains the results of the data analysis. Section 5 is devoted to the discussion and conclusion of the research.

2. Literature Review

2.1 Car dependency

Many cities around the world are faced with excessively car-dominated daily travel patterns, a phenomenon that was coined as car dependency and is currently considered a serious and growing international problem (Lewis and Grande del Valle, 2019). Nevertheless, the term car dependency has been interpreted in different ways. Litman and Laube (2002) argue that car dependency is associated with high rates of car travel per capita and is characterized by car-oriented land use patterns, in combination with lack of alternative transport options. Merom et al. (2018) define car dependency as permanently leaning on the car as the only transport mode.

Some scholars draw a line between different groups of car users and conclude that excessive car use solely is not a sufficient condition for car dependency. They believe that the overall circumstances of the users should be accounted for. Also, Handy et al. (2005) suggest that people who drive a car as a result of their own choice should be treated differently from those who drive it because they do not have any other option. Mattioli et al. (2016) conceive car dependency as occurring at three different levels: the level of the city, the level of the individual, and the level of the trip, all of which could be car dependent, regardless of whether the other levels are. Car dependency can be defined both in terms of objective variables such as frequency of use and the number of cars available in the household, and subjective variables like attitudes and norms (Minster et al., 2016). Based on the results of a survey, Hunecke et al. (2010) employed cluster analysis to find five different car dependent groups that differ in terms of norms, values and travel behaviour. Highlighting that car dependency can be interpreted in various ways, Von Behren et al. (2018) assert that also factors like lack of knowledge on public transport or observing car use as emotional or instrumental need to be taken into account when it comes to car dependency.

Studying the literature on car dependency teaches us that various definitions are circulating, with the most complex and complete conceptualisations referring to the car dependency of individuals, rather than cities. However, because our own analysis builds on the research tradition using data collected at the level of metropolitan areas, we propose to use car dependency as a proxy for car use in the remainder of the current article.

2.2 Externalities of car dependency

Data on car use reveal that in general, the car is both the most suitable and the preferred transport mode from a user's perspective. However, the use of cars entails many disadvantages for society, so-called externalities which have been extensively described in the literature.

2.2.1 Climate change and air pollution

Van Wee (2013) identifies three important environmental problems that stem from the transport sector; the first one being climate change caused by CO_2 emissions; the second problem is related to acidification of the environment including agricultural land; and the third one is large scale air pollution as the result of both emissions from the transport sector and chemical reactions that happen in the atmosphere. Private cars are a major source of greenhouse gases and gasoline vehicles emit pollutants such as carbon monoxide (CO), nitrogen oxide (NO_x) and hydrocarbons (HC) (Parry et al., 2007). From a global city perspective, Kryzanowski et al. (2014) identified Delhi as the conurbation with the highest concentration of $PM_{2.5}$ among 56 global cities studied, while other heavily air polluted cities are Lagos and Beijing. Bickel et al. (2006) estimated the annual environmental costs of road transport in 17 European countries, comprising costs of climate change and air pollution, at 86,600 million Euros.

2.2.2 Traffic congestion

Cravioto et al. (2013) observe congestion as the waste of time that is associated with the excessive use of the limited capacity of road infrastructure. In the U.S. alone, urban road congestion results in 3.7 billion hours of delay annually (Schrank & Lomax 2005). One of the driving forces of traffic congestion is the disproportionate growth in private vehicles on the one side and limited possibilities for the supply of infrastructure on the other side, which is a common issue in many, if not most, metropolitan areas (Hensher & Button, 2003). The result of a global study on 975 cities by Inrix (2019) demonstrated that Rome, Paris and Dublin are among the top 10 cities with the largest number of hours lost in congestion annually.

2.2.3 Noise pollution

The European Environment Agency (2014) estimated that 90% of health impact generated by noise is related to road traffic. Noise pollution from road traffic is mainly measured based on three variables: the level of noise, the affected population, and a cost factor per decibel (Koyama and Kishimoto, 2001). Taking a global city perspective, Knops (2017) shows that Chinese and Indian cities such as Beijing, Guangzhou, Delhi and Mumbai are the noisiest ones out of a selection of 50 cities worldwide. Certain developed cities including Barcelona, Paris, Madrid and Moscow are counted among those with the highest levels of noise pollution. In a study conducted by Delucchi and Hsu (1998), the cost of noise pollution was estimated as up to 25 USD cents per kilometer of car travel.

2.2.4 Road safety

Annually, more than 1.2 million people are killed worldwide, and more than 50 million experience non-fatal injuries in road accidents (World Health Organisation, 2015). Road traffic accidents affect the economy of low, medium and high income countries on average by 1%, 1.5% and 2% respectively. Besides, traffic related trauma is an important cause of death and disability worldwide (Paniker at al., 2015). Out of a sample of cities discussed by Business Insider (2015), Johannesburg and Delhi show very problematic with 15 and 9.1 traffic fatalities per 100,000 inhabitants respectively. Among developed cities, Moscow, at 7, has one of the highest rates.

In addition, more externalities of car travel exist, although they are less studied. They correspond to emergency services, natural resource depletion, water pollution and urbanisation. Although calculating these costs is not straightforward, estimates vary around 10% of the cost of the more obvious road transport externalities, as listed above (INFRAS et al. 2007; Hensher and Button, 2003).

2.3 Determinants of car dependency

Our literature review yields a set of variables that impact car use, including aspects of the built environment, socio-economics and demographics, car ownership, public transport, lifestyle and residential self-selection (Hong et al., 2014; Corpuz et al., 2006; Kenworthy, 2018; Cervero & Kockelman, 1997; Vance and Hedel, 2007; Corpuz et al., 2006; Nolan, 2010; Zegras 2010; Trubka et al., 2010; Oakil et al., 2016; Chee & Fernandez, 2013; Axhausen, 2008; Giuliano & Dargay, 2005; Cao et al., 2007).

