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Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries

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ABSTRACT

Few attempts have been made to investigate quantitatively and systematically the impact of urbanization on transport energy use for countries of different stages of economic development. This paper examines the influence of urbanization on national transport and road energy use for low, middle and high income countries during 1975–2005, using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model. After controlling for population size, income per capita and the share of services in the economy, the main results suggest that urbanization influences national transport and road energy use positively. However, the magnitude of its influence varies among the three income groups. Changes in urbanization appear to have a greater impact on transport and road energy use in the high income group than in the other groups. Surprisingly, the urbanization elasticities of transport and road energy use in the middle income group are smaller than those of the low income group. This study not only sheds further light on the existing literature, but also provides policy makers with insightful information on the link between urbanization and transport energy use at the three different stages of development.

Keywords: Urbanization; Transport energy use; Development stages.

JEL classification: R49; Q41; Q56

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1. Introduction

Movements of people, goods and information are fundamental components of societies. As societies modernize, such movements increase and shift towards motorized transport modes. While these changes have positive effects on economic development, they bring several negative impacts to both individuals and societies, namely traffic congestion, accidents, noise, land take, energy use, air pollution and carbon dioxide (CO_2) emissions (hereafter emissions) (Rodrigue et al., 2006). In 2005, the transport sector consumed more than half of the oil used worldwide, and was responsible for about one quarter of energy-related emissions globally. The world transport energy use and emissions are projected to rise by over 50% by 2030 (IEA, 2008a). This will not only pose great challenges, but also means that the transport sector could play a significant role in ascertaining sustainability.

However, any policy or strategy aimed at reducing transport emissions requires a better understanding of travel demand and transport energy demand. Population and economic growth have been suggested as the key drivers of transport demand (Chemin, 2009; Rodrigue et al., 2006; Schäfer, 2006; Scholl et al., 1996). The larger the population size of a country grows, the greater its transport demand will be (Chemin, 2009). Population growth magnifies aggregate transport demand (Scholl et al., 1996). Economic growth leads to an increase in vehicle (including cars, trucks and buses) ownership and mobility demands, thus increasing transport energy consumption. (Rodrigue et al., 2006; Schäfer, 2006; Schäfer and Victor, 2000). In addition to the aforementioned factors, urbanization and its related features such as urban form and urban density have been increasingly acknowledged as important factors in explaining travel demand and transport energy use in recent years.

Urbanization has been observed as a phenomenon of modernization that involves social, economic and ecological transformations. Socially and economically, it increases the concentration of population and economic activity in relatively small settlement areas, defined as urban areas by each country. There were about 3.42 billion people living in urban areas in 2009, accounting over half of the world's population (UN, 2010). MGI (2011) estimated that about 80% of the global gross domestic product (GDP) in 2007 was produced in cities. Ecologically, urbanization increases built-up areas, altering land use, land cover and the function of ecosystems. According to Angel et al. (2005), the average annual growth rate of global urban areas was 3.2% between 1990 and 2000, significantly higher than that of the global urban population. High concentrations of people and economic activity in expanding urban areas are often associated with high levels of movements of passengers and freight, which have important implications for transport energy use and emissions.

Some scholars suggest that urbanization increases transport energy use (APERC, 2007; Jones, 2004; Parikh and Shukla, 1995; Rodrigue et al., 2006), while Liddle (2004) argues that urbanization in developed countries is associated with less transport energy use. In line with this argument, Liddle and Lung (2010) report that urban households in the US drive less than their rural counterparts. IEA (2008b) also reports that each urban dweller consumes 11% less transport energy than the average US resident. These appear to imply that urbanization may have a negative correlation with transport energy use. However, over the past five decades, growth in US urban areas has outpaced growth in their population, causing urban density to fall and travel distances to rise (Hankey and Marshall, 2010; Marshall, 2007). A similar trend is observed globally by Angel et al. (2005), who find that a decline in urban density of developed countries is faster than that of developing ones.

The existing literature has shown some mixed results, implying that the relationship between urbanization and transport energy use is complex and remains inconclusive. The findings by Liddle (2004) and IEA (2008b) deserve further scrutiny as they are subject to several limitations and uncertainties. Liddle (2004) derived a negative correlation between urbanization and road energy use per capita from a relatively small sample data at 10-year intervals without controlling for economic activity variables other than income. Some researchers note that the changes in industrial and services activities also influence passenger and freight demand (EEA, 2008; Jones, 2004; Rodrigue et al., 2006). The results from IEA (2008b) were estimated using only the year 2006 data with several assumptions. Apart from the aforementioned limitations, few attempts have been made to investigate quantitatively and systematically the influence of urbanization on transport energy use for countries of different levels of economic development. This creates an unfortunate knowledge gap that needs to be filled.

This paper estimates the impact of urbanization (*the percentage of the urban population in the total population*) on national transport and road energy use for low, middle and high income countries during 1975–2005 using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model. Specifically, it attempts to differentiate changes in transport and road energy use attributable to urbanization from income, population size and the share of services in GDP for the three income groups. This study differs from the existing literature in three ways. First, it estimates urbanization's impact on not only national transport energy use, but also national road transport energy use for the low, middle and high income countries using the STIRPAT model. Second, it controls for the share of services, which has been ignored by previous studies. Third, it addresses statistical concerns over the endogeneity of urbanization rigorously.

The paper is organized in following sections. Section 2 presents the literature review and hypotheses. Section 3 details the empirical model, data and method. Section 4 analyzes the relevant variables descriptively. Section 5 discusses the empirical results. Section 6 concludes the study.

2. Literature review and hypotheses

2.1. Literature review

To lay a foundation for a better understanding of the link between urbanization and transport energy use, we discuss briefly factors accounting for transport energy use from decomposition perspectives together with travel trends and patterns. Dargay and Gately (1997) suggested that road energy use is determined by three factors: the number of vehicles (units), the annual utilization of vehicles (kilometers/year) and the average fuel intensity (liters/kilometer). Alternatively, Eom and Schipper (2010) and Shipper et al. (2000) illustrated that total transport energy use can be influenced by transportation activity (passenger-kilometers or tonne-kilometers) of all modes, the modal share of modes (cars, trucks, buses, ship and air) in total activity (percent), and the energy intensity of each mode (liters or megajoules/passenger-kilometers or tonne-kilometers). These two perspectives suggest that vehicle ownership, vehicle use (number of trips and trip distances), modal structure and fuel economy are the determinants of road energy use.

