Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 3250 - 3263, 2005

CHANGE IN PRICE AND INCOME ELASTICITY OF GASOLINE DEMAND IN JAPANESE CITIES, 1980's – 1990's

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Abstract: In this paper, the elasticities of fuel price and income for household gasoline consumption and their change from 1980's to 1990's are estimated for Japanese cities using data from Japan's Family Income and Expenditure Survey, consciously taking into consideration local characteristics. Income elasticity decreases from the 1980's to the 1990's in both major and the non-major cities, and price elasticity decreases in major cities. A decline in these elasticities of household car ownership ratio plays a major role. Simultaneously, population density elasticity increases. This suggests that economic tools work at the early stage, but in the later stage, land use control to increase population density plays a relatively important role.

Key Words: gasoline demand, price and income elasticities, population density

1. INRODUCTION

The decline in oil demand was offset by the growth in transport oil demand, and as a result International Energy Agency (IEA) oil demand levels in 2001 were comparable to those in 1973. The most important reason behind the growth in transport demand is the increased use of cars for passenger travel. Car ownership levels have risen by 100% or more in many countries since 1973, and while car engines have become more efficient over the years, cars have also become larger, heavier and more powerful. This has served to limit improvements in average fuel efficiency. Consequently, oil use for cars grew by almost 50% between 1973 and 1998 (IEA (2004)). In order to reduce transport energy use, technological, economic, infrastructure and urban form policies have been reviewed and implemented.

Elasticity is one of the basic indicators when discussing policy impacts. In the transport sector, a large number of studies have been conducted to estimate the elasticities over the years (recent review, see Hanly, Mark et. al (2002), Molly Espey (1998)). One of the interesting results on income and price elasticity of transport demand and/or gasoline use is that the elasticities tend to decrease over years. For example, when we compare Dahl (1995), a review paper based on 1990's research, and Sterner (1991), also a review paper based on 1980's research, the average value of long-term income and price elasticity changes from 1.21 to 0.72 and -0.86 to -0.65, respectively (Table 1).

Table 1. Change in Income and Fuel Price Elasticity

		Dahl and Sterner (1991)	Dahl (1995)
Income	Short Term	0.48	0.19 (-0.1 – 0.85)
	Long Term	1.21	0.72 (-4.5 – 1.22)
Fuel Price	Short Term	-0.26	-0.13 (-0.0 - -2.13)
	Long Term	-0.86	-0.65 (0.0 - -5.0)

Note: average value, parenthesis shows the range

Is this decreasing tendency also applicable for Japanese cities? If so, then the pricing approach would be less effective than other non-economic policies in especially developed countries. In other words, economic tools should be applied strategically in developing countries to reduce gasoline consumption.

On the other hand, based on meta-analysis, Espey (1998) showed that short-term gasoline demand price responsiveness appears to have declined over time, yet the long-term price elasticity appears to have increased over time (from pre-1974 to post-1981). He pointed out that fuel efficiency technological change affected long-term elasticity greatly.

The purpose of this paper is to estimate the elasticities of fuel price and income for household gasoline consumption and how their change from 1980's to 1990's is estimated for Japanese cities. Generally, the value of elasticity changes by model form, in particular, with/without vehicle ownership (Espey (1998)). In this paper, we implement almost the same model used in Tanishita et al. (2004) that explicitly considers interdependency between car ownership and usage. However, in that model, technological change in fleets is ignored, as road fleet average fuel economy in the 1990's is almost constant. In this paper, we consider not only local characteristics such as population density[1] and road infrastructure, but also technological change.

Section 2 describes the general model and factors considered for city level analysis. Section 3 describes the data and the variables included in the analysis. In Section 4, the two components of the model, or the car-ownership ratio and gasoline consumption per car, are respectively

[1] An enormous amount of research has shown that population density is strongly correlated with the amount of gasoline consumed (ex. Banister and Banister (1995) and Peter Newman and Jeffrey Kenworthy (1999), p.101).

estimated. The price and income elasticity for major and non-major Japanese cities are then shown using of the estimated components. Section 5 concludes and discusses some of the implications for this policy.

