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Kobe University, Kyushu University

2016

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Abstract

This study empirically examines the demographic determinants of car ownership in Japan between 1980 and 2009. Unique car cohort data, composed of the car age and 11 car types, at the prefectural level, is analyzed. The primary reason for examining the demographic determinants of car ownership in Japan is because Japan is projected to face radical demographic changes in the next few decades. These projected changes include depopulation and an aging population with diminishing household size. This study will be the first empirical study of the car cohort model with large countrywide observations in the recent literature. This study classifies the demographic determinants into five categories: (I) longitudinal factors, (II) economic factors, (III) natural factors, (IV) social factors, and (V) other transports. Although some tendencies vary among car types, this study finds the following tendencies of ordinary car ownership (compact four-wheel drive trucks and regular and compact passenger cars). Regarding the longitudinal factors, the long-run effect is much higher than average in the recent literature, whereas the semi elasticity of car age is approximately -7%. Regarding the economic factors, the elasticities of income and fuel price on car ownership tend to be less intense than in earlier studies. Regarding the natural factors of population increase, the elasticities of population and average household size on car ownership tend to be negative. This indicates that a decrease in population and household size in Japan will accelerate car ownership. In addition, the ratio of elderly people has various effects depending on car types. Regarding the social factors of population increase, car ownership tends to be encouraged by the concentration of population within prefecture, and increased and decreased for relatively new (aged 2-11) and old (aged 12+) cars, respectively, by the concentration of population across prefectures. The former is probably due to a composite effect in urban and rural areas, whereas the latter may be a quick update cycle due to an effect of urbanization. Regarding other transports, the degrees of train and bus use tend to be negatively associated with ordinary car ownership. However, these effects are considerably small and often insignificant as in the literature.

Key words: car cohort; demographic determinants; car ownership in Japan; car aggregated model

JEL classification: L62, R10, R40

1. Introduction

This study examines the determinants of car ownership in Japan between 1980 and 2009, by constructing and analyzing a unique database. Focus is placed on the demographic determinants of car ownership at the prefectural level, including the population, population density, and income, because Japan is projected to face radical demographic changes, such as an aged society with a smaller population, in the near future (e.g., toward 2060; see National Institute of Population and Social Security Research (IPSS), 2012). The study data consists of an aggregated number of registered cars (i.e., car cohort data), which are decomposed into prefectures, the initial registered year (i.e., car age), and car types. The data is obtained from the Automobile Inspection and Registration Information Association (AIRIA) in Japan, and is available for the years of 1980 through 2009. This study uses a dynamic regression model to analyze the data. The data is divided into two age groupings: cars aged between 2 and 11 years (ages 2-11) and cars aged 12 and over (ages 12+). There are 11 type of cars, and hence, 22 specifications.

The prediction of car ownership is considered important, especially for the industry and the government, because the automobile industry is a key industry in Japan. Table 1 shows key economic and demographic variables in Japan from 1970 to 2010. According to the Economic and Social Research Institute (ESRI), Cabinet Office, Government of Japan (various years), the gross domestic product (GDP) share of transportation equipment in Japan, where the automobile industry accounts for a large percentage, has been relatively constant for four decades, indicating the economic importance of the automobile industry. It had consistently decreased between 1970 and 2000 (4.1%, 3.6%, 2.9%, and 2.4% in 1970, 1980, 1990, and 2000, respectively). It then slightly increased to 2.9% in 2010.

According to the car data from 1970 through 2010, new car sales peaked in 1990, while car ownership (i.e., the registered number of vehicles) has consistently been increasing. According to the Japan Automobile Manufacturers Association, Inc. (JAMA) (2015), the number of new vehicle sales, except for motorcycles, increased annually from 1970 (4.1 million) through 1990 (7.7 million) (Table 1). It then decreased to 5.9 in 2000 and 4.9 million in 2010 and increases to 5.5 million in

2014. On the other hand, car ownership in Japan has consistently increased since 1966 (AIRIA, 2015). The total number of owned cars, including light vehicles (i.e., with a cubic capacity of 660 cubic centimeters (cc) or less) and light motorcycles, is 16, 37, 57, 74, 78, and 80 million in 1970, 1980, 1990, 2000, 2010, and 2014, respectively (Table 1). While the growth rate has been decreasing recently, these values indicate that there is still a large demand for car ownership.

From an economic aspect, a prediction of car ownership is useful in relation to significant business demand. On the other hand, from an environmental aspect, the prediction is also important. This is because the 80 million registered vehicles in Japan (in 2014) cause huge externalities, such as greenhouse gas (GHG) emissions and traffic jams.

The primary reason to examine the demographic determinants of car ownership in Japan is because Japan is projected to face radical demographic changes in the next few decades (Table 1). According to the Statistics Bureau, Ministry of Internal Affairs and Communications (MIAC), Japan (2012a; 2012b; 2015a), the population in Japan increased from 1970 (104,665 thousand) to its peak in 2010 (128,057 thousand). It then started to decrease; in 2014, it was 127,083 thousand people. The population size is expected to decrease further over the next few decades, with the ageing of the population and the spread of smaller family types such as nuclear families (i.e., a pair of adults and their children), dual income no kids families, and single families. Consequently, it is important to examine the determinants of Japanese car ownership, even if it is just at the aggregated level, as it will help industry and the government to predict future demand.

In this investigation, we create prefectural level data, using aggregated vehicle data from 1980 through 2009. We apply a dynamic regression model. Note that this study has several advantages and limitations. Regarding the advantages, our dataset has a relatively large number of observations covering the whole nation; the data is divided at the prefectural level into car type, car age, car maker, and car brand. Car cohort is considered in this data set, which means that certain car groups are used as observations in the model, and they age 1 year in the next year. Car ages or age structure is seldom examined in the literature, due to data limitations. The car cohort data is aggregated data, which has some advantages. Generally, aggregated data has little sample selection bias and is suited to examine the determinants for predictions (de Jong et al., 2004). Note that disaggregated data is more popular than aggregate data in the recent transportation literature (Anowar et al., 2014; Ortúzar and Willumsen, 2011).

The contribution of this study is divided into two parts. Firstly, this study will be the first empirical study of the car cohort model with large countrywide observations in the recent literature. Several Japanese studies use car cohort information as part of a sequence of their simulation models, but they are not basic empirical studies. In addition, this study analyzes not only passenger cars, which are popular in the earlier studies, but also other vehicles such as trucks, buses, and motorcycles.

The other contribution is to examine the elasticity of car ownership with respect to demographic and social determinants because there are few recent studies examining demographic elasticities of car ownership in Japan (e.g., Sun et al., 2014). We classify the determinants into five categories: (I) longitudinal factors, (II) economic factors, (III) natural factors, (IV) social factors, and (V) other transports. We consider ordinary cars are compact four-wheel drive trucks and regular and compact passenger cars, and summarize the results as follows.

Regarding the longitudinal factors (I), we consider the long-run effect of car ownership and car age. The long-run effects are approximately 10 and 5.56 times at car aged 2-11 and 12+. They are higher than average in the recent literature (Goodwin et al., 2004; Graham and Glaister, 2004). Also, the semi elasticity of car age (1 year) is approximately −7%, which is seldom reported in the literature.

Regarding the economic factors (II), we use income and fuel price (gasoline price), considering the consumer price index (CPI) as a control variable for the general cost of living. The elasticities of income and fuel price on car ownership tend to be less intense than in the earlier studies (Goodwin et al., 2004; Dunkerley et al., 2014). Regarding the elasticities of income, the regular passenger cars have similar elasticity (0.766 in the long-run) as in the literature, whereas the other compact cars are lower than the typical value in the literature. Regarding the elasticities of fuel price, car ownership is not associated with the gasoline price among the cars aged 2-11, whereas the elasticity for the cars aged 12+ is more intense (approximately −0.2 in the short-run) than that found in the previous studies of Goodwin et al. (2004) and Dunkerley et al. (2014).

The natural factors (III) and social factors (IV) stem from the idea that the population increase is caused by a natural increase (e.g., birth rate) and a social increase (e.g., migration). Regarding the natural factors (III), we consider population size, average household size, and the ratio of elderly people (over 65 years of age). As the results may be counterintuitive, the elasticities of population and average household size on car ownership tend to be negative. Therefore, a smaller population and household size in Japan will lead to more car ownership. This result is similar to those of Ritter and Vance (2013) and Whelan (2007), which project that car ownership will increase in Germany and Great Britain, respectively, for the next two decades. In addition, the ratio of elderly people has various effects depending on car types. One tendency is that, in terms of the cars aged 2-11, the higher ratio of elderly people is associated with less compact cars and more regular cars.

Regarding the social factors (IV), we use the percentage of the population located in a densely inhabited district (DID rate; population in DID divided by total population) and net migration rate (net migration increase divided by total population). DID is the basic area unit holding more than 4,000 people per km^2. Hence, the DID rate represents people concentration in prefecture, or a lower degree of rural areas. On the other hand, the net migration rate indicates the popularity of prefectures. As a result, car ownership tends to be encouraged by a concentration of population within a prefecture (the DID rate), and increased and decreased for relatively new (aged 2-11) and old (aged 12+) cars, respectively, by concentration of population across prefectures (the net migration rate). The former is probably due to a composite effect in urban and rural areas, whereas the latter is a quick update cycle due to an effect of urbanization (e.g., Matas and Raymond, 2008; Sun et al., 2014).

Regarding other transports (V), we consider train and bus use, which is the number of gross users of train and bus divided by total population. The estimated elasticities for the train and bus use to car ownership are negative as in Matas and Raymond (2008). However, these elasticities are considerably small and often insignificant as in Dargay and Vythoulkas (1999).

The rest of this paper is structured as follows. Section 2 reviews the car ownership models in the transportation literature and discusses the potential determinants by comparing the previous studies. Sections 3 and 4 explain the model and dataset, respectively. Section 5 discusses the regression results and Section 6 concludes with implications and limitations of this study.

2. Background

2.1 Car ownership in Japan

Growth in the Japanese car market has slowed recently; however, demand is still high. The total number of registered vehicles, since 1970, has consistently increased over time (Table 1). More specifically, the number of vehicles, excluding light vehicles and motorcycles, rapidly increased before 1980 (31.7 million), peaked between 1998 and 2004 (over 53 million), and began to slightly decrease from 2005 to 2009 (50 million) (AIRIA, 1981-2010) (Figures 1 and 2). Note that it implies that the number of light vehicles and motorcycles also rapidly increased from 5.6 million in 1980 to 28.8 million in 2009 (AIRIA, 2015).

Figure 1 illustrates that the number of registered vehicles, except for light vehicles and motorcycles, can be divided into 11 car types (AIRIA, 1981-2010). The 11 car types include: #1 regular trucks, #2 compact four-wheel trucks, #3 compact three-wheel trucks, #4 trailing trucks, #5 regular buses, #6 compact buses, #7 regular passenger cars, #8 compact passenger cars, #9 special purpose cars, #10 large-sized special cars, and #11 motorcycles (Table 2). Note that types #3, 4, 5, and 6 are not shown in Figure 1, because the numbers are small. Note that in Figures 1 and 2, yearly data includes data within 3 months (i.e., from January to March) of the next year, because the statistics report is published in each fiscal year (Appendix Table A1 summarizes the number of registered vehicles of car types and age in each decade from 1980 to 2009).

Figure 1 illustrates that one of the most significant changes in the three decades of this study is that the number of #7 regular passenger cars has consistently increased, from 1989 (1.3 million) until 2004 (16.4 million). On the other hand, the number of #2 compact four-wheel trucks and #8 compact passenger cars has recently been decreasing. More specifically, the number of compact four-wheel trucks went from 7.1 million in 1980 to 6.5, 5.3, and 3.9 million in 1990, 2000, and 2009, respectively. In a similar way, the number of compact passenger cars went from 21 million in 1980 to 31 million in 1991 and 1994, and then decreased to 23.7 million in 2009. This suggests that there is heterogeneity of car ownership among the various car types.

Figure 2 illustrates that the number of registered vehicles (except for light vehicles and motorcycles) divided by the initial registered years (i.e., car age), can be separated into 13 categories: within 3 months (i.e., from January to March of the next year), each age between 1 and 11, and ages 12+. Note that this study does not use the data of within 3 months, because of the yearly dynamic model. This car data is characterized as car cohort data, where a car cohort of a certain age becomes 1 year older in the next year (e.g., a car group that is 1 year old in 1980 becomes 2 years old in 1981). Therefore, new car sales have a large effect on the entire structure of car age, because a decrease in new car sales means a decrease in the inflow of the entire car stock.

New car sales, in which this study considers cars that are age 1 (i.e., except for the data of "within 3 months" of the next year), had increased from 4.1 million in 1980 to 6 million in 1990, where 1990 was the peak; numbers decreased to 4.1 and 2.9 million in 2000 and 2009, respectively (Appendix Table A1). On the other hand, the car numbers for cars aged 12+ tended to increase consistently and exponentially from 0.6 million in 1980 to 2.5, 6.1, 12.9 million in 1990, 2000, and 2009, respectively (Appendix Table A1). This indicates that the aged society progresses in the car stock as well as in the population in Japan, although it does not necessarily mean that older people buy older cars.