While growth in vehicle ownership is mainly due to income growth (Chemin, 2009; Dargay et al., 2007), the growth rate of vehicle ownership varies across different stages of economic development. Based on pool data from 45 countries during 1960–2002, Dargay et al. (2007) found that at low levels of income, vehicle ownership grows slowly, and then accelerates as income rises, and finally decelerates as saturation is approached. Moreover, Schäfer (2006) analyzed data from 11 regions worldwide during 1950–2000, and found that income not only influences levels of passenger mobility positively, but also affects transport modes. Rising income encourages travelers to shift from non-motorized to motorized transport modes. At high levels of income, they gradually shift from low-public transportation (buses and low-speed rail) to faster transport modes, namely private automobiles, aircraft and high-speed rail. Similarly, Rodrigue et al. (2006) characterized the early stage of economic development as a shift from non-motorized to motorized forms of transport, while the second stage as the development of public transportation and increased automobile use. The role of public transportation starts declining, and it is replaced gradually by automobiles in the third stage. In addition to affecting passenger mobility, economic growth influences freight transport and trip purposes. EEA (2011) found a strongly positive correlation between economic growth and freight transport activity for a sample of the 27 European countries. While in developing countries, commuting trips still predominate, leisure, shopping and personal business trips account for a significant share of total trips in developed countries (Chemin, 2009; EEA, 2008).

In addition to economic factors, transport activity and transport energy use are influenced by population growth and urbanization. The larger the population size of a country grows, the greater its transport demand will be (Chemin, 2009). Population growth is one of the driving forces of transport demand (Schäfer, 2006; Scholl et al., 1996). Similarly, Rodrigue et al. (2006) argued that urbanization increases both the quantity of passengers and freight, and the distance over which passengers and freight are carried in two ways. First, growth in urban population increases movements of passengers and freight. Second, as a result of urbanization, urban areas grow, implying longer travel distances. To cope with longer travel distances with a constant travel time budget of 1.2 hours per day, urban dwellers gradually shift towards faster transport modes, particularly automobiles.

Similarly, APERC (2007) suggested that urbanization contributes to increased transport energy demand by encouraging motorization and increasing travel distances. In the absence of public mass transit, urban dwellers in the initial stage of urbanization depend largely on automobiles for their mobility. As urbanization progresses, they tend to move toward city outskirts for better environmental quality, spacious yet affordable housing, resulting in longer travel requirements from periphery cities to the urban core areas, thus entailing greater amounts of transport energy use. The contribution of urbanization to travel distances was also noted by Hankey and Marshall (2010), who analyzed 142 cities in the US during 1950–2000 and found that urban density has declined over time, implying increased vehicle-kilometers traveled (VKT), transport energy use and emissions. A continued decline in urban density was also witnessed worldwide, while the annual decline rate is faster in developed countries than in developing ones (Angel et al., 2005). Historically, spread-out cities or urban sprawls were used to characterize North American, Australian and New Zealand cities; however, this phenomenon is also occurring in European and Asian cities (Rodrigue et al., 2006).

Alternatively, Jones (2004) argued that urbanization increases transport energy use in three ways. First, it facilitates economic specialization, the expansion of production and market territories by supplying labor forces and consumers, and by increasing labor division. This increases movements of raw materials, semi-finished products and finished products. Second, to sustain urban life, most food needs to be transported from outside cities using fuel-using transport modes. Third, residences and workplaces are often separated in urban settings, where require motorized commuting over longer distances than in rural areas. This argument was supported quantitatively by Parikh and Shukla (1995), who found a positive correlation between urbanization and road energy use per capita for a sample of 45 developing countries during 1965–1987.

In contrast, Liddle (2004) examined the relationship between urbanization and road energy per capita using a sample of 23 high income countries at 10-year intervals, finding a negative correlation between them. Based on the results, Liddle (2004) argued that highly urbanized societies are associated with less passenger transport demand. In line with this argument, IEA (2008b) reported that total energy consumption per capita in the US, the European Union, Australia and New Zealand in 2006 was slightly lower than their national average. In the US, each urban dweller consumes 11% less transport energy than the national average (IEA, 2008b). Liddle and Lung (2010) also noted that VKT per household are lower in urban areas of the US than in its rural areas, while they found a positive association between urbanization and total transport emissions in the fixed effects model for a sample of 17 high income countries over the period 1960–2005.

Apart from the aforementioned factors, transport demand and transport energy use are likely to be influenced by changes in industrial, commercial and business activities. The mobility of goods (raw materials, semi-finished and finished products) is closely related to the nature of economic activities such as manufacturing, commercial and service activities (Rodrigue et al., 2006). Based on an extensive literature review and case studies in Europe, EEA (2008) suggested that an increase in manufacturing activities affects freight transport activity positively, while a rise in tourism, retail, business and educational activities has a positive influence on passenger transport demand. This implies that changes in the share of industry and services in GDP may affect transport and road energy use. However, they have scarcely been studied empirically. In this study, we consider only the share of services for three reasons. First, the transport sector is one of the sub-sectors of services. All value added generated from transport is included as part of the service sector. Second, the share of services appears to explain the variation in transport and road energy use better than the share of industry. Third, the share of service and industry are highly correlated in the high income group. (see Tables A.2 and A.3 in Appendix A). Dropping the share of industry barely changes the value of R-squared and the coefficient of services.

2.2. Hypotheses

Although there are some conflicting results, the majority of existing studies appear to suggest that urbanization influences transport energy use positively for three main reasons. First, it contributes to increased travel distances (e.g., Hankey and Marshall 2010; Rodrigue et al., 2006). Second, it increases the mobility of passengers and freight (Jones, 2004; Rodrigue et al., 2006). Third, it encourages the use of faster transport modes, particularly automobiles (APERC, 2007; Rodrigue et al., 2006). These lead us to hypothesize that urbanization has a positive influence on transport energy use (*hypothesis 1*).

The existing literature conveys little information on how urbanization's impact on transport energy use may differ among the low, middle and high income countries. For aggregate energy use and emissions, Poumanyvong and Kaneko (2010) found a differential impact of urbanization among the three income groups, and suggested that the impact on energy use is greater in the high income countries than in the low and middle income countries. The differential impact of urbanization on total emissions among different levels of economic development was also reported by Fan et al. (2006) and Martínez-Zarzoso et al. (2011).