2. MODEL

The model presented in this paper is quite simple and is given by the equation below (Tanishita *et al* (2004)).

$$G_i = O_i * U_i \tag{1}$$

Where, G_i: gasoline demand per household in city i
O_i: car-ownership ratio in city i
U_i: gasoline demand per car in city i

The above model lets us analyze the roles of the car-ownership rate and average gasoline demand rate separately. Espey (1998) pointed out that vehicle ownership was certainly a significant explanatory variable for the demand for gasoline, and exclusion of such a measure would be expected to bias the results. In addition, an obvious advantage is that it allows us to examine how large a fraction of a long-term reduction in fuel demand, due to a fuel price increase, is the result of a reduction in a particular type of car stock or a decrease in overall gasoline consumption.[2]. The authors model these two components, which are shown on the right-hand side of Equation (1). Following the convention of earlier models, we assume that car ownership and gasoline demand per car are affected by the following factors:

1) Disposable income
2) Fuel price
3) Car-related costs other than fuel (e.g., insurance, parking and maintenance costs, ownership taxes)
4) Vehicle technology and fleet composition (average fleet fuel economy)
5) Lagged variables (car-ownership ratio, gasoline demand per car)
6) Urban structure
    a) Population density
    b) Transport infrastructure (e.g., road area, no. of rail stations)

It should be noted that these two components are not assumed to be independent of each other. This seems intuitively plausible when considering budget constraints. That is, gasoline demand per car will generally decrease as the number of cars increases in a household, which

[2] In Japan, more than 95% of cars are gasoline-powered vehicles. Therefore, I omit vehicles powered by other means in this analysis.

is positively linked to household income. Simultaneously, overall car ownership will be affected by total fuel expenditures, which is a product of gasoline price and demand. Hence, price and income elasticity of gasoline demand is affected via this interaction.

The basic equation for estimating both the car-ownership ratio and the gasoline demand per car is carried out using a log-log functional form. The authors assumed that the components are influenced by a lag effect in a discrete and independent manner. This simplifies the econometrics considerably, as we need not use simultaneous equation methods.

$$LnO_{it} = \alpha_0 + \alpha_1 LnO_{it-1} + \alpha_2 Ln(P_{it-1}U_{it-1} + D_{it-1}) + \alpha_3 LnI_{it} + \sum_k \alpha_k Ln\mathrm{X}_k \tag{2}$$

$$LnU_{it} = \beta_0 + \beta_1 LnU_{it-1} + \beta_2 LnO_{it-1} + \beta_3 LnP_{it} + \beta_4 LnI_{it} + \sum_k \alpha_k LnX_k \tag{3}$$

Where,
O : Car ownership ratio (Cars/Household)
U : Gasoline demand per car
P : gasoline price D : car - related cost other than fuel cost
I : Income X : Other variables
α, β : Parameters i : City t : year

I assumed car ownership ratio is determined by income, car ownership ratio in previous period, car ownership cost (= fuel cost + other cost such as parking cost, maintenance cost and insurance etc.) and other regional variables.

In each model, parameter α and β show short-term elasticities (MacKinnon et. al. (1983)). However, long-term elasticity is not simple because of the interaction between these equations. I built a computer program to estimate this value. In addition, long-term elasticity is not a constant value because equation (2) is not a simple log-linear model regarding gasoline demand per car. In this paper, long-term elasticity was calculated by increasing price and income by 10%, respectively.

3. DATA

In this paper, the authors use data from Japan’s "*Household Income and Expenditure Survey*" for gasoline demand per household. This survey also contains data on disposable income, car-ownership costs, etc. aggregated for the capital cities of Japan’s 47 prefectures. The number of cars was obtained from the "*Statistics on Number of Automobiles Owned*". Using these two data sets, the authors calculated gasoline demand per car and car-ownership cost per car by city and year.

Japan's "*Household Income and Expenditure Survey*" has limitations regarding econometric analysis. That is, samples are merely for a total of 96 households for each city and the data only covers a 10-year period for the 1980's (1980-1990) and 10-year period for the 1990's (1990-2000). Therefore, in order to increase the number of samples and improve statistical validity, cities are classified into major and non-major cities on the basis of population density. I defined 9 capital cities located in 3 major metropolitan areas in Japan (Tokyo, Nagoya, Osaka) as major cities. They have a relatively rich supply of public transport (mainly subway or suburban rails). For example, in 3 major metropolitan areas, modal share of public transport (passenger-km) is about 53% in 1999. On the other hand, the share is only 28% in the whole of Japan (Ministry of Land, Infrastructure and Transport (1999)). Therefore, by using pooled time-series and cross-sectional data, the authors will verify the hypothesis that price and income elasticities for gasoline demand differs for major and non-major cities and decrease from the 1980's to 1990's.

