Growth of Distance Traveled and Convergence across Global Cities

Ryosuke Abe[a] (Correspondig author)
[a]Department of Civil Engineering, the University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-7451; Fax: +81-3-5841-7496
E-mail: abe-r@ip.civil.t.u-tokyo.ac.jp

Hironori Kato[b]
[b]Department of Civil Engineering, the University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-7451; Fax: +81-3-5841-7496
E-mail: kato@civil.t.u-tokyo.ac.jp

Abstract
Slower growth rates of passenger travel have recently been reported in many developed economies. This paper describes the long-run growth of the urban transportation market in an attempt to understand the current situation in this regard. First, assuming that the distance traveled represents the market size for urban transportation, this study sets a hypothesis that the initial gap of distance traveled per capita across cities could have narrowed over time under current transportation technologies (i.e., car and modern transit). Next, this study verified the convergence of distance traveled per capita empirically using a global city dataset that covers developed economies from 1960 to 2000. The results showed that distance traveled per capita converged in the postwar period across cities with/without controls that represent cities' characteristics. Further, the modal share of a city did not affect the growth rate of distance traveled per capita; U.S. cities had a higher growth rate in the postwar period; and a lower population density of a city increased the growth rate of per capita distance traveled.

Keywords: Distance traveled, urban transportation, long-run analysis, international comparison

1. Introduction

Slower growth rates in car use (Goodwin and Van Dender, 2013) and passenger travel have recently been reported in many developed economies. In particular, the slowing growth of distance traveled draws particular attention (Metz, 2010). For example, Millard-Ball and Schipper (2011) show that in the past 30 years the growth of energy use in passenger transportation of developed countries was mostly a result of increases in distance traveled. The slowing growth of distance traveled might therefore generate a broad range of discussion, including its implications for longer-term policy relating to climate change (Banister and Hickman, 2013) and the forecasts that assume travel demand will continue to rise along with income (Millard-Ball and Schipper, 2011).

Meanwhile, large differences are currently observed across global cities in the modal share of passenger trips. For example, the share of car trips is the highest in U.S. cities (89% on average over the cities), followed by the cities in Western Europe (50%) and in developed Asia (39%) while the share of public-transit trips is 3%, 19%, and 32%, respectively (UITP, 2001). Cities with extreme patterns of urban transportation are typically described as “car cities” and “modern-transit cities” or “transit metropolis” (Barter, 2004; Cervero, 1998; Newman and Kenworthy, 1996).

Before motorization commenced, however, the transportation patterns were more or less similar across cities, in which public transit used to be the major means of urban transportation. Particularly, most cities in the current developed countries have experienced the “electric streetcar (tramway) era.” For example, in most major U.S. cities, an extensive network of electric streetcars continued to be used in the 1950s, although they had started to decline in the late 1920s and had mostly disappeared by 1960 (Muller, 2004; Vuchic, 2007). Electric streetcar systems in major cities in Europe and Japan were also closed by around 1970 and much earlier in the UK and France (Aoki et al., 2000; Costa and Fernandes, 2012). The electric streetcar was replaced by the bus in some developed cities, whereas the role of public transit was reduced by increasing use of private passenger cars in other cities.

Thus, we can briefly summarize the development of the urban transportation market; in terms of the transportation technology, any city in the postwar developed countries could have potentially introduced both options: car and modern-transit. In other words, under those current transportation technologies, the urban transportation market has developed during the postwar period.

This study highlights the long-run growth of the urban transportation market under current transportation technologies. In the economic growth literature, it is widely known that national economies, as measured in Gross Domestic Product (GDP) per capita, have converged across OECD member countries in the postwar period, where the initial gap across those economies narrowed over time (e.g., Acemoglu, 2008; Barro and Sala-i-Martin, 2004). Recent economic studies have focused on cities’ population and employment growth (e.g., Duranton and Turner, 2012; Glaeser et al., 1995; Henderson and Wang, 2007; Michaels et al., 2012). This study assumes distance traveled represents the market size of urban transportation. It hypothesizes that cities with lower distance traveled per capita might have had higher growth rates of distance traveled per capita. Meanwhile, the cities with higher distance traveled per capita might have had lower growth rates; consequently, the initial gap of distance traveled per capita across cities might have narrowed over time. This may be regarded as the convergence hypothesis for the distance traveled per capita.

This study aims to empirically justify the convergence of the distance traveled per capita with a global-city dataset covering developed economies from 1960 to 2000. The remainder of the paper is organized as follows. The assumptions and a working hypothesis are shown after a literature review on the long-run issues of the urban transportation market. Next, the analytical method and empirical data are explained. Then the results of the empirical analysis are presented with discussion. Finally, the paper concludes with further issues.

2. Literature review

Many studies have analyzed overall patterns or those long-run trends of the urban transportation market by using an approach of international comparison. They may be categorized into two types: the first type analyzes the process of urban transportation development in the context of the developing world. They include, for example, Barter (2004), Dick and Rimmer (2003), Hook and Replogle (1996), and Rimmer (1988). The second type analyzes the differences in transportation markets between automobile-dependent U.S. cities and relatively transit-oriented/compact-structured European cities. They include, for example, Nivola (1999) and Pucher (1995; 1988). These studies have unveiled the factors affecting the overall patterns or those long-run trends of the urban transportation market, such as a series of public policies including car-related policy, land/house regulation, and subsidies for public transportation and for road construction (Pucher, 1988); the socio-economic conditions, land-use patterns, transportation policy, and culture and attitude (Buehler, 2010); and choice of investment in transportation infrastructure, income change and economic growth, interdependence between transportation and land-use, transportation policy, cost of fuel, vehicle, and parking, and choice of technology (Barter, 1999). Approaches other than urban or transportation planning analysis, such as the technology diffusion research, also deal with the long-run impacts of transportation technology, including Costa and Fernandes (2012) and Grübler (1990).

Statistical analyses have been also applied to isolating the critical factors determining overall patterns of urban transportation markets for global cities. Most studies use the datasets, collected in McIntosh et al. (2014), UITP (2006, 2001), Kenworthy et al. (1999), and Newman and Kenworthy (1989a), which include cross-sectional time-series data of urban transportation and land-use for global cities. Using these datasets, descriptive analysis (Kenworthy and Laube, 1999; Newman and Kenworthy, 1989b) and multivariate analysis (Acharya and Morichi, 2007; Albalate and Bel, 2011; Cameron et al., 2003; Ingram and Liu, 1998, 1997; McIntosh et al., 2014; Souche, 2010; van de Coevering and Schwanen, 2006) have been conducted[1]. In addition, Besson et al. (2004, 2003) uses an original cross-sectional time-series dataset across cities in the UK and France. In recent years, disaggregate studies using international datasets (mostly between two countries) have also been conducted (Buehler, 2010; Giuliano and Dargay, 2006; Giuliano and Narayan, 2003; Senbil et al.,

[1] Table 2 provides the major findings from these studies.