Research has consistently shown that the built environment influences car use (Nielsen et al., 2013; Yin & Sun, 2018; Sun et al., 2017). A meta-analysis carried out by Ewing and Cervero (2010) demonstrated that Vehicle Kilometers Traveled (VKT) per capita is mainly associated with the measures of accessibility to destination, and secondly to street network design. Based on the 2001 Household Travel Survey for California, Brownstone and Golob (2008) found that falling below a density of 1000 housing units per square mile corresponds with a 4.8% growth in VKT and a 5.5% growth in fuel consumed per household. Built environment characteristics such as higher density and transit-oriented development could bring down car use (Jiang et al., 2017; Boarnet, 2011). In a study in Rajkot, India, it was found that higher levels of land use mixture are associated with the use of alternatives to the car (Munshi, 2016). In Flanders, Belgium, Boussauw et al. (2010) found that higher density facilitates the use of alternative modes, including walking, cycling and public transport. Liu and Shen (2011) suggest that a combination of higher levels of accessibility, which is characterized by land use mix, density of population and jobs together with street connectivity, may reduce annual household VKT significantly. In a meta-analysis carried out on 23 planning studies from 18 metropolitan areas in the US, Bartholomew and Ewing (2008) estimated that increasing density could drop VKT by 17% by 2050, compared to a “business as usual” scenario. In another meta-analysis, Leck (2006) showed that residential density is the strongest element of the built environment when it comes to mode choice, in comparison with mixed land use and street configuration. As the result of evaluating several studies on the linkage between built environment variables and car use, Ding & Cao (2019) found residential density and employment density being the most influential variables.

Whereas the built environment is important to the objectives of our research, we must acknowledge that socio-economic and demographic characteristics generally have more explanatory power when it comes to car use (Potoglou & Kanaroglou, 2008; Zhou et al., 2021; Stead, 2001). A study on 34 European cities, for example, suggests that if the urban form variables are combined with socio-economics, the explanatory power of the former increases (Le Néchet, 2012). Moreover, Kotval-K and Vojnovic (2015) found that socio-economic class to a large extent determines the frequency and length of car trips in Detroit; household income, education and employment status are positively correlated with frequency and length of car trips. In the Netherlands, Yang and Timmermans (2013) estimated that if income goes up by 10%, both the number of cars and fuel consumption (which reflects car use here) increase by 4%. A study in Montreal (Manaugh et al., 2010) showed that the level of individual income is associated with the number and length of car trips per day. Gender and working status impact car travel too; men and full-time employees drive more, which also means that in general men with full-time jobs and high incomes consume more vehicle kilometers than other groups. Likewise, gender and monthly income were recognised to affect car travel for shopping trips in Shenyang, China (Li et al., 2018).

Public transport as a major alternative to the car has been the subject of many studies on car travel. It is commonly found that people take more car trips, if they live far from public transport (Buehler, 2011). Moreover, effects of built environment features on car travel appear to be significant only if they are combined with public transport supply (Bento et al., 2005). Manchester Metrolink (2001) reported that their service cut 5 million car journeys in the city annually. Mulalic and Rouwendal (2020) found that the extension of a metro system in Copenhagen has reduced the car ownership rate and vehicle kilometers travelled. On the other side of the coin, some scholars believe that public transport supply has only negligible impact on car travel. For example, Younes (1995) by focusing on London, Berlin and Stuttgart showed that growth in rail transport ridership was the result of attracting people from other public transport modes rather than cars. Parkhurst (2000) also found bus-based park and ride facilities mainly redistribute car travel instead of alleviating it.

Among other variables impacting car use, we also observe car ownership. Previous research suggests that car ownership is associated with higher levels of car travel (Handy et al., 2005; Scott and Axhausen, 2006). He & Thøgersen (2017) reported that car ownership is the most important determinant of car use. Car ownership can affect future car use among young adults (Oakil et al., 2016). Fuel price has also been identified as a relevant variable concerning car travel. By studying a representative sample of individuals in the Netherlands, Yang and Timmermans (2013) found a negative relationship between fuel price and car travel time expenditure. A 10% increase in fuel price led to 1.4% reduction in road traffic in the short term, and a 2.8% drop in the long term (Delsaut, 2014). Traffic congestion affects car travel too. Sardari (2018) suggests that congestion has a negative impact on VKT and doubling the delay caused by it accounts for 20% reduction of VKT. Sweet and Chen (2011) showed that traffic congestion can lead to a shift of trips from cars to public transport.

Only a limited number of studies examined car use and its driving forces in a collection of global cities. Most of these studies, on which the current paper builds, explore a range of global cities from a comparative perspective, assessing how variance in hypothetically relevant and important factors affect levels of car travel. In one of the most cited studies of this kind, Kenworthy and Laube (1999) found a negative correlation between urban density and VKT per capita. In a global study of 26 cities, McIntosh et al. (2014) revealed that increasing urban density and public transport kilometers of service by 1% reduces VKT by 0.2% and 0.16% respectively. Cameron et al. (2004) demonstrated that growth in wealth and consequently car ownership led to higher levels of car use. Moreover, higher density of cities such as Singapore and Hong Kong compared to others such as Perth can explain important variance in car ownership rates between them and in cities like Munich and Stockholm, the impact of transit-oriented development is evident in decreasing car ownership growth rates. By providing a minimum degree of urban density and restructuring urban areas on public transport corridors, it is feasible to reduce car dependency in cities (Newman and Kenworthy, 2006). Cameron et al. (2003) reported that the effect of urban form on car use is substantial and dense cities are associated with lower levels of car travel. These studies mostly emphasise built environment and especially density as the central determinant of car dependency and suggest it is feasible to manage car travel through growing density in urban areas. These findings have been greatly received by international organisations over the last decades as a solution to excessive car use. For instance, the UN Habitat Global Report on Human Settlements (2009 and 2001) cites several works of Newman and Kenworthy. Similarly, the World and European Sustainable Cities (2010) report, published by the European Commission, used Newman and

Kenworthy's findings on the inverse relationship between density and energy consumption of the transport sector to support the role of densification in combating car travel. In Appendix A, a summary of reviewed studies on determinants of car dependency is presented.

It is remarkable that in almost all studies that examine car dependency of global cities from a comparative perspective, the scholars Newman, Kenworthy and Laube appear to have a stake, either as authors or as source of inspiration. Other studies that follow the same line of reasoning were carried out on a range of cities within only one country, such as Safira and Chikaraishi (2019) on 69 Japanese cities, or Cervero and Murakami (2010) on 370 urbanized areas in the U.S. Other related studies are Van de Coevering and Schwanen (2003) who used data extracted from a Newman and Kenworthy study in order to re-evaluate the original results, and Bussiere et al. (2019) who included just four metropolitan areas in their analysis. Additionally, Bojkovic et al. (2018) focused on car use in a limited number of European cities. Hence, our research should be observed as a fresh look of car dependency in a varied collection of global cities after the seminal works by Newman, Kenworthy and Laube. We aim to build on their work and update it through exploring a unique and recent database on travel in global cities.