The ageing of car ownership is probably due to improvements in car durability (i.e., a lower maintenance cost as in Matas and Raymond (2008)) and the growing market for used cars. Because of competition in the car industry, each car maker is required to develop more durable and safe cars with cheaper prices. Through the development of the used car market, consumers can choose new or old cars.

This study hypothesizes that such changes in car ownership are affected by demographic factors, such as population, population density, and income. This is because the registered vehicle numbers appear to have a long-term trend. More specifically, while the vehicle number, except for light vehicles and motorcycles, peaked around 2004 (over 53 million), the total people population in Japan peaked in 2010 (128 million) (MIAC, 2012a; 2012b; 2015a) (Table 1). Because Japan is projected to face radical changes in its demographics, this study is important, as it will inform industry and the government in identifying the demographic determinants of car ownership.

2.2 Model classification from the previous studies

The transportation literature has examined car (including bus, truck, and motorcycle) ownership and use for more than 50 years (Ingram and Liu, 1999; Whelan, 2007). Previous studies have often examined car ownership, instead of car use, because of data availability (Ingram and Liu, 1999; de Jong et al., 2004). In this case, car ownership is assumed to be greatly related to car use. Among the car ownership models, de Jong et al. (2004) review the relatively recent studies (i.e., mainly in the late 1990s and early 2000s), classifying the models into 10 types based on 16 criteria. de Jong et al. (2004) and Ortúzar and Willumsen (2011) note that models depend highly on the data characteristics and are roughly divided into two types: the aggregate data model (e.g., Dargay, 1999, 2002; Ingram and Liu, 1999) and the disaggregated data model (e.g., Matas and Raymond, 2008; Ritter and Vance, 2013; Sun et al., 2014; Whelan, 2007).

Aggregate data means that observations are summarized by certain categories, such as country and people cohorts. Disaggregate data is usually observed at the household or individual level, and has become more popular in recent years in the transportation literature, because of its flexibility (Anowar et al., 2014; Ortúzar and Willumsen, 2011). Note that recent studies at the disaggregate level are summarized in Anowar et al. (2014), who review 83 studies (since 1990) using disaggregate data and divide them into the following four types: exogenous static models, endogenous static models, exogenous dynamic models, and endogenous dynamic models.

de Jong et al. (2004) further divide car models at the aggregate level into the following 4 models: aggregated time series models, aggregated cohort models, pseudo panel models, and aggregate car market models. The aggregated cohort models use cohort data from people, rather than car cohort data. Among them, the car cohort model belongs to the aggregate time series models.

Few studies have adopted car cohort data. In the recent literature, the car cohort model is used in Morisugi and Ohno (1997) and Hayashi et al. (2001), who both focus on the Japanese car market. Morisugi and Ohno (1997) construct a simulation model system of car cohort types to predict the number of diesel automobiles and the NOx volume. This information is used to analyze the impact of the policy to reduce the number of diesel automobiles in Japan. The model system is roughly divided into three parts. Firstly, a cohort model predicts the ownership transfer between diesel and gasoline automobiles in the market of sedans and small-trucks, using time series data from 1974 to 1991, obtained from AIRIA. The first model consists of three sub-models: a trend model, choice model, and survival model. A simulation analysis is then carried out, as if the policy is implemented, to reduce the number of diesel automobiles. Finally, a model based on the input-output analysis is constructed to predict the price change, due to the policy implementation (i.e., the light-oil price/tax).

Following the car cohort model system developed in Morisugi and Ohno (1997), Hayashi et al. (2001) structure a model system to assess the effect of a car-related taxation scheme on the total life cycle of CO_2 emissions and the total tax revenue. Focusing on the 1989 tax reform in Japan, the authors treat three stages of cars: car purchase, ownership, and usage, for the 5 sub-models. Among the sub-models, a car cohort survival model is the core part of the model system. The authors use the car market data in Japan from 1980 to 1994 and demonstrate that car ownership (including disposal/repurchase and choice of car class) is affected by the purchase and ownership taxes, rather than the car usage tax. Following the results, when doubling the ownership tax rate, CO_2 emissions by the production, maintenance, and disposal of vehicles do not experience a significant change; however, CO_2 emissions by driving are going to decrease, due to the shift in car classes with less of a degree of engine displacement (i.e., from an engine displacement of over 2000 cc to a displacement of 2000 cc and less than 2000 cc). The authors also find that varying the balance of the car related taxes can increase government revenue.

Unlike the models in Morisugi and Ohno (1997) and Hayashi et al. (2001), this study adopts an empirical analysis. This is because the focus of this study is to identify the demographic determinants of car ownership, rather than conduct some simulations, such as policy implementation. While these authors examine car ownership at the national level, this study focuses on car ownership at the prefectural level (47 prefectures), for all of Japan.

2.3 Determinants of car ownership

The demographic factors of car ownership have been empirically investigated, especially at the disaggregate level, in the recent studies such as Matas and Raymond (2008), Ritter and Vance (2013), Whelan (2007), and Sun et al. (2014). Ritter and Vance (2013) and Whelan (2007) predict car ownership in the future in Germany and Great Britain, respectively. Following the model in Whelan (2007), Matas and Raymond (2008) analyze the determinants of car ownership in Spain from 1980 to 2000. Sun et al. (2014) examine the demographic determinants of car ownership in Osaka metropolitan area in Japan from 1970 to 2010.

Ritter and Vance (2013) suggest that a change in household size can play an important role in car ownership, using household-level data for Germany. In Germany, as well as Japan, the average household size is projected to decrease from 2.04 in 2009 to 1.97 in 2030. Their simulation shows that a larger household size reduces the total number of cars, even when the overall population is constant. This indicates that smaller size households less efficiently use or share their car(s) within the households, leading to more car ownership.

Whelan (2007) develops a car ownership model in Great Britain at the disaggregate level to forecast car ownership, focusing on demographic factors. In Great Britain, car ownership has increased from 2.55 million in 1951 to 26.96 million in 2001. At the same time, the numbers of households also increased from 14.5 million in 1951 to 24.6 million in 2001. From 2001 to 2031 in Great Britain, although the population is projected to increase (from 60.43 to 63.85 million), the society is projected to age (i.e., decrease and increase in the number of children and retired people, respectively) and the number of single families will increase. Using data from the Family

Expenditure and National Travel Surveys, the author simulate that the total number of vehicles is expected to increase by 42% from 2001 to 2031.

In Spain, according to the Spanish Household Budget Survey (Matas and Raymond, 2008), household car ownership was 51.2% in 1980; that number increased to 63.1% and 72.6% in 1990 and 2000, respectively. The authors examine the determinants of car ownership using disaggregated survey data and find that the effect of total household expenditures (a proxy for income) is highly significant and stable over time, although the effect varies depending on the level of car ownership and the area (i.e., rural and urban areas). They also find that car ownership is negatively affected by the quality of public transport in the large municipalities, and that the ageing of the population will only have a weak effect; consequently, the increasing effect of the ageing population on car ownership (i.e., increases in car ownership) will vanish around 2020.

In recent Japanese literature, Sun et al. (2014) examine the structural changes in car ownership and usage in the Osaka metropolitan area in Japan, using large cross-sectional datasets from 1970 to 2000 (person trip data). They use a simultaneous equation model system of disaggregated data. In the model, the endogenous variables are car ownership, total car travel time, and proportion of trips by car, whereas the exogenous variables are related to lifecycle stage, residential area, and age of each individual. As results of car ownership, regarding the residential area, the ownership is more encouraged in the undeveloped (rural) areas and autonomous areas than in highly commercial and mixed commercial areas. Regarding the lifecycle stage, all-adult families and older single families have the highest and lowest willing to own cars, respectively. Regarding age, elderly people (age 65-74 and 75+) tend to own fewer cars than the younger people. Their predicted values show that average car ownership per household increased from 0.40 in 1970 to 1.32 in 2000 (2.8 times). As an interesting point, the changes in car ownership were caused by changes in structural relationships (the coefficients) and demographic factors (the explanatory variables). The changes in the structural relationships have a positive effect (3.3 times higher than in 1970), whereas the changes in the demographic factors have a negative effect (15% lower than 1970).

In the transportation field, a few informative review papers examine the elasticities of car demand. A representative review is conducted by Goodwin et al. (2004), who examine 69 studies with 175 different equations using datasets from 1929 to 1991. Note that a contemporary literature review is done in Graham and Glaister (2004), but the authors focus on road traffic and fuel demand, rather than the demographic factors of car ownership. More recently, Dunkerley et al. (2014) review 23 studies out of 154 studies from the published and grey literature and summarize the determinants of road transportation driving demand.

Following the literature and the data limitations, this study uses car age and the following 11 demographic variables as potential model determinants (i.e., dependent variables): income, gasoline price, CPI, population size, the population density, household size, the percentage of people over 65 years old, the DID rate, the net migration rate, train use, and bus use. This sub-section introduces how each of the determinants is treated in the transportation literature.

2.3.1 The long-run effect

In the transportation literature, the long-run effect is considered important for predicting car demand or ownership. This is because vehicles are durable goods with relatively expensive prices. Therefore, it usually takes time for households to adjust to changes in their circumstances (Dargay, 2002). Goodwin et al. (2004) review 86 equations among the 175 reviewed equations that are dynamic models (i.e., partial adjustment models), and summarize that the long-run elasticities tend to be two or three times larger than the short-run elasticities. Note that similar values are reported in Graham and Glaister (2004). Consequently, this study adopts a dynamic model of a vehicle-cohort.

2.3.2 Income

Among the determinants of car ownership in this study, income is one of the most commonly used in the transportation literature. Goodwin et al. (2004) illustrate that the average elasticity of vehicle stock, with respect to income, is 0.32 and 0.81 in the short- and long-run of the dynamic estimation, respectively, and 1.09 in the static estimation. Similar values are found in

Graham and Glaister (2004), who report that the income elasticities of car ownership average 0.28 (between 0.24 and 0.34) and 0.74 (between 0.3 and 1.1) in the short- and long-run, respectively.

Dunkerley et al. (2014) suggest that the income elasticity of car demand in the literature ranges between 0.5 and 1.4 in the long-run, which is broader than the range of the fuel elasticity of car demand. These values indicate that the income elasticity of car demand is relatively high, but is likely to be less than 1.5, as the maximum, in the long-run. Dunkerley et al. (2014) also discuss that the income elasticity depends on the data type, functional form, and income, which is calculated from GDP or household income (or expenditure).

For an income variable, this study uses the prefectural income per capita obtained from ESRI (2015), which is similar to the GDP measure. The prefectural average income is calculated based on the gross prefectural product and the summing of the three incomes: compensation of employees, property income, and business income. Because of including business income, this value may not fully represent household income levels, and is considered larger than the average monthly salary.

2.3.3 Gasoline price and CPI

The gasoline price, as the fuel price, is one of the key variables used in the transportation literature. The absolute values of the fuel price elasticity of car ownership (i.e., the elasticity is usually negative) are often observed to be lower than the absolute values of the income elasticity. Goodwin et al. (2004) show that the average elasticity of the vehicle stock, with respect to fuel price, is −0.08 and −0.25 in the short- and long-run in the dynamic estimation, respectively; it is −0.06 in the static estimation. On the other hand, Dunkerley et al. (2014) summarize that the fuel price elasticities in the surveyed literature take on a value range between −0.1 and −0.5, while the largest value (−0.79) is observed during long distance holiday travels.

As Dunkerley et al. (2014) note, fuel price elasticities are basically measured in two ways: per unit of consumption or unit of distance travelled. This study uses the retail gasoline price, which is observed in each prefecture and measured as a unit of consumption (yen per liter). Note that in each of the car types, we cannot divide the car types by the types of fuels (e.g., gasoline, diesel, and liquefied petroleum gas). Therefore, we use the retail gasoline price as the representative fuel price in each prefecture. This data is obtained from MIAC (2015b) and the Oil Information Center (OIC), Institute of Energy Economics, Japan (2015). In addition, note that because the prefectural income per capita and gasoline price are nominal prices, we use the prefectural CPI obtained from the MIAC (2015c) as a control variable for the effect of the level of prices.

2.3.4 Population measures

As the demographic factors are related to population, this study uses total population, population density, and the rate of the population in the DID. This data is obtained from IPSS (2015). Dunkerley et al. (2014) review that although there is no theoretical information about the population elasticity in the published papers, there are many studies that include demographic explanatory variables in the empirical models. The authors say that the population elasticities of car ownership appear complex and may be positive, negative, or insignificant, depending on the research settings. The authors also suggest that, compared with the total population, the population density may have different effects on car ownership.

The Japanese population is expected to decrease in the long-run. According to IPSS (2012), the population in Japan was approximately 128 million in 2010 (Table 1). The population is projected to be 116 and 87 million people in 2030 (8.9% decrease) and 2060 (32.3% decrease), respectively.[1] Regarding the estimation of car ownership in Japan, an important question becomes whether fewer people lead to less car ownership, as is discussed in Ritter and Vance (2013). Intuitively, this appears true, because fewer people mean a smaller demand of car ownership. However, when the population size decreases, other demographic factors, such as the population density and distribution, may change, potentially causing complex effects on car ownership.

