The Demand for Automobile Fuel Efficiency in Taiwan

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The Asian Conference on Sustainability, Energy & the Environment 2014
Official Conference Proceedings
0783

Abstract
Based on the data for Taiwan's automobile industry, we explore consumers' preferences over various automobile characteristics and responses to increasing fuel expenditures. We find that while consumers prefer more fuel efficient automobiles, the preference for higher power is insignificant when endogeneity issues are fully accounted for, which reflects for a small and crowded country with strict speed limits, having a high-performance automobile is less attractive—a very different result compared to those of existing studies, which are mostly focused on the U.S. market. We also find that while higher oil prices discourage automobile sales, consumers prefer heavier automobiles, which may have better ride quality and safety features. Moreover, since for an average consumer in Taiwan, purchasing an automobile constitutes a higher expenditure share than that of a U.S. consumer, the automobile demand in Taiwan might be more elastic, and our findings confirm this argument.

Keywords: Automobile Demand, Instrumental Estimation

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I. Introduction

Increasing fuel demand has made Taiwan import over 99.98% of the crude oil supply in 2012, of which almost 30% was upgraded to gasoline by local refineries, and around two thirds of the gasoline was consumed domestically (Bureau of Energy, 2012). To reduce the dependence on imported crude oil feedstock and to cut greenhouse gas emissions, the government has been trying to reduce gasoline consumption by encouraging the production and purchase of more fuel efficient automobiles.

Nevertheless, during year 2000 and 2005, the consumption of gasoline increased by 11.8% from 8,201 million liter oil equivalent (MLOE) to 9,168 MLOE, despite the more than 22% increase in domestic gasoline price during that period. Although gasoline consumption declined down to 8,242 MLOE in 2008 due to the price peak of crude oil in that year, it went up again to around 8,588 MLOE in 2011, as presented in **Figure I.1**. The rising gasoline price in recent years has brought the fuel efficiency of automobiles in the spotlight. Although **Figure I.2** shows that as the gasoline price growth rate goes up, gasoline consumption growth rate tends to decline, both automobile manufacturers and policy makers are interested in learning more accurate information regarding consumers' responses to increasing fuel expenditure (NT$ per kilometer).

While research on consumers' preferences on fuel efficiency (kilometers traveled per liter of gasoline) is of great interest to many people, one of the challenges in conducting empirical studies on this was to account for the endogeneity issue of automobile prices and unobservable product characteristics. For instance, while fuel efficiency is observable to econometricians, other product characteristics such as prestige, style, and ride quality are usually not. These unobservable characteristics are included in the error term and are, unfortunately, correlated with at least one of the regressors − the automobile price. To solve this, Berry et al. (1995) presented a framework that considers the correlation between the automobile price and unobservable characteristics, and thus improved the estimations of cost and demand parameters.

However, Berry et al. assumes in the estimation strategy that unobserved characteristics are exogenously fixed, and they are uncorrelated with observed characteristics such as fuel efficiency levels. These assumptions imply that automobile makers cannot choose a combination of product characteristics endogenously in response to rising gasoline prices or fuel efficiency regulations. Recent studies by Gramlich (2010), Klier and Linn (2010a), and Klier and Linn (2010b) relax these constraints and as a result, automobile makers can also choose various product characteristics as well as prices of their products in response to changes in economics environment.

Although the advancement made by recent studies has improved the quality of estimation, they have focused exclusively on the U.S. automobile markets rather than those of other countries. We believe the example of Taiwan is worthy of studying since the economic and geological conditions are very different from those of the U.S. For instance, purchasing a automobile constitutes a higher expenditure share for an average Taiwanese consumer compared to the U.S. case, which suggests the estimate for the own-price elasticity of automobile demand may be quite different from that of the U.S. Further, as a small and crowded country, the road condition of Taiwan is very different from that of the U.S., and this is likely to affect consumers' preferences. For instance, while Klier and Linn (2010a) finds that the U.S. consumers value the increase in power more than a proportional increase in fuel efficiency, are those findings still applicable to a small country such as Taiwan? Are consumers in Taiwan more sensitive to the automobile price, and if so, to what extent? In fact, we have relatively limited knowledge to answer these questions so far.