3.Data and method

3.1. Data

The data for the present research are obtained from the Mobility in Cities Database (MCD, 2015). MCD is the third and most recent edition of a data collection exercise on travel in global cities, and was published by the International Association of Public Transport (UITP) in 2015 with 2012 as the data reference year. This is a long-standing and major UITP dataset, which is updated regularly. A dedicated team of three people, including the lead author of the current paper, worked full-time for two years and a half , from 2014 to 2016, on data collection and analysis for its most recent edition. Each member of the team was in charge of working on specific metropolitan areas (MAs) The database offers data on major aspects of daily mobility patterns including private and public transport variables, modal share, length and duration of trips in a collection of cities. Moreover, a number of variables that reflect characteristics of the built environment and socioeconomics are available. One variable was generated by combining the raw variables population density and jobs density.[1] Then, the MCD database was supplemented by a standardized congestion index, and with a retail gasoline price metric. The standardized congestion index, provided by Inrix[2], is defined as the annual number of hours that an average driver loses in traffic congestion in a city. Data on retail gasoline prices were obtained from the website Globalpetrolprice.com. With the aim of using meaningful numbers, we applied purchasing power parity (PPP) to the price of gasoline and included the result in the model. All variables are presented in Table 1. The dataset comprises 63 MAs from five regions. The definition of a metropolitan area in this project was the result of a compromise between the economic area containing the bulk of

[1] More information on the MCD dataset and how to access it can be found here: https://www.uitp.org/publications/mobility-in-cities-database/.

[2] Inrix is a global transport data provider that publishes their congestion index on a large number of cities every year, feeding their congestion based ranking of cities which is called Interactive Ranking & City Dashboards.

daily home-work journeys, which is also referred to as the labour catchment area, and administrative delineations that may be sub-optimal from the point of view of the study of mobility. Seven MAs were removed from the set after having been assessed as unreliable or insufficient, including the absence of data on key variables. Eventually, 56 MAs were retained and included in the analysis (Table 2). Apart from the dataset, a report was published with a number of main findings on the database (Mobility in Cities Database Synthesis Report, 2015). It includes a concise analysis and presents the most striking observations on the database.

Before the start of the data collection, sound and transparent definitions of all elements of the database were developed, which were then meticulously implemented. Availability of data on the diverse set of variables at predefined geographical scale was ensured. Figure 1 illustrates the geographical distribution of MAs studied and examples of demarcations of two MAs.

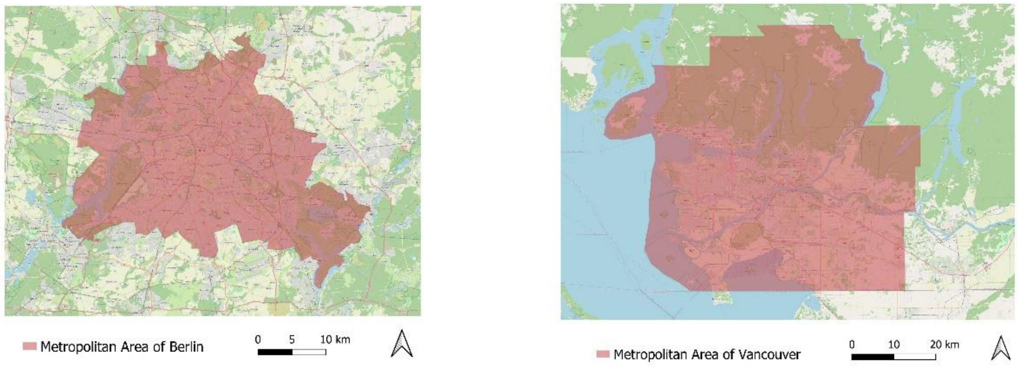

Figure 1. World map showing the MAs included in the study (above) and examples of the demarcation of the Metropolitan Area of Berlin (bottom left) and Vancouver (bottom right)

Data were collected by referring to a wide range of reliable sources that were usually developed locally. In regard to the categories of variables, national statistics offices (e.g., Istat in Italy or Statistics Bureau of Japan), transport departments and municipalities were the primary data source for built environment variables. National statistics offices were consulted to obtain data on socioeconomics. Data on public transport variables were mainly found in the annual reports of public transport operators (e.g., MVG in Munich or RTA in Dubai), whereas private transport data were accessible through household mobility surveys (e.g., the Sydney HTS Report). Whenever data were not available from such sources, staff in corresponding organisations were contacted in order to assist in obtaining data. The data were checked systematically to improve data quality. First, the team confronted the collected values with their own expert knowledge of reasonable ranges of all variables, as such identifying numbers that did not seem plausible. Second, data collected on every MA were systematically compared to older, comparable data on the same MA, and unexpected changes were examined. Third, the data on a particular MA were compared with similar or nearly identical MAs in terms of socio-economics, built environment characteristics, travel behavior and other influential factors. Finally, any irregular findings remaining were reviewed. On that occasion, the team returned to the sources and eventually decided to keep or remove/replace them. In terms of limitations of this exercise, we mention that some difficulties have been faced in compiling data on some variables in the majority of MAs. Besides, even though this database covers a wider range of MAs compared to some earlier studies, the sample is still relatively small. Although the original intention was to study areas with various sizes and populations, this goal was only achieved partially, making the database still not fully representative. Since all data employed are aggregate at the level of MAs, more complex local determinants of travel behaviour, such as residential self-selection (e.g., Cao et al., 2009; Diao and Ferreira, 2014), could not be included in our analysis. For the same reason, data on socio-economic variables are limited to what could be collected at the considered geographical scale level.