The population and population density at the national level in Japan peaked around 2010. Japan has also experienced an expansion in the non-rural areas since 1970 (Table 1). According to

[1] Population projection in IPSS (2012) is based on the assumptions of medium fertility and medium mortality.

IPSS (2015), from 1970 to 2010, the population density within the DID decreased from approximately 8,690 people per km^2 to 6,757 people per km^2 (Table 1). On the other hand, the population in the DID consistently increased from approximately 56 million in 1970 to 86 million people in 2010; during that time, the DID area also increased from 6,444 km^2 (1970) to 12,744 km^2 (2010). These values describe how well the non-rural areas expanded and how moderate the population concentration was in each DID. To assess how these changes affect car ownership, this study uses the population density and the DID rate from the IPSS (2015).

In addition to the decrease in population size in the long-run, Japan is projected to face further demographic changes: smaller families, a larger ageing society, and population migration across the prefectures. Consequently, this study considers three other demographic factors: average household size, the population rate of people over 65 years old, and the net migration rate; this data is obtained from IPSS (2015) and MIAC (2012a; 2012b).

According to MIAC (2012a; 2012b), the average household size in Japan has been decreasing from 3.22 people in 1980 to 2.99, 2.67, and 2.43 in 1990, 2000, and 2010, respectively (Table 1). It clearly indicates a trend toward smaller household types such as nuclear families and single families. As such, we now want to know whether smaller household sizes (or equivalently, higher number of households) lead to greater car ownership, as discussed in Ritter and Vance (2013).

The aging of the population is also a serious issue in Japan. IPSS (2012) illustrates that the population that is over 65 years old was 29.5 million in 2010 (23.0% of the whole values) (Table 1); it is projected to be 36.9 million in 2030 (31.6%) and peak at 38.8 million in 2042 (36.8%). After the peak in 2042, the percentage of elderly people is projected to increase because of a relative decrease in the whole population size.

Ritter and Vance (2013) and Matas and Raymond (2008) analyze what this aging society means to car ownership in Germany and Spain, respectively. In Japan, an important characteristic to consider is that elderly people tend to maintain their driver's licenses. The National Police Agency, Japan (2013) stated that 63.3% of people (i.e., 81 million) had driver's licenses in 2010; of those, elderly people with driver's licenses (over 65 years of age) were 30.1% (8.9 million).

Because most of elderly people tend to be retired, the car demand for business use should be smaller, suggesting that there is a high possibility that a more aged society leads to less car ownership. However, following the relatively high ratio of elderly people with driver's licenses, perhaps a more elderly society will result in more car ownership. For example, the elderly people may have a large demand for nursing care, and hence, for large-sized cars or special purpose cars.

Ritter and Vance (2013) analyze the effect of age categories on car ownership (i.e., share of 20-39, 40-64, and 65 and older) using a multinomial regression model, and examine household car ownership behavior in Germany. The results illustrate that the coefficient for the share of people 65+ is not negative, but less than the coefficient for the share of people aged 20-39 and 40-64, indicating that elderly people are less likely to own their cars younger people. On the other hand, Matas and Raymond (2008) argue that the ageing society in Spain only has a weak increasing effect on car ownership; however, they believe that the effect would vanish over the next two decades.

In addition, in Japan, people are likely to concentrate in the popular prefectures. Representative areas include the Tokyo metropolitan district (i.e., Tokyo, Kanagawa, Saitama, and Chiba), Aichi, as a metropolitan area of Tokai, and Fukuoka, as metropolitan area of Kyushu. An exceptional prefecture is Shiga, which is popular as a commuter prefecture of Kyoto and Osaka because of the development of transportation such as bullet and conventional trains and express highways. In other words, the other areas will experience shrinking populations in terms of social increase. As such, does the increase in the population in the representative areas lead to higher car ownership numbers? Intuitively, this holds true, because people that move are expected to bring their own vehicles with them. However, the opposite effect may occur. This is because the metropolitan areas have already been more urbanized than other areas, possibly making life without vehicles easier.

This study examines the effect of net migration on car ownership, using the net migration ratio, the ratio of people moving-into an area as compared to the total population, as an explanatory variable. This value takes on a positive value in popular areas, such as Tokyo and Aichi, and a negative value in unpopular areas.

2.3.5 Train and bus use

According to the transportation literature, the degree of public transportation development is expected to be related to car ownership. Dargay and Vythoulkas (1999) examine car ownership behaviors using pseudo panel data of the peoples' cohort in United Kingdom for the years of 1981 to 1993 in a dynamic cohort model. The authors use the retail price index for the transportation components: car purchase costs, car running costs, and public transport fares. The coefficient on public transport fares is found to be positive, but not statistically significant, indicating that public transport prices do not affect car ownership behavior. Instead, the authors note that public transport supply and accessibility, rather than price, may influence car ownership. Matas and Raymond (2008) find a significantly negative effect of the quality of public transport on car ownership in Spain.

Accordingly, this study examines how public transport supply and accessibility affects car ownership behavior, using train and bus use variables. The train (or bus) use is the total number of train (or bus) users in relation to the total population in the log-form; this data is obtained from the Institution for Transport Policy Studies (ITPS) (1985-2010). When the original value (i.e., not in the log-form) is 10, people in the prefecture use trains or buses 10 times a year, on average. Note that because Okinawa had no train until 2002, the original variable for train use in this prefecture is zero, until 2002; therefore, before taking the log-form, we substitute a small value (i.e., 0.001) for the zero value.

3. Methodology

3.1 Research strategy

This study aims to examine the demographic determinants of car ownership, using car cohort data from 1970 to 2009 in Japan. This study uses the determinants raised in the previous section. The contribution of this study is divided into twofold. First, this study will be the first empirical study in recent literature of the car cohort model with large countrywide observations. In the literature, cohort data usually refers to people cohorts rather than car cohorts. Several Japanese studies use car cohort information as part of a sequence of their simulation models, but they are not basic empirical studies. The other is that this study provides estimated elasticities between car ownership and social demographic factors in Japan. In the recent literature, there are few studies that examine demographic determinants of car ownership in Japan at the national level (e.g., Sun et al., 2014).

We divide the demographic and social determinants into the following five categories: (I) longitudinal factors, (II) economic factors, (III) natural factors, (IV) social factors, and (V) other transportation. This study considers corresponding contributions to the literature as follows.

Regarding longitudinal factors (I), this study examines the long-run effect and the effect of car age on car ownership. The long-run effect is the main issue in the aggregated model literature, whereas the effect of car age is little investigated because of data limitations. The long-run effect is often estimated as two or three times larger than the short-run elasticities (Goodwin et al., 2004; Graham and Glaister, 2004). If the long-run effect is larger, an effect of a certain determinant will last more strongly than expected from the literature. On the other hand, the car age effect is considered to represent the outflow rate (or scrap rate) of car ownership. This effect can be interpreted as a rough standard to determine how much car ownership outflows in a year.

Regarding economic factors (II), we focus on income and fuel price, which are also popular in the literature (Goodwin et al., 2004; Graham and Glaister, 2004; Dunkerley et al., 2014). Recently, a tax for eco-friendly cars was introduced in Japan, running from 2009 for a definite term. The car taxation system in Japan can be divided into 3 stages: acquisition (taxation for acquisition value with car age and consumption tax), car ownership (tax related to engine displacement and car weight tax), and car use (fuel tax, consumption tax, and car liability insurance premiums). However, this study cannot directly estimate the tax elasticities of car ownership. This is because car specifications (e.g., price, weight) are needed to estimate the approximate amount of car taxes. Instead, we estimate income and fuel price elasticities indirectly, and compare their elasticities with the literature. That is, larger elasticities imply that economic conditions related to the eco-car tax will have a greater effect on car ownership. Note that we include CPI in the model in order to control the level of prices.

One of the main focuses in this study is on examining how demographic factors affect car ownership. The natural factors (III) and social factors (IV) stem from the idea that a population increase is caused by a natural increase (e.g., birth rate) and a social increase (e.g., migration). Regarding natural factors (III), this study examines the effects of population, household size, and the elderly people on car ownership. Population effect on car ownership is inconclusive in the literature (see Dunkerley et al., 2014). We specifically use population and population density (i.e., population divided by prefectural area) because a number of studies include them (Dunkerley et al., 2014). However, these two variables are coupled by definition because the prefectural area (i.e., denominator of the population density) is constant over time. Therefore, we interpret both effects as a composite effect of population in the model as noted in the below subsection. Household size is also an important factor in the literature. Several studies show that a smaller household size leads to more car ownership (e,g., Ritter and Vance, 2013; Whelan, 2007). The determinate elderly people is also popular, especially in the literature with disaggregate data. Some studies show the elderly people are less likely to own cars than the younger people (e.g., Ritter and Vance, 2013; Sun et al., 2014). Because our dataset includes not only passenger cars but also trucks, buses, and motorcycle, this study will make a unique contribution to the literature about the car preferences of an aging society.

Regarding social factors (IV), this study focuses on demographic movement within and across prefectures (the DID rate and the net migration rate, respectively) to examine the type of effects people concentration has on car ownership. The DID rate tends to increase over time in Japan, indicating the expansion of non-rural areas within prefectures (Table 1). On the other hand, the net migration rate indicates that people are likely to concentrate in certain popular prefectures, such as Tokyo metropolitan district recently. Many studies with disaggregated data above (Matas and Raymond, 2008; Ritter and Vance, 2013; Sun et al., 2014; Whelan, 2007) show that those in rural areas or small towns tend to own more cars than in urban areas. Our focus is on the whole effect of social increase in population at the prefectural level.

Regarding other transports (V), we consider the train and bus used in the model. As noted above, the effect of other transport on car ownership is inconclusive. The effect is not significant in the U.K. (Dargay and Vythoulkas, 1999) and significantly negative in Spain (Matas and Raymond, 2008). As in the Osaka study (Japan), Sun et al. (2014) note that although car ownership has drastically increased from 1970 to 2000, corresponding traveling time and trips have only marginally increased during the same period. This implies that determinants of car ownership in Japan are different from those of car use, which are likely to be related to other transport use. Accordingly, we expect that although the other transports may have a negative effect on car ownership, the effect may be weak.

3.2 Model

This study aims to examine the demographic determinants of car ownership, using the car ownership (*N*) numbers as a dependent variable in an empirical model. We use a dynamic regression model in order to predict car numbers, rather than a static model, because the factors of car ownership may take time to adjust to changes, as discussed in Dargay (2002). Basically, the static model does not indicate how certain determinants take time to adjust to the environment. Following Dargay (2002), this study assumes that desired long-run car ownership $\ln N^{*}_{i,r,j,t}$ (i.e., *N* in the log-form) of a car maker or brand *i* in region *r* at car age *j* in year *t* is expressed as follows:

$$\ln N^{*}_{i,r,j,t} = f\left(D_{r,t}, i, r, j, t\right) \quad (1)$$

where $D_{r,t}$ denotes the demographic factors in region *r* in year *t*. Note that the demographic factors, *D*, do not correspond to the car maker or brand *i* and car age *j*.

This study refers to Equation 1 as the car cohort model. A characteristic of the car cohort model is that the observed, or desired, car ownership numbers, *N* or N^{*}, is identified for each car age.

That is, the car ownership at a certain age j in year t, $N_{i,r,j,t}$ or $N^*_{i,r,j,t}$, gets 1 year old in the next year, $N_{i,r,j+1,t+1}$ or $N^*_{i,r,j+1,t+1}$.

The partial adjustment model assumes that a difference in the current and lagged observed values, $\ln N_{i,r,j,t} - \ln N_{i,r,j-1,t-1}$, may not lead immediately to a difference in the desired long-run car ownership numbers and a lagged observed value, $\ln N^*_{i,r,j,t} - \ln N_{i,r,j-1,t-1}$. As noted previously, this is because it may take time to adjust to the changes in car ownership. In the model, the factors gradually affect the difference in the current and lagged observed values with some proportion θ as follows:

$$\ln N_{i,r,j,t} - \ln N_{i,r,j-1,t-1} = \theta\left(\ln N^*_{i,r,j,t} - \ln N_{i,r,j-1,t-1}\right). \tag{2}$$

Equation 2 can be rewritten as follows:

$$\begin{aligned}\ln N_{i,r,j,t} &= \theta \ln N^*_{i,r,j,t} + (1-\theta)\ln N_{i,r,j-1,t-1} \\ &= \theta f\left(D_{r,t}, i, r, j, t\right) + (1-\theta)\ln N_{i,r,j-1,t-1}\end{aligned} \tag{3}$$

where $\theta f\left(D_{r,t}, i, r, j, t\right)$ is a short-run effect of the demographic factors given i, r, j, and t on the desired level of long-run car ownership. We estimate the coefficient using a regression model. When dividing the estimated coefficient by θ, the values represent the long-run effect of the demographic factors.

As noted previously, the data obtained from AIRIA (1981-2010) consist of count data classified by car ages from 1 to 11 years, car ages over 12 years (12+), and the 11 car types. Regarding the car age, because there is no lagged variable, this study excludes the dependent variable at age 1. Also, because we cannot identify each of ages from the car data at ages 12+, unlike at ages 2-11, this study runs the regression model using data for ages 2-11 and ages 12+, separately.