To fill this gap, we conduct the research based on 15-year panel data of Taiwan, which include sales of domestically produced automobiles, observable product characteristics of automobiles, as well as gasoline prices and other macroeconomic variables from 1997 to 2011. We present results on how gasoline price, product characteristics, and automobile price affect automobile sales based on various model settings and estimation strategies.

The rest of our study is organized as follows: Section II demonstrates the model settings, Section III presents the estimates and explores implications of the results, and Section IV provides conclusions and future research directions.

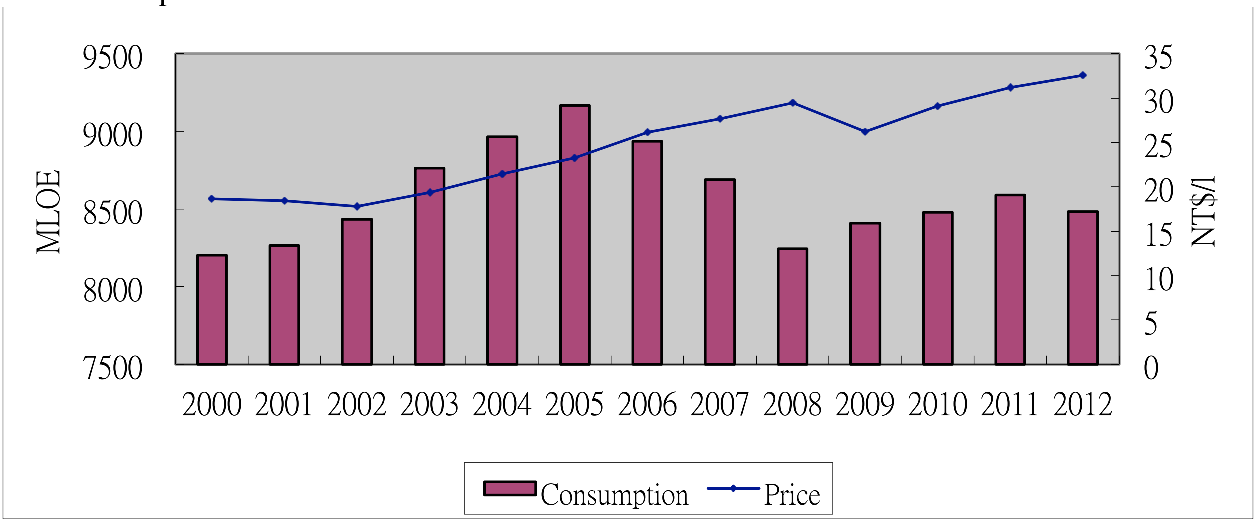

Figure I.1. Motor Gasoline Consumption and Price in Taiwan

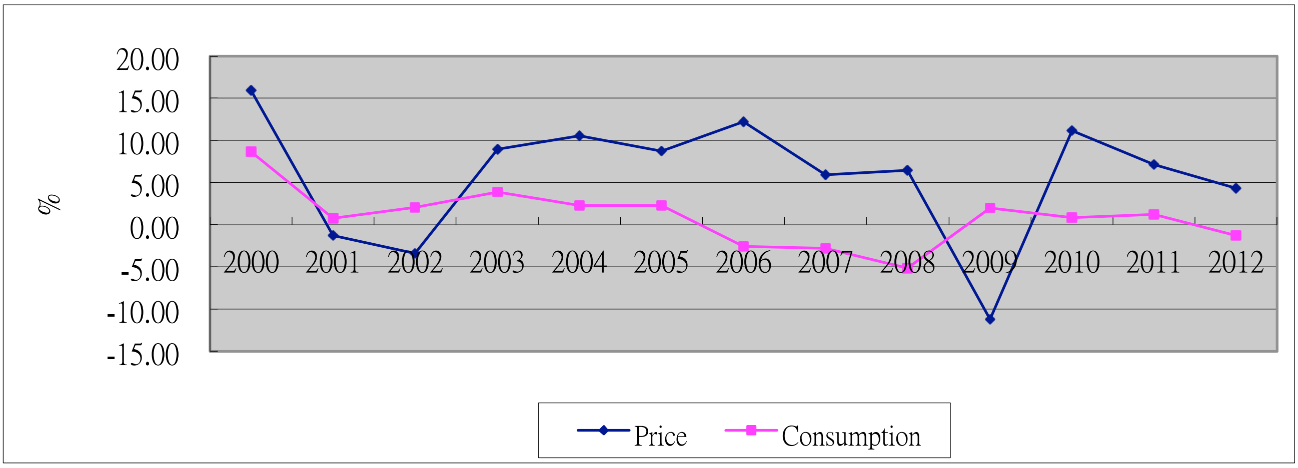

Figure I.2. Growth Rates of Gasoline Price and Gasoline Consumption in Taiwan

II. Model

This section presents the decision-making problem of an automobile buyer (and henceforth the consumer) who will either purchase a new automobile or a pre-owned automobile. It also demonstrates how to apply the strategies of Klier and Linn (2010b) and Gramlich (2010) on identifying the parameters.

II.1 Basic Framework

Similar to Berry et al. (1995), let us assume that for consumer i, the utility of choosing product j can be represented by:

$$U_{ij} = U(p_j, x_j, \xi_j, \varphi_i;\ \theta) \qquad (2.1)$$

where p_j, x_j, and ξ_j are the price, observed characteristics, and unobserved characteristics (to the econometrician) of product j, respectively, and φ_i is the characteristics of consumer i. In the expression above, θ is the parameter vector to be estimated. With this setting, consumer i chooses product j if and only if the following condition holds:

$$U\left(p_j, x_j, \xi_j, \varphi_i;\ \theta\right) \geq U(p_k, x_k, \xi_k, \varphi_i;\ \theta) \qquad \forall k = 0, 1, 2, \ldots, j, \ldots, J \qquad (2.2)$$

