Journal of Global Environment Engineering, Vol. 11, pp. 59-73, 2006

TRANSPORT ENERGY INTENSITY AND MOBILITY TRENDS IN THE WORLD

FROM 1980 TO 1995

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Abstract

In this paper, I analyze the passenger transport energy intensity and mobility in world cities from 1980 to 1995 using data from Millennium Cities Database (UITP) and An International Sourcebook of Automobile Dependence in Cities 1960 - 1990 (Editor: Kentworthy, Jeff and Laube, Felix). I will demonstrate how the environmental Kuznets curve (EKC) hypothesis holds in private and public transport energy intensity (MJ/p-km) and its break point of per capita GRP is around 22,000-26,000 USD (1995PPP) respectively. Combined with an estimation of mobility explicitly taken population density in the analysis, I demonstrate how population density control is effective in low-density cities and early stages of economic development.

KEYWORDS: *environmental Kuznets curve, transport energy intensity, mobility, population density*

1. Introduction

Passenger transport is one of the most growing sectors in energy use. There are mainly two measures for reducing total energy consumption and CO_2 emissions in the transport sector. One is reduction of energy intensity and the other is reduction of mobility.

There are two objectives in this study. The first aim is to verify the hypothesis of an environmental Kuznets curve (EKC) in passenger transport energy intensity. The basic notion of this hypothesis is that resource use increases, and environmental degradation worsens during the early stages of development, to be followed by improvement in the later stages. This hypothesis has been tested in various fields since Grossman and Krueger (1995). However, there is little discussion on transport energy and city level analysis[1]. The second aim is to explore the reduction potential of population density control on passenger transport energy use in cities. I analyze energy intensity and mobility using per capita GRP and population density. The reduction potential of energy use is shown when per capita GRP grows together with an increase/decrease in population density.

In this study, I will answer the following questions.

(a) Is environmental Kuznets curve (EKC) hypothesis also found in transport energy intensity in world cities?

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Table 1. Drivers of transport energy use

	Early stage	Later stage
Worse	● Motorization ● Low density urbanization ● Congestion	● Vehicle weight and power ● Vehicle amenities
Improvement	● Traffic management ● Pavement	● Vehicle drag ● Engine efficiency ● Fuel economy regulation ● Environmental consciousness

Many factors affect energy intensity (Table 1). As for a plus factor, which signifies efficiency improvement factors, there are vehicle technology, traffic management, and fuel economy regulations etc. On the other hand, however, the weight of vehicles, the need for high performance (acceleration, safety etc.) and in-car equipment (air conditioner, GPS and so on), and a reduction in average vehicle ridership has the worse energy use per passenger kilometers. During the early stages of development, energy intensity worsens due to vehicle ownership and congestion, subsequently followed by development in the later stages by improving technology and people's consciousness.

(b) How does population density affect efficiency and mobility?

Kenworthy and Newman (1999) show that there is a strong relationship between population density and transport energy. However, Mindali et al (2004) showed that there is no direct relation between urban density and energy consumption using Newman and Kenworthy (1989) 1980's data and Co-Plot technique. In this study, we expand the time period, reexamine the population density data and build a model considering the nonlinear relationship between energy use and population density.

Cameron et al (2004) showed that car ownership as well as population growth was a major influence on growth in urban mobility and urban sprawl had significantly less influence, although it has been significant in the USA, Canadian and Australian cities. However, car ownership may be affected by population density[2].

This paper explores not only mobility equation but also energy intensity equation of private and public passenger transport focusing on income, population density and gasoline prices from 1980 to 1995. It indicates the future passenger transport energy use and effectiveness of policy measures.

2. Methodology

To verify the above questions, I analyze the relationship between mobility and energy intensity, and per capita GRP and population density cross section data using multi-regression analysis. As indices for mobility, we use passenger-kilometer (p-km) / person of private and public transport. I also demonstrate the share of private transport using a logit model. As for energy intensity indices, I use Mega Joule (MJ) / p-km. Following the simple expressions used in econometrics, I prepare the following equations for the analysis. Equations for mobility and energy intensity (multi regression model):

(Semi-log model)

$$Y_{it} = \alpha_0 + \alpha_1 \ln(GRP_{it}) + \alpha_2 (\ln(GRP_{it}))^2 + \alpha_3 \ln(DEN_{it}) + \sum_j \alpha_j (X_{jit}) + \varepsilon_{it} \quad (1)$$

(log-linear model)

$$\ln(Y_{it}) = \alpha_0 + \alpha_1 \ln(GRP_{it}) + \alpha_2 (\ln(GRP_{it}))^2 + \alpha_3 \ln(DEN_{it}) + \sum_j \alpha_j (X_{jit}) + \varepsilon_{it} \quad (2)$$