However, given that there are various differences between the low, middle and high income countries, particularly vehicle ownership, vehicle use, transport modes, trip purposes and urban density, we hypothesize that the magnitude of urbanization's impact on transport energy use is likely to differ among them (*hypothesis 2*). We further hypothesize that the impact in the high income countries may be greater than in the low and middle income countries for four reasons (*hypothesis 3*). First, vehicle ownership per capita at both national and city levels in the high income countries is significantly higher than in the low and middle income countries (Dargay et al., 2007; Kenworthy and Laube, 2002). Second, urban densities of developed countries are not only substantially lower, but also decrease at a faster rate than in developing countries (Angel et al., 2005). Third, the share of private motorized modes in all trips is significantly larger in cities of developed countries than in those of developing ones (Kenworthy and Laube, 2002). Fourth, the share of total passenger-kilometers traveled by automobile is very high in developed countries compared with developing ones (Schäfer, 2006).

3. Empirical model, data and estimation methods

3.1. Empirical model

In this study, we employ the STIRPAT model ($I_i = aP_i^b A_i^c T_i^d u_i$) (Dietz and Rosa, 1994; York et al., 2003), which has been increasingly used to investigate interaction between socioeconomic changes and the environment. In the model, I represents total environmental impact, including energy use and emissions, which is determined by a multiplicative combination of three factors: population size (P), GDP per capita (A) and technology or the impact per unit of economic activity (T). T can be disaggregated into multiple variables other than A and P that influence I (York et al., 2003), depending on types of environmental impact being investigated. For instance, Shi (2003) analyzed national emissions and used the share of industry and services in GDP to express *T*, while York (2007) studied national energy use, and used urbanization to represent *T*. Economic structure and urbanization were used to express *T* in an analysis of energy use and emissions (Poumanyvong and Kaneko, 2010). Liddle and Lung (2010) studied transport emissions and used urbanization and the ratio of rail network to total road network to express *T*. In this study, we include urbanization (*URB*) and the share of services (*SV*) in GDP as part of *T*. The share of industry is excluded from the model because it barely explains the variation in transport energy use, and is highly correlated with the share of services (see Tables A.2 and A.3 in Appendix A). In the STIRPAT model, the subscript *i* denotes the unit of analysis, *a* is the constant term, *b*, *c* and *d* are parameters are to be estimated, and *u* is the error term. After taking natural logarithms of both sides of the STIRPAT model and rearranging it, the empirical model for the panel data of total transport and road energy use can be written as follows.

$$\ln Energy_{it} = \alpha_i + \beta_1 \ln (P_{it}) + \beta_2 \ln (A_{it}) + \beta_3 \ln (URB_{it}) + \beta_4 \ln (SV_{it}) + u_{it} \qquad (1)$$

where *P*, *A*, *URB and SV* denote population size, GDP per capita, urbanization and the share of services in GDP, respectively. The subscript *i* and *t* represent countries and years, respectively. β_1, β_2, β_3 and β_4 are the parameters to be estimated, while *u* is the disturbance term. α_i captures all time-constant unobserved country-specific factors (e.g., geographic, climatic and cultural characteristics) that may affect transport energy use, but yet to be included in the model. The fixed effects model (FE) can be estimated by either the within estimator or the least squares dummy variable regression (LSDV) (Wooldridge, 2002).

3.2. Data and estimation methods

This study uses a balanced panel of 92 countries during 1975–2005 (see Table A.1 in Appendix A). As presented in Table 1, data on transport and road energy use are derived from IEA (2009a, 2009b). Data on population, urbanization, the share of industry and services in GDP are obtained mainly from the World Bank (2007). However, the GDP data were missing in a number of countries. We filled the missing values in with the data from IEA (2009a, 2009b). The GDP information from the IEA database is considerably comparable to the World Bank's database as the former is constructed mainly based on the latter. The data on services and industry were also missing in several countries. Fortunately, we found the missing information in the United Nations online database (UN, 2009). There are some discrepancies between the UN database and the World Bank's database. However, for our sample, replacing the missing data with the UN information seems to be appropriate as most of the UN information fits with the non-missing data from the World Bank.

Table 1

Description of the variables used in the analysis for the period 1975–2005.

Variable	Definition	Unit	Data source
Population *(P)*	Mid year population	Number	World Bank (2007)
GDP per capita *(A)*	Gross domestic product divided by mid year population	US$ in PPP (2000 prices)	World Bank (2007)
Share of industry in GDP *(IND)*	Industrial sector value added expressed as a percentage of GDP	Percent	World Bank (2007) and UN (2009)
Share of services in GDP *(SV)*	Service sector value added expressed as a percentage of GDP	Percent	World Bank (2007) and UN (2009)
Urbanization* *(URB)*	The percentage of the urban population in the total population	Percent	World Bank (2007)
Total transport energy use	Energy used to cover all transport activity (international aviation, domestic aviation, road, rail, pipeline, domestic navigation and non-specified) regardless of the economic sector to which it is contributing.	Kilotonne of oil equivalent (ktoe)	IEA (2009a, 2009b)
Total road energy use	Energy used in road vehicles, agricultural and industrial highway use.	Kilotonne of oil equivalent (ktoe)	IEA (2009a, 2009b)

* To some extent the definition of 'urban areas' varies across countries. However, as there is no better alternative measure of urbanization, we employ the measure most commonly used by the World Bank and the United Nations.

Prior to our estimation, we first check whether the unobserved country-specific effects are present using the Wald test. The test results indicate that they are present, so we cannot accept a common intercept for all countries. Second, we test the null hypothesis that whether unobserved country-specific effects are uncorrelated with *P*, *A*, *URB* and *SV* in all models using the Hausman test. The null hypothesis is rejected, suggesting that the fixed effects models are more appropriate than the random effects models. However, if serial correlation is present, the standard errors of the FE models will be biased, causing the estimates to be less efficient (Drukker, 2003). To check for the presence of autocorrelation, the Wooldridge (2002) test for autocorrelation in the FE model is used. The results show that there is autocorrelation in our models.