While $k\backslash 0 = \{1, 2, \ldots, J\}$ is the set of new automobiles, the choice 0 represents the outside option for consumer i, which is the purchase of a pre-owned automobile since we focus on automobile buyers. The expression means that for consumer i, choosing product j over others will yield the highest possible utility level. While Berry et al. considers the correlation between price p_j and the unobserved characteristics ξ_j, it assumes that ξ_j is exogenous to firms. Klier and Linn (2010b) and Gramlich (2010), on the other hand, extends the framework of Berry et al. and propose strategies without assuming ξ_j exogenous to firms. Therefore, our study will base on these two approaches, which are illustrated below.

II.2 The strategy of Klier and Linn (2010b)

In (2.1), let us consider $x_j = \{dpm_j, ptw_j, weight_j\}$ where dpm_j is dollar per distance traveled, ptw_j is power to weight ratio, and $weight_j$ is the weight of product. Since data for consumers' characteristics are unavailable, (3.1) is expressed as follows with ε_{ij} representing the error term of the estimation:

$$U_{ij} = U\left(p_j, dpm_j, ptw_j, weight_j, \xi_j, \varepsilon_{ij}\right) = \delta_j + \varepsilon_{ij} \qquad (2.3)$$

In (2.3), $\delta_j = \delta(p_j, dpm_j, ptw_j, weight_j, \xi_j)$, which is the average utility level of consumer i derived from the characteristics of product j. The error term ε_{ij} represents the consumer-specific shock when consumer i purchases product j. Assuming the utility function is linear and separable, we have:

$$\delta_j = \alpha \ln p_j + \beta_d dpm_j + \beta_h ptw_j + \beta_w weight_j + \xi_j \qquad (2.4)$$

Klier and Linn (2010b) implement a nested multinomial logit (NML) model so that a consumer first decides whether to buy a new automobile or not, then selects a class of automobile, and finally chooses a product (automobile model).[1] To implement the NML model, we classify new automobiles into C categories so that each product j belongs to one class c. For convenience, we define a class set

[1] While for a NML model, independence of irrelevant alternatives (IIA) still exists for choices within the same class, choices from different classes do not subject to IIA. Therefore, NML model is less restrictive compared to a non-nested multinomial logit.