Other explanatory variables are shown in Table 2. Data acquired from the national census, such as the number of workers and a ratio classifying workers by industry, are obtained for every five years. Missing data is obtained using linear interpolation.

Table 2. Variables for Model Estimation

Variables (Unit)	**Source (Organization)**
Fuel price (Yen/liter)	Retail Price Statistics (Statistics Bureau, MPHPT)
Disposable income (Yen)	Household Income and Expenditure Survey (MPHPT)
Car-related costs – parking fee, insurance, ownership taxes, maintenance cost (Yen/car)	
Population density in densely inhabited districts (person/ha)	National Census City Planning Statistics (MLIT)
Road length (km)	Road Statistics (MLIT)
Number of cars	Statistics on Number of Automobiles Owned (AIRA)
Official fleet average fuel economy (liter/km)	Survey report by METI

Note: I combined these variables for model estimation (e.g., road length per capita, fuel price / disposable income, etc.). MPHPT: The Ministry of Public Management, Home Affairs, Posts and Telecommunications, MLIT: Ministry of Land, Infrastructure and Transport, AIRA: Automobile Inspection & Registration Association, METI: Ministry of Economy, Technology and Industry. All monetary values are adjusted using Consumer Price Index (CPI).

Table 3 shows the change in average values of variables in Table 2 from 1980's to 1990's. In Japan, real average disposable income did not increase because of economic depression, however, average car ownership ratio and average gasoline consumption per car increased in both the whole cities and major cities.

Table 3. Change in Average Values from 1980s to 1990s

Variables	cities	'80s	'90s	%change
Fuel Price (yen / liter)	whole	121	110	-9.1
		(6.7)	(6.6)	
	major	120	109	-9.2
		(5.8)	(6.3)	
Disposal Income (thou. yen / year)	whole	5,990	5,985	-0.1
		(559)	(622)	
	major	6,019	5,846	-2.9
		(512)	(519)	
Car-related costs (yen/ month)	whole	16,897	15,974	-5.5
		(1,886)	(2,083)	
	major	17,727	17,355	-2.1
		(1,721)	(2,112)	
Population Density (pers./km2)	whole	6,573	6,422	-2.3
		(1,970)	(1,952)	
	major	8,556	8,513	-0.5
		(2,239)	(2,101)	
Road Length (km)	whole	1,873	2,532	35.2
		(2,000)	(1,986)	
	major	3,374	4,293	27.2
		(2,717)	(2,661)	
Car Ownership ratio (vehicles/HH)	whole	0.70	0.93	32.9
		(0.16)	(0.24)	
	major	0.57	0.76	33.3
		(0.12)	(0.17)	
Gasoline Consumption per car (liter)	whole	447	471	5.4
		(78)	(77)	
	major	405	420	3.7
		(55)	(60)	

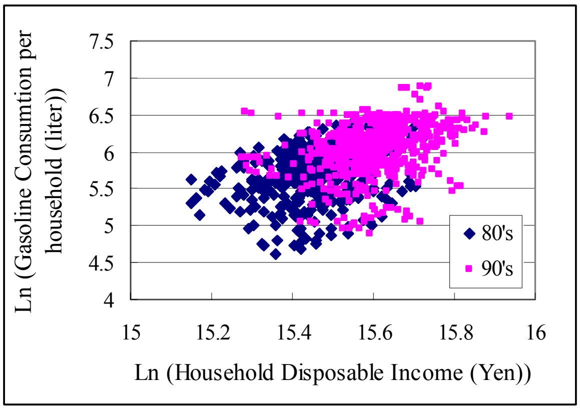
Note: Parentheses show the standard deviation of panel data and HH means households.
All monetary values are adjusted as constant prices in 2000.

Figure 1 shows the relationship between income and gasoline consumption per household, and car ownership and gasoline consumption per car. Needless to say, income is one of the important factors to explain gasoline consumption but we still have many inconsistencies. It is not easy to find; car ownership and use (gasoline consumption per car) tend to have negative correlation in each cities.