Moreover, the presence of groupwise heteroskedasticity is dectected in all the models after applying the modified Wald test for group-wise heteroscedasticity developed by Greene (2000). For the sake of brevity, the aforementioned test results are not shown in this paper. To address autocorrelation and heteroscedasticity, the FE models with Newey–West corrected standard errors (Newey and West, 1987) are applied. Henisz (2002) suggested that this standard error correction method has several advantages over the Prais–Winsten estimation proposed by Beck and Katz (1995), and the feasible generalized least squares developed by Parks (1967). First, it is not only computationally simpler, but also easily addresses autocorrelation that is higher order than one. Second, it does not assume that different cross-sectional units share a common autocorrelation parameter. Third, when using robust covariance matrix estimator, it does not need to drop observations from one or more time periods. Hence, the FE models with Newey–West corrected standard errors using three lags determined by the selection technique proposed by Newey and West (1994) are employed. It is worth noting that year dummies are not included in the models because of two causes. Most of the Wald tests reject the inclusion of the year dummies. In addition, including many dummies in the models not only reduces degrees of freedom, but also may aggravate the problem of multicollinearity among the explanatory variables (Baltagi, 2005).

We begin our estimation with the whole sample of 92 countries regardless of the stage of economic development. This means that the slope coefficients of *P*, *A*, *URB and SV* are assumed to be identical across different levels of development. The validity of this assumption needs to be tested. To address our three hypotheses and test this assumption, we divide the whole sample into three sub-samples: low, middle and high income groups, based on country classifications in 2004 (World Bank, 2009). The low income group consists of 21 countries with per capita national gross income (GNI) ≤ US$765. The middle income group comprises 40 countries with per capita GNP between US$766 and US$9,385. The high income group consists of 31 countries with per capita GNP > US$9,385. It should be noted that the middle income group comprises 25 lower and 15 upper middle income countries. These two income groups are merged into the middle income group for three reasons. First, a sample of 15 upper middle income countries does not represent their population adequately. Second, a small number of cross-sectional units with long periods of time raise statistical concerns over the consistency of the FE models (Wooldridge, 2002). Third, the estimation results of the three income groups would relate to previous studies more easily (e.g., Luzzati and Orsini, 2009; Martínez-Zarzoso et al., 2011; Poumanyvong and Kaneko, 2010).

In addressing another econometric concern over the endogeneity of the repressors in the models, particularly urbanization, the instrumental variables (IV) or two-stage least squares (2SLS) estimator is considered. However, the presence of autocorrelation and heteroscedasticity, the standard errors of the standard IV estimator are inconsistent, preventing valid inference (Baum et al., 2007). To deal with autocorrelation and heteroscedasticity, we apply the Generalization Method of Moments (GMM) estimator introduced by Hansen (1982). The standard IV estimator can be seen as a special case of the GMM estimator (Baum et al., 2007). Selecting instrumental variables that are correlated with urbanization at the same time orthogonal to the error terms is critical. In the absence of desirable external instrumental variables, similar to Martínez-Zarzoso et al. (2011), we first instrument urbanization with its first and second lags. To check the validity of the selected instruments, the Hansen test of overidentifying restrictions is applied. The null hypothesis is that the instruments are all exogenous. The test results show that they are valid instruments in all the models except for Model 8 (transport energy use in high income group). The *p*-values of the Hansen test in some models are above 0.1 (10%), but relatively small, implying the instruments may not be strongly exogenous. In stead of the first and second lags, we instrument urbanization with its second and third lags. The *p*-values improve and are noticeably larger than 10% in all the models except for Models 8 and 16. Hence, for these two models, the first and second lags of urbanization are used, while the rest of the models are instrumented with the second and third lags. Based on the GMM estimation, we further test whether urbanization can be treated as exogenous by applying an endogeneity test proposed by Baum et al. (2003). This test is similar to the Hausman endogeneity test, but it is robust to heteroscedasticity. Similar to Martínez-Zarzoso et al. (2011), the test results suggest that urbanization can be treated as exogenous in all the models. Therefore, the FE models with Newey–West corrected standard errors are preferred.

In regard to endogeneity problems, we also consider applying more sophisticated estimation techniques such as the difference and system GMM estimators proposed by Arellano and Bond (1991) and Blundell and Bond (1998), respectively. However, these two estimators are more appropriate for short panel data (large cross-sectional units with short periods of time) (Roodman, 2009). Applying them to long panel data creates many instruments, which could cause biased estimates of parameters (Roodman, 2009; Windmeijer, 2005). In addition, since urbanization in some countries does not vary much over time, the difference and system GMM estimators can be subject to another bias.

4. Descriptive analysis of the relevant variables

4.1. Composition of transport energy use and its annual change

In order to examine the composition of transport energy use and its annual change, we first divide transport energy use into three main sub-sectors: road, rail and other transport (international aviation, domestic aviation, road, rail, pipeline transport, domestic navigation and non-specified transport). As illustrated in Fig. 1 (a), (b) and (c), road transport energy use accounted for a larg percentage share of the total transport energy use in all the three income groups compared with the other sub-sectors. In the low income group, the share of road transport energy use increased significantly from about 62% in 1975 to almost 92% in 2005. In the middle income group, it decreased from 91.2% in 1975 to 85.4% in 1985, but then rose again to 93% in 2005. The high income group also experienced an increase in their road energy use share, but the percentage increase was relatively steady from around 82% in 1975 to about 87% in 2005. In contrast to the road energy use share, the rail energy use share declined in all the income groups. The percentage decline was more pronounced in the low income group than in the other groups. Moreover, Fig. 1 (d) indicates that total transport and road energy use grew in all the three income groups between 1975 and 2005. The average annual growth rate of transport energy use in the low income group was about 3.8 %, noticeably faster than in the middle (3.6%) and high (1.8%) income groups. A similar trend was evident for road energy use.