2009; Yamamoto, 2009).

These international comparative studies have provided evidence regarding the determinants of transportation patterns in cities. The transportation pattern refers to the conditions within the transportation market, such as the modal share in cities. Further, these studies have also provided the basis and motivation of empirical analysis in other transportation research.

However, two important issues in the topic of long-run urban transportation market are not well explored in existing studies. First, there is relatively a lack of evidence on the size of the transportation market or travel demand in the long run, for example, how the market size has been determined. Consequently, we do not have sufficient tools to understand the long-run change in the size of travel demand. Second, there is still a lack of understanding of the mechanism for long-run changes in the transportation pattern of cities, despite knowing the factors affecting the transportation pattern of cities. One possible criticism is that analyses heavily relied on demand-side explanations. For example, car share is high in a city because service levels of car travel are high in the city. However, this does not answer the question of why the service levels of car travel have remained high in that city. Accounting for the long-run supply mechanism, including planning processes, and integrating it into the analysis, are necessary when we discuss long-run changes in the system or the market as a whole. This study contributes insights on the first issue that is not well addressed in existing studies.

3. Hypothesis

3.1 Measures

This study assumes that distance traveled represents the size of the urban transportation market. Distance traveled, or person-kilometer traveled, in a city is one of the typical performance indicators and could be a measure of output and consumption in the urban transportation market. Specifically, this study uses the distance traveled "per capita" for cross-sectional comparisons between cities with different population sizes[2]. Data on distance traveled is available over the long run in many cities.

Transportation researchers have generally preferred using performance indicators such as distance traveled because they provide direct policy-relevant evidence. Among many performance indicators, the distance traveled has become of greater concern in recent policy discussion on climate change (Banister, 2011; Boarnet, 2011). For example, the reduction of distance traveled is a required behavioral change for the reduction of greenhouse gas emissions in urban transportation (Åkerman and Höjer, 2006; Geurs and van Wee, 2004; Hickman and Banister, 2007).

It should be noted that distance traveled cannot be used to evaluate the quality of transportation services. For example, the changes in the quality of a given transportation mode, such as a more comfortable in-vehicle environment and fewer traffic accidents, cannot be captured only by observing the distance traveled. In addition, distance traveled might not reflect differences in the quality between

[2] If the growth rate of distance traveled per capita had increasing or decreasing returns to the population size of a city (called positive or negative scale effects), the regression analysis could verify it (Section 5.2).

transportation modes, such as more private space and better door-to-door mobility using cars than public-transit. This paper highlights quantitative changes rather than qualitative changes for analyzing the long-run trends in urban transportation markets.

3.2 Convergence of the distance traveled per capita

This study predicts convergence of distance traveled per capita in the postwar period simply based on two assumptions, both of which have been presented in past transportation research[3]. The first assumption is the constant average travel time. This has recently been raised by Metz (2010, 2008) and is generally known as the "travel time budget." This is where an average individual in a city, region, or country allocated relatively stable amount of time for his/her daily travel over the years, for example, at around 1.1 hours per day. This constant average travel time over the years has been observed globally (Schafer, 1998; Schafer and Victor, 2000; Zahavi and Talvitie, 1980). It should be noted that the constant average travel time was most applicable at the aggregate level of a city, region, or country while there was a high degree of variation in travel time expenditure at the disaggregate level (Mokhtarian and Chen, 2004). Further, the constant average travel time is not necessarily applicable in the future market. Nevertheless, the constant average travel time appears to be an appropriate assumption for the average trend of travel time expenditure in cities over the recent past.

The second assumption is diminishing returns of service levels in urban transportation. Whereby the marginal increase in average travel speed in a given city declines as the capital stock per capita in the urban transportation market increases, under current transportation technologies (i.e., car and modern-transit in the postwar developed countries). Strictly, we want to assume the diminishing returns of the potential service levels where the transportation supply might exert, as the service levels could reflect demands in the transportation market as well. Axhausen et al. (2011, 2008) shows the long-run evidence of diminishing increases in the municipality-level road or public-transit accessibility constructed using data for the supply of transportation network in Switzerland. This may imply diminishing returns of the supply-based service levels in the urban transportation market, although the changes in accessibility could reflect the changes in land-use as well.

Combining the above two assumptions leads to the following hypothesis: "growth of distance traveled per capita declines alongside capital accumulation in urban transportation markets given current transportation technologies." This would imply that a city with a lower distance traveled per capita (i.e., lower stock of physical capital per capita) might have had higher growth rate of distance traveled per capita whereas another city with a higher distance traveled per capita might have had lower growth rate of distance traveled per capita. If the above hypothesis were correct, the initial gap of distance traveled per capita across cities would be expected to have narrowed over time. This could be regarded as the "β convergence" (Sala-i-Martin, 1996) of distance traveled per capita across cities.

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[3] In addition, the factors relative to the general market might predict the convergence of urban transportation market, for example, based on the neoclassical models in macroeconomics.

4. Method

4.1. Empirical methods for verifying unconditional and conditional convergences

This study verifies two types of convergence. The first is an unconditional convergence of distance traveled per capita across cities. This is supported if there is a negative correlation between initial distance traveled per capita and its growth rate. The other is a conditional convergence of distance traveled per capita across cities. This is supported if there is a negative relationship between initial distance traveled per capita and its growth rate after controlling for the differences in cities' characteristics.

The growth rate of distance traveled per capita is defined as annual average growth rate in T interval, which is formulated as $\gamma_{y_{t+T,t}} = (1/\mathrm{T}) \cdot \ln(y_{t+T}/y_t)$ where y_t is distance traveled per capita at a time t and T is a time interval in years. Note that T is typically assumed as 10 years or longer in a long-run empirical analysis, because the growth rate over intervals as short as five years is often influenced considerably by short-term and temporary forces that are not typically considered in the long-run analysis (Barro and Sala-i-Martin, 2004).