Note that, therefore, the specification using cars aged 12+ is not the car cohort model, but just an aggregated model in a precise sense. On the other hand, to analyze the heterogeneity of the car types, this study runs the regression model using each of the 11 car types. Therefore, this study estimates the 22 specifications: the 2 age groups, 2-11 and 12+, multiplied by the 11 car types. The regression model is specifically expressed as follows:

$$\begin{aligned} \ln N_{i,r,j,t} = {} & \beta_1 + \beta_2 \ln N_{i,r,j-1,t-1} + \beta_3 j + \beta_4 \ln Income_{r,t} + \beta_5 \ln GasP_{r,t} \\ & + \beta_6 CPI_{r,t} + \beta_7 \ln Pop_{r,t} + \beta_8 \ln Density_{r,t} + \beta_9 HSize_{r,t} \\ & + \beta_{10} \ln Over65_{r,t} + \beta_{11} \ln DIDR_{r,t} + \beta_{12} MigR_{r,t} + \beta_{13} \ln Train_{r,t} \\ & + \beta_{14} \ln Bus_{r,t} + \beta_i + \beta_r + \beta_t + e_{i,r,j,t} \end{aligned} \quad (4)$$

Starting from the first term to the last: *j* denotes the car age *j,* which takes on values from 2 to 11. Note that when using the sample of ages 12+, *j* is not considered in the model, because there is no observation. ln*Income* denotes the prefectural average income in the log-form. ln*GasP* is the retail gasoline price (yen per liter) at the nominal price in the log-form. *CPI* is the prefectural CPI, which is standardized as 100 in 2000. ln*Pop* is the prefectural total population in the log-form. ln*Density* is the prefectural population density (people per km^2) in the log-form. *HSize* is the prefectural average household size. ln*Over65* is the population ratio over 65 years of age at the prefectural level, which is population over 65 ages divided by total population, in the log-form. ln*DIDR* is the DID rate, which is population in DID divided by total population, in the log-form. *MigR* is the net migrating rate of a certain prefecture from the other prefectures, which is net increase in migration divided by total population. ln*Train* and ln*Bus* are the ratios of cumulative numbers of train and bus users to total population, respectively, in the log-form. β_i, β_r, *and* β_t are the fixed effects of the car maker or brand *i*, region *r*, and year *t*, respectively, and *e* denotes the error term. Note that the fixed effects of the car maker or brand are only considered when the corresponding car makers or brands are observed (see Table 2).

There are seven variables using population size (*Pop*): ln*Pop*, ln*Density*, ln*Over65*, ln*DID*, *MigR*, ln*Train*, and ln*Bus*. This is problematic when interpreting the effect of ln*Pop* because population (*Pop*) is indeed included in the seven variables. Specifically, there is a close relationship between ln*Pop* and ln*Density* because the denominator of *Density* (= *Pop*/*Area*) is area size (*Area*), which is constant over time. On the other hand, the other five variables are not problematic to some degree. This is because the numerators are not constant over time although the denominators are population size. In this sense, we interpret ln*Pop* and ln*Density* as a composite variable of ln*Pop*. Specifically, we consider $\beta_7 \ln Pop + \beta_8 \ln Density$ in Equation 4 can be converted as follows:

$$\beta_7 \ln Pop_{r,t} + \beta_8 \ln Density_{r,t} = \left(\beta_7 + \beta_8\right) \ln Pop_{r,t} - \beta_8 \ln Area_{r,t} . \tag{5}$$

From Equation 5, the effect of ln*Pop* is $(\beta_7+\beta_8)$ rather than β_7. This is because $-\beta_8 \ln Area$ in RHS is constant over time.

4. Data

The data in this study consists of the number of automobiles owned according to the initial registered year, the prefectural demographic characteristics, the gasoline price data, and the train and bus use from 1980 to 2009. Table 3 shows the descriptive statistics (Appendix Tables A2 and A3 show correlation matrix of car aged 2-11 and 12+, respectively). As noted previously, the car ownership data comes from AIRIA (1981-2010).[2] The prefectural demographic data comes from ESRI (2015), IPSS (2015), and MIAC (2012a; 2012b). The gasoline price data consists of the retail price in Tokyo in 1980-1986; this data is provided by MIAC (2015b). The prefectural retail price in 1987-2009 data is provided by the OIC (2015). There is no prefectural gasoline price data before 1987; hence, we use the retail price in Tokyo as substitute variable for each prefecture. Besides, the prefectural CPI comes from MIAC (2015c). The prefectural CPI of this study is a value in each of the prefectural capitals. It is standardized as 100 in 2000 in each prefecture. In addition, the train and

[2] Because AIRIA (1981-2010) are not electric data, we entry data by hand or optical character recognition. In order to reduce data errors as much as possible, we check whether summation of each of car aged values is equal to total value (in the last column of data table).

bus availability data in each prefecture comes from the ITPS (1985-2010).

This study uses 11 car types; some of these types are classified further (Table 2). More specifically, data on compact four-wheel trucks (#2), regular passenger cars (#7), and compact passenger cars (#8) can be classified according to domestic car makers (e.g., Toyota) and car brands (e.g., Toyota Prius). We merge the longitudinal statistics data using common labels, such as car brand names. These three types are considered ordinary cars, as they are popular among consumers; therefore, these types are the main focus in this study.

Data for regular trucks (#1) and compact three-wheel trucks (#3) can be classified by the domestic car makers. To control for the unobserved fixed effects, we control the fixed effects for the car brands and domestic makes when using data for #2, #7, and #8 and data for #1 and #3, respectively. Note that other types, which are trailing truck (#4), regular bus (#5), compact bus (#6), special purpose car (#9), large-sized special car (#10), and motorcycle (#11), have only total numbers and cannot be further sub-divided by the makers or the brands.

The total number of observations is 3,611,755 at ages 2-11 and 336,143 at ages 12+ (Appendix Table A4 shows the number of observations of each car type at car aged 2-11 and 12+). Note that because of taking the log-form, the data does not include the observations where car ownership is zero. For example, the number of observations of #3 at ages 2-11 is really small (682), because compact three-wheel trucks were little produced or registered during the period.

In terms of the prefectural demographic data from ESRI (2015), there are four different computation methods for the average income: 1) system of national accounts 1968 (68SNA): 1980 benchmark from 1955 to 1980, 2) 68SNA: 1990 benchmark from 1980 to 1999, 3) 93SNA: 1995 benchmark from 1990 to 2003, and 4) 93SNA: 2000 benchmark from 1996 to 2009. Based on the ratio of the overlapping time span, this study connects those data to the third benchmark. Therefore, this conversion implicitly assumes the percentage deviations of these SNAs are the same within the overlapping span. Also, note that this study uses the overall CPI in the prefectural capital from MIAC (2015c) as a proxy for the prefectural CPI, because of the data limitations.

The average household size (*HSize*), the population ratio of over 65 years old (ln*Over65*), the net migrating rate (*MigR*), the population density (ln*Density*), and the DID rate (ln*DIDR*) are calculated from the IPSS (2015) and MIAC (2012a; 2012b) data. The five variables are observed every 5 years. Therefore, by adopting a linear interpolation method, this study estimates the unobserved values between the observed values every 5 years.

In terms of train and bus use, ITPS (1985-2010) does not provide data between 1976 and 1984. Therefore, we adopt a linear interpolation method using the data from 1975 and 1985. This study estimates the unobserved values between 1976 and 1984.

5. Results

5.1 Longitudinal factors

Tables 4 and 5 illustrate the estimated results, using the car ownership data for cars aged 2-11 and 12+, respectively. This section carefully checks each of the independent variables. The coefficient for the lagged dependent variables is statistically significantly different from zero and positive in all of the 22 columns. For car ownership of cars aged 2-11 (Table 4), the smallest coefficient is 0.409 for car type #10 (Column 10); the largest coefficient is 0.927 for car type #3 (Column 3). On the other hand, for the car ownership of cars aged 12+, the smallest coefficient is 0.582 for car type #5 (Column 5), whereas the largest coefficient is 0.939 for car type #1 (Column 1). Therefore, the long-run effects are 1.69-13.70 times and 2.39-16.39 times higher than the short-run effects at ages 2-11 and 12+, respectively, depending on the car types.

When focusing on the ordinary cars (i.e., #2 compact four-wheel trucks, #7 regular passenger cars, and #8 compact passenger cars), the coefficient is approximately 0.9 (0.878, 0.906, and 0.916) for cars aged 2-11 and 0.82 (0.817, 0.821, and 0.823) for cars aged 12+; Therefore, the long-run effects are approximately 10 and 5.56 times larger than the short-run effects at ages 2-11 and 12+, respectively. This indicates that the long-run effect of this study is somewhat larger than in Goodwin et al. (2004) and Graham and Glaister (2004), who report that the long-run effect is approximately three times larger than the short-run effect.

The coefficient for car age is statistically significantly different from zero and negative in all of the car types, except for the compact three-wheel trucks (#3: Column 3 of Table 4). The lowest and highest values of the significant coefficients are −0.085 (#11) and −0.017 (#5), respectively. The coefficient for the ordinary cars (#2, 7, and 8) is approximately −0.07 (−0.075, −0.063, and −0.076, respectively), indicating that an increase in age of 1 year leads to an additional 7% decrease in car ownership in the short-run. For example, the car age effects on car ownership range from a 13.1% drop at age 2 to a 53.7% drop at age 11 (i.e., $\exp(-0.14) - 1$ and $\exp(-0.77) - 1$, respectively) in the short-run. This indicates that the age effect on car ownership appears to be fairly large.

5.2 Economic factors

Regarding cars aged 2-11, the coefficient for income (ln*Income*) is statistically significantly different from zero and positive for 5 car types (#2, 4, 7, 8, and 10) and negative for 1 car type (#5). On the other hand, regarding the cars aged 12+, the coefficient for ln*Income* is statistically significantly different from zero and positive for 1 car type (#2) and negative for 3 car types (#5, 10, and 11). This indicates that prefectures with a higher income are more likely to own cars aged 2-11 and not to own cars aged 12+.

Regarding the ordinary cars (#2, 7, and 8), the coefficient for ln*Income* is less than 0.1 (0.036, 0.072, and 0.024 for #2, 7, and 8, respectively) for the cars aged 2-11 and 0.119 for #2 (not significant for #7 and 8) for the cars aged 12+. Therefore, the elasticities in the long-run are 0.295, 0.766, and 0.286 for #2, 7, and 8 for the cars aged 2-11, respectively, and 0.650 for #2 for cars aged 12+. These values are slightly lower than the values in Goodwin et al. (2004) and Dunkerley et al. (2014). This also reveals that the elasticity of #7 is relatively similar to the values from the previous studies.

The coefficient for gasoline price (ln*GasP*) is statistically significantly different from zero and positive for 3 car types (#4, 10, and 11) in terms of the cars aged 2-11 (Table 4). On the other hand, the coefficient is statistically significantly positive for 1 car type (#4) and negative for 5 car types (#1, 2, 3, 5, and 7) for the cars aged 12+ (Table 5). The tendencies are clearly different between the cars aged 2-11 and the cars aged 12+, indicating that a rise in gasoline prices is likely to lead to a decrease in the number of cars aged 12+; at the same time, there is no effect, or even an increase, in cars aged 2-11 for some car types.

Among the ordinary cars (#2, 7, and 8), ownership is not associated with the gasoline price among the cars aged 2-11, whereas the short-run elasticity for the cars aged 12+ is approximately −0.2 (−0.200 and −0.262 for #2 and 7, respectively). This value is more intense than that found in the previous studies of Goodwin et al. (2004) and Dunkerley et al. (2014). Additionally, this study shows that gasoline prices primarily affect older cars (cars aged 12+) in Japan.

5.3 Natural factors of population increase

Table 6 shows the estimated effect of ln*Pop* based on Equation 5. Columns (1) and (2) show the estimated results of ln*Pop* and ln*Density* from Tables 4 and 5. Column (3) calculates joint coefficient ((1)+(2)) and tests joint significance as to whether the coefficient equals zero by linear Wald test. The joint coefficient for (ln*Pop*) is statistically significantly different from zero and positive for 4 car types (#5, 6, 9, and 11) and negative for 5 car type (#1, 4, 7, 8, and 10) in regard to cars aged 2-11. On the other hand, the joint coefficient is significantly negative for the 6 car types (#1, 3, 4, 5, 6, and 7) in regard to cars aged 12+. We note that these results are similar to the estimated results that simply remove ln*Density* from the model (Appendix Table A5 shows 22 estimated coefficients of ln*Pop* in the model which removes ln*Density* from Equation 4).

The results may be counterintuitive, in that they indicate that the population elasticities are not only positive, but also negative depending on car types. The positive elasticities are found in buses (#5 and 6), special purpose cars (#9), and motorcycles (#11) for cars aged 2-11. This indicates that the number of cars owned is expected to be reduced when population decreases, probably because corresponding vehicle demand is accordingly reduced. Especially, the elasticities are highest (1.539) for regular buses (#5) and lowest (0.187) for special purpose cars (#9). On the other hand, most of the elasticities are significantly negative (in the 5 and 6 car types of cars aged 2-11 and 12+, respectively). This indicates in most case when the population decreases, car ownership will be encouraged. This may be because a smaller population in a certain prefecture leads to a higher degree of living area per capita, increasing car demand per capita in total. The elasticities are somewhat intense and less than −1, and highest (−0.804) for regular buses (#5) for cars aged 12+ and lowest (−0.136) for regular trucks (#1) for cars aged 2-11.