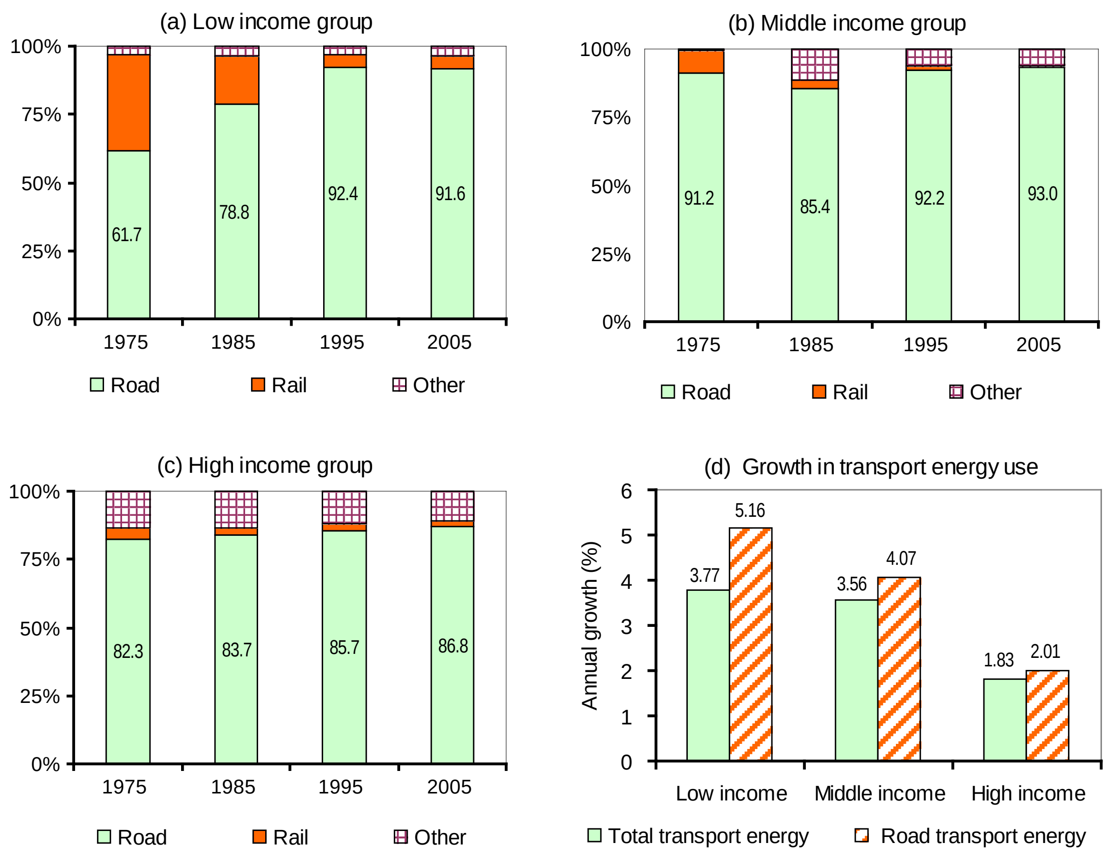

Fig. 1. Composition of transport energy use and its annual change during 1975–2005 (calculated using data from IEA (2009a, 2009b)).

4.2. Urbanization, urban density and road energy use

On average, Fig. 2 (a) suggests that the higher the income per capita of a country, the higher its urbanization level and road energy use per capita. However, the average annual growth rate of urbanization and road energy use per capita between 1975 and 2005 varied among the low, middle and high income groups. The growth rate of urbanization in the low income group was almost 1.6% per annum, while it was about 1% and 0.3% in the middle and high income groups, respectively. In contrast, the annual growth rate of road energy use per capita between 1975 and 2005 was 0.72% in the low income group, significantly lower than that of the middle (1.93%) and high (1.95%) income groups. Fig. 2 (b) illustrates that the higher the income per capita of a country, the lower its urban density. It also shows that the average urban density of cities in the low, middle and high income countries declined notably between 1990 and 2000. The decline rate was 2.5% per annum in cities of the low income countries, while it was 1.95% and 2.2% in cities of the middle and high income countries, respectively. This means that built-up area per person increased at a corresponding rate of the decline in urban density.

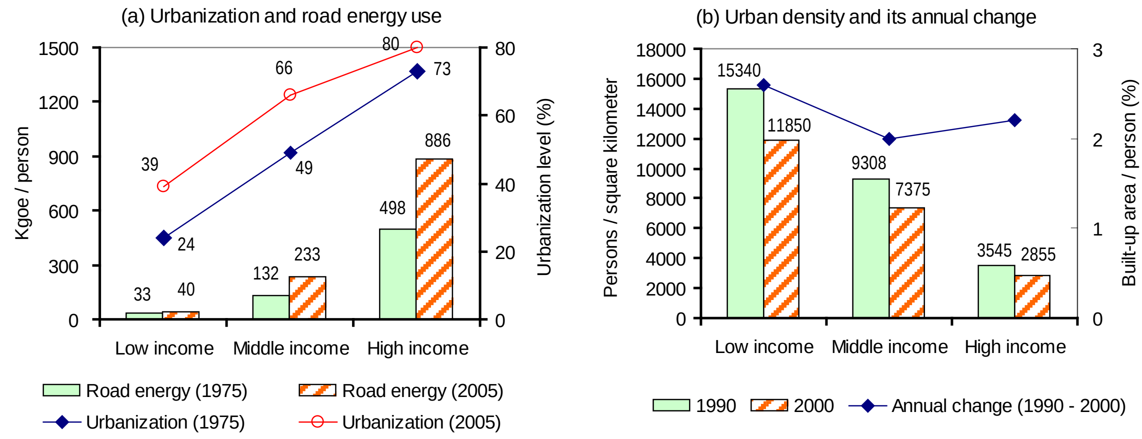

Fig. 2. Urbanization, road energy use per capita and urban density by income group. Data on urbanization and road energy use were from the World Bank (2007) and IEA (2009a, 2009b), while data on urban density were adapted from Angel et al. (2005). *kgoe* denotes kilograms of oil equivalent.

4.3. Vehicle ownership and vehicle use

At the country level, Fig. 3 (a) suggests that the higher the income per capita of a country, the higher its vehicle ownership per 1,000 people. In 2002, one out of every two people owned a vehicle in the high income countries, while it was about one out of every seven people in the middle income countries. In the low income countries, approximately one out of every 69 people owned one vehicle. However, the average annual growth rate of vehicle ownership between 1960 and 2002, in the low and middle income countries was 5.8% and 6%, respectively, slightly higher than that of the high income countries (4.9%). At the city level, as shown in Fig. (b), car ownership per 1,000 people in 1995 varied across the 11 countries and regions. Nonetheless, it was substantially high in cities of the developed countries and regions compared to cities of the developing countries and regions. Moreover, the figure appears to suggest that car use is closely related to levels of car ownership.