The unconditional convergence of distance traveled per capita could be verified by a simple correlation coefficient, $\mathrm{cor}(\gamma_{y_{t+T,t}}, \ln y_t)$. Meanwhile, a function for verifying the conditional convergence of distance traveled per capita is defined as: $\gamma_{y_{t+T,t}} = f(\ln y_t, controls)$ where $controls$ is a vector of control variables such as characteristics of cities.

Choice of the control variables generally depends on model assumptions. Neoclassical models in economic growth studies typically assume that the growth rate of an economy is positively related to a gap between its current state and its own steady state. Here, a large gap produces a higher growth rate and vice versa. However, different economies could have different steady states if they have different technological and behavioral parameters. Thus, holding steady states constant across economies, we should find a positive relationship between the growth rate of an economy, and the gap between its current state and steady state. To do this, we use controls as a proxy for the steady state (e.g., Acemoglu, 2008; Barro and Sala-i-Martin, 2004). Empirically, a growth regression is used to examine the determinants of differences in the levels of per capita income between countries, using many hypothetical determinants proposed by theorists, amongst which is convergence (e.g., Durlauf et al., 2008). This study chooses the control variables based on the existing studies related to transportation and urban planning. Note that the steady state of the market is the situation where the variables considered in the system (model) have a constant growth rate.

A linear regression model is assumed to verify the conditional convergence as follows:

$$\gamma_{y_{t+T,t}} = \alpha + \beta \cdot \ln y_t + \mathrm{X}_\mathrm{t}'\boldsymbol{\theta} + \varepsilon_\mathrm{t} \tag{1}$$

where $\mathrm{X_t}$ is a vector of control variables at t; ε_t is a disturbance term at t; and α, β, $\boldsymbol{\theta}$ are unknown parameters.

4.2. Data

A global city dataset is used to develop a sample dataset used in the empirical analysis. This covers 39 major cities in the world, including 3 Asian, 6 Australian, 11 West European, and 19 North American cities in the years of 1960, 1970, 1980, 1990, and 2000. All cities belong to the OECD member countries as of the year of 2000, or are developed Asian cities including Hong Kong and Singapore. The included cities were determined by the availability of data. They are listed in Table 1. The global city dataset contains data on (1) transportation market, (2) urban form, (3) general market and gasoline price, (4) demographic condition, (5) geography, (6) institution, (7) region/country-specific, and (8) year-specific.

4.2.1 Transportation market and urban form

The transportation data consist of information on a city's (1) average growth rate of distance traveled per capita, (2) distance traveled per capita, and (3) share of car use in the distance traveled. The distance traveled per capita in each city was computed as follows: first, annual distance traveled by public transit is calculated by summing annual passenger kilometers of rail, bus, and streetcar (tram), while that by car is calculated by multiplying annual vehicle kilometers traveled by average car occupancy; next, the total annual distance traveled is calculated by summing the above two distances; and finally the distance traveled per capita is computed by dividing the total annual distance traveled by city population. Note that this measure of distance traveled does not include the distance traveled by motorcycle.

Our measure of the distance traveled is the motorized distance traveled. That is, the distance traveled made by non-motorized transportation modes (NMT) such as walking and bicycle are not included. However, although the share of person trips made by NMT is not necessarily small in developed cities, the distance traveled per capita by NMT was much smaller than by the motorized transportation modes. This implies our measure could capture the actual trends of distance traveled per capita well.

Next, the urban form data consist of information on city's (1) population, (2) average growth rate of population, (3) area, (4) population density, (5) population density in the central business district (CBD), (6) population density in inner area, and (7) share of employees in the CBD out of total employment in the city.

Sources in computing the above data are McIntosh et al. (2014) and UITP (2006) for the year of 2000, and Kenworthy et al. (1999) for the years of 1960, 1970, 1980, and 1990. The data in these sources are measured at the metropolitan or actual urbanized (built-up) area base rather than the administrative jurisdiction base.

4.2.2. General market, gasoline price, and demographic condition

The general market data consist of information on the country's (1) GDP per capita in 2005 prices, (2) annual growth rate of GDP per capita, (3) consumption share of GDP per capita, (4) national government consumption share of GDP per capita, and (5) Gini index in 2000. The data were collected from Heston et al. (2012) except for the Gini index in 2000, which was collected from the World Bank (2015).

Next, the gasoline price is defined as the pump price for gasoline at national levels in 2000, which was collected from the World Bank (2015). It is assumed that this captures the cross-city difference as of the year 2000, as well as the historical tendency of gasoline prices in each county (Ingram and Liu, 1997).

Finally, the demographic condition data consist of information on the country's (1) male population share, (2) age distribution, (3) employment by sector, (4) share of workers in the population, and (5) educational level. The data were collected from international historical statistics (Mitchell, 2008a, 2008b, 2008c) for all years.

City-level data for the general market, gasoline price, and demographic condition were unfortunately unavailable. The country's variable is an approximate to the city's one. Note that the data for Hong Kong covers Hong Kong only not China as a whole.

4.2.3 Geography, institution, region/country-specific, and year-specific

The geography data consist of information on city's (1) latitude, (2) longitude, (3) annual rainfall, and (4) average monthly sunshine hours. The latitude and longitude of a city are those of the municipal office's location of the city. The meteorological data were collected from the data provided by the relevant organization of the city or county.

Next, institution data is defined as a dummy variable where it is 1 if the city is a national capital and 0 otherwise. Region/country-specific data are defined as six dummy variables of Asian, Australian, Canadian, European, U.S. cities, and Hong Kong, where it is 1 if the city is located in each region or country (city) and 0 otherwise. Finally, year-specific data are defined as four dummy variables regarding the 1960s, 1970s, 1980s, and 1990s, where it is 1 if the growth rate of distance traveled per capita was observed in each decade and 0 otherwise.

4.2.4 Sample datasets for empirical analysis

Three sample datasets are constructed using the above global city dataset for use in the empirical analysis. The sample datasets 1 and 2 are used for the analysis of unconditional convergence; sample dataset 1 contains 118 observations on 39 cities in 10-year intervals while the sample dataset 2 contains 19 observations on 19 cities in 40-year intervals (Table 1). Meanwhile, sample dataset 3 is used for the analysis of conditional convergence. This contains 107 observations on 39 cities, where the number of observations in dataset 3 is slightly smaller than in dataset 1 due to the data limitations of the explanatory variables used. Table 2 shows descriptive statistics of sample dataset 3. Table 2 also lists major findings on the variables, which were collected from the studies using the dataset of McIntosh et al. (2014), UITP (2006, 2001), Kenworthy et al. (1999), and Newman and Kenworthy (1989a), as well as a description of the variables.