4. RESULTS

4.1 Car Ownership Ratio

Table 4 shows the parameter estimation results of car ownership ratio for the whole cities and major cities. Each parameter except for intercept and household car ownership ratio in previous year represents the short-term elasticity with respect to car ownership ratio.



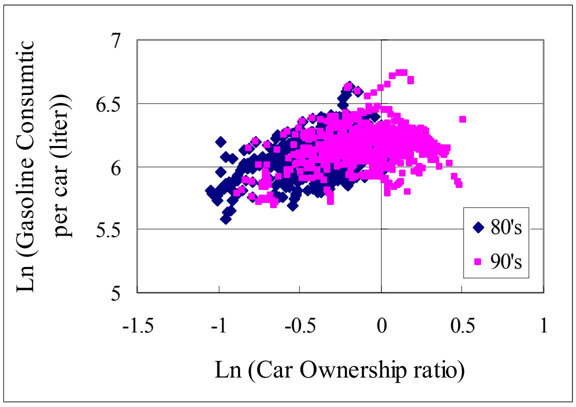


Figure 1. Relationships between Income and Gasoline Consumption per Household (left), and Car Ownership and Gasoline Consumption per Car (right).

Table 4. Estimated Parameters of Car Ownership Ratio

	The whole cities		Major cities	
	1980's	1990's	1980's	1990's
Intercept	-0.50 (-1.98)	0.87 (3.94)		1.54 (2.17)
O-1	0.97 (151.11)	0.92 (123.20)	0.995 (68.17)	0.83 (28.58)
INC	0.063 (3.64)	0.050 (3.72)		0.098 (2.28)
OC	-0.039 (-2.71)	-0.11 (-7.98)		-0.16 (-4.28)
OC/INC			-0.010 (-3.25)	
DEN		-0.039 (-5.65)		-0.13 (-3.57)
R2	0.98	0.99	0.98	0.98
No. of samples	470	470	80	80

Note: O-1: Household car ownership ratio in previous year, OC: car ownership cost which consists of fuel and other car related costs, INC: disposable income per household, DEN: population density, all values are transformed using logarithm. Values in the parenthesis show t-value. OC/INC variables means that same but opposite signed coefficient (elasticity) is assumed for income and ownership cost.

In the 1980's, population density is not statistically significant; however, it became a significant variable in the 1990's.

Income is a key variable but the value (short-term elasticity) decreased from the 1980's to the 1990's for the non-major cities. The coefficient of ownership ratio in previous years declines from the 1980's to the 1990's. Therefore, long-term income elasticity declines if gasoline demand per car does not change. Income and ownership cost elasticities for major cities are higher than that for non-major cities. On the other hand, ownership cost and population density elasticities increased.

In the 1980's, a coefficient of car ownership ratio in previous year is almost 1 for major cities. I believe this is caused by migration in particular; youth migration from rural areas to the city. Subsequently, I will re-estimate considering the migration factor in the near future.

4.2 Gasoline Consumption per Car

Estimation results of gasoline consumption per car, which is another component of gasoline consumption, are shown in Table 5.

Table 5. Estimated Parameters of Gasoline Consumption per Car

	The whole cities		Major cities	
	1980's	1990's	1980's	1990's
Intercept	2.22 (8.20)	0.66 (2.74)	1.82 (2.22)	
U-1	0.89 (57.62)	0.92 (59.07)	0.72 (13.70)	0.77 (12.70)
O-1	-0.031 (-2.07)	-0.027 (-1.98)	-0.10 (-2.10)	
P				-0.25 (-2.58)
INC				0.19 (3.73)
P/INC			-0.14 (-2.10)	
DEN	-0.092 (-6.08)	-0.048 (-3.22)	-0.19 (-3.85)	
FE	-0.073 (-4.75)	0.018 (2.69)		
CAR				-0.095 (-3.56)
ROAD				0.11 (3.35)
R2	0.92	0.92	0.87	0.84
No. of samples	470	470	80	80

Note: U-1: Gasoline consumption per car in previous year, O-1: car ownership ratio in previous year, P: gasoline price, FE: official fleet average fuel economy, CAR: no of cars, Road: road length in the city, other variables are same as Table 3 and all variables are transformed using logarithm. Values in the parenthesis show t-value. P/INC variables means the same but opposite signed coefficient (elasticity) is assumed for income and fuel price.