Table 1. Variables, their description and sources

Variable	Description	Source
Built environment Population density	Population divided by the surface of the metropolitan area	National statistics offices

Population and jobs density	Sum of population and number of jobs in the metropolitan area divided by the surface of the metropolitan area	National statistics offices
Population density of urbanised surface[3]	Population divided by the surface of urbanised area	National Statistics offices-Municipalities
Population and jobs density of urbanised surface	Sum of population and number of jobs divided by the surface of the urbanised area	National Statistics offices-Municipalities
Road network density	Total length of all categories of (open to public) roads in the metropolitan area divided by the surface of the metropolitan area	National Statistics offices-Transport departments
Length of road network per 1000 inhabitants	Total length of all categories of (open to public) roads in the metropolitan area divided by the every 1000 inhabitants of the metropolitan area	National Statistics offices-Transport departments
Surface dedicated to transport infrastructure	-	Municipalities-Transport departments
Socio-economics		
Population of the metropolitan area	-	National Statistics offices
Number of households in the metropolitan area	-	National Statistics offices
GDP of metropolitan area	-	National Statistics offices
Number of jobs in the metropolitan area	-	National Statistics offices
Public transport		
Public transport fleet size per million inhabitants	Total number of public transport vehicles by every million inhabitants of the metropolitan area (for rail modes, every carriage is considered as a vehicle)	Public transport operators' annual report
Public transport reserved routes per urban hectare	Total length of routes dedicated to any public transport mode by surface of the metropolitan area	Public transport operators' annual report Public transport operators' annual report
Average public transport speed	-	Public transport operators' annual report

[3] The urbanised surface refers to the built-up land surface, that is, residential, office, commercial and industrial areas (including warehouses and waste storage areas), public utilities, hospitals, schools, cultural centres, parks, gardens, sports fields, transport infrastructures (roads and motorways, railway tracks, airports), and derelict areas. On the other hand, the urbanized surface does not include sea, lakes, rivers and waterways, farmland, woods, meadows and other "natural" zones (flood plains, rocky points, etc.) and large recreational zones.

Annual public transport vehicle-km per capita Annual public transport journeys per capita	Kilometres of service offered by all public transport modes annually by population of the metropolitan area Annual number of boardings in all public transport vehicles by population of the metropolitan area	Public transport operators' annual report Public transport operators' annual report
Private transport Car ownership rate Average car trip length Average car trip duration	Number of registered passenger cars in the metropolitan area by 1000 inhabitants Average length of a car trip in the metropolitan area Average duration of a car trip in the metropolitan area	National Statistics offices-Household mobility surveys Household mobility surveys Household mobility surveys
Congestion index	The number of hours that an average person spends in traffic congestion annually	Inrix
Gasoline price	The average yearly retail price of a litter of gasoline	Globalpetrolprice.com
Dependent variables Car modal share VKT per capita	Share of daily trips made by car out of all daily trips made by any possible transport mode (excluding informal transport) Total kilometres covered by private cars in the metropolitan area by population of metropolitan area	Household mobility surveys Household mobility surveys

Table 2. List of metropolitan areas by regions

Europe	Athens, Barcelona, Berlin, Birmingham, Brussels, Budapest, Copenhagen, Dublin, Geneva, Glasgow, Gothenburg, Hamburg, Helsinki, Lisbon, London, Madrid, Milan, Moscow, Munich, Oslo, Paris, Prague, Rome, Stockholm, Strasburg, Tallinn, Turin, Vienna, Warsaw, Zurich
North America	Chicago, Montreal, Phoenix, Portland, Vancouver
East/Southeast Asia and ANZ	Beijing, Brisbane, Delhi, Hong Kong, Shizuoka, Singapore, Sydney, Tokyo
Middle East	Abu Dhabi, Ankara, Dubai, Izmir, Jerusalem, Kocaeli, Mashhad, Tehran
Africa	Casablanca, Johannesburg, Lagos, Tshwane

3.2. Modelling approach

We use Ordinary Least Squares (OLS) regression to model car dependency of the MAs included in our database. We consider this analysis to be exploratory, supplementing and updating the work of

Newman, Kenworthy & Laube (e.g., Newman & Kenworthy, 1989; Kenworthy & Laube, 1999; Newman & Kenworthy, 2006). Although OLS can provide insights into the way in which measurable variables have an impact on car dependency at the macro level, we first would like to draw attention to the following cautions.

> 1) For statistical purposes, the sample size is small, which may mean that some hypothesized associations will not prove statistically significant, even if they would be actually present and identifiable form larger samples.
>
> 2) The demarcation of the MAs was done on the basis of local administrative boundaries, as implemented in the MCD. Although the developers of MCD tried to survey comparable metropolitan areas, they met difficulties that are related to the intrinsically geographical problem of how the demarcation of metropolitan areas could be standardized, given the wide range of physical city types that exist worldwide.
>
> 3) The unit of observation used is the “metropolitan area (MA)”. However, it must be emphasized that a metropolitan area is a highly complex spatial and social entity, and that considering it as a statistical unit is a gross simplification of reality, which ignores individual characteristics of the residents, users, and elements of the built environment that together compose the metropolitan area.

In our analysis, we consider the modal share of cars, and the number of vehicle kilometres travelled per capita, both within the metropolitan areas, as dependent variables, while we employ the following categories of variables as independent in the model: built environment, socio-economic characteristics, intensity of supply and use of public and private transport, severity of road congestion, and gasoline price levels (as presented in Table 1).

Although multivariate Ordinary Least Squares (OLS) regression is a rather rough analytical technique, we argue that given the limitations of the dataset, OLS is an appropriate analytical tool, which will potentially add to earlier bivariate analyses such as those performed by Newman, Kenworthy & Laube. OLS allows to estimate the magnitude of the respective contributions of the various variables included, thus confirming or falsifying hypothetical simultaneous impacts on car modal share, and has proven to be a suitable tool for analyses that deal with not so large samples of cities (Van de Coevering & Schwanen, 2006), as is clear from earlier, similar studies (e.g., Zegras, 2010; IBI, 2000).

In order to meet model assumptions, the distribution of variables was tested for normality. Variables that did not meet the normality requirement were logarithmically transformed, which resulted in distributions that approached normality. Logarithmic transformation was applied to the following variables: density of urbanised area, public transport journeys per capita and public transport kilometres of service per capita. Another expected difficulty with respect to the model specification, in particular when including variables that are aggregate in nature, is the possibility that some of the dependent variables are strongly correlated. Therefore, we eliminated some of the originally selected variables as to keep the Variance Inflation Factor (VIF) below 5. (Soltani et al., 2018, Kutner et al., 2005).

Based on a Pearson’s correlation matrix, several combinations of variables that showed to be statistically significantly correlated with the dependent variables were tested, after which model combinations were ranked based on the R^2 values obtained.