Equation for private transport share (logit model):

$$\ln(Y_{it} /(1-Y_{it})) = \alpha_0 + \alpha_1 \ln(GRP_{it}) + \alpha_2 (\ln(GRP_{it}))^2 + \alpha_3 \ln(DEN_{it}) + \sum_j \alpha_j (X_{jit}) + \varepsilon_{it} \quad (3)$$

where, Y: explained variable, GRP: per capita GRP, DEN: population density, X_j: other j-th explanatory variable (including dummy variables), i: city, t: year, α : parameters, ε_{it} : error term with normal distribution $\sim N(0, \sigma^2)$

These equations are easy to understand the estimated parameters. For example, elasticities for mobility and energy intensity are expressed as follows. If EKC hypothesis holds, α_2 becomes a negative value with statistically significance.

α /Y : semi-log model

α : log-linear model

3. Data

List of cities (metropolitan areas) and year used for the analysis in each city are listed in **Appendix A**. The following sources were used to collect data on population density, mobility and energy use.

1. UITP Millennium Database of Towns and Regions

   The total population of the 100 cities selected is over 400 million in 1995, of which some 250 million live in 40 cities in developing countries or in countries in transition. Nearly all the world's major urban centers (over 10 million inhabitants) have been selected, as have nearly all cities with more than 2 million inhabitants in which UITP has a member.

2. An International Sourcebook of Automobile Dependence in Cities 1960-1990

   A large, reliable digest of urban data regarding land use, transportation, and energy use data for 46 cities are recorded in 1960, 1970, 1980 and 1990. It is lacking in some older data, particularly in developing countries.

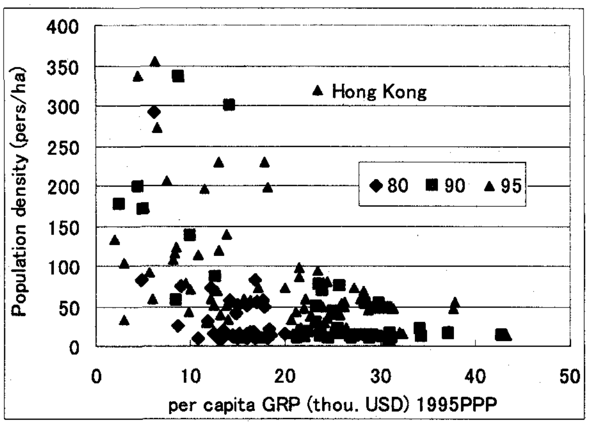
On population density, Standard Metropolitan Statistical Areas (SMSA) are used for US cities. As the data in the above materials is about 1.4-2 times higher than the governmental data in Canada in 1995, I adopted the governmental data for 1995 and adjusted values for 1980 and 1990 using the ratio between these. In other cities, I use the above data because the difference between governmental data (not always consistent with area size) and the above data is less than 20% for 1995[3].

In addition to the above two data source, I collect per capita Gross Regional Product (GRP) data from national or regional statistics for 1990 and 1995. However, unfortunately I do not have accurate data for 1980. As all cities are located in OECD countries except for Hong Kong and Singapore, I assume that growth rate of per capita GRP in the city is the same as that in the nation at 1980[4]. I also lack transport operating cost data for 1980 and 1990. Therefore I collect gasoline price data for country level and introduce dummy variables for urban rail and suburban rail (1: if the city rail lines, 0: otherwise). I use 1995 PPP for currency conversion.

However, reexamination should be required on per capita GRP, population density and fuel price in the further study. In addition, definition of city boundary may greatly affect the results. Considering the uncertainty of data, I will show the plural estimation results.

The top of Figure 1 shows the relationship between per capita GRP (1995 PPP) and population density. Overall, population density decreases with income. Most cities with high population density are Asian cities. Population density of US, Canada and Australian cities are quite low. However, two patterns can be seen for city growth: income growth and an increase/decrease in population density. In addition, income growth is generally faster than population density change.

Figure 2 shows the relationship between per capita GRP and energy intensity (MJ/p-km). The EKC hypothesis appears to be accurate though points vary widely. In addition, population density, gasoline price and public transport services are omitted in this figure. We should take these factors into consideration for the analysis.