Gasoline consumption per car decreases with an increase in car ownership ratio or number of cars. In addition, the coefficients are almost constant between the 1980's and the 1990's.

Income and fuel price are not statistically significant for the whole cities. These factors may be reflected in other variables (car ownership ratio, fuel economy etc.). Still, these are significant, and coefficients of gasoline consumption per car in previous variables are lower in major cities. In addition, short-term elasticities increased from the 1980's to the 1990's.

Furthermore, road provision increases gasoline use in major cities in 1990's, not population density and fuel economy. Congestion (CAR and ROAD variables) might be reflected for gasoline consumption.

Gasoline consumption per car could be easily influenced in the past, as a coefficient of gasoline consumption per car in previous year increases from 1980's to 1990's.

Fuel economy is also an important variable for the non-major city. However, the interpretation is not easy. In the 1980's gasoline consumption per car decreases with fuel economy improvement; however, it increases in the 1990's. When I estimate gasoline consumption per household as static model, the coefficient of fuel economy is negative both in the 1980's and the 1990's; this may be caused by a correlation between U-1, DEN and FE variables (Appendix).

4.3 Change in Elasticities

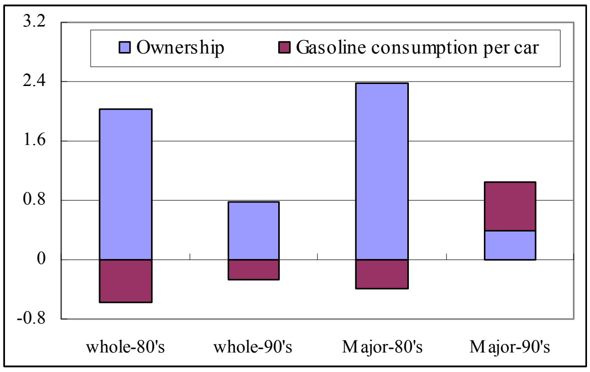
Combined with these two equations, I calculated the elasticities of gasoline demand (Table 6). Decomposition of long term income and fuel price elasticity is also shown in Figure 2.

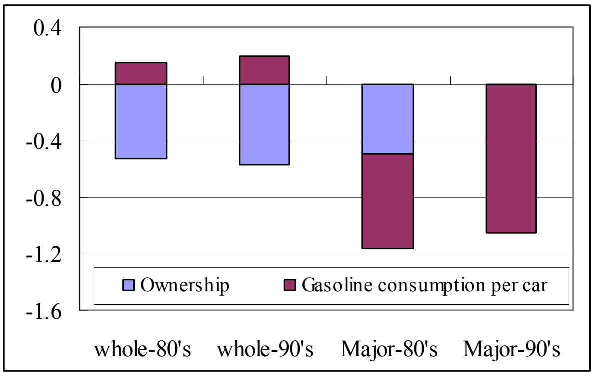
Table 6. Change in Elasticities of Gasoline Consumption from 1980's to 1990's

		The whole cities			Major cities		
		1980's	1990's		1980's	1990's	
Income	Short term	0.06	0.05	→	0.14	0.10	↓
	Long term	1.44	0.51	↓	1.98	0.40	↓
Fuel Price	Short term	-0.014	-0.039	↑	-0.14	-0.30	↑
	Long term	-0.38	-0.38	→	-1.16	-1.05	↓
Ownership Cost other than fuel	Short term	-0.025	-0.071	↑	-0.007	-0.11	↑
	Long term	-0.68	-0.69	→	-1.12	-0.32	↓
Population Density	Short term	-0.092	-0.087	↓	-0.19	-0.13	↓
	Long term	-0.58	-0.77	↑	-0.39	-0.50	↑
Road Supply	Short term					0.11	
	Long term					0.39	

Note: These results are based on 10% increase in each variable. ↑: more than 5% elastic from 1980's to 1990's.
→: within 5% change in elasticity from 1980's to 1990's, ↓: more than 5% inelastic from 1980's to 1990's

Long-term fuel price elasticity is smaller than ownership cost elasticity in the whole city. In contrast, fuel price elasticity in major cities is larger than ownership cost elasticity. In major cities, as the service level of public transport is relatively higher than that of non-major cities, people simply change travel mode with fuel price increase. However, in non-major cities, people have no alternatives to car use. Taking relatively low income into consideration, fuel tax increase has regressive effects.