Table 1
Cities in the global city dataset and observations for sample datasets 1 and 2

Year	All (1960, 1970, 1980, 1990, 2000)	1960, 1980, 1990, 2000	1970, 1980, 1990, 2000	1960, 1970, 1980, 1990	1980, 1990, 2000	1970, 1980, 1990	1980, 1990
Asia			Hong Kong	Tokyo			Singapore
Australia	Brisbane, Melbourne, Perth, Sydney			Adelaide		Canberra	
Western Europe	Amsterdam, Copenhagen, Hamburg, London, Munich, Paris, Stockholm			Brussels	Frankfurt, Vienna, Zurich		
North America	Calgary, Chicago, Denver, Los Angeles, New York, Phoenix, San Francisco	Ottawa	Washington, D.C.	Boston, Winnipeg	Houston, Montreal, Toronto, Vancouver	Detroit, San Diego	Portland, Sacramento
No. cities (n = 39)	18	1	2	5	7	3	3
No. obs. in sample dataset 1 (for 10-year intervals, n = 118)	72	2	6	15	14	6	3
No. obs. in sample dataset 2 (for 40-year intervals, n = 19)	18	1	0	0	0	0	0

Table 2
Descriptive statistics of sample dataset 3 (107 observations)

Category	Variable	Unit and	Major findings[a]	Mean	Standard

		description			deviation
Transportation market	Average growth rate of distance traveled per capita	Growth of distance traveled per capita in 10-year intervals.		0.016	0.015
	Distance traveled per capita (log)	km per capita per year. Logarithm of distance traveled per capita (= by car plus by public transit).		9.078	0.425
	Share of car use	Distance traveled by car divided by total distance traveled.		0.832	0.177
Urban form	Population (log)	Million persons.		0.713	1.066
	Average growth rate of population	Growth of population in 10-year intervals.		0.013	0.017
	Area size (log)	Thousand km^2.		–0.290	1.185
	Population density (log)	Persons per km^2.	Negative effect on car use and ownership (Cameron et al., 2003; Ingram and Liu, 1998, 1997; Kenworthy and Laube, 1999; McIntosh et al., 2014; Newman and Kenworthy, 1989b).	7.910	0.753
	Population density in the CBD (log)	Persons per km^2.		8.393	1.002
	Population density in inner area (log)	Persons per km^2.		8.596	0.805
	Share of employees in the CBD out of total employment	%.	Positive effect on the modal share of public transit (van de Coevering and Schwanen, 2006).	0.194	0.092
General market and gasoline price	GDP per capita	USD in thousands in 2005 prices (National-level)	Effect on car ownership (Ingram and Liu, 1998, 1997).	21.890	5.600
	Average growth rate of GDP per capita	Growth of GDP per capita in 10-year intervals (National-		0.023	0.010

		level).			
	Consumption share of GDP per capita	(National-level).		68.590	5.515
	Government consumption share of GDP per capita	(National-level).		8.637	1.973
	Gini index in 2000	(National-level).	Positive effect on supply of the public transit (Albalate and Bel, 2011).	0.351	0.058
	Pump price of gasoline in 2000	USD per liter (national-level).	Negative effect on car ownership (Ingram and Liu, 1998, 1997). Effect on travel demand (no. of person trips) (Souche, 2010).	0.700	0.251
Demographic condition	Share of male population			0.492	0.008
	Share of population aged 15–39			0.038	0.031
	Share of population aged 40–64			0.268	0.024
	Share of population aged >65			0.112	0.025
	Share of workers in the population aged >15			0.569	0.120
	Share of workers in manufacturing industry	(National-level).		0.239	0.069
	Share of workers in construction industry			0.067	0.015
	Share of workers in commerce and finance industry			0.248	0.055
	Share of workers in services industry			0.289	0.071
	Share of people (students) in primary and secondary schools in the			0.771	0.167

	population aged 5-19			
Geography	Latitude	Effect on supply of public transit (Albalate and Bel, 2011).	31.170	30.633
	Longitude		−11.530	93.840
	Yearly rainfall mm		769.500	434.380
	Mean monthly sunshine hours		2324.000	633.380
Institution	Dummy for political capital	Positive effect on supply and demand of public transit (Albalate and Bel, 2011).	0.336	-
Region/ country-specific	Dummy for Asian cities		0.056	-
	Dummy for Australian cities (reference category)		0.168	-
	Dummy for Canadian cities		0.131	-
	Dummy for European cities		0.318	-
	Dummy for Hong Kong		0.019	-
	Dummy for U.S. cities		0.327	-
Year-specific	Dummy for the 1960s (reference category)		0.168	-
	Dummy for the 1970s		0.224	-
	Dummy for the 1980s		0.355	-
	Dummy for the 1990s		0.252	-

[a] The major findings on the variables were collected from the studies using the dataset of McIntosh et al. (2014), UITP (2006, 2001), Kenworthy et al. (1999), and Newman and Kenworthy (1989a).

5. Results

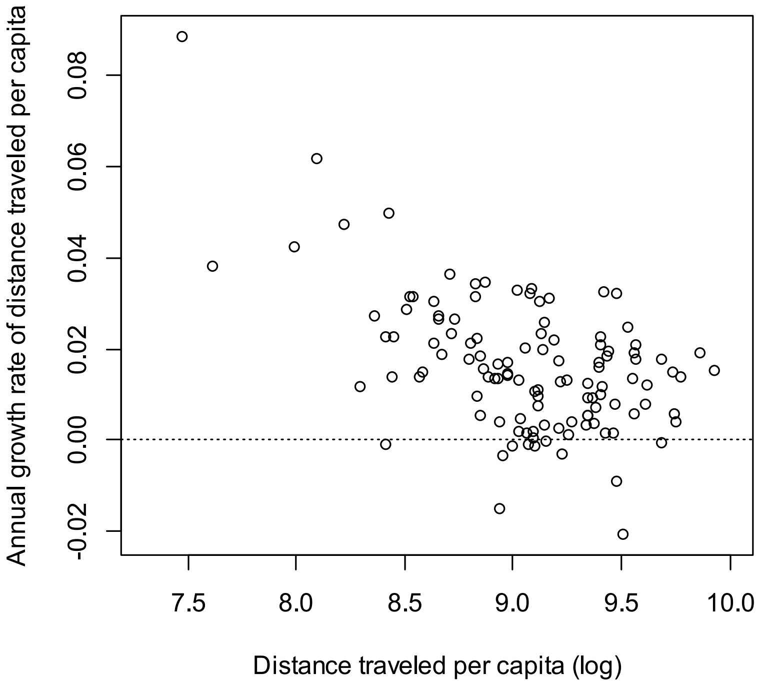
5.1. Unconditional convergence of distance traveled per capita

The unconditional convergence is statistically tested with sample dataset 1 (10-year intervals) and sample dataset 2 (40-year intervals). Figure 1 shows the relationship between the annual average growth rate in 10-year intervals of distance traveled per capita, versus the distance traveled per capita.