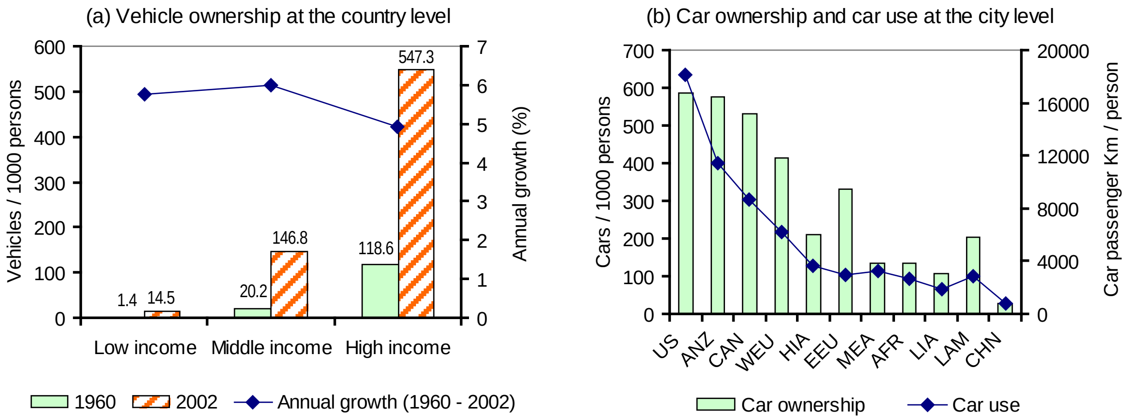

Fig. 3. Vehicle ownership and vehicle use at the country and city level by income group and region. Data on vehicle ownership and its growth rate at the country level were adapted from Dargay et al. (2007), whereas data on car ownership and car use were obtained from Kenworthy and Laube (2002). US: the US, ANZ: Australia and New Zealand, CAN: Canada, WEU: Western Europe, HIA: High income Asia, EEU: Eastern Europe, MEA: the Middle East, AFR: Africa, LAM: Latin America, CHN: China.

4.4. Modal split at the regional and city level

Fig. 4 (a) illustrates the modal split of short distance trips (fewer than 3.1 kilometres) per day per person in 11 regions and countries in the 1990s, while Fig. 4 (b) presents the modal split of all daily trips at the city level of 11 countries and regions in 1995. At the regional level, short distance travel by private vehicle predominate in developed regions such as North America, Oceania, Western Europe and high income Asia. In contrast, in developing regions and countries, walking, cycling and mass transit are the main modes of short distance trips. A similar trend is evident at the city level. As illustrated in Fig. 4 (b), cities of the high income countries and regions depend heavily on automobiles for their daily trips.

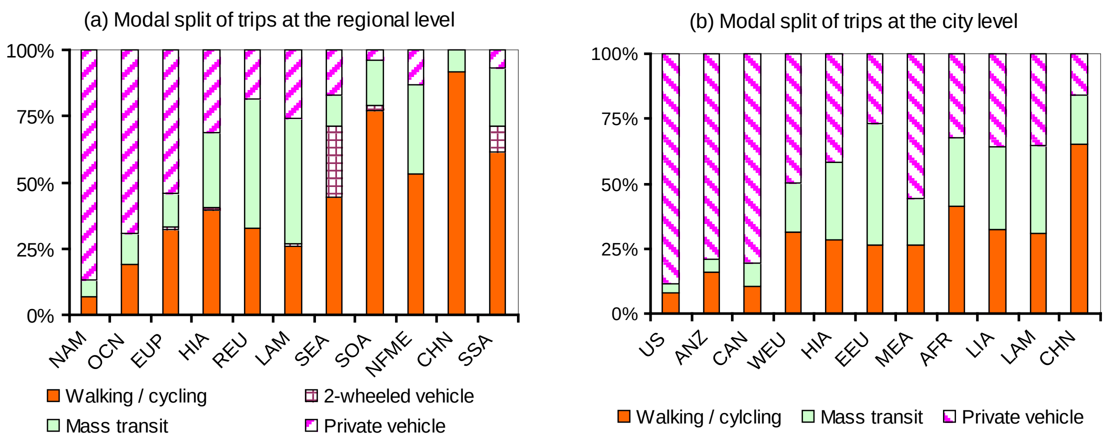

Fig. 4. Modal split of trips at the regional and city level. Data on the modal split of short distance trips (≤ 3.1 km) at the regional during the 1990s were from Papon (1998), while data on the modal split of all daily trips at the city level in 1995 were derived from Kenworthy and Laube (2002). NAM: North America, OCN: Ociania, EUP: European Union, HIA: High income Asia, REU: Rest of Europe, SEA: South East Asia, SOA: South Asia, NFME: North Africa and the Middle East, CHN: China, SSA: Sub-Sahara Africa, US: the US, ANZ: Australia and New Zealand, CAN: Canada, WEU: Western Europe, EEU: Eastern Europe, MEA: the Middle East, AFR: Africa, LAM: Latin America, CHN: China.

4.5 Road energy intensity in the service sector

Fig. 5 illustrates the average road energy intensity of the service sector in the low, middle and high income countries during 1975–2005. It shows that energy intensity of services in the middle income countries was higher than the low and high income countries between 1990 and 2005. All the three income groups experienced some fluctuation in their road energy intensity in the service sector during 1975–2005. However, their average annual change rate of road energy intensity in the service sector was positive between 1975 and 2005. The average annual growth rate in the low income group was 0.89%, while it was 0.52% in the middle income group. These figures were substantially greater than that of the high income group(0.02%).

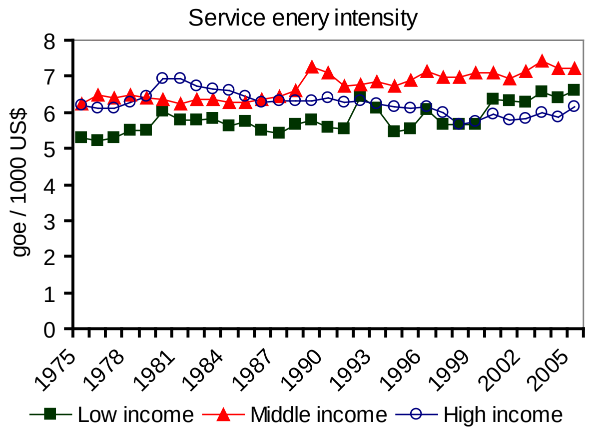

Fig. 5. Road energy intensity of the service sector (total road energy use divided by service sector value added). Calculated using data from the World Bank (2007) and IEA (2009a, 2009b). *goe* denotes grams of oil equivalent. *US$*: US$ in PPP 2000 prices.