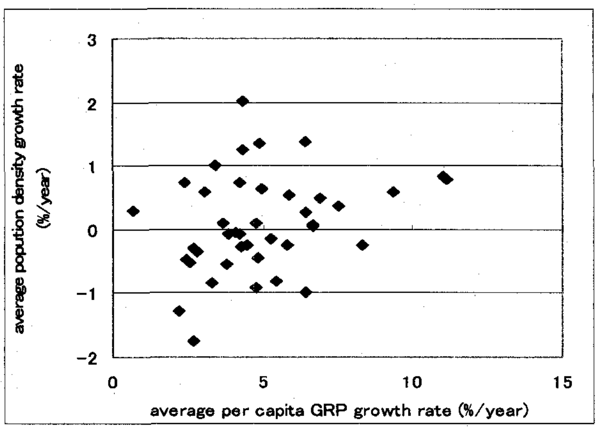


Figure 1. Change in per capita GRP (1995PPP) and population density
(Top: absolute value / Bottom: average growth rate)

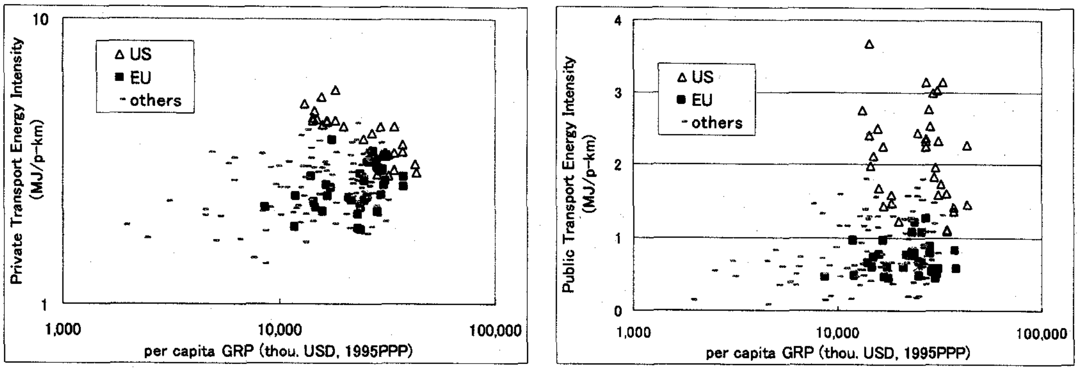


Figure 2. Per capita GRP and transport energy intensity
(Left: private transport / Right: public transport)

4. Results

4.1 Passenger transport mobility and share of private transport

Table 2 shows the estimation results. Passenger kilometers by private and public transport modes seem to continue growing with per capita GRP. Espey (1998) suggests that income and short run price elasticities in the US are smaller than those in other counties. However, dummy variables based on a hypothesis that income and price elasticities differ by region are not statistically significant in this model. Therefore a different intercept is used for US cities. I Introduced dummy variables with time (80US and 9095US etc.) for the variables which represent changes in vehicle technology and road infrastructures. When I use regional dummy variables (80US and 9095US) for a total (private +

public) mobility log-linear model, gasoline price becomes statistically insignificant. Share of private transport increases with per capita GRP and decreases with population density and private transport cost. I could not obtain statistically significant value for parameter of urban rail. One possible reason is that population density has a high correlation with urban rail existence.

4.2 Private Transport

Combining the above two models, we can derive private and public transport mobility (passenger-km/cap). However, I also estimate private and public transport mobility directly because I could not obtain equations with high accuracy due to data limitation. Energy efficiency is also estimated (Table 3).

There are three differences between total and private mobility models. The first, in the private passenger transport model, urban rail dummy is statistically significant. This means that urban rail (suburban rail and subway) plays a role in the reduction of private transport mobility. Secondly, in the log-log model, a square term of per capita GRP is statistically significant, although the break point exceeds the maximum value in all cities. Finally, income and gasoline price elasticity is higher than that for the total mobility model. Furthermore, as population density elasticity is almost -0.5, private

Table 2. Estimated results of transport mobility and modal share in log of variables

	Total Mobility (p-km/cap)			Private Modal Share	
Form	Semi-log	Log-linear		Log-linear	
	A1	**A2**	A3	B1	**B2**
Intercept		**7.12** **(16.93)**	6.82 (16.92)		
GRP	1,565 (19.41)	**0.31** **(7.79)**	0.34 (9.19)	0.47 (14.34)	**0.48** **(15.40)**
DEN	-1,939 (-10.52)	**-0.33** **(-13.51)**	-0.31 (-12.75)	-0.81 (-11.16)	**-0.83** **(-11.53)**
Gaso	-817 (-1.80)	**-0.11** **(-2.04)**		-0.47 (-2.45)	**-0.32** **(-1.82)**
Dummy Urban				-0.47 (-3.75)	
Urban*GRP	-17.5 (-0.55)				**-0.050** **(-3.98)**
80US			0.18 (2.39)	1.22 (4.87)	
9095US			0.23 (3.61)	0.83 (3.59)	
US	4,335 (9.17)				**1.06** **(5.72)**
R^2	0.81	**0.80**	0.82	0.78	**0.78**
Samples	168				

Note: All variables are transformed using a logarithm. All monetary values are converted using 1995PPP. Parentheses show t-value. GRP: per capita GRP (USD), DEN: population density (pers/ha), Gaso: gasoline price (USD/liter). Others are dummy variables; Urban (1:Cities in OECD countries, 0: otherwise), Urban*GRP: (per capita GRP for cities in OECE countries, 0: other cities, 80US (1: US cities in 1980, 0: otherwise), 9095US (1: US cities in 1990 and 1995, 0: otherwise), US (1: US cities, 0:otherwise). These definitions are common to the following tables.

transport mobility almost grows in proportion to the square root of area size.