Regarding the ordinary cars (#2, 7, and 8), the effects of population tend to be negative but are considerably different among car types. The joint coefficients are not significant for #2, the most intense for #7 (−0.356 and −0.584 for the cars aged 2-11 and 12+, respectively), and moderate for #8 (−0.178 and not significant for the cars aged 2-11 and 12+, respectively). These results indicate that a 1% decrease in population in the future leads to no increase in #2 and an increase in car ownership by 0.4% to 0.6% for #7 and by 0.2% for #8 (only for the cars aged 2-11).

The coefficient for household size (*Hsize*) is statistically significantly different from zero and negative for 6 car types (#1, 2, 5, 7, 8, and 10) and positive for 1 car type (#3) in terms of the cars aged 2-11. On the other hand, the coefficient is significantly negative for the 9 car types (#1, 2, 3, 5, 6, 7, 8, 9, and 11) in terms of the cars aged 12+.

Regarding the ordinary cars (#2, 7, and 8), the coefficients are approximately −0.2 to −0.3 for the cars aged 2-11 (−0.144, −0.192, and −0.215, respectively) and the cars aged 12+ (−0.174, −0.366, and −0.330, respectively). This indicates that a 0.1 person decrease in the average household size leads to a 2% or 3% increase in car ownership. This effect suggests that a smaller household size (or higher numbers of households) leads to more car ownership.

The coefficient of the ratio of elderly people (ln*Over65*) is statistically significantly different from zero and positive for 3 car types (#4, 5, and 7) and negative for 6 car types (#1, 2, 6, 8, 10, and 11) in terms of the cars aged 2-11. On the other hand, the coefficient is statistically significantly positive for 1 car type (#8) and negative for 4 car types (#1, 2, 5, and 6) for the cars aged 12+. The estimated signs vary among the car types, but are likely to be negative, rather than positive. Regarding the ordinary cars (#2, 7, and 8), the signs also vary. One tendency is that, in terms of the cars aged 2-11, the higher ratio of elderly people is associated with less compact cars (#2 and 8) and more regular cars (#7). This indicates that elderly people need larger-sized cars, probably because of their needs for nursing care, rather than business use. On the other hand, in terms of cars aged 12+, the higher ratio of elderly people is correlated with less compact trucks (#2), but more compact passenger cars (#8). More #8 cars may reflect the situation that elderly people do not frequently use cars, but have to own cars, just in case they need them. This may be due to the lower maintenance costs (Matas and Raymond, 2008). It shows that elderly people's preference of car ownership in Japan appears somewhat complex, and therefore, requires further examination.

5.4 Social factors of population increase

The coefficient for the DID rate (ln*DIDR*) is statistically significantly different from zero; positive for 3 car types (#2, 4, and 7) and negative for 3 car types (#5, 10, and 11) in terms of the cars aged 2-11. It is significantly positive for 3 types (#2, 5, and 7) and negative for no type in terms of the cars aged 12+. The signs vary among the car types, but are likely to be positive, especially for cars aged 12+. This indicates that car ownership tends to increase in the prefectures with a higher DID rate. This is probably due to a composite effect in urban and rural areas. That is, urbanization may increase or decrease car demand per capita, whereas rural areas experience further expansion of living area per capita, accelerating car demand per capita. These effects result in positive and negative effects in total for #2, 4, and 7 and for #10 and 11, respectively. An exceptional case is for the regular bus (#5), and the elasticity is negative and positive for cars aged 2-11 and 12+, respectively. This implies that an upgrade cycle of regular bus in prefectures with a higher DID rate is more likely to be delayed than those with a lower DID rate, leading to a lower and higher ownership for cars aged 2-11 and 12+, respectively (hence, the regular buses are rapidly aging).

Regarding the ordinary cars (#2, 7, and 8), the signs tend to be positive. The elasticities for cars aged 2-11 and 12+ are 0.053 and 0.241 for #2, 0.090 and 0.120 for #7, and insignificant for #8, respectively. This indicates that car ownership is more likely to increase in the prefectures with a higher DID rate. This may suggest that a composite effect in urban and rural areas results in a positive effect on car ownership.

The coefficient for the net migration rate (*MigR*) is statistically significantly different from zero and positive for 3 types (#5, 6, and 7) and negative for 3 types (#4, 9, and 10) in terms of the cars aged 2-11. It is not significantly positive for any car type, but is significantly negative for 4 types (#4, 7, 8, and 10) in terms of the cars aged 12+. This suggests that the relationship between net migration and car ownership is likely to be negative, indicating that car ownership is less necessary in the more popular prefectures (with higher net migration rate) than the other unpopular prefectures. As an exceptional case, positive signs are found among buses and regular passenger cars (#5, 6, and 7) for cars aged 2-11, indicating that the prefectures with a higher net migration rate have higher needs for large cars to carry more people.

Regarding the ordinary cars (#2, 7, and 8), the coefficients are likely to be positive (0.755 for #7; insignificant for #2 and 8) and negative (−4.376 and −4.035 for #7 and 8, respectively; insignificant for #2) for cars aged 2-11 and 12+, respectively. This indicates that people in more popular prefectures (with a higher net migration rate) are more likely to own relatively new cars (aged 2-11) and scrap or sell old cars (aged 12+) than in less popular prefectures. In other words, an upgrade cycle of car ownership in more popular prefectures will be unchanged for #2, much quicker for #7, and mildly quicker for #8 than in less popular prefectures. This is probably because consumer preferences for car values are different, depending on the degree of urbanization. For example, used car market in more popular prefectures may be more liquid than in less popular prefectures, resulting in a higher accessibility (or a larger demand) for cars aged 2-11 and a larger replacement demand (or a lower demand) for cars aged 12+.

5.5 Other transports

The coefficient for train use (ln*Train*) is statistically significantly different from zero and positive for 1 type (#6) and negative for 6 types (#2, 5, 7, 8, 9, and 11) in terms of the cars aged 2-11. It is significantly positive for 3 types (#1, 5, and 6) and negative for 1 type (#8) in terms of the cars aged 12+. The result indicates that the relationship of train use and car ownership tends to be negative for cars aged 2-11 and positive for cars aged 12+. Because the types #5 and 6 are buses, it also indicates that the prefectures with higher train use tend to have fewer regular buses aged 2-11, more regular buses aged 12+ and more compact buses. On the other hand, regarding ordinary cars (#2, 7, and 8), the results illustrate a negative relationship between train use and car ownership, especially for cars aged 2-11, implying that train use (or availability) substitutes for car use (or car ownership).

The coefficient for bus use (ln*Bus*) is statistically significantly different from zero and positive for 4 types (#5, 6, 10, and 11) and negative for 2 types (#4, 7, and 8) in terms of the cars aged 2-11. It is significantly positive for 4 types (#1, 3, 5, and 6) and negative for 3 types (#4, 7 and 8) in terms of the cars aged 12+. Because types #5 and 6 are buses, the positive relationship between bus availability and bus ownership is intuitive. On the other hand, among ordinary cars, passenger cars (#7 and 8) are less likely to be owned in the prefectures with more bus use, implying that bus use, as well as train use, substitutes for passenger car use (or ownership).

We note that among the ordinary cars (#2, 7, and 8), the elasticities for the train and bus use to car ownership are considerably small. Of the cars aged 2-11, the largest (most sensitive) effects are −0.008 and −0.014 for train and bus use in the short-run, respectively (hence, −0.095 and −0.149 in the long-run, respectively). These values suggest that the development of public transportation only has a considerably small effect on car ownership.

6. Conclusions and implications

This study examines the demographic determinants of car ownership in Japan, using unique aggregated car ownership data for the years of 1980 through 2009. The data is classified into 11 car types and 2 car age categories: cars aged 2-11 and cars aged 12+. Using the 22 categorizations separately, this study adopts a dynamic car cohort regression model. This study uses the 11 demographic determinants at the prefectural level. The determinants include: the average income, the retail gasoline price, CPI, total population, the population density, the average household size, the percentage of people over 65 years of age to the total population, the DID rate, the net migration ratio, the train use, and the bus use. These determinants are further classified into the five categories: (I) longitudinal factors, (II) economic factors, (III) natural factors, (IV) social factors, and (V) other transports.

Among the car types, one of the most important categories for policy implications should be ordinary cars. Therefore, focusing mainly on ordinary cars, we summarize the results and associated implications as follows. The results show that the longitudinal factors (I) are intense in Japan. The long-run effects are approximately 10 and 5.56 times for cars aged 2-11 and 12+, which is higher than average in the recent literature (Goodwin et al., 2004; Graham and Glaister, 2004). This implies that Japanese consumers may have conservative behavior regarding car ownership. That is, a certain policy implementation may seem ineffective in the short-run, but can result in drastic effects on car ownership in the long-run. Also, the semi elasticity of car age (1 year) is approximately −7%. Although there is no study for comparison, this value seems to have a certain effect on car ownership. It implies that the outflow rate (or scrap rate) of car ownership is on average 7% in a year. If the number of new car sales (inflow) is more than 7% of the gross number of car ownership, total car ownership will increase. Therefore, this value can be one of the criteria for predicting car ownership at the macro level.

Regarding economic factors (II), the elasticities of income and fuel price on car ownership are less intense than in earlier studies. The elasticities of income tend to be relatively smaller (less than 0.1 in the short-run) than those in previous studies (Goodwin et al., 2004). However, the elasticity for the regular passenger cars is the highest (0.766 in the long-run at cars aged 2-11), and this value is similar to the literature. This implies that a car tax imposition in Japan is less effective in changing car ownership behavior than in other countries, except for the regular passenger cars. On the other hand, the elasticities of fuel price are significantly negative (approximately −0.2) only for old cars (car aged 12+). The fuel price does not much affect car ownership for newer cars (cars aged 2-11), as in Sun et al. (2014), who indicate car ownership and car use (traveling time and trips) are not so correlated each other in Osaka (Japan). On the other hand, the elasticity of fuel price for old cars (cars aged 12+) as higher than in the typical literature implies that fuel tax or fuel efficiency will appeal to users of old cars.

Regarding natural factors (III) of population increase, as the results may be counterintuitive, the elasticities of population and average household size on car ownership tend to be negative. The decrease in population and household size in Japan indicates that a smaller population and household size will encourage more car ownership in the future. This result is similar to those of Ritter and Vance (2013) and Whelan (2007), which project that car ownership will increase in Germany and Great Britain, respectively (we note, however, that the total population is projected to decrease in Germany toward 2030 and increase slightly in Great Britain toward 2031, whereas average household size tends to decrease in the both countries). This may be because a smaller population in a certain prefecture results in a higher degree of living area per capita, encouraging car demand per capita. It may also be because an increase in nuclear families or single life disturbs the efficiency of car sharing within a certain household, as is determined in Ritter and Vance (2013). We note, however, the elasticities of population are considerably different among car types. They are not significant for the compact four-wheel trucks, −0.4 to −0.6 for the regular passenger cars, and −0.2 for the compact passenger cars (only for the cars aged 2-11). Therefore, the effect is much higher for the regular passenger cars and moderate for the compact passenger cars. On the other hand, the semi elasticities of household size (person) are similar among car types and ages, and approximately −0.2 to −0.3.

In addition, the ratio of elderly people has various effects depending on car types, rather than just lower car ownership than younger people as in many studies (e.g., Ritter and Vance, 2013; Sun et al., 2014). This implies that it is important for policy makers to face car demand by the elderly people because more flexible transportation services for elderly people will be necessary. One tendency is that, regarding cars aged 2-11, elderly people prefer regular passenger cars to compact cars. This is probably because of the need for nursing care, rather than driving a car to work. Another tendency is that the prefectures with more elderly people tend to own more compact passenger cars aged 12+. This indicates that an upgrade cycle is delayed in these areas, probably because of the car dependency and lower maintenance costs (Matas and Raymond, 2008).

Regarding social factors (IV) of population increase, although many studies show that rural areas tend to own more cars than other urban areas (e.g., Matas and Raymond, 2008), we find the whole effect of the social increase is somewhat complex. As a general trend, car ownership is encouraged by the concentration of a population within a prefecture (the DID rate), and increased and decreased for new (aged 2-11) and old cars (aged 12+), respectively, by the concentration of a population across prefectures (the net migration rate). The former (the DID rate) indicates that the expansion of the non-rural areas within prefectures encourages car ownership. This is probably due to a composite effect in urban and rural areas. That is, urbanization may increase or decrease car demand per capita, whereas rural areas experience further expansion of living area per capita, accelerating car demand per capita. These effects result in a positive effect in total. On the other hand, the latter (the net migration rate) suggests people in more popular prefectures are more likely to own relatively new cars (aged 2-11) and scrap or sell old cars (aged 12+) than in less popular prefectures. This implies that an upgrade cycle of car ownership in more popular prefectures (e.g., Tokyo) will be quicker for passenger cars (#7 and #8), probably because consumer preferences for car values are different depending on the degree of urbanization. One possibility is that, as urbanization progresses, used car market in more popular prefectures may be more liquid than in less popular prefectures, resulting in a higher accessibility for relatively new cars (aged 2-11) and a larger replacement demand for old cars (aged 12+). From this result, policy makers should consider that some urban planning, such as a compact city, can result in an increase of car ownership in total. Also, policy makers may be able to adjust an upgrade cycle of car ownership by enhancing the liquidity of used car market. For example, a higher liquidity of the market can be more effective to reduce cars with low fuel efficiency in unpopular prefectures.