Each dot in the figure represents a city's logarithmic distance traveled per capita in 1960, 1970, 1980, or 1990, and its corresponding annual growth rate of distance traveled per capita from 1960 to 1970, 1970 to 1980, 1980 to 1990, or 1990 to 2000, respectively.

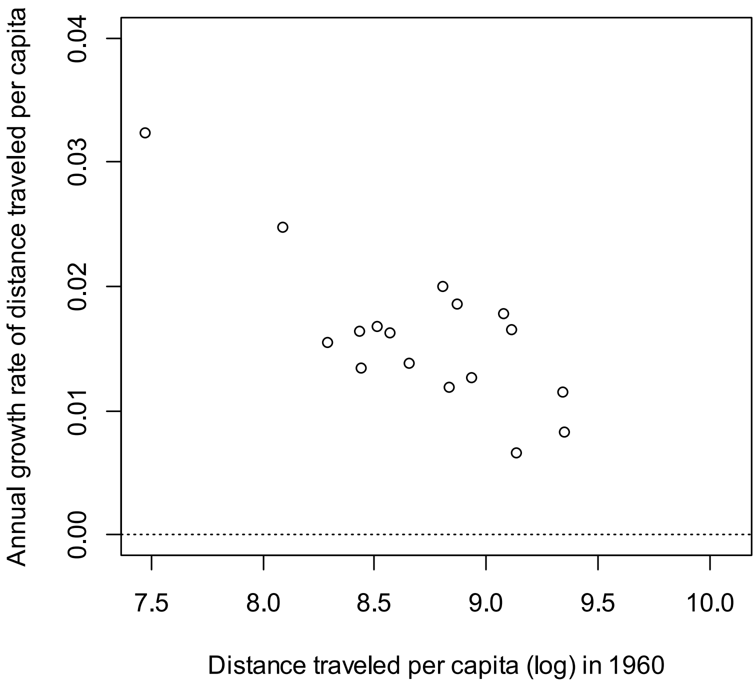
Figure 2 shows the relationship between the annual average growth rate in a 40-year interval of the distance traveled per capita, versus the distance traveled per capita. Each dot in the figure represents a city's logarithmic distance traveled per capita in 1960 and its corresponding annual growth rate of distance traveled per capita from 1960 to 2000.

The results indicate a negative relationship between the logarithmic distance traveled per capita and the growth rate of distance traveled per capita. The correlation coefficient is –0.419 ($p < .01$) for 10-year intervals (Figure 1) and is –0.698 ($p < .01$) for 40-year intervals (Figure 2). The negative relationship suggests that there is unconditional convergence of distance traveled per capita.



Note: Unit of the distance traveled is kilometers per year. n = 118 (39 cities)

Figure 1 Growth rate (annual average over 10 years) versus distance traveled per capita



Note: Unit of the distance traveled is kilometers per year. n = 19 (19 cities)

Figure 2 Growth rate (annual average over 40 years) versus distance traveled per capita

5.2. Conditional convergence of distance traveled per capita

The conditional convergence is statistically tested using a linear regression model formulated in Eq. (1) using sample dataset 3. The model uses the annual average growth rate of distance traveled per capita in 10-year intervals of 1960–70, 1970–80, 1980–90, and 1990–2000 as the dependent variable. The explanatory variables are the values in 1960, 1970, 1980, and 1990 or the annual growth rates of 1960–70, 1970–80, 1980–90, and 1990–2000, respectively. The 38 explanatory variables used in the analysis are listed in Table 2.

The models are estimated with ordinary least squares (OLS) approach and two-stage least squares (2SLS) approach. The 2SLS estimation can take account of endogeneity of the explanatory variables by introducing instruments. In our case, the endogeneity could be caused by measurement error of distance traveled per capita. Then we assume that the instruments in the 2SLS estimation are all variables other than transportation market and urban form. These instruments are considered as mostly exogenous for the urban transportation market.

Table 3 shows estimation results of the OLS and 2SLS models. They show that the coefficient estimates of the distance traveled per capita (log) are significantly negative in both models, which implies the conditional convergence of distance traveled per capita[4]. Additionally population density, growth rate of population, growth rate of GDP per capita, share of workers in construction industry, government consumption share, as well as dummies for U.S. cities, the 1980s, and the 1970s, also

[4] In the OLS model, the heteroscedasticity and serial correlation in the error term were not statistically significant as a result of the White test and Durbin-Watson test, respectively.

have significant effects both in the OLS and 2SLS models[5].

Table 3
Estimation results for the growth rate (annual average over 10 years) of distance traveled per capita

Variable	OLS			2SLS		
	Coefficient		Std. Error	Coefficient		Std. Error
Log (distance traveled per capita)	–0.0470	***	0.0053	–0.0488	***	0.0079
Log (population)	–0.0016		0.0011	–0.0014		0.0011
Log (population density)	–0.0145	***	0.0026	–0.0158	***	0.0034
Growth rate of population	–0.1302	**	0.0606	–0.1358	**	0.0612
GDP per capita	0.0005		0.0003	0.0005		0.0004
Growth rate of GDP per capita	0.3702	***	0.1385	0.3796	***	0.1392
Share of workers in construction industry	0.1199	*	0.0637	0.1241	*	0.0645
Government consumption share	–0.0015	**	0.0007	–0.0015	**	0.0007
Dummy for U.S. cities	0.0168	***	0.0035	0.0165	***	0.0036
Dummy for the 1980s	0.0053	**	0.0022	0.0053	**	0.0022
Dummy for the 1970s	0.0057	*	0.0029	0.0057	*	0.0029
Constant	0.5366	***	0.0635	0.5632	***	0.0931
No. observations	107			107		
Adjusted R-squared	0.633			0.632		

***p < .01, **p < .05, *p < .1
Note: The dependent variable is the annual average growth rate of distance traveled per capita in 10-year intervals of 1960–70, 1970–80, 1980–90, and 1990–2000. Instruments in the two-stage least squares are the variables for the general market, gasoline price, demographic condition, geography, institution, region/country-specific, and year-specific.