On private transport energy intensity (MJ/p-km), a correlation coefficient is not high, as I do not consider other local characteristics on fleet composition and congestions as well as path dependency. Though t-values are not high with 95% significant level, EKC hypothesis is sustained. The break point is around 22,000 USD (1995PPP). When I use only 1980 data in US and European cities, U-shaped curve and per capita GRP in 1980 is less than 20,000 USD (1995 PPP). Oil shock might cause this change. At a nation level, on road vehicle fuel efficiency has been decreasing since 1973 for US and 1980 for Europe except for Japan.

Population density for European cities and wealthy Asian cities variables are positive. Congestion levels may be reflected in population density. However, the average fuel efficiency decreases with population density when we use pooled data. People may tend to have smaller cars in higher population density by land area constraints. On the other hand, the US (and Canada) dummy is statistically significant. This indicates that the average vehicle weight in these cities, which is a major determinant of fuel economy, is relatively lighter than that of US/Canada/Australian cities.

Table 3. Estimated results of private transport mobility and energy intensity in log of variables

Index	Mobility (p-km/cap)				Energy Intensity (MJ/p-km)		
Form	Semi-log	Log-linear			Log-linear		
	C1	C2	C3	**C4**	D1	D2	**D3**
Intercept		4.65 (7.84)	-8.18 (-1.71)	**-6.72** **(-1.28)**			**-5.69** **(-1.99)**
GRP	1,578 (20.17)	0.59 (10.70)	3.38 (3.32)	**3.05** **(2.72)**	0.76 (22.41)	0.15 (3.83)	**1.32** **(2.15)**
GRP^2			-0.15 (-2.77)	**-0.13** **(-2.21)**		-0.075 (-1.83)	**-0.066** **(-2.01)**
DEN	-2,369 (-13.25)	-0.50 (-13.45)	-0.51 (-14.33)	**-0.51** **(-13.89)**			
Gaso	-1,118 (-2.51)	-0.24 (-3.14)	-0.14 (-1.81)	**-0.13** **(-2.21)**	-0.13 (-2.51)	-0.15 (-2.89)	**-0.20** **(-4.39)**
Urban*GRP	-74.4 (-2.40)						
EU+WELASIADEN					0.035 (3.28)	0.047 (3.77)	
80US		0.27 (2.48)		**0.24** **(2.13)**	0.73 (10.79)	0.76 (10.93)	**0.46** **(7.91)**
9095US				**0.14** **(1.25)**	0.28 (3.71)	0.35 (4.16)	**0.11** **(2.25)**
US	4,817 (10.51)		0.18 (2.25)				
MC							**-0.37** **(-4.17)**
R^2	0.86	0.86	0.86	**0.86**	0.60	0.61	**0.62**
GRP*			77,719	**102,565**		16,480	**21,756**
Samples	168						

Note: EU+WELASIADEN: (Population density in EU and wealthy Asian cities (Singapore, Hong Kong and Japanese cities) 0: other cities), MC dummy: (1: Chinese city + Ho Chi Minh City, Bangkok, Manila and Taipei) , 0: otherwise) GRP*: break point of GRP in quadratic function (PPP USD 1995)

Gasoline price elasticity of energy intensity is greater than that of mobility. This suggests people choose more fuel-efficient cars instead of decreasing driving mileage when gasoline price rises.

4.3 Public Transport

Basically, by calculating the value of total (private+ public) mobility minus the value of private mobility, we can obtain public transport mobility (Table 4). However, the correlation was very low. In the case of the log-linear model, R^2 is only 0.39. This means that we should collect other data related to public transport such as frequency, cost, speed, accessibility and so on. Further study is required. Here, I estimate the equations directly. As public transport mobility and public transport energy intensity (MJ/p-km) has a close relationship, I introduce two PT dummies for cities that have relatively high and low public transport usage instead.