5. Empirical results and discussion

Table 2 presents the estimation results of transport energy use, while Table 3 reports the estimation results of road transport energy use. As the test results of endogeneity show that urbanization can be treated as exogenous, the FE models are preferred because they are more efficient and consistent than the GMM models. As shown in Tables 2 and 3, the impact of urbanization on road energy use is very similar to its impact on aggregate transport energy use. However, as transport energy use comprises several sub-sectors (including domestic navigation and pipeline transport) that may not be related to urbanization well, our main interpretations focus on only the road energy use models (Models 9, 11, 13 and 15).

Model 9 shows that without consideration of the stages of development, population, income per capita and the share of services in GDP influence road energy use positively. A 1% increase in population size, income per capita and the share of services raises road energy use by 1.15%, 0.84% and 0.49%, respectively. The elasticity of road energy use with respect to urbanization is positive (0.49) and statistically significant. This supports our first hypothesis and is consistent with the argument that urbanization contributes to increased transport energy use (APERC, 2007; Jones, 2004; Parikh and Shukla, 1995; Rodrigue et al., 2006).

However, the results of Models 11, 13 and 15 suggest that the impact of population, income and services on road energy use is positive but varies among the low, middle and high income groups. The elasticity of road energy use to population change is about 1.37 in the middle income group, noticeably higher than in the low (0.71) and high (1.15) income groups. In contrast, a 1% rise in income per capita in the low income group raises road energy use by almost 1.07%, while in the middle and high income groups by 0.84% and 0.61%, respectively. The elasticities of road energy use with respect to changes in the share of services are positive in all the three income groups. This supports the argument that a rise in service activities increases transport demand and transport energy use (EEA, 2008). The elasticity of road energy use with respect to services in the low income group is 0.6, noticeably larger than that of the other income groups. This is consistent with the fact that the annual growth rate of the road energy intensity in the service sector in the low income group is faster than that of the other groups (see Fig. 5). However, the elasticity of road energy use to services in the middle income group is 0.28, surprisingly smaller than that of the high income group (0.53).

Similar to the effects of population, income and services, urbanization has a positive influence on road energy use in all the three income groups. However, the magnitude of the influence varies between them. These findings are consistent with our second hypothesis that given several differences, namely vehicle ownership, vehicle use, transport modes, trip purposes and urban density among the low, middle and high income countries, urbanization's impact on road energy use is likely to differ among them. A 1% rise in urbanization increases road energy use in the low, middle and high income groups by 0.81%, 0.37% and 1.33%, respectively. The urbanization elasticity of road energy use in the high income group is greater than in the other groups, thus supporting our third hypothesis. This is also consistent with an early study by Poumanyvong and Kaneko (2010), who found the impact of urbanization on aggregate energy use in the high income countries is larger than in the low and middle income countries. It is quite surprising that the urbanization elasticity of road energy use in the middle income group is smaller than in the low income group. However, this phenomenon could occur as a result of various factors, including changes in urban density and transport infrastructures. As illustrated in Fig. 2 (b), the annual decline rate of urban density in the middle income group is slightly slower than in the other groups. Second, the middle income group is in the stage of development of public transportation (Rodrigue et al., 2006), while the low income group gradually shifts from non-motorized towards motorized transport, and the high income group shifts from low-speed public transport towards faster transport modes, particularly automobiles (Schäfer, 2006).

Overall, the results of this study show that holding population size, income per capita and the share of services constant, urbanization increases rather than decreases national road energy use. They also suggest that the influence of urbanization differs among the low, middle and high income countries. The magnitude of the influence is higher in the high income group than in the other groups. This empirical evidence opposes the claim that urbanization contributes to a decrease in road energy use in the high income countries (Liddle, 2004).

Table 2
Estimation results for transport energy use.

Variable	Whole sample		Low income		Middle income		High income	
	FE (1)	GMM (2)	FE (3)	GMM (4)	FE (5)	GMM (6)	FE (7)	GMM (8)
ln*P*	1.091**	1.008**	0.613**	0.658**	1.247**	1.190**	1.140**	1.097**
	(0.066)	(0.060)	(0.131)	(0.135)	(0.084)	(0.078)	(0.084)	(0.084)
ln*A*	0.773**	0.837**	0.975**	0.980**	0.810**	0.921**	0.535**	0.600**
	(0.045)	(0.043)	(0.140)	(0.134)	(0.069)	(0.060)	(0.060)	(0.047)
ln*URB*	0.473**	0.600**	0.830**	0.816**	0.455**	0.520**	1.190**	0.948**
	(0.110)	(0.107)	(0.168)	(0.187)	(0.164)	(0.123)	(0.373)	(0.292)
ln*SV*	0.420**	0.356**	0.483**	0.528**	0.219**	0.237**	0.470**	0.399**
	(0.061)	(0.055)	(0.152)	(0.138)	(0.071)	(0.066)	(0.085)	(0.082)
Observations	2852	2576	651	588	1240	1120	961	899
R^2	0.985		0.956		0.977		0.995	
Uncentered R^2		0.698		0.592		0.751		0.831
Hansen test		2.460		0.643		1.352		4.007
(*p*-value)		(0.117)		(0.423)		(0.245)		(0.045)
Endogeneity		0.339		1.696		0.104		0.019
test (*p*-value)		(0.561)		(0.193)		(0.747)		(0.890)
URB elasticity	0.473	0.600	0.830	0.816	0.455	0.520	1.190	0.948

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita, *URB* denotes urbanization and *SV* denotes percent GDP from services. FE (Fixed Effects); GMM (Generalized Method of Moments). Newey–West corrected standard errors are in parentheses. ** $P < 0.01$; ** $P < 0.05$.

Table 3
Estimation results for road transport energy use.