Although the multivariate approach contributes to the consistency of the analysis, it may obfuscate direct interpretation of the results to some extent. In order to shed more light on the actual meaning of the results of the OLS regression, we have additionally disentangled and plotted all statistically significant bivariate correlations between 'car modal share' as the dependent variable, and the independent variables in the model. By doing so, we were able to discern between individual MAs and assess their individual contribution to the result of the analysis.

In particular the outlier MAs, namely those MAs that do not fit the observed patterns well, are an important source of information for developing hypotheses about how properties of MAs may influence local levels of car dependency. While a discussion of bivariate subplots and observed outliers is beyond the scope of this paper, these will be at the basis of further research that will examine the reasons behind the position of a selection of MAs in these subplots.

4. Results

In this section, we will explore the relationship between a number of specified hypothesized driving forces of car travel, considered as independent variables in the model, and two representative characteristics of car dependency, namely car modal share and vehicle kilometres travelled (VKT) per capita, considered as dependent variables.

4.1. Car modal share based model

Descriptive statistics with respect to the variable car modal share and the independent variables included in the final model are shown in Table 3. Results of the model analysis, including metrics of goodness of fit are summarised in Table 4. Significances are expressed as p-values, with thresholds specified at 5% and 10%.

Not all variables with a hypothesized impact appear to have a statistically significant impact on car modal share. Out of the subset of variables related to the built environment, combined population and jobs density of the urbanised area shows a significant and negative association with car modal share. Surprisingly, out of four types of density measured and under the specific conditions of our analysis, metrics of compactness that include both residential and workplace density are most representative for the type of built environment that makes cars less appealing. Focusing on MAs, Singapore, Hong Kong, Barcelona and Tokyo are identified as the perfect examples of such an association. The second subset of variables included in the model are related to public transport, which could complement dense urban development (Boussauw et al., 2018). Public transport kilometres of service and journeys per capita show a negative association with car modal share. This reinforces the idea that both increased supply and demand of public transport could reduce car dependency. This result supports the corresponding part of findings in the literature (Buehler, 2011; Bento et al., 2005). The circumstances in MAs such as Prague, Warsaw, Berlin and Vienna support these correlations on the ground. Some MAs like Tokyo, Singapore and Vienna were found to be areas where densification was put in place and combined with extensive public transport service and use, resulting in low levels of car dependency.

Further and in line with expectations, gasoline price is negatively associated with prevalence of car travel in cities. Moreover, car ownership and the level of congestion both appear to be associated with higher shares of car travel. In relation to the joint impact of gasoline price and car ownership, we observe Portland, Phoenix, Brisbane, Abu Dhabi, Dubai and Vancouver as MAs that stand out of our collection, where massive car ownership rate and inexpensive fuel (considering GDP) resulted in notably high car use. The positive relationship between the level of congestion and car travel was not anticipated, since indications of a reverse relationship were found in the literature (Sweet and Chen, 2011).

Based on a comparison of standardised Beta coefficients, the variable ‘density of the urbanised area’ proves to have the greatest impact on car modal share. The variables ‘public transport journeys per capita’ and ‘gasoline price’ are ranked next. It is important to note that although two of the variables show an association that is only significant at a p-level of 10%, R^2 is over 80% which is remarkably high.

With respect to a number of other variables, the analysis did not reveal any significant relationship with car modal share. For instance, this was the case for the variable ‘ratio of road length by 1000 inhabitants’. This can possibly be explained by the fact that road is a kind of infrastructure that serves different transport modes, not merely private cars. Therefore, expanding roads can in principle increase chances of using other modes too. Variables of public transport supply, with the exception of the variable kilometres of service did not play a significant role either; which may be explained by collinearity among them as they basically mirror the same concept. Besides, public transport kilometres of service was also identified by other scholars as showing a significant association with the level of car use (e.g., MacIntosh et al., 2014).

	Car modal share	Car ownership rate (no. of cars/1000 inhabitants)	Annual public transport kilometers of service per capita	Annual public transport journeys per capita	Density of urbanized area (residents+ jobs/ha)	Gasoline price after ppp (USD¢/liter)
Mean	44.9%	404.7	81.4	280.8	95.9	183.7
Median	40.5%	414.3	78.5	220.3	71.5	171.0
Std. Deviation	20.8	165.0	46.9	208.7	81.7	75.9
Minimum	7.6%	70	2	17	8.3	79
Maximum	84.0%	841	259	1041	357.8	412

Table 3. Variables included in the final model- Car modal share (before logarithmic transformation if it was the case)

Table 4. Summary of OLS results for car modal share

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics VIF
(Constant)	127.966	15.665		8.169	.000	
Car ownership rate*	.026	.015	.184	1.778	.087	1.412
Congestion Index**	.088	.038	.237	2.317	.029	1.377
*Density of urbanized area***	-19.788	7.732	-.358	-2.559	.017	2.564
*PT journeys per capita***	-13.633	6.391	-.292	-2.133	.043	2.458
*PT km of service per capita***	-11.197	4.859	-.219	-2.304	.029	1.184
Gasoline price (after applying ppp)*	-.094	.050	-.241	-1.860	.074	2.202

Dependent Variable: Car modal share

** *Significant at 5%, * Significant at 10%,* R^2= 0.802- Logarithmically transformed variables are shown in italic

4.2. Vehicle Kilometres Travelled (VKT) per capita based model

In a similar fashion, we attempted to build a model that considers VKT per capita as the independent variable. Descriptive statistics of variables included in the final model are illustrated in Table 5. After having assessed the explanatory power of various combinations of hypothetically contributing variables, even the model with the highest R^2 does not meet expectations (Table 6). Like the previous model, significances are expressed as p-levels with 5% and 10% as thresholds. Only two dependent variables, namely 'gasoline price' and 'car ownership rate', appeared to be significantly associated with VKT per capita. The latter one's p-level is just below 10%, while R^2 is slightly above 50% in this model. Gasoline price showed a greater influence compared to car ownership rate. The significant impact of both variables is in line with what was found by earlier research. Besides, both variables appeared as significant in the car modal share model too.