On energy intensity, the EKC hypothesis is sustained. However, gasoline price is not statistically significant while it was significant for an explanation of mobility. Of course, public transport energy intensity may have no relation with gasoline price, but further study is strongly required as energy

Table 4. Estimated results of public transport mobility and energy intensity in log of variables

Index	Mobility (p-km/cap)		Energy Intensity (MJ/p-km)			
Form	Semi-log	Log-linear	Log-linear			
	E1	**E2**	F1	F2	F3	**F4**
Intercept		**5.79 (26.87)**		-14.92 (-2.19)	-0.51 (-0.73)	**-12.11 (-2.41)**
GRP			0.21 (2.62)	3.21 (2.21)	0.13 (2.01)	**2.55 (2.39)**
GRP^2				-0.17 (-2.14)		**-0.13 (-2.21)**
DEN	413.5 (13.27)	**0.25 (4.90)**		-0.19 (-3.52)	-0.27 (-6.54)	**-0.26 (-6.34)**
Gaso	342.4 (1.84)	**0.19 (3.05)**	-0.47 (-4.06)	-0.30 (-2.55)	-0.084 (-1.02)	
Urban			-0.22 (-2.62)	-0.15 (-1.75)		
Train			-0.081 (-0.84)	-0.091 (-1.05)		
Urban*GRP	48.2 (3.17)	**0.041 (4.96)**			-0.017 (-2.57)	**-0.018 (-2.70)**
Train*GRP		**0.029 (3.05)**				
80US			1.70 (2.20)	0.58 (4.00)		
9095US			1.32 (1.69)	0.51 (3.60)		
WEL ASIA			-0.70 (-4.54)	-0.53 (-3.39)		
US	-503.2 (-2.36)	**-0.81 (-7.04)**			0.41 (4.95)	**0.48 (5.79)**
PT1		**0.81 (7.81)**			-0.27 (-3.49)	**-0.27 (-3.42)**
PT2		**-2.10 (-6.10)**			0.66 (3.22)	**0.67 (3.23)**
R^2	0.39	**0.77**	0.63	0.63	0.76	**0.76**
GRP*				15,481		**25,929** (wo urban and suburban rail) **24,154** (w urban and suburban rail)
Samples	168					

Note: Train: (1: cities with rail and/or light rail and/or subways, 0: otherwise), Train*GRP: (per capita GRP for cities with rail and/or light rail and/or subway, 0: otherwise), PT1: (1: Frankfurt, Munich, Tokyo, Osaka, Singapore, Hong Kong, Prague, Budapest, Rio de Janeiro, San Paulo, Bogotá, Johannesburg, Harare and Chinese cities, 0: otherwise), PT2: (1: Ho Chi Ming City and Riyadh, 0: otherwise)

efficiency and mobility has a high correlation. The break point of public transport is greater than that of private transport based on this result. The absolute value of population density elasticity of energy efficiency is almost the same as mobility.

Overall, US cities have higher mobility (p-km/capita) and energy intensity (MJ/p-km) in private transport. However, I can assume the same elasticities in other cities. In Appendix B, I show the estimated results of elasticities.

On public transport mobility, income elasticity is quite low (less than 0.1). The absolute value of gasoline price elasticity (0.19) is larger than that of private transport mobility (0.13). On the other hand, the absolute value of population density elasticity (0.25) is smaller than that of public transport (0.51).

4.4 Per capita Passenger Transport Energy Use

I can draw mobility and energy intensity curves in a hypothetical city using the above estimated results (Figure 3). I use the shaded equations in Table 2-4 (A2, B3, C4, D3, E2, F4) from the view point of value of R-square and AIC. Moreover, I adapt an average population density and gasoline price of US and EU cities in 1980, 1990 and 1995 (please see **Appendix B** for the value in 1980 and1995) and assume urban rail exists in all contingent cities. I also added a city with 100(pers./ha) population density and 0.95 (USD/liter) gasoline price for the representative city except for US and EU cities[5].

Mobility keeps growing with per capita GRP. In a world-regional context, Schafer and Victor (2000) demonstrated that time and monetary budgets were stable over space and time, and that per capita traffic volume grows in proportion to per capita income. This study doesn't include ship and air, but the tendency is consistent with it. Conversely, energy intensity starts to decline around 22,000 USD. Mobility in the US is overwhelming although a difference of energy intensity between the US and the EU is decreasing.

Combined with the above results, I calculated per capita passenger transport energy use (Figure 4). By decreasing income elasticity of mobility and improving energy efficiency in cars, the slope decreases towards 0. However, I are unable to find a negative slope. In addition, non-surface transport such as air and ships are not considered in this analysis. Therefore, without an effort to reduce mobility, particularly private transport, or further technological improvement, passenger transport energy use will continue to grow in the near future.