Regarding other transports (V), the degree of train and bus use tends to be negatively associated with ordinary car ownership as in Matas and Raymond (2008). This result is intuitive and indicates that the development of public transportation decreases the amount of car ownership. However, the elasticities of train and bus use to car ownership are considerably small and often insignificant as in Dargay and Vythoulkas (1999). The elasticities of train and bus use are at most approximately −0.1 and −0.15, respectively, in the long-run. This result implies that the development of public transportation will only have a small effect on car ownership. It also implies the degrees of car ownership and car use are not substantially coupled with each other as in Sun et al. (2014).

Along with the results and implications, several limitations of this study are raised. Firstly, regarding our dataset, this study uses aggregated data at the prefecture level. Aggregated data is suited for this kind of prediction for car ownership, but does not correspond well for the smaller areas, such as the city level. For example, using car data at the city level, we will be able to profoundly discuss more detailed issues, such as how a compact city affects car ownership. We note that it may be possible to estimate car numbers by dividing by the car numbers proportionally using some information, such as the city-level statistics of car numbers; however, this division results in a huge number of observations, potentially causing computational problems.

Another limitation is that we do not assess the car use behavior. Car ownership is economically important, especially for industries or government; however, when considering externalities such as GHG emissions or traffic, the degree of the externalities largely depends on how to use the cars. Although car numbers are expected to be related to car use, to some extent, a more careful examination of car use is required for transportation policy.

Finally, we do not consider car prices and other car attributes, due to data limitations. Because car ownership is an economic behavior, an estimation of the car price elasticity to ownership is desirable. It is also worth considering both consumer conditions and supplier conditions through examining the car attributes, such as size, engine, and fuel efficiency.

Acknowledgements

This work was supported by JSPS KAKENHI Grant number JP26000001 and JP26740054 and Grant for Environmental Research Projects of the Sumitomo Foundation (Grant number 133128). We would like to thank the two anonymous reviewers for their constructive comments.

References

Anowar, S., Eluru, N., Miranda-Moreno, L.F., 2014. Alternative Modeling Approaches Used for Examining Automobile Ownership: A Comprehensive Review. Transport Reviews 34 (4), 441–473. doi:10.1080/01441647.2014.915440

Automobile Inspection and Registration Information Association [AIRIA]. 2015. Number of automobiels owned. <http://www.airia.or.jp/publish/statistics/number.html> [Accessed 9 August 2015].

Automobile Inspection and Registration Information Association [AIRIA]. 1981-2010. Number of automobiles owned by initial registered year.

Dargay, J.M., Vythoulkas, P.C., 1999. Estimation of a Dynamic Car Ownership Model Approach. Journal of Transport Economics and Policy 33 (3), 287–301.

Dargay, J.M., 2002. Determinants of car ownership in rural and urban areas: a pseudo-panel analysis. Transportation Research Part E: Logistics and Transportation Review 38 (5), 351–366. doi:10.1016/S1366-5545(01)00019-9

de Jong, G., Fox, J., Daly, A., Pieters, M., Smit, R., 2004. Comparison of car ownership models. Transport Reviews 24 (4), 379–408. doi:10.1080/0144164032000138733

Dunkerley, F., Rohr, C., Daly, A., 2014. Road traffic demand elasticities: A rapid evidence assessment. RAND Corporation Research Reports No. RR-888-DFT. <http://www.rand.org/pubs/research_reports/RR888.html> [Accessed 9 August 2015]

Economic and Social Research Institute, Cabinet Office, Government of Japan [ESRI]. (various years). Annual Report on National Accounts. <http://www.esri.cao.go.jp/jp/sna/data/data_list/kakuhou/files/files_kakuhou.html> [Accessed 9 August 2015].

Economic and Social Research Institute, Cabinet Office, Government of Japan [ESRI]. 2015. Prefectural Accounts. <http://www.esri.cao.go.jp/jp/sna/data/data_list/kenmin/files/files_kenmin.html> [Accessed 9 August 2015].

Goodwin, P., Dargay, J., Hanly, M., 2004. Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. Transport Reviews 24 (3), 275–292. doi:10.1080/0144164042000181725

Graham, D.J., Glaister, S., 2004. Road Traffic Demand Elasticity Estimates: A Review. Transport Reviews 24 (3), 261–274. doi:10.1080/0144164032000101193

Hayashi, Y., Kato, H., Teodoro, R.V.R., 2001. A model system for the assessment of the effects of car and fuel green taxes on CO_2 emission. Transportation Research Part D: Transport and Environment 6 (2), 123–139. doi:10.1016/S1361-9209(00)00021-3

Ingram, G.K., Liu, Z., 1999. Motorization and the Provision of Roads in Countries and Cities, Policy

Research Working Papers. The World Bank. doi:10.1596/1813-9450-1842

Institution for Transport Policy Studies [ITPS]. 1985-2010. Annual Report of Local Transportation.

Japan Automobile Manufacturers Association, Inc [JAMA]. 2015. Automobile industry in Japan: Four-wheel vehicles — Sales. <http://www.jama.or.jp/industry/four_wheeled/index.html> [Accessed 9 August 2015].

Matas, A., Raymond, J.-Ll., 2008. Changes in the structure of car ownership in Spain. Transportation Research Part A: Policy and Practice 42 (1), 187–202. doi:10.1016/j.tra.2007.08.005

Morisugi, H., Ohno, E., 1996. NOx Reduction Effects of the Policy to Reduce Diesel Automobiles and its Influence on Price Change, in: Hayashi, Y., Roy, J. (Eds.), Transport, Land-Use and the Environment. Kluwer Academic Publishers TRES4, pp. 171–190. doi:10.1007/978-1-4757-2475-2_9

National Institute of Population and Social Security Research [IPSS], 2012. Population Projections for Japan (January 2012): 2011 to 2060. <http://www.ipss.go.jp/syoushika/tohkei/newest04/sh2401top.html> [Accessed 9 August 2015]

National Institute of Population and Social Security Research [IPSS]. 2015. Population Statistics: XII. Prefectural Statistics. <http://www.ipss.go.jp/syoushika/tohkei/Popular/Popular2015.asp?chap=0> [Accessed 9 August 2015].

National Police Agency, Japan. 2013. Statistics of driver’s license in 2010. <https://www.npa.go.jp/toukei/menkyo/index.htm> [Accessed 9 August 2015].

Oil Information Center, Institute of Energy Economics, Japan [OIC]. 2015. General retail price: gasoline, diesel oil, and lump oil at oil station. <https://oil-info.ieej.or.jp/price/price.html> [Accessed 9 August 2015].

Ortúzar, J.D.D., Willumsen, L.G., 2011. Modelling Transport, Fourth Edition. John Wiley & Sons, Ltd, Chichester, UK. doi:10.1002/9781119993308

Ritter, N., Vance, C., 2013. Do fewer people mean fewer cars? Population decline and car ownership in Germany. Transportation Research Part A: Policy and Practice 50, 74–85. doi:10.1016/j.tra.2013.01.035

Statistics Bureau, Ministry of Internal Affairs and Communications, Japan [MIAC]. 2012a. Historical Statistics of Japan: Chapter 2 Population and Households. <http://www.stat.go.jp/english/data/chouki/02.htm> [Accessed 9 August 2015].

Statistics Bureau, Ministry of Internal Affairs and Communications, Japan [MIAC]. 2012b. Population Estimates: Time Series 2000 - 2010. <http://www.e-stat.go.jp/SG1/estat/ListE.do?bid=000001039703&cycode=0> [Accessed 9 August 2015].

Statistics Bureau, Ministry of Internal Affairs and Communications, Japan [MIAC]. 2015a.

Population Estimates: Annual Report 2014. <http://www.e-stat.go.jp/SG1/estat/ListE.do?lid=000001132435> [Accessed 9 August 2015].

Statistics Bureau, Ministry of Internal Affairs and Communications, Japan [MIAC]. 2015b. Retail Price Survey: Retail price of gasoline for automobiles (brand code: 7301) in Tokyo (1966-latest month). <http://www.stat.go.jp/data/kouri/doukou/8.htm> [Accessed 9 August 2015].

Statistics Bureau, Ministry of Internal Affairs and Communications, Japan [MIAC]. 2015c. Consumer Price Index (Standardized in 2010): City class, local city, metropolitan area, and prefectural capital (middle classification index). <http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001033708&cycode=0> [Accessed 9 August 2015].

Sun, Y., Susilo, Y.O., Waygood, E.O.D., Wang, D., 2014. Detangling the impacts of age, residential locations and household lifecycle in car usage and ownership in the Osaka metropolitan area, Japan. Journal of Zhejiang University SCIENCE A 15, 517–528. doi:10.1631/jzus.A1300345

Whelan, G., 2007. Modelling car ownership in Great Britain. Transportation Research Part A: Policy and Practice 41 (3), 205–219. doi:10.1016/j.tra.2006.09.013

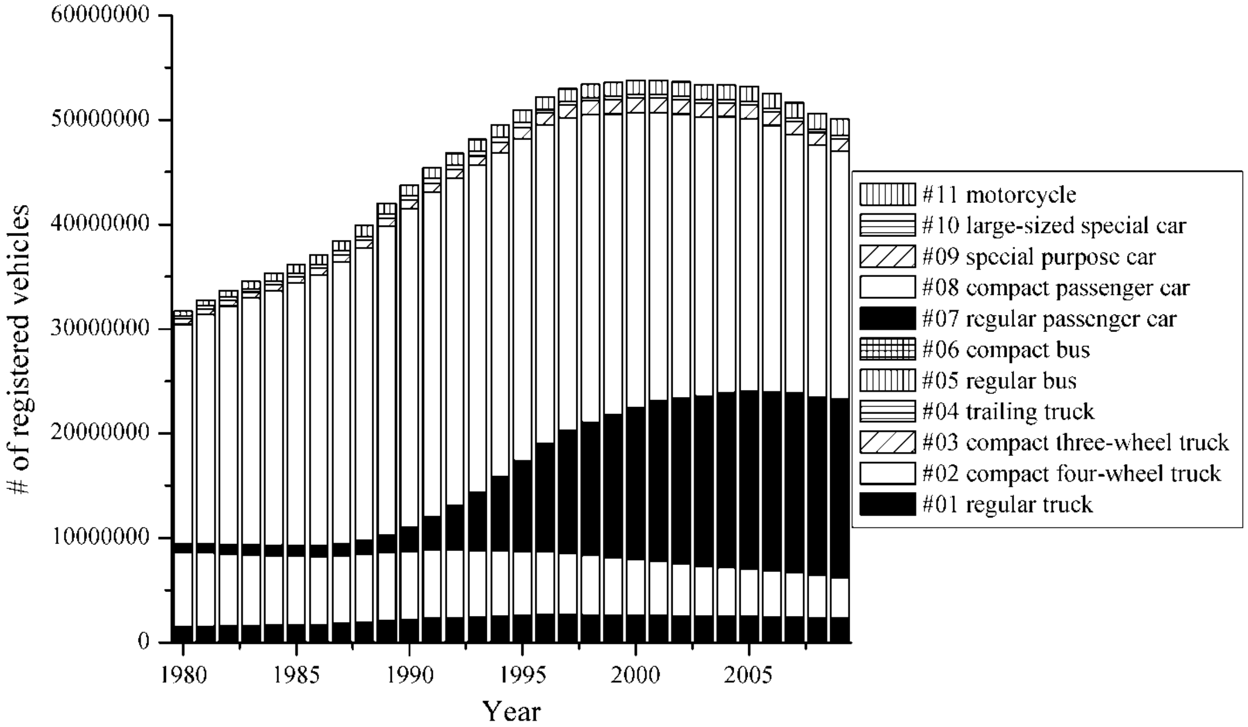

Figure 1. The number of registered vehicles: car types

Notes: #3, 4, 5, and 6 are not shown because of small numbers of vehicles. In this figure, data of each year includes data of within 3 months (from January to March) of the next year (see Figure 2). Source: AIRIA (1981-2010).