Table 5. Variables included in the final model-VKT per capita (before logarithmic transformation if it was the case)

	VKT per capita	Gasoline price after ppp (USD¢/liter)	Car ownership rate (no. of cars/1000 inhabitants)
Mean	4184.0	45.5	403.2
Median	3339.5	38.9	441.1

Std. Deviation	2845.4	28.0	193.4
Minimum	519	7.4	70
Maximum	10944	134.0	841

Table 6. Summary of OLS results for VKT per capita

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics
	B	Std. Error	Beta	t	Sig.	VIF
(Constant)	4386.709	2355.157		1.863	.078	
Gasoline price (after applying ppp)**	-22.472	7.883	-.568	-2.851	.010	1.594
Car ownership rate*	4.668	2.673	.314	1.746	.097	1.299
PT kilometers of service per capita	976.934	1176.106	.148	.831	.416	1.273

Dependent Variable: Vehicle kilometers Travelled (VKT) per capita

** *Significant at 5%, * Significant at 10%*, R^2= 0.527- Logarithmically transformed variables are shown in italic

5. Discussion and conclusion

This research explored the influence of the following groups of variables on car use at the level of global MAs: built environment, public and private transport, socio-economic characteristics, traffic congestion, and gasoline price. Our purpose was to build a multivariate model, based on an up-to-date dataset, that would recreate and improve earlier research of the strand that was initiated by Newman, Kenworthy and Laube (NKL). The Mobility in Cities Database (MCD, 2015) was used as data source, which offered extensive data on these variables in 56 metropolitan areas around the world. MCD was complemented by two external data sources. We hypothesized an effect on two different variables that represent car dependency: (1) car modal share and (2) VKT per capita. Employing OLS regression, the analysis indicated that car ownership rate, level of congestion, density of the urbanized area, public transport journeys per capita, public transport kilometers of service per capita and gasoline price were significantly associated with car modal share, while gasoline price and car ownership appear to be significantly correlated with VKT. Our findings confirm that car use is determined by a mixture of driving forces, as represented by the various variables included in our models.

Concerning the ongoing debate on the possibility of controlling built environment features as to make car use decline, combined population and jobs density of the urbanised area turned out to be significant from our analysis. The impact of this metric showed to be the most important out of the range of variables considered, which is consistent with previous research (Litman, 2010; Sallis et al., 2012; Badoe & Miller, 2000). Mostly Southeastern Asian, and some European MAs are illustrative of this pattern.

Among those variables that are related to public transport, the annual number of journeys and kilometers of service by population showed a significant and negative association with car modal share. This underscores the essence of investment in public transport infrastructure and operations and also hints at encouraging its use in order to reduce car travel (Toro-Gonzalez et al., 2020). European, particularly Eastern European MAs and some Southeastern Asian MAs are the evidence of these observed associations. Fuel price is known as a long-standing determinant of car use (Chi, 2016; Kwon & Lee, 2014), and our research confirms its expected negative association with car modal share and VKT per capita. Moreover, it was anticipated and confirmed that possessing a car is correlated with car travel (Van Acker & Witlox, 2010). American MAs are the pioneers on this followed by Australian, rich Middle Eastern and Canadian MAs. Then, the level of congestion was found to increase the likelihood of car use. This is the only variable with an unexpected influence, being not in line with earlier research where it was found that congestion-prone cities usually offer good alternative travel options and are thus less car dependent than average.

Although our model partly corroborates NKL's general findings, confirming the role of urban density and public transport, it is still possible to draw a line between certain findings of their studies and ours, and discuss some discrepancies between observed effects of variables on car dependency. First, we found that combined population and jobs density of the urbanised area is the variable with the most significant impact, which is different from the (unidimensional) population density metric as used in a number of NKL-inspired studies such as McIntosh et al. (2014) or Kenworthy & Laube (1999). While we identified public transport supply and demand as counter indicators of car use, NKL chiefly point to public transport kilometers of service or transit-oriented developments as supply side variables that influence car travel (Newman & Kenworthy, 2006; Kenworthy, 2018; Cameron et al., 2004). Moreover, we included fuel price and congestion index as two new variables, both proving to be significant, suggesting that these variables need to be considered in future research. In addition, some NKL-inspired papers discuss the impact on car travel of a number of variables that did not stand out in our own research. For instance, Cameron et al. (2003) emphasise the role of the urban area's size, while this is not obvious from our analysis. This could partly be explained by collinearity between the size of the metropolitan area and other independent variables. Litman & Laube (2002) found a negative relationship between regional economic development indicated by GRP per capita and car dependency, while this was not observed in our analysis. Newman et al. (2016) focused on theory of urban fabrics and explored the influence of three types of urban fabrics on car dependency, whereas the nature of this study does not allow us to re-examine these reported associations.

The difficulties we encountered to build a multivariate regression model on the basis of data that are aggregate within metropolitan areas, as to reproduce and better substantiate the findings of NKL, is striking. Although it turned out to be possible to build such a model for car modal share, we did not manage to develop a similar model for VKT. Although the explanatory power of the car modal share model was at the high side, levels of significance did not meet expectations. The VKT model suffered from missing data in the sample of metropolitan areas, but this is insufficient as an explanation of the lack of statistically significant correlation. Nevertheless, we have used one of the best applicable datasets of its sort, which we have enriched with publicly available data. We suspect that part of the explanation for the only partial confirmation of the NKL hypothesis that could be obtained from our models is the inability to account for more granular data in a model that uses metropolitan areas as a statistical unit. Although our car modal share model demonstrates that besides density, also other variables are significantly associated with car use, we believe that significant relationships observed do not explain car travel exhaustively. Levels of significance are moderate, and important hypothetical determinants that play at the level of the individual or the household could not be accounted for. Non-included variables such as residential self-selection (Wolday et al., 2019), age (Winters et al., 2015), distribution of incomes, and even attitudes (Zhou & Wang, 2019) complicate observed correlations. In more detailed analysis, where not a metropolitan area but a household or an individual would be the unit of analysis, the latter variables might even show greater association with car use (Bagley & Mokhtarian, 2002; Cervero & Duncan, 2003).