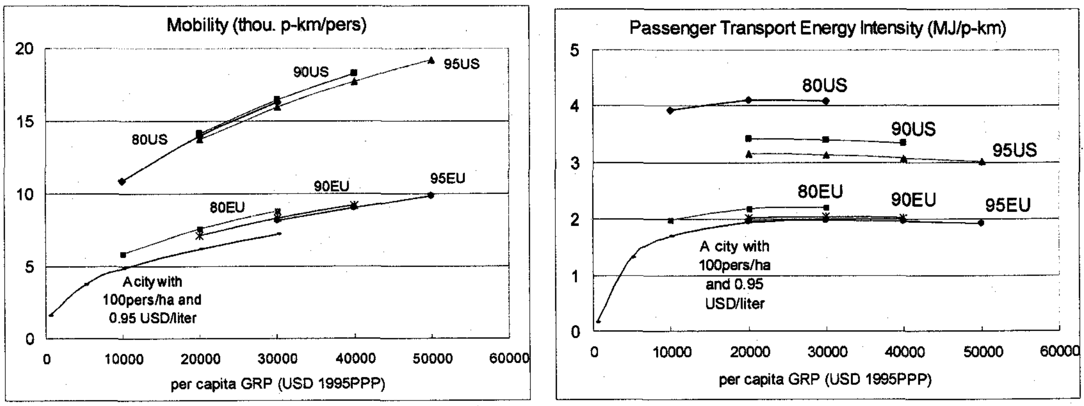


Figure 3. Passenger transport mobility and energy intensity in hypothetical city

Note: Ranges in curves are set based on actual data range but not same as actual range.

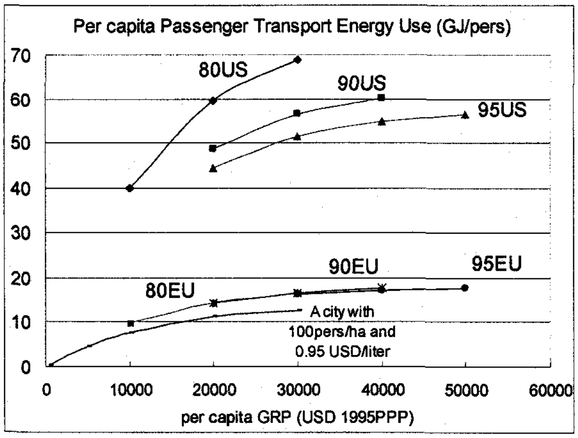


Figure 4. Per capita passenger transport energy use in hypothetical city
Note: Ranges in curves are set based on actual data range but not same as actual range. Mean value of population density and gasoline price in US and EU change from 1980 to 1995

5. Simulation – per capita GRP growth with/without decreasing in population density

These estimated results on private transport show that population density elasticity of per capita private transport energy use is greater than gasoline price elasticity. In this section, therefore, I examine the impact of income (here, per capita GRP) growth path in a city with an increase and decrease in population density on per capita passenger transport energy use.

I assume the same amount of per capita GRP growth (5,000USD) and population density (±5 pers/ha). Concrete values and simulation results are shown in Table 5 and Figure 5.

The results of the high income and low-density case may not be reasonable, because in general, income grows faster than population density. In this case with an increase in population density, as energy intensity of private transport is almost constant and private mobility decreases, the total per capita energy use is reduced. In other cases, per capita energy use increases because private mobility

Table 5. Setting and results of simulation

	per capita GRP (USD)		Pop. Den. (pers/ha)			fuel price	per capita transport energy use (MJ/pers)			
	base	case1/2	base	case 1	case 2	(USD/liter)	base	case1	case2	change rate
	a	b	c	d	e	f	g	h	i	j = (i - h)/g
H-Inc H-Den	20,000	25,000	80	85	75	1	13,062	13,912	14,777	0.07
H-Inc L-Den	20,000	25,000	20	25	15	1	25,562	25,198	32,407	0.28
L-Inc H-Den	5,000	10,000	80	85	75	1	4,910	8,478	8,995	0.11
L-Inc L-Den	5,000	10,000	20	25	15	1	9,342	15,159	19,391	0.45

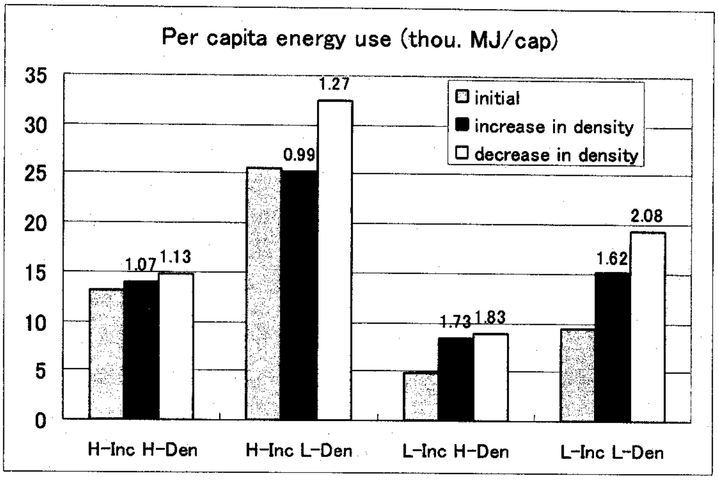


Figure 5. Comparison of per capita energy use

Note: values in the figure show ratio to initial per capita energy use

keeps growing. In particular, in low-density cases with a 25% decrease in population density, the increase rate of per capita energy use is greater than that of income.