6. Discussion

The empirical analyses unveiled both unconditional and conditional convergences of distance

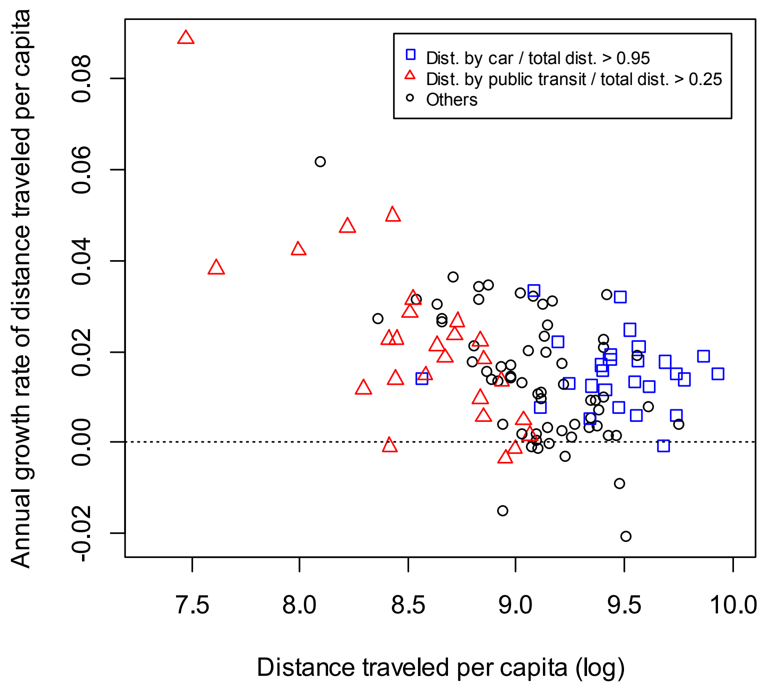
[5] Robustness of the model results was verified using Bayesian Model Averaging (BMA) as the estimation method. The BMA results (without instruments) showed that, in terms of the posterior inclusion probability of the variables, only three variables, including the distance traveled per capita (log), population density (log), and the dummy for U.S. cities, were more robustly related to the dependent variable than the average level of the variables.

traveled per capita across developed cities in the postwar period. This provides relatively strong evidence of the convergence of distance traveled per capita. This study hypothesized the convergence using the assumptions on travel time expenditures of individuals and (supply-based) service levels in the transportation network. Particularly in this study, the sample covering developed cities might have reduced differences across cities in consumer preferences, and resulting travel behavior, compared to the case covering developing cities as well. Further, there was a similarity in the production technology used in the urban transportation market across developed countries in the postwar period (i.e., car and modern-transit). These might have contributed to the clear convergence pattern in the urban transportation market.

The evidence obtained in this study could also provide a suggestion for the current condition of the transportation market. For example, slower growth rates of passenger travel and distance traveled are found in recent studies (e.g., Millard-Ball and Schipper, 2011; Metz, 2010). The clear convergence pattern of distance traveled per capita in this study means that distance traveled per capita itself strongly explained its long-run growth rate. Further, this convergence could be attributable to the diminishing returns of (supply-based) service levels in the transportation network, under current transportation technologies, implying one of the reasons for the recent slowing growth of passenger travels.

The empirical analysis also suggested the factors explaining differences in the growth rate of distance traveled per capita across cities, after accounting for their levels of distance traveled per capita. For example, Table 3 showed that cities with lower population density had a significantly higher growth rate. This is well supported by other studies that have shown the (local) population density has negative effects on the vehicle kilometers traveled (Ewing and Cervero, 2010). Table 3 also showed that U.S. cities have experienced higher growth rates than other cities in the postwar period. The mechanism behind this is still unclear, but there are three related issues which may explain this finding. First, U.S. cities might have had higher capital accumulation per capita for current transportation technologies than other cities from the early stage of the postwar period. For example, U.S. cities have histories where they adapted to automobile technology much earlier than other cities. This process has been well documented such that automobiles already accounted for about 80% of all passenger miles by the 1930s in Los Angeles (Fogelson, 1993). This implies that, overall, they might have converged or reached their steady states earlier than other cities in the development process of urban transportation markets. Then the problem might be set as higher growth rates in U.S. cities after the overall convergence in those cities. Second, we cannot distinguish whether growing after convergence is applicable only to U.S. cities or to cities in general. Third, in the former case, the higher growth in U.S. cities may come from the characteristics of transportation policy in the U.S. This relates to the discussion in Pucher (1995, 1988).

The potential impact of the modal share on growth rates may be a key policy concern. Figure 3 illustrates the distance traveled per capita versus its growth rate with the modal share of each city in different years. The square plot indicates that a city in a specific year has higher car-use distance traveled per capita, where the distance traveled by car divided by the total distance traveled is greater than 0.95; the triangle plot indicates that a city in a specific year with higher public-transit distance traveled per capita, where the distance traveled by public transit divided by the total distance traveled is greater than 0.25; and the circle plots are other data. This shows that longer distance traveled per capita tends to be correlated with a higher car share, while shorter distance traveled per capita is correlated with a higher public-transit share. However, it should be noted that Table 3 showed that there was no significant effect of the modal share (car share) on the growth rate of distance traveled per capita. Therefore, what is a reason for the seemingly positive relationship between them? One possible explanation would be spurious correlation. For example, higher population density could decrease vehicle kilometers traveled (Ewing and Cervero, 2010) or distance traveled while it possibly also leads to a lower share of car use in a city at the same time. This might imply that we need to analyze separately how factors affect the distance traveled per capita (i.e., market size) and the modal share in the analysis of long-run dynamics for the urban transportation market.



Note: Unit of the distance traveled is kilometers per year. n = 118 (39 cities)

Figure 3 Growth rate (annual average over 10 years) versus distance traveled per capita (with the modal share of cities)

7. Conclusions

This study first sets a hypothesis that the initial gap of distance traveled per capita across cities could have narrowed over time under current transportation technologies (i.e., car and modern-transit). Then it showed the convergence of distance traveled per capita empirically with the global city dataset that covers the experiences of developed countries, both with and without using controls representing cities' characteristics. Our empirical analysis also showed the modal share did not affect the growth rate of distance traveled per capita. Instead, U.S. cities had a higher growth rate of distance traveled per capita in the postwar period, and a lower population density of a city increased the growth rate. The results help understand how the size of transportation market or travel demand has been determined in the long run.