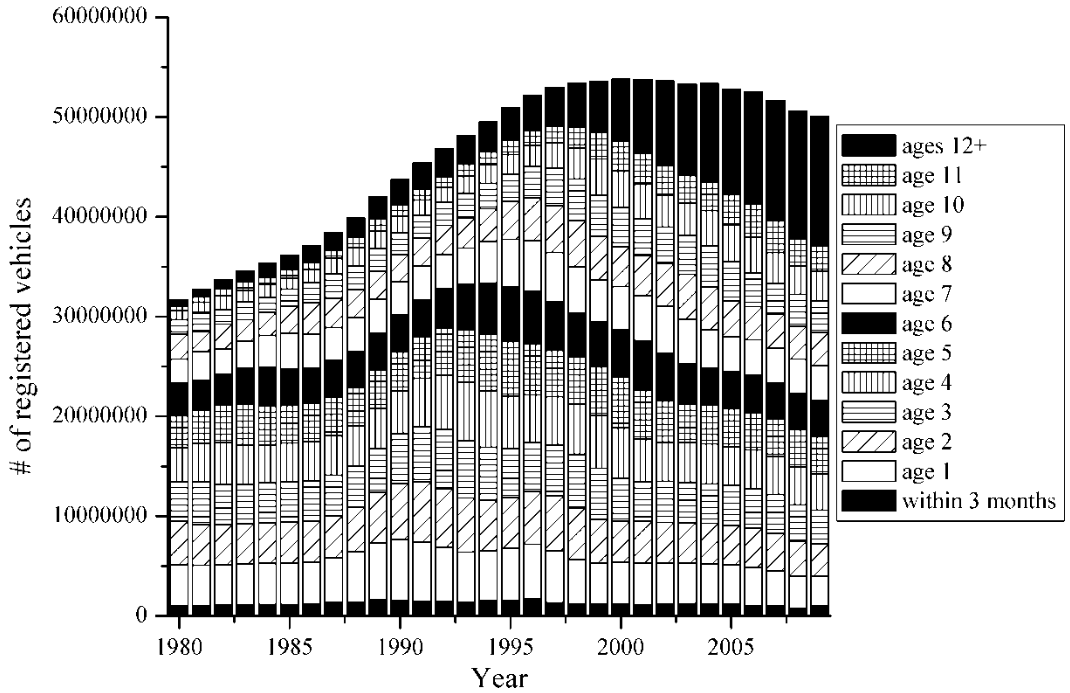

Figure 2. The number of registered vehicles: car age

Notes: Data in each year includes data of within 3 months (from January to March) of the next year following the original data format. Source: AIRIA (1981-2010).

Table 1. Key economic and demographic variables in Japan from 1970 to 2010

Variables	Unit	1970	1980	1990	2000	2010	Later or projection	Source
GDP share of transportation equipment	%	4.1%	3.6%	2.9%	2.4%	2.9%		ESRI (various years)
# of new vehicle sales (four wheels)	million	4.1	5.0	7.7	5.9	4.9	5.5 (2014)	JAMA (2015)
# of owned cars	million	16	37	57	74	78	80 (2014)	JAMA (2015)
(Except for light vehicles and light motorcycles)	million	—	31.7	43.7	53.8	50.0 (2009)		AIRIA (1981-2010)
Population (whole of Japan)	million	104	117	123	127	128	116 (2030) and 87 (2060)	IPSS (2012, 2015)
Population over 65 years	million	7.3	10.6	14.9	22.0	29.5	36.9 in 2030 and peak at 38.8 in 2042	IPSS (2012, 2015)
Population over 65 years (%)	%	7.0%	9.1%	12.0%	17.4%	23.0%		
Population in DID	million	56	70	78	83	86		IPSS (2015)
DID rate (population in DID divided by total population)	%	53.5%	59.7%	63.2%	65.2%	67.3%		
DID area	km^2	6,444	10,015	11,732	12,457	12,744		IPSS (2015)
Population density (whole of Japan)	people/km^2	280	314	332	340	343		IPSS (2015)
Population density within the DID	people/km^2	8,690	6,983	6,661	6,648	6,757		IPSS (2015)
Average household size	person	3.41	3.22	2.99	2.67	2.43		MIAC (2012a; 2012b)

Notes: Population projection in IPSS (2012) is based on the assumptions of medium fertility and medium mortality. DID stands for the population located in a densely inhabited district, which is the basic area unit holding more than 4,000 people per km^2.

Table 2. Vehicle types of this study

#	Category	# of wheels	Size	Total emission (cc)	Classification	
					by domestic maker	by brand
1	regular truck	4 or more	larger than four-wheel compact vehicle	(same as on the left)	Yes (9)	—
2	compact four-wheel truck	4 or more	length: 4.7 m or less; width: 1.7 m or less; height: 2.0 m or less	660-2000	Yes (12)	Yes (137)
3	compact three-wheel truck	3	larger than three-wheel small truck	660 or more	Yes (3)	—
4	trailing truck	4 or more	larger than four-wheel compact vehicle	(same as on the left)	—	—
5	regular bus	4 or more	larger than four-wheel compact vehicle	(same as on the left)	—	—
6	compact bus	4 or more	larger than four-wheel compact vehicle	(same as on the left)	—	—
7	regular passenger car	4 or more	larger than four-wheel compact vehicle	(same as on the left)	Yes (10)	Yes (309)
8	compact passenger car	4 or more	length: 4.7 m or less; width: 1.7 m or less; height: 2.0 m or less	660-2000	Yes (10)	Yes (472)
9	special purpose car	unlimited	unlimited	unlimited	Yes (12)	—
10	large-sized special car	unlimited	unlimited	unlimited	—	—
11	motorcycle	2	larger than small motorcycle	250 or more	—	—

Notes: This table shows the 11 vehicle types in the data of this study. Classification denotes that whether the total numbers of vehicles can be divided into by domestic makers (e.g., Toyota) or by vehicle brands (e.g., Toyota Prius). The 12 observed domestic car makers are Daihatsu Motor Co., Ltd., Hino Motors, Ltd., Isuzu Motors, Ltd., Mitsubishi Motors Corp., Nissan Motor Co., Ltd., UD Trucks Corp., Mazda Motor Corporation, Toyota Motor Corp., Fuji Heavy Industries Ltd., Honda Motor Co., Ltd., Suzuki Motor Corp., and the others. The values in the parentheses (after 'Yes') denote that the net numbers of observed domestic makers or vehicle brands.

Table 3. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
car ages 2-11					
ln*N*	3,611,755	4.135	2.033	0.000	10.464
car age (*j*)	3,611,755	5.916	3.111	1.000	11.000
ln*Income*	3,611,755	7.839	0.214	7.158	8.439
GasP	3,611,755	121.498	20.256	86.083	172.000
CPI	3,611,755	97.716	6.482	76.700	107.500
ln*Pop*	3,611,755	14.527	0.736	13.292	16.384
Density	3,611,755	664.763	1135.174	70.560	5962.760
HSize	3,611,755	2.948	0.333	2.066	3.818
Over65	3,611,755	0.168	0.048	0.064	0.291
DIDR	3,611,755	0.501	0.189	0.234	0.981
MigR	3,611,755	−0.001	0.003	−0.011	0.014
Train	3,611,755	81.710	121.994	0.000	733.457
Bus	3,611,755	38.064	22.082	6.050	118.821
ln*GasP*	3,611,755	4.786	0.163	4.455	5.147
ln*Density*	3,611,755	5.837	0.978	4.256	8.693
ln*Over65*	3,611,755	−1.829	0.300	−2.749	−1.236
ln*DIDR*	3,611,755	−0.756	0.350	−1.453	−0.019
ln*Train*	3,611,755	3.654	1.661	−6.908	6.598
ln*Bus*	3,611,755	3.472	0.591	1.800	4.778
car age 12+					
ln*N*	336,143	4.158	2.068	0.000	11.424
ln*Income*	336,143	7.845	0.206	7.158	8.439
GasP	336,143	122.082	19.858	86.083	172.000
CPI	336,143	98.062	6.151	76.700	107.500
HSize	336,143	2.916	0.334	2.066	3.818
ln*Pop*	336,143	14.527	0.737	13.292	16.384
Density	336,143	665.546	1137.644	70.560	5962.760
Over65	336,143	0.173	0.049	0.064	0.291
DIDR	336,143	0.502	0.189	0.234	0.981
MigR	336,143	−0.001	0.003	−0.011	0.014
Train	336,143	81.283	122.086	0.000	733.457
Bus	336,143	36.954	21.973	6.050	118.821
ln*GasP*	336,143	4.792	0.160	4.455	5.147
ln*Density*	336,143	5.837	0.980	4.256	8.693
ln*Over65*	336,143	−1.798	0.305	−2.749	−1.236
ln*DIDR*	336,143	−0.752	0.349	−1.453	−0.019
ln*Train*	336,143	3.652	1.629	−6.908	6.598
ln*Bus*	336,143	3.436	0.602	1.800	4.778

Table 4. Regression result of car aged 2-11

Category	(1) #1		(2) #2		(3) #3		(4) #4		(5) #5		(6) #6	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
lnN_{t-1}	0.835***	0.002	0.878***	0.001	0.927***	0.011	0.675***	0.007	0.473***	0.011	0.433***	0.006
j (age)	−0.062***	0.000	−0.075***	0.000	−0.003	0.003	−0.055***	0.001	−0.017***	0.001	−0.045***	0.001
ln*Income*	0.047	0.035	0.036**	0.015	0.040	0.292	0.415***	0.087	−0.328***	0.065	0.008	0.054
ln*GasP*	−0.042	0.055	0.024	0.027	0.135	0.345	0.294**	0.145	0.140	0.107	−0.015	0.088
CPI	0.001	0.001	−0.006***	0.001	0.003	0.010	−0.007**	0.003	−0.008***	0.002	−0.007***	0.002
ln*Pop*	−0.805	0.557	−0.656**	0.267	0.359	4.385	−2.981*	1.559	12.074***	1.371	0.918	0.952
ln*Density*	0.669	0.563	0.639**	0.268	−0.231	4.424	2.498	1.571	−10.535***	1.366	−0.271	0.953
HSize	−0.375***	0.056	−0.144***	0.023	1.179*	0.624	0.003	0.122	−0.463***	0.110	0.113	0.078
ln*Over65*	−0.237***	0.039	−0.173***	0.016	−0.300	0.238	0.140*	0.080	0.118*	0.061	−0.174***	0.056
ln*DIDR*	−0.029	0.036	0.053***	0.016	0.580	0.356	0.753***	0.093	−0.427***	0.064	−0.061	0.058
MigR	−0.437	0.618	0.408	0.315	−6.823	5.211	−8.030***	1.689	5.356***	1.276	3.433***	1.111
ln*Train*	−0.002	0.002	−0.003**	0.001	0.092	0.070	−0.003	0.006	−0.034***	0.006	0.011***	0.003
ln*Bus*	0.016	0.012	0.003	0.006	−0.069	0.102	−0.109***	0.030	0.160***	0.024	0.135***	0.020
constant	10.837*	6.266	8.697***	3.005	−8.971	47.201	35.241**	17.520	−135.760***	15.216	−9.789	10.768
dummies												
maker	Yes (8)		No		Yes (2)		No		No		No	
brand	No		Yes (132)		No		No		No		No	
year	Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)	
prefecture	Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)	
obs	129,637		674,659		682		14,938		14,970		14,993	
R-squared	0.964		0.959		0.978		0.936		0.935		0.912	

Notes: ***, **, and * stand for the statistical significant level at 1%, 5%, and 10%, respectively. Coef. and S.E. denote coefficient and robust standard error, respectively. In the rows of dummies, the numbers in the parentheses represent the numbers of dummy variables.

Table 4. Regression result of car aged 2-11 (cont.)