Income Elasticity | Fuel Price elasticity

Figure 2. Decomposition of Long Term Fuel Price Elasticity of Gasoline Consumption per Household (% change with 1% increase of fuel price)

Income elasticity decreases greatly between the 1980's and the 1990's. This is mainly caused by a reduction in income elasticity of vehicle ownership (Figure 2).

Price elasticity (fuel price and car-related cost) in major cities also decreases from the 1980's to the 1990's. The 1980's decrease in vehicle ownership contributes to the reduction of gasoline consumption per household. However, in the 1990's, almost all reduction comes from car use (Figure 2). In the non-major cities, price elasticity is almost the same.

Conversely, population density elasticity increases. This indicates that monetary factors become gradually inelastic and physical urban structure change becomes more effective in reducing gasoline consumption.

5 CONCLUSIONS

In this paper, I demonstrated that as in the US, income and price elasticities in Japanese cities decrease from the 1980's to the 1990' in major cities. Decreases in income elasticity are seen not only in major cities but also non-major cities. Car ownership ratio plays a particularly major role in this change.

Population density elasticity increases between the 1980's and the 1990's. Income, vehicle and fuel prices shape urban structure (population density). Thus population density gradually affects gasoline consumption. Land use policies take a long time to have any effect. Both economic and land use policy are therefore combined together.

Hammer et al. (2003) in fact, shows that low gasoline price makes it difficult to increase in gasoline tax. In addition, as Greene (1999) demonstrated, fuel economy is not an exogenous variable, as I assumed in this paper, but is affected by income or price in the long-term. Taking population density and technological aspects into consideration, I will verify the initial hypothesis for Asian counties and cities.

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APPENDIX

Estimation of gasoline consumption per household

In this paper, I divide gasoline consumption per household into car ownership ratio and gasoline consumption per car and build a model respectively to take interdependency between car ownership and usage into consideration. However, needless to say, we can directly estimate elasticities of gasoline consumption per household (Table A1). Here, demonstrate the results of the static model, as the parameters of the dynamic model are quite different from that in the main text.

The equation is as follows.

$$\ln(G_{it})=\Sigma\alpha_j \ln(X_{ijt})+\varepsilon_{it} \quad \text{(A.1)}$$

Where, G_{it}: gasoline consumption per household in city i and year t

X_{ijt}: explanatory variables (income, fuel price, ownership cost other than fuel cost, population density and official fleet average fuel economy) item j in city i and year t.

α_j: parameters

ε_{it}: normally distributed error term

Table A1. Estimation Results of Static Model for Gasoline Consumption per Household

	The whole cities			Major cities		
	80's	90's		80's	90's	
Intercept	12.59 (7.06)	16.50 (10.41)		17.26 (3.19)	12.32 (3.57)	
INC	0.88 (10.27)	0.42 (7.62)	↓	0.77 (4.86)	0.91 (4.56)	↑
P	-1.26 (-6.04)	-0.88 (-5.71)	↓	-2.09 (-2.14)	-1.19 (-2.71)	↓
V	-0.23 (-3.71)	-0.15 (-3.10)	↓	-0.35 (-2.60)	-0.30 (-2.93)	↓
DEN	-0.99 (-24.99)	-1.02 (-21.44)	↑	-1.07 (-12.79)	-1.09 (-12.28)	↑
FE	-0.31 (-5.38)	-0.18 (-4.99)	↓		-0.14 (-13.28)	
R2	0.76	0.83		0.86	0.87	
No. of samples	470	470		80	80	

Note: V: car-related cost (ownership cost other than fuel cost), other variables are the same as the variables in Table 3 and 4. All variables except for fuel economy are transformed using logarithm.

The sign of coefficient of fuel economy is negative in both the 1980's and the 1990's though different estimation results were obtained for gasoline consumption per car.

As correlation of fuel economy and income is relatively high in major cities in 1980's, FE variable is not statistically significant. Therefore, comparison of income elasticity between the 1980's and the 1990's may be inappropriate.

Excluding the income elasticity change in major cities, all other elasticity changes are consistent with the result in the main text. However, the values of fuel price elasticity are higher, and values of ownership cost and population density elasticity are smaller than long-term elasticity in Table 5. Espey (1998) suggested that exclusion of vehicle ownership generally results in more price and more income-elastic estimates. Further estimation using different forms and estimation techniques is required.