For reducing per capita transport energy usage, a higher population density growth rather than income growth is needed. In addition, the lower the initial population density and per capita GRP becomes, the higher the population density growth is required. This indicates the importance of population density control particularly in low-density cities and early stages of economic development.

6. Conclusion

- The environmental Kuznets curve (EKC) hypothesis is sustained in private and public transport energy intensity (MJ/p-km). The break points of per capita GRP are around 22,000 - 26,000 USD (1995PPP) respectively. However, per capita passenger transport energy use continues to grow with income due to mobility growth.
- US cities have higher mobility (p-km/capita) and energy intensity (MJ/p-km) in private transport.
- Population density elasticity of per capita passenger transport energy use is about 0.5 and this is higher than gasoline price elasticity.
- Population density control is effective in low-density cities and early stages of economic development.

In this analysis, I assume per capita GRP, population density, gasoline price and public transport as exogenous and independent variables, but in fact, these variables are not independent. As Hammar et al (2004) suggested, low population density with high gasoline demand might make it difficult to raise gasoline taxes. Densely public transport service networks in city centers may reduce diffusion of urban areas. It is also said that road infrastructure supply by income growth generates traffic (ex. Cervero: 2003).

One problem of this research is the quality of data. This data on per capita GRP, population density and fuel price should be reexamined. Definition of city may greatly affect the results. In addition, appropriate indicators that show the service level of public transport should be added instead of dummy variables. Therefore a city transport energy related database is crucial for further analysis. In addition, error autocorrelation and heteroskedasticity should be considered in the estimation.

One remaining question is whether these results for urban areas can be applied to rural areas. In other words, can we explain the country level transport energy use just by combining estimates of the whole area using this model? Finally, an analysis of non-motorized transport as well as non-surface and freight transport is required for a greater understanding of transport energy use.

Acknowledgements

I am most grateful to Jayant Sathaye at Lawrence Berkeley National Laboratory and three anonymous referees for very helpful comments and suggestions.

Notes

[1] On recent discussions about EKC hypothesis, please refer to Rothman (1998), Halkos and Tsionas (2001) and Martinez-Zarzoso and Bengochea-Morancho (2004) etc. In addition, Kopits and Cropper (2003) demonstrated how the per capita income at which the motor vehicle fatality rate begins to decline is in the range of incomes at which other externalities begin decline.

[2] For example, Tanishita et al. (2004) showed that population density was one of the key variables to explain car ownership ratio in Japanese cities as well as household income.

[3] The data collection method used by Newman and Kenworthy is subject to inconsistencies due to different definitions used by the respondents and inaccuracies. It is crucial for further study to build a worldwide city database based on consistent definitions of cities.

[4] This is based on the fact the average per capita income growth rate in the US cities is almost same as that in the US.

[5] These values are within the range of real cities.

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Appendix A. List of Cities and year used for the analysis

Country	City	1995	1990	1980
Austria	Graz	O		
Austria	Vienna	O	O	O
Belgium	Brussels	O	O	O
Denmark	Copenhagen	O	O	O
Finland	Helsinki	O		
France	Lyon	O		
France	Marseille	O		
France	Nantes	O		
France	Paris	O	O	O
Germany	Berlin	O		
Germany	Dusseldorf	O		
Germany	Frankfurt	O	O	O
Germany	Hamburg	O	O	O
Germany	Munich	O	O	O
Germany	Ruhr	O		
Germany	Stuttgart	O		
Greece	Athene	O		
Italy	Milan	O		
Italy	Bologna	O		
Italy	Rome	O		
Netherland	Amsterdam	O	O	O
Norway	Oslo	O		
Spain	Barcelona	O		
Portugal	Madlid	O		
Sweden	Stockholm	O	O	O
Switzerland	Berne	O		
Switzerland	Geneva	O		
Switzerland	Zurich	O	O	O
United Kingdom	Glasgow	O		
United Kingdom	London	O	O	O
United Kingdom	Manchester	O		
United Kingdom	Newcastle	O		
Chez	Prague	O		
Roumania	Budapest	O		
Poland	Cracow	O		
Canada	Calgary		O	O
Canada	Edomonton		O	
Canada	Montreal	O	O	
Canada	Ottawa	O	O	O
Canada	Toronto	O	O	O
Canada	Vancouver	O	O	O
Canada	Winnipeg		O	O
United States	Atlanta	O		
United States	Boston		O	O
United States	Chicago	O	O	O
United States	Denver	O	O	O
United States	Detroit		O	O
United States	Houston	O	O	O
United States	Los Angeles	O	O	O
United States	New York	O	O	O
United States	Phoenix	O	O	O
United States	Portland		O	O
United States	Sacramento		O	O
United States	San Diego	O	O	O
United States	San Francisco	O	O	O
United States	Washington D.C.	O	O	O