Variable	Whole sample		Low income		Middle income		High income	
	FE (9)	GMM (10)	FE (11)	GMM (12)	FE (13)	GMM (14)	FE (15)	GMM (16)
ln*P*	1.146**	1.056**	0.706**	0.720**	1.374**	1.316**	1.146**	1.100**
	(0.065)	(0.060)	(0.128)	(0.139)	(0.090)	(0.084)	(0.089)	(0.086)
ln*A*	0.842**	0.895**	1.073**	1.081**	0.839**	0.936**	0.608**	0.654**
	(0.045)	(0.042)	(0.132)	(0.132)	(0.066)	(0.060)	(0.068)	(0.051)
ln*URB*	0.488**	0.612**	0.806**	0.830**	0.373*	0.430**	1.325**	1.104**
	(0.108)	(0.108)	(0.169)	(0.200)	(0.173)	(0.144)	(0.392)	(0.302)
ln*SV*	0.483**	0.412**	0.598**	0.622**	0.280**	0.295**	0.529**	0.452**
	(0.061)	(0.053)	(0.149)	(0.135)	(0.066)	(0.061)	(0.089)	(0.086)
Observations	2852	2576	651	588	1240	1120	961	899
R^2	0.984		0.958		0.977		0.994	
Uncentered R^2		0.714		0.628		0.756		0.831
Hansen test		1.215		0.038		1.765		2.498
(*p*-value)		(0.270)		(0.845)		(0.184)		(0.114)
Endogeneity		0.003		0.932		0.124		0.110
test (*p*-value)		(0.958)		(0.334)		(0.725)		(0.741)
URB elasticity	0.488	0.612	0.806	0.830	0.373	0.430	1.325	1.104

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita, *URB* denotes urbanization and *SV* denotes percent GDP from services. FE (Fixed Effects); GMM (Generalized Method of Moments). Newey–West corrected standard errors are in parentheses. *** $P < 0.01$; * $P < 0.05$.

It is worth noting that we checked the potential nonlinear relationship between urbanization and transport energy use qualitatively and quantitatively. Qualitatively, road energy use was plotted against urbanization. Quantitatively, the quadratic term of urbanization was included and tested in all the models. Since we did not find any meaningful relationship between them, it was dropped.

6. Conclusion

This article examines systematically the influence of urbanization on national transport and road energy use in the low, middle and high income countries during 1975–2005. After controlling for population size, income per capita and the share of services in GDP, the main findings show that urbanization has a positive influence on national transport and road energy use in all the three income groups. The magnitude of the influence appears to vary among them. For instance, a 1% increase in urbanization raises national road energy use in the low, middle and high income countries by 0.81%, 0.37% and 1.33%, respectively. This implies that urbanization in the high income countries has a greater impact than in the low and middle income countries. The impact of urbanization in the middle income countries is surprisingly smaller than in the low income countries. The results also suggest that population, income and the share of services contribute to an increase in aggregate transport and road energy use. Their contributions differ notably among the three income groups.

This study not only sheds further light on the existing literature, but also provides policy maker with insightful information on the link between urbanization and transport energy use. Urbanization not only increases movements of passengers and freight, but also contributes to decreased urban densities and increased automobile use. Any policy aimed at curbing urbanization’s impact on transport energy demand must address its associated externalities, particularly urban sprawl and automobile dependency. Reducing urban sprawl could reduce VTK and transport energy use, thereby contributing to emission reduction (Hankey and Marshall, 2010).

As the findings of this study are derived from a national-level analysis using a relatively imperfect measure of urbanization, they should be interpreted at the national level with care. The results do not imply changes in city transport energy use as a result of their population growth. Rather, they imply changes in national transport energy use as a result of a 1% increase in the percentage of population living in urban areas. In the absence of better alternative measures of urbanization, and consistent historical data at the city level, these preliminary results shed further light on the link urbanization and transport energy use. Hopefully, this study will encourage further investigation into this regard.

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Appendix A

Table A.1
List of the countries used in the analysis (1975–2005).

1. Low income group (21 countries)

Bangladesh, Benin, Cameroon, Congo, Rep., Cote d'Ivoire, Ghana, Haiti, India, Kenya, Mozambique, Myanmar, Nicaragua, Nigeria, Pakistan, Senegal, Sudan, Tanzania, Togo, Vietnam, Zambia, Zimbabwe

2. Middle income group (40 countries)

Algeria, Argentina, Bolivia, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Gabon, Guatemala, Honduras, Hungary, Indonesia, Iran, Jamaica, Jordan, Lebanon, Libya, Malaysia, Mexico, Morocco, Panama, Paraguay, Peru, Philippines, Poland, Romania, South Africa, Sri Lanka, Syria, Thailand, Tunisia, Turkey, Uruguay, Venezuela

3. High income group (31 countries)

Australia, Austria, Bahrain, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Hong Kong (China), Iceland, Ireland, Israel, Italy, Japan, Kuwait, Malta, Netherlands, New Zealand, Norway, Portugal, Qatar, Saudi Arabia, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States

Table A.2
Correlation matrix for all variables (whole sample and low income group).

	Whole sample					Low income group				
Variable	*Road*	*Pop*	*A*	*URB*	*SV*	*Road*	*Pop*	*A*	*URB*	*SV*
Road	1					1				
Pop	0.667	1				0.833	1			
A	0.521	–0.212	1			0.120	–0.151	1		
URB	0.376	–0.314	0.803	1		–0.015	–0.384	0.443	1	
SV	0.241	–0.093	0.466	0.428	1	–0.192	–0.271	0.383	0.118	1
IND	0.264	–0.099	0.411	0.417	–0.344	0.154	–0.018	0.239	0.316	–0.216

Notes: all variables are in natural logarithmic form. *Road* denotes road transport energy use. For the sake of brevity, total transport energy use is not shown in this table.

Table A.3
Correlation matrix for all variables (middle and high income groups).

	Middle income group					High income group				
Variable	*Road*	*Pop*	*A*	*URB*	*SV*	*Road*	*Pop*	*A*	*URB*	*SV*
Road	1					1				
Pop	0.883	1				0.960	1			
A	0.308	0.007	1			0.349	0.191	1		
URB	0.169	–0.14	0.597	1		–0.176	–0.274	0.214	1	
SV	–0.10	–0.17	0.003	0.244	1	0.275	0.354	0.030	–0.016	1
IND	0.290	0.193	0.344	0.138	–0.75	–0.147	–0.238	–0.031	0.071	–0.903

Notes: all variables are in natural logarithmic form. *Road* denotes road transport energy use. For the sake of brevity, total transport energy use is not shown in this table.