We therefore argue that exploring car dependency at the level of metropolitan areas, with all its limitations, is quite unique and valuable (Diao & Ferreira, 2014), but taking individuals and their diverse socio-economic characteristics, attitudes and habits into consideration, would make it possible to reach a more comprehensive list of car dependency driving forces. In Images 2 and 3 we portrayed two correlations between density and an indication of car use; one belongs to a well-known NKL study (Newman & Kenworthy, 1989), the other one is our own analysis. Despite both graphs illustrate that higher density is associated with lower car use, we believe that as long as the effects of other variables have not been captured simultaneously, we cannot derive straightforward conclusions from this graph or generalize that regardless of other possibly existing correlations, compact development is the silver bullet solution to adjust levels of car dependency in metropolitan areas.

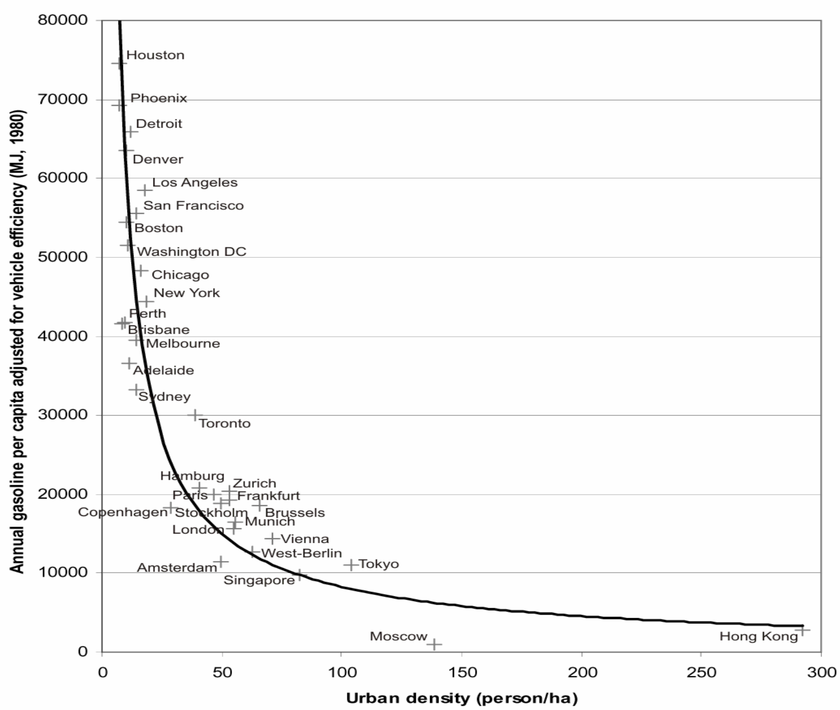

Image 2. Scatterplot on correlation between density and gasoline consumption in Newman & Kenworthy (1989)

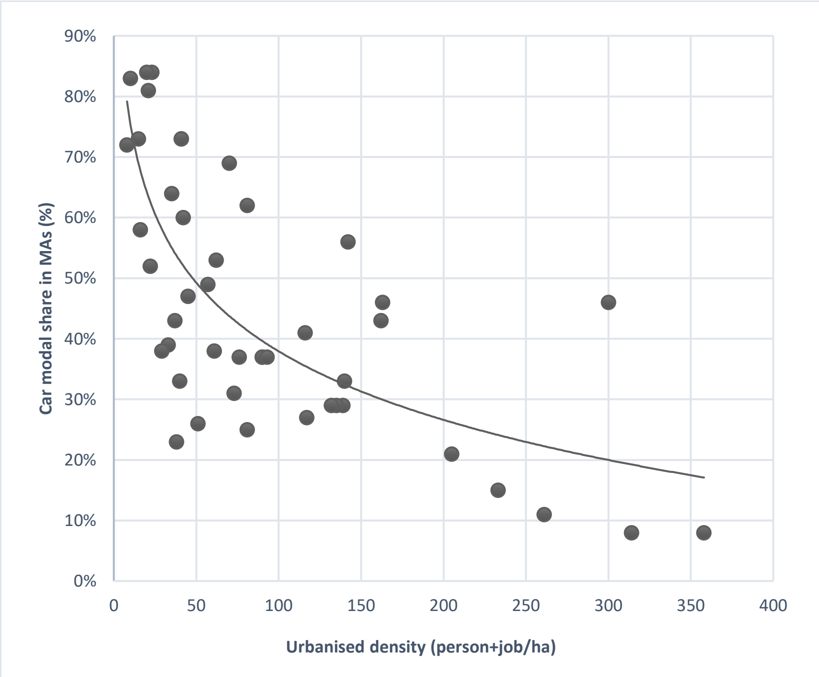

Image 3. Scatterplot on correlation between density and car modal share in this study

The above considerations do not mean that the analyses of NKL, many of which are bivariate in nature, are flawed, but they do have consequences for the scope, interpretation and practical application of the results in urban planning. This was already noted by Mindali et al. (2004), who suggested that the variation in the impact of built environment characteristics of different zones in a single metropolitan area could be explained by unobserved variables such as socio-economic characteristics. Zhang et al. (2012) came up with similar findings. Ewing et al. (2017) believe densities of urban areas with massive difference in size are not comparable, and suggest that other built environment variables ("D" variables) are embedded in the density metric, once measured at an aggregate level.

While the latter statement urges for exercising caution when analysing the impact of density, it would also mean that capturing the contribution of a more exhaustive set of built environment variables is possible by using aggregate data. However, other views are present in the literature as well (see Hong et al., 2014). Concerning the size of the metropolitan area, Giuliano and Dargay (2006) report a negative relationship between distance travelled and residential density, while the size of the city seems to play no role. Although this touches to the broader question of scalability and the modifiable areal unit problem in geographical analysis, differences in results generally could stem from other factors such as inconsistency in methodology or the quality of analysed data (Van Acker & Witlox, 2011). These various and in some cases even contradictory findings suggest to abstain from developing one general recommendation to all MAs struggling with car dependency. Although we are not the first authors who take a critical, research-based, stance towards the NKL approach, it is remarkable how easily the NKL thesis has been cited and accepted in many urban and regional planning policies all over the world, without thorough qualification or a critical look at the local societal processes that are behind the notion of density.

From our findings, we derive following policy implications. Enhancing density could be relevant in controlling car traffic. Nonetheless, it is not a silver bullet and cannot solely determine the extent of car use. As this study showed, densification needs to be combined with other policies, such as promoting alternative transport accessibility and providing incentives to promote its use, especially with respect to public transport. Moreover, from a transport economics perspective, our analysis confirmed that rising fuel price as a direct cost of car travel could be effective in reducing car dependency. Whereas all these policies are important in controlling car use, it should be kept in mind that at the level of the individual or the household, car travel is explained by a number of unobserved variables that are not all amenable to policy interventions.