Country	City	1995	1990	1980
Brazil	Curitiba	O		
Brazil	Sao Paulo	O		
Colombia	Bogota	O		
Israel	Tel Aviv	O		
Iran	Teheran	O		
Saudi Arabia	Riyadh	O		
Egypt	Cairo	O		
Senegal	Dakar	O		
South Africa	Cape Town	O		
South Africa	Johannesburg	O		
Tunisia	Tunis	O		
Zimbabwe	Harare	O		
Japan	Osaka	O		
Japan	Sapporo	O		
Japan	Tokyo	O	O	O
(China)	Hong Kong	O	O	O
Singapore	Singapore	O	O	O
India	Mumbai	O		
India	Chennnai	O		
Indonesia	Jakarta	O	O	
Indonesia	Surabaya		O	
Malaysia	Kuala Lumpur	O	O	
PR China	Beijing	O		
PR China	Shanghai	O		
PR China	Guangzhou	O		
Philippine	Manila	O	O	
Korea, South	Seoul	O	O	
Philippine	Manila	O	O	
Taiwan	Taipei	O		
Thailand	Bangkok	O	O	
Viet Nam	Ho Chi Minh City	O		
Australia	Aderade		O	O
Australia	Brisbane	O	O	O
Australia	Canberra		O	O
Australia	Melbourne	O	O	O
Australia	Perth	O	O	O
Australia	Sydney	O	O	O
New Zealand	Wellington	O		
Total		85	46	36

Appendix B. Transport Mobility and Energy Intensity Elasticity

Elasticity			Total Mobility	Private Mobility	Private Energy Intensity (MJ/p-km)	Public Mobility	Public Energy Intensity (MJ/p-km)	Average Value (1980 -1995)
Income (GRP per capita)	US	log-linear	0.37	0.38	-0.2 - -0.1	0.09	0	16,479 - 32,661
	EU	log-linear	0.24	0.24	0	0.06	-0.03	15,277 - 27,977
	ASIA	log-linear	0.27	0.53	0.07-0.12	0.14	0.35 - -0.58?	
	pool	semi-log	1.57 - 0.02	1.58 - 0.02				
	pool	log-linear	0.34	0.59	0.40 - -0.09	0.08	0.82- -0.13	
			0.31	1.31 - 0.18 a				
Pop. Density (pers/ha)	US	log-linear	-0.44	-0.53	0	1.38	-0.27	12.8 - 14.0
	EU	log-linear	-0.23	-0.32	0.39	0	0	54.3 - 49.4
	ASIA	log-linear	-0.34	-0.37	0	2.2 - -2.2	0.40?	
	pool	semi-log	-1.94 - -0.04	-2.37 - -0.03				
	pool	log-linear	-0.31 -0.33	-0.50 -0.51	0	0.25	-0.26	
Gasoline Price (USD/liter)	US	log-linear	0	0	0	0	0	0.68- 0.33
	EU	log-linear	0	0	0	0	0	1.04 - 0.71
	ASIA	log-linear	0	-0.80	-0.26	0	-0.92?	
	pool	semi-log	-0.82 - -0.01	-1.12 - -0.01				
	pool	log-linear	0	-0.24	-0.20	0.19	0	
			-0.11	-0.13				
Public Transport	US	log-linear	0	0	0	↑	-0.40	dummy variables
	EU	log-linear	0	0	0	↑	-0.36	
	ASIA	log-linear	0.68	0	0	↑	-0.32?	
	pool	log-linear	0	0	0	↑	↑	
note							(with Urban rail)	
break point of per capita GRP				a) 102,565	21,756		25,929(24,154)	(USD 1995PPP)

Note: Values in US, EU and ASIA column are estimated results using only regional data.
Values with question mark in ASIA are statistically insignificant.
Left hand side values with range in all columns are elasticities when per capita GRP is 1,000 USD and right hand side values are elasticities when per capita GRP is 43,000 USD.