Category	(7) #7		(8) #8		(9) #9		(10) #10		(11) #11	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
lnN_{t-1}	0.906***	0.001	0.916***	0.001	0.783***	0.002	0.409***	0.006	0.411***	0.006
j (age)	−0.063***	0.000	−0.076***	0.000	−0.065***	0.000	−0.026***	0.001	−0.085***	0.001
ln*Income*	0.072***	0.016	0.024**	0.011	0.010	0.038	0.122*	0.065	0.034	0.076
ln*GasP*	0.034	0.024	−0.013	0.017	−0.089	0.060	0.365***	0.107	0.187*	0.109
CPI	−0.002***	0.001	−0.002***	0.000	0.002**	0.001	0.007***	0.002	0.000	0.003
ln*Pop*	−1.906***	0.305	−0.385**	0.187	−0.574	0.608	6.517***	1.144	−6.126***	1.559
ln*Density*	1.550***	0.308	0.207	0.188	0.761	0.619	−6.761***	1.153	6.888***	1.571
HSize	−0.192***	0.023	−0.215***	0.017	−0.062	0.059	−0.445***	0.097	0.022	0.107
ln*Over65*	0.045***	0.016	−0.024**	0.012	0.021	0.040	−0.722***	0.063	−0.368***	0.083
ln*DIDR*	0.090***	0.018	0.004	0.012	−0.004	0.043	−0.201***	0.074	−0.230**	0.107
MigR	0.755**	0.327	0.153	0.217	−1.331**	0.618	−5.091***	1.259	0.392	1.344
ln*Train*	−0.002**	0.001	−0.008***	0.001	−0.008***	0.003	−0.005	0.004	−0.016***	0.005
ln*Bus*	−0.014***	0.005	−0.006*	0.004	−0.008	0.013	0.098***	0.023	0.094***	0.031
constant	23.883***	3.434	6.629***	2.105	7.491	6.817	−71.467***	12.855	68.871***	17.585
dummies										
maker	No		No		Yes (11)		No		No	
brand	Yes (289)		Yes (453)		No		No		No	
year	Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)	
prefecture	Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)	
obs	927,568		1,649,282		155,557		14,476		14,993	
R-squared	0.954		0.960		0.939		0.931		0.915	

Table 5. Regression result of car aged 12+

	(1)		(2)		(3)		(4)		(5)		(6)	
Category	#1		#2		#3		#4		#5		#6	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
lnN_{t-1}	0.939***	0.005	0.817***	0.004	0.935***	0.009	0.883***	0.014	0.582***	0.176	0.850***	0.019
ln*Income*	−0.018	0.075	0.119**	0.051	−0.126	0.129	−0.001	0.074	−0.610***	0.225	0.067	0.082
ln*GasP*	−0.278***	0.103	−0.200**	0.086	−0.305*	0.165	0.229**	0.117	−0.613**	0.310	−0.167	0.122
CPI	0.004*	0.002	−0.010***	0.002	0.007	0.005	−0.001	0.003	−0.030*	0.018	−0.004**	0.002
ln*Pop*	−0.740	1.377	−3.826***	0.998	−3.377	3.282	−3.001**	1.464	−7.036*	4.138	−6.972***	1.520
ln*Density*	0.348	1.379	3.926***	1.005	3.061	3.349	2.772*	1.459	6.232	4.062	6.667***	1.492
HSize	−0.316***	0.097	−0.174**	0.071	−0.321*	0.169	−0.096	0.106	−0.842**	0.350	−0.433***	0.105
ln*Over65*	−0.279***	0.070	−0.312***	0.049	−0.136	0.125	−0.013	0.076	−0.700*	0.370	−0.546***	0.090
ln*DIDR*	0.046	0.081	0.241***	0.054	0.040	0.133	0.129	0.086	0.439*	0.234	0.015	0.076
MigR	−0.361	1.259	0.000	0.959	2.700	2.175	−5.164***	1.432	−0.145	3.415	−2.047	1.531
ln*Train*	0.015***	0.004	−0.002	0.003	0.009	0.006	−0.001	0.004	0.034**	0.017	0.014***	0.003
ln*Bus*	0.047*	0.028	−0.016	0.019	0.102**	0.044	−0.053*	0.031	0.398**	0.181	0.081***	0.027
constant	11.464	15.451	44.660***	11.183	41.360	36.134	35.307**	16.426	94.876*	48.674	81.235***	17.491
dummies												
maker	Yes (8)		No		Yes (2)		No		No		No	
brand	No		Yes (124)		No		No		No		No	
year	Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)	
prefecture	Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)	
obs	12,554		74,161		3,383		1,363		1,363		1,363	
R-squared	0.987		0.949		0.978		0.997		0.896		0.993	

Notes: ***, **, and * stand for the statistical significant level at 1%, 5%, and 10%, respectively. Coef. and S.E. denote coefficient and robust standard error, respectively. In the rows of dummies, the numbers in the parentheses represent the numbers of dummy variables.

Table 5. Regression result of car aged 12+ (cont.)

Category	(7) #7		(8) #8		(9) #9		(10) #10		(11) #11	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
lnN_{t-1}	0.821***	0.004	0.823***	0.002	0.855***	0.012	0.899***	0.020	0.701***	0.110
ln*Income*	0.097	0.063	0.049	0.040	0.023	0.109	−0.102*	0.057	−0.255**	0.110
ln*GasP*	−0.262**	0.104	−0.094	0.060	−0.137	0.152	0.210	0.148	−0.149	0.124
CPI	−0.001	0.002	0.001	0.001	0.004	0.003	0.000	0.002	−0.008**	0.004
ln*Pop*	−6.130***	1.255	−1.981**	0.805	−2.247	1.680	3.461**	1.565	−7.397**	2.921
ln*Density*	5.546***	1.264	1.958**	0.811	2.104	1.717	−3.438**	1.553	7.453**	2.989
HSize	−0.366***	0.088	−0.330***	0.059	−0.334*	0.175	−0.051	0.087	−0.321*	0.188
ln*Over65*	−0.044	0.061	0.082**	0.041	−0.164	0.116	−0.012	0.063	0.058	0.135
ln*DIDR*	0.120*	0.071	0.024	0.046	0.140	0.136	−0.067	0.054	−0.146	0.173
MigR	−4.376***	1.223	−4.035***	0.801	−1.974	1.473	−2.722**	1.120	1.187	1.927
ln*Train*	−0.002	0.003	−0.009***	0.002	−0.002	0.008	0.003	0.003	0.000	0.005
ln*Bus*	−0.059***	0.023	−0.030**	0.015	0.011	0.041	0.001	0.024	0.014	0.044
constant	74.255***	14.139	24.901***	9.062	27.574	18.800	−38.291**	17.781	89.656***	33.934
dummies										
maker	No		No		Yes (11)		No		No	
brand	Yes (202)		Yes (345)		No		No		No	
year	Yes (28)		Yes (28)		Yes (28)		Yes (28)		Yes (28)	
prefecture	Yes (46)		Yes (46)		Yes (46)		Yes (46)		Yes (46)	
obs	66,847		158,024		14,406		1,316		1,363	
R-squared	0.945		0.944		0.961		0.995		0.990	

Table 6. Elasticity of population size

Category	(1)		(2)		(3)	
	ln*Pop*		ln*Density*		(1) + (2)	
	Coef.	S.E.	Coef.	S.E.	Coef.	F-value (Wald test)
Car aged 2-11						
#1	−0.805	0.557	0.669	0.563	−0.136	5.78**
#2	−0.656**	0.267	0.639**	0.268	−0.017	0.48
#3	0.359	4.385	−0.231	4.424	0.128	0.13
#4	−2.981*	1.559	2.498	1.571	−0.483	15.44***
#5	12.074***	1.371	−10.535***	1.366	1.539	261.43***
#6	0.918	0.952	−0.271	0.953	0.647	56.35***
#7	−1.906***	0.305	1.550***	0.308	−0.356	218.09***
#8	−0.385**	0.039	0.207	0.272	−0.178	102.62***
#9	−0.574	0.608	0.761	0.619	0.187	10.63***
#10	6.517***	1.144	−6.761***	1.153	−0.244	7.32***
#11	−6.126***	1.559	6.888***	1.571	0.762	40.96***
Car aged 12+						
#1	−0.740	1.377	0.348	1.379	−0.392	13.17***
#2	−3.826***	0.998	3.926***	1.005	0.100	1.81
#3	−3.377	3.282	3.061	3.349	−0.316	3.74*
#4	−3.001**	1.464	2.772*	1.459	−0.229	3.55*
#5	−7.036*	4.138	6.232	4.062	−0.804	7.25***
#6	−6.972***	1.52	6.667***	1.492	−0.305	4.83**
#7	−6.130***	1.255	5.546***	1.264	−0.584	36.48***
#8	−1.981**	0.805	1.958**	0.811	−0.023	0.14
#9	−2.247	1.68	2.104	1.717	−0.143	0.78
#10	3.461**	1.565	−3.438**	1.553	0.023	0.04
#11	−7.397**	2.921	7.453**	2.989	0.056	0.10

Notes: Columns (1) and (2) show the estimated coefficients and robust standard errors of ln*Pop* and ln*Density*, respectively, from Tables 4 and 5. Column (3) shows joint coefficient ((1) + (2)) and F-value of linear Wald test which tests whether the joint coefficient equals zero. ***, **, and * stand for the statistical significant level at 1%, 5%, and 10%, respectively.

Appendix Table A1. The number of registered vehicles (car types and age: unit is thousand cars)

Year	1980	1990	2000	2009
Car types				
#1	1,502	2,206	2,582	2,304
#2	7,110	6,538	5,389	3,906
#3	14	2	1	1
#4	57	89	134	152
#5	107	115	110	109
#6	123	131	125	120
#7	480	1,934	14,163	16,699
#8	21,064	30,503	28,202	23,720
#9	505	791	1,431	1,188
#10	289	423	323	324
#11	445	1,000	1,308	1,524
Total	31,695	43,730	53,770	50,046
Car age				
Within 3 months	1,026	1,560	1,227	987
1	4,122	6,096	4,181	2,980
2	4,352	5,643	4,055	3,250
3	3,964	4,964	4,334	3,399
4	3,412	4,292	5,041	3,633
5	3,205	3,913	5,126	3,714
6	3,250	3,700	4,756	3,632
7	2,392	3,321	4,295	3,505
8	2,544	2,746	3,985	3,312
9	1,429	2,170	3,946	3,137
10	894	1,662	3,606	2,984
11	484	1,159	3,057	2,571
12+	617	2,504	6,160	12,943
Total	31,695	43,730	53,770	50,046

Appendix Table A2. Correlation matrix: car aged 2-11

	ln*N*	*j* (age)	ln*Income*	ln*GasP*	*CPI*	ln*Pop*	ln*Density*	*HSize*	ln*Over65*	ln*DIDR*	*MigR*	ln*Train*	ln*Bus*
ln*N*	1.000												
j (age)	−0.112	1.000											
ln*Income*	0.126	0.003	1.000										
ln*GasP*	−0.004	0.006	−0.559	1.000									
CPI	0.005	0.018	0.735	−0.691	1.000								
ln*Pop*	0.273	0.000	0.437	−0.052	0.060	1.000							
ln*Density*	0.189	−0.001	0.450	−0.051	0.065	0.746	1.000						
HSize	−0.070	−0.041	−0.479	0.309	−0.600	−0.353	−0.296	1.000					
ln*Over65*	−0.119	0.045	0.261	−0.344	0.653	−0.402	−0.415	−0.513	1.000				
ln*DIDR*	0.210	0.004	0.405	−0.097	0.159	0.827	0.748	−0.485	−0.332	1.000			
MigR	0.092	−0.015	0.304	−0.077	0.032	0.323	0.391	0.075	−0.350	0.261	1.000		
ln*Train*	0.152	−0.005	0.421	0.007	0.021	0.545	0.440	−0.218	−0.148	0.392	0.267	1.000	
ln*Bus*	0.126	−0.027	−0.135	0.261	−0.386	0.515	0.424	0.074	−0.644	0.566	0.160	0.255	1.000

Appendix Table A3. Correlation matrix: car aged 12+

	ln*N*	ln*Income*	ln*GasP*	*CPI*	ln*Pop*	ln*Density*	*HSize*	ln*Over65*	ln*DIDR*	*MigR*	ln*Train*	ln*Bus*
ln*N*	1.000											
ln*Income*	0.219	1.000										
ln*GasP*	−0.067	−0.500	1.000									
CPI	0.179	0.707	−0.622	1.000								
ln*Pop*	0.271	0.444	−0.045	0.047	1.000							
ln*Density*	0.184	0.459	−0.046	0.054	0.747	1.000						
HSize	−0.269	−0.454	0.228	−0.596	−0.333	−0.281	1.000					
ln*Over65*	0.090	0.233	−0.252	0.651	−0.397	−0.409	−0.537	1.000				
ln*DIDR*	0.232	0.401	−0.081	0.146	0.826	0.746	−0.470	−0.325	1.000			
MigR	0.050	0.321	−0.091	0.015	0.351	0.421	0.083	−0.373	0.283	1.000		
ln*Train*	0.129	0.436	0.011	0.018	0.555	0.453	−0.215	−0.151	0.406	0.283	1.000	
ln*Bus*	0.005	−0.109	0.206	−0.383	0.527	0.433	0.087	−0.644	0.576	0.189	0.270	1.000

Appendix Table. A4 The number of observations

Car types	Car aged 2-11	Car aged 12+
#1	129,637	12,554
#2	674,659	74,161
#3	682	3,383
#4	14,938	1,363
#5	14,970	1,363
#6	14,993	1,363
#7	927,568	66,847
#8	1,649,282	158,024
#9	155,557	14,406
#10	14,476	1,316
#11	14,993	1,363
Total	3,611,755	336,143

Appendix Table A5. Alternative regression results of ln*Pop* (removing ln*Density*)

	ln*Pop*	
	Coef.	S.E.
Car aged 2-11		
#1	−0.143***	0.056
#2	−0.024	0.025
#3	0.130	0.348
#4	−0.510***	0.122
#5	1.644***	0.096
#6	0.649***	0.086
#7	−0.370***	0.024
#8	−0.181***	0.018
#9	0.179***	0.056
#10	−0.164*	0.090
#11	0.688***	0.118
Car aged 12+		
#1	−0.395***	0.108
#2	0.060	0.074
#3	−0.352**	0.150
#4	−0.259**	0.124
#5	−0.869***	0.311
#6	−0.336**	0.143
#7	−0.630***	0.096
#8	−0.042	0.062
#9	−0.164	0.157
#10	0.063	0.119
#11	−0.036	0.167

Notes: This table represents alternative regression results of ln*Pop*, removing *lnDensity* from the regression model. Each row corresponds to each of sample sets from #1 to #12 at the car ages 2-11 (Table 4) and 12+ (Table 5), respectively. Coef. and S.E. denote coefficient and robust standard error, respectively. ***, **, and * stand for the statistical significant level at 1%, 5%, and 10%, respectively.