Further issues are summarized. First, future work should use a broad range of samples. For example, the empirical analysis of cities within a country might be beneficial due to the sample number and quality of data, although potentially at the cost of a smaller variation of the samples. In addition, more detailed data, including institutional characteristics of cities, could be employed as potential determinants of the growth of urban transportation markets. The second issue relates to the long-run dynamics for the transportation pattern or modal share. There is still a lack of understanding of the mechanism for long-run changes in the transportation pattern, despite an understanding of the factors affecting it.

This type of long-run evidence on the urban transportation market, including this research, could further provide policy suggestions for future mobility, particularly in cities in the developing stages. First, the clear convergence pattern of distance traveled per capita, observed under current transportation technologies, implies that the level of distance traveled per capita could have a dominant role in explaining its long-run growth rate. The speed of convergence, as shown in this study, as well as other effects, could be utilized in the prediction of future mobility in those cities. Second, policy instruments, such as investments in public-transit, might have different impacts on the future transportation pattern of a city, depending on the market size or development stage of urban transportation. For example, the level of market size at the starting point of adaptation to current transportation technologies (e.g., rapid motorization) might differ between developing cities and developed cities at a similar stage in their income levels. This difference might produce severer transportation problems in today's developing cities (e.g., huge demands on low stocks). Thus, ultimately, we would need to understand the mechanism for long-run changes in the transportation pattern with reference to the market size.

The ignorance of the long-run dynamics of the urban transportation market may result in a huge loss of sustainability in the long-run. Further insights can be provided to transportation policy by expanding research in these directions.

References

Acemoglu, D. (2009) *Introduction to Modern Economic Growth*. Princeton University Press, Princeton.

Acharya, S.R. and Morichi, S. (2007) Motorization and role of mass rapid transit in East Asian megacities. *IATSS Res*., 31, 6–16.

Åkerman, J. and Höjer, M. (2006) How much transport can the climate stand?—Sweden on a sustainable path in 2050. *Energy Policy*, 34, 1944–1957.

Albalate, D. and Bel, G. (2010) What shapes local public transportation in Europe? Economics, mobility, institutions, and geography. *Transp. Res. Part E Logist. Transp. Rev*., 46, 775–790.

Aoki, E., Imashiro, M., Kato, S., and Wakuda, Y. (2000) *A History of Japanese Railways 1872–1999*. East Japan Railway Cultural Foundation, Tokyo.

Axhausen, K.W., Dolci, C., Fröhlich, P., Scherer, M., and Carosio, A. (2008) Constructing time-scaled maps: Switzerland from 1950 to 2000. *Transp. Rev*., 28, 391–413.

Axhausen, K.W., Frölich, P., and Tschopp, M. (2011) Changes in Swiss accessibility since 1850. *Res. Transp. Econ.*, 31, 72–80.

Banister, D. (2011) The trilogy of distance, speed and time. *J. Transp. Geogr.*, 19, 950–959.

Banister, D. and Hickman, R. (2013) Transport futures: Thinking the unthinkable. *Transp. Policy*, 29, 283–293.

Barro, R.J. and Sala-i-Martin, X.X. (2004) *Economic Growth*, 2nd edition. MIT Press, Massachusetts.

Barter, P.A. (2004) Transport, urban structure and “lock-in” in the Kuala Lumpur Metropolitan Area. *Int. Dev. Plan. Rev*., 26, 1–24.

Barter, P.A. (1999) An international comparative perspective on urban transport and urban form in Pacific Asia: The challenge of rapid motorisation in dense cities. Ph.D. Thesis, Murdoch University, Australia.

Boarnet, M.G.A. (2011) Broader context for land use and travel behavior, and a research agenda. *J. Am. Plan. Assoc*., 77, 197–213.

Bresson, G., Dargay, J., Madre, J.L., and Pirotte, A. (2004) Economic and structural determinants of the demand for public transport: An analysis on a panel of French urban areas using shrinkage estimators. *Transp. Res. Part A Policy Pract*., 38, 269–285.

Bresson, G., Dargay, J., Madre, J.L., and Pirotte, A. (2003) The main determinants of the demand for public transport: A comparative analysis of England and France using shrinkage estimators. *Transp. Res. Part A Policy Pract*., 37, 605–627.

Buehler, R. (2010) Transport policies, automobile use, and sustainable transport: A comparison of Germany and the United States. *J. Plan. Educ. Res*., 30, 76–93.

Cameron, I., Kenworthy, J.R., and Lyons, T.J. (2003) Understanding and predicting private motorised urban mobility. *Transp. Res. Part D Transp. Environ*., 8, 267–283.

Cervero, R. (1998) *The Transit etropolis: A Global Inquiry*. Island Press, Washington, D.C.

Costa, Á. and Fernandes, R. (2012) Urban public transport in Europe: Technology diffusion and market organisation. *Transp. Res. Part A Policy Pract*., 46, 269–284.

Dick, H.W. and Rimmer, P.J. (2003) *Cities, Transport and Communications: The Integration of Southeast Asia since 1850*. Macmillan, Basingstoke.

Duranton, G. and Turner, M.A. (2012) Urban growth and transportation. *Rev. Econ. Stud*., 79, 1407–1440.

Durlauf, S. N., Kourtellos, A., and Tan, C. M. (2008) Are any growth theories robust? *Econ. J*., 118, 329–346.

Ewing, R. and Cervero, R. (2010) Travel and the built environment: A meta-analysis. *J. Am. Plan. Assoc*., 76, 265–294.

Fogelson, R. M. (1993) *The Fragmented Metropolis: Los Angeles, 1850–1930*, new edition. University of California Press, Oakland.

Geurs, K.T. and van Wee, B. (2004) Backcasting as a tool for sustainable transport policy making: The environmentally sustainable transport study in the Netherlands. *Eur. J. Transp. Infrastruct. Res*., 4, 47–69.

Giuliano, G. and Dargay, J. (2006) Car ownership, travel and land use: A comparison of the US and Great Britain. *Transp. Res. Part A Policy Pract*., 40, 106–124.