Appendix A. Summary of reviewed papers

Studies explained car use through contextual characteristics

Author(s)	Category of variable(s) studied	Study location	Main findings	Model type
Nielsen et al. (2013)	Built environment	Denmark	Density, connectivity and diversity enhances odds of using alternative modes to car	OLS regression
Yin & Sun (2018)	Built environment	China	Encouraging dense development can decrease car use	Multilevel logit regression model
Sun et al. (2017)	Built environment	Shanghai, China	Dense development can be helpful in decreasing travel distance and wider use of alternative modes	Discrete-continuous copula-based model
Ewing & Cervero (2010)	Built environment	Meta-analysis	Accessibility to destinations and street network design impact VKT most	-
Brownstone and Golob (2008)	Built environment	California, USA	Low density increases VKT	SEM
Jiang et al. (2017)	Built environment	Jinan, China	High density and bus rapid transit development reduce car traffic	Multinomial logistic model and double, hurdle model
Boarnet (2011)	Built environment	Meta-analysis	Transit-oriented development reduces car travel	-

Munshi (2016)	Built environment	Rajkot, India	High land use mixture promotes use of alternatives to car	Multinomial logit model
Boussauw et al. (2010)	Built environment	Flanders, Belgium	High land use density is associated with fewer car trips	OLS- Spatial, lag- Spatial error
Liu & Shen (2011)	Built environment	Baltimore, USA	High land use mixture, density and street connectivity decline car trips	Regression analysis
Bartholomew and Ewing (2008)	Built environment	Meta-analysis	Promoting density reduces VKT in the long-term	-
Leck (2006)	Built environment	Meta-analysis	Density affects mode choice more than any other BE variable	-
Ding and Cao (2019)	Built environment	Washington , USA	Residential density and employment density affect car us more than any other BE variable	Cross-classified multilevel model
Potoglou & Kanaroglou (2008)	Socio-economics and demographics	Hamilton, Canada	Socio-economic variables play an important role in car ownership	Multimodal logistic regression
Zhou et al. (2021)	Socio-economics and demographics	Nanjing, China	Socio-demographics of people are associated with their daily activities and travel behaviors	Markov-chain-based mixture model, logistic regression
Stead (2001)	Socio-economics and demographics	UK	Socio-economic variables are more important than land use variables when it comes to travel patterns	-
Kotval-K & Vojnovic (2015)	Socio-economics and demographics	Detroit, USA	Higher household income, education and employment is associated with higher car use	Regression
Yang &Timmermans (2013)	Socio-economics and demographics	Netherlands	High income enhances car ownership and use	Seemingly unrelated regression
Le Néchet (2012)	Socio-economics	Europe	The combined impact of urban form and socio-	Regression

	and demographics		economics on share of trips made by car is stronger.	
Manaugh et al. (2010)	Socio-economics and demographics	Montreal, Canada	High income and working status together with being man increase chance of car travel	Factor analysis-cluster analysis
Li et al. (2018)	Socio-economics and demographics	Shenyang, China	Gender and monthly income affect car use	Binary Logistic regression
Buehler (2011)	Public transport	Germany and USA	Living far from public transport is led to higher car travel	Multinomial Logit Model
Bento et al. (2005)	Public transport	114 urban areas, USA	Built environment would affect car travel, only if it is paired with public transport supply	-
Mulalic & Rouwendal (2020)	Public transport	Copenhagen, Denmark	Higher supply of public transport reduces car ownership rate and vehicle kilometers travelled	Discrete choice model
Younes (1995)	Public transport	London, Berlin and Stuttgart	Growth in rail ridership is due to attracting passenger from other public transport modes and not cars	-
Parkhurst (2000)	Public transport	Eight park & ride facilities in the UK	Park & ride facilities do not reduce car use	No specific model-monitoring changes in ridership of different transport modes
Handy et al.(2005)	Car ownership	Austin, US	Car ownership affects car use	No specific model-descriptive analysis of interviews' results
Scott & Axhausen (2006)	Car ownership	Karlsruhe, Germany	There is a more complicated relationship between car ownership and use than what is mainly known	bivariate ordered probit models
He & Thøgersen (2017)	Car ownership	Guangzhou, China	Car ownership is the most important determinant of car use	Bayesian hierarchical models
Oakil et al (2016)	Car ownership	Netherlands	Car ownership in the household	-

			enhances chance of car use among younger adults	
Yang & Timmermans (2013)	Fuel price	Netherlands	Fuel price has a negative relationship with car travel	Seemingly unrelated regression
Delsaut (2014)	Fuel price	France	Increasing fuel price reduces road traffic	OLS regression
Sardari (2018)	Traffic congestion	USA	Doubling traffic congestion decreases VKT by 20%	-
Sweet and Chen (2011)	Traffic congestion	Chicago, USA	Increasing traffic congestion is led to shift from car to public transport	Using GPS travel survey and regional agency for planning data

Studies explained car use in global cities

Authors	Categories of Variables studied	Main findings	Model type
Kenworthy and Laube (1999)	Car ownership, GRP, density, public transport, modal share, trip length and duration, costs of proving public and private transport infrastructure	Higher density is associated with less car use	Bivariate regression
McIntosh, Trubka, Kenworthy and Newman (2014)	Car ownership, GRP, density, public transport, modal share, trip length and duration, costs of proving public and private transport infrastructure	Increasing density and public transport kilometers of service by 1% reduces VKT by 0.2% and 0.16% respectively	SEM and log-log model
Cameron, Lyons and Kenworthy (2004)	Car ownership, GRP, density, public transport, modal share, trip length and duration, costs of providing public and private transport infrastructure	-Higher car ownership results in higher car use, -Better public transport service reduces car dependency	-
Newman and Kenworthy (2006)	Car ownership, GRP, density, public transport, modal share, trip length and duration, costs of proving public and	Higher density and restructuring cities based on public transport decline car dependency	Bivariate regression

	private transport infrastructure		
Cameron, Kenworthy and Lyons (2003)	Car ownership, GRP, density, public transport, modal share, trip length and duration, costs of proving public and private transport infrastructure	Density and transit-oriented development affect the level of car ownership	Dimensional analysis

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