Giuliano, G. and Narayan, D. (2003) Another look at travel patterns and urban form: The US and Great Britain. *Urban Stud*., 40, 2295–2312.

Glaeser, E., Scheinkman, J., and Shleifer, A. (1995) Economic growth in a cross-section of cities. *J. Monet. Econ*., 36.

Goodwin, P. and Van Dender, K. (2013) "Peak Car" — Themes and issues. *Transp. Rev*., 33, 243–254.

Grübler, A., 1990. *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*. Physica-Verlag, Heidelberg.

Henderson, J.V. and Wang, H.G. (2007) Urbanization and city growth: The role of institutions. *Reg. Sci. Urban Econ*., 37, 283–313.

Heston, A., Summers, R. and Aten, B. (2012) Penn World Table Version 7.1. Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Hickman, R. and Banister, D. (2007) Looking over the horizon: Transport and reduced CO_2 emissions in the UK by 2030. *Transp. Policy*, 14, 377–387.

Hook, W. and Replogle, M. (1996) Motorization and non-motorized transport in Asia. *Land Use Policy*, 13, 69–84.

Ingram, G.K. and Liu, Z. (1998) *Vehicles, Roads, and Road Use: Alternative Empirical Specifications, Policy Research Working Paper 2036*. World Bank, Washington, D.C.

Ingram, G.K. and Liu, Z. (1997) *Motorization and the Provision of Roads in Countries and Cities, Policy Research Working Paper 1842*. World Bank, Washington, D.C.

Kenworthy, J.R. and Laube, F.B. (1999) Patterns of automobile dependence in cities: An international overview of key physical and economic dimensions with some implications for urban policy. *Transp. Res. Part A Policy Pract*., 33, 691–723.

Kenworthy, J.R., Laube, F., Newman, P., Barter, P.A., Raad, T., Poboon, C., and Guia, J.B. (1999) *An International Sourcebook of Automobile Dependence in Cities 1960–1990*. University Press of Colorado, Boulder.

Newman, P.G., and Kenworthy, J.R. (1989a) *Cities and Automobile Dependence: An International Sourcebook*. Gower Publishing, Brookfield.

Newman, P.W.G. and Kenworthy, J.R. (1989b) Gasoline consumption and cities. *J. Am. Plan. Assoc*., 55, 24–37.

Newman, P.W.G. and Kenworthy, J.R. (1996) The land use-transport connection, An overview. *Land use policy*, 13, 1–22.

Nivola, P.S. (1999) *Laws of the Landscape: How Policies Shape Cities in Europe and America*. Brookings Institution Press, Washington D.C.

McIntosh, J., Trubka, R., Kenworthy, J. and Newman, P. (2014) The role of urban form and transit in city car dependence: Analysis of 26 global cities from 1960 to 2000. *Transp. Res. Part D Transp. Environ*., 33, 95–110.

Metz, D. (2008) The myth of travel time saving. *Transp. Rev*., 28, 321–336.

Metz, D. (2010) Saturation of demand for daily travel. *Transp. Rev*., 30, 659–674.

Michaels, G., Rauch, F. and Redding, S.J. (2012) Urbanization and structural transformation. *Q. J. Econ*., 127, 535–586.

Millard-Ball, A. and Schipper, L. (2011) Are we reaching peak travel? Trends in passenger transport in eight industrialized countries. *Transp. Rev*., 31, 357–378.

Mitchell, B.R. (2008a) *International Historical Statistics: Africa, Asia & Oceania, 1750–2005*. Palgrave Macmillan, London.

Mitchell, B.R. (2008b) *International Historical Statistics: Europe, 1750–2005*. Palgrave Macmillan, London.

Mitchell, B.R. (2008c) *International Historical Statistics: The Americas 1750–2005*. Palgrave Macmillan, London.

Mokhtarian, P.L. and Chen, C. (2004) TTB or not TTB, that is the question: A review and analysis of the empirical literature on travel time (and money) budgets. *Transp. Res. Part A Policy Pract*., 38, 643–675.

Muller, P.O. (2004) Transportation and urban form: Stages in the spatial evolution of the American metropolis, *The Geography of Urban Transportation* eds S. Hanson and G. Giuliano, pp. 59–85. Guilford Press, New York.

Pucher, J. (1995) Urban passenger transport in the United States and Europe: A comparative analysis of public policies. *Transp. Rev*., 15, 211–227.

Pucher, J. (1988) Urban travel behavior as the outcome of public policy: The example of modal-split in Western Europe and North America. *J. Am. Plan. Assoc*., 54, 509–520.

Rimmer, P.J. (1988) *Rikisha to Rapid Transit: Urban Public Transport Systems and Policy in Southeast Asia*. Pergamon Press, Sydney.

Sala-i-Martin, X.X. (1996) The classical approach to convergence analysis. *Econ. J.*, 106, 1019–1036.

Schafer, A. (1998) The global demand for motorized mobility. *Transp. Res. Part A Policy Pract.*, 32, 455–477.

Schafer, A. and Victor, D.G. (2000) The future mobility of the world population. *Transp. Res. Part A Policy Pract.*, 34, 171–205.

Senbil, M., Kitamura, R. and Mohamad, J. (2009) Residential location, vehicle ownership and travel in Asia: A comparative analysis of Kei-Han-Shin and Kuala Lumpur metropolitan areas. *Transp.*, 36, 325–350.

Souche, S. (2010) Measuring the structural determinants of urban travel demand. *Transp. Policy*, 17, 127–134.

Union International des Transports Publics (UITP) (2001) Millennium Cities Database for Sustainable Mobility (CD-ROM). UITP, Brussels.

Union International des Transports Publics (UITP) (2006) Mobility in Cities Database (CD-ROM). UITP, Brussels.

Van de Coevering, P. and Schwanen, T. (2006) Re-evaluating the impact of urban form on travel patterns in Europe and North-America. *Transp. Policy*, 13, 229–239.

Vuchic, V.R. (2007) *Urban Transit Systems and Technology*. John Wiley & Sons, Hoboken.

World Bank, World Bank Open Data, <http://data.worldbank.org>, (retrieved on April 10, 2015).

Yamamoto, T. (2009) Comparative analysis of household car, motorcycle and bicycle ownership between Osaka metropolitan area, Japan and Kuala Lumpur, Malaysia. *Transp.*, 36, 351–366.

Zahavi, Y. and Talvitie, A. (1980) Regularities in travel time and money expenditures. *Transp. Res. Rec.*, 13–19.