$\mathbb{C} = \{c | c \in \{0, 1, 2, \ldots, C\}\}$ so that the outside option $j = 0$ (purchasing a pre-owned automobile) is the single element of class 0.

The error term in (2.3) can be decomposed into the class shock ω_{ic} common for all automobiles within the same class, and the idiosyncratic shock η_{ij} that follows an independent and identically distributed (i.i.d.) extreme value distribution:

$$\varepsilon_{ij} = \omega_{ic} + (1 - \sigma)\eta_{ij} \tag{2.5}$$

In (2.5), a higher σ means that, when purchasing product j, consumer i receives less idiosyncratic shock and more class shock. Therefore, σ determines the level of shock similarity when choosing the same class. Based on this setting, we can derive the conditional probability of choosing product j given that class c is chosen:

$$s_{j|c} = \frac{e^{\frac{\delta_j}{1-\sigma}}}{D_c}\text{; where } D_c = \sum_{j \in c} e^{\frac{\delta_j}{1-\sigma}} \tag{2.6}$$

In (2.6), the conditional probability can also be interpreted as the share of product j within class c. Similarly, the probability of choosing class c, or the share of class c out of $\mathbb{C}$, can be written as:

$$s_c = \frac{D_c^{1-\sigma}}{\sum_{c \in \mathbb{C}} D_c^{1-\sigma}} \tag{2.7}$$

We can derive the share of product j, which is also the unconditional probability choosing product j:

$$s_j = s_c \cdot s_{j|c} = \frac{e^{\frac{\delta_j}{1-\sigma}}}{D_c^{\sigma}\left[\sum_{c \in \mathbb{C}} D_c^{1-\sigma}\right]} \tag{2.8}$$

The outside option is the only element of class 0, and its share function can be written as:

$$s_0 = \frac{1}{\sum_{c \in \mathbb{C}} D_c^{1-\sigma}} \tag{2.9}$$

Taking the log transformations of (2.6), (2.8) and (2.9) and rearranging terms, the regression model for the share of product j can be written as:

$$\ln s_j - \ln s_0 = \sigma \ln s_{j|c} + \alpha \ln p_j + \beta_d dpm_j + \beta_h ptw_j + \beta_w weight_j + \xi_j \tag{2.10}$$

In (3.10), since ξ_j includes firm-chosen product characteristics that are unobservable to econometricians but could correlate with observable characteristics on the right side of (2.10), Klier and Linn (2010b) uses an instrumental variable (IV) approach (also called two-stage least squares regression) such that observable characteristics of other product j' with the same engine platform as j are used to instrument for those of j.

II.3 The strategy of Gramlich (2010)
In (2.1), let us consider $x_j = \{dpm_j, qual_j, \boldsymbol{X}_j\}$ where the dpm_j (dollar per distance traveled) follows the same definition as in (2.3), $qual_j$ is the observable characteristics of quality including horsepower and weight, etc., and $\boldsymbol{X}_j$ includes the macroeconomic variables including GDP growth rate and per capita GDP, etc. Thus, similar to (2.3), now (2.1) can be written as:

$$U_{ij} = U(p_j, dpm_j, qual_j, \boldsymbol{X}_j, \xi_j, \varepsilon_{ij}) = \delta_j + \varepsilon_{ij} \qquad (2.11)$$

Let us define mpg_j as the distance traveled per unit of fuel by product j. Gramlich (2010) uses $\ln mpg_j$ to measure $qual_j$ based on the negative association (statistically significant) between these two variables, and represents δ_j as:

$$\delta_j = \alpha p_j + B_d dpm_j + \beta_m \ln mpg_j + \boldsymbol{B}\boldsymbol{X}_j + \xi_j \qquad (2.12)$$

While Gramlich (2010) set up a three-level nest structure to classify products,[2] we find the structure is not suitable for our data because in Taiwan's market, there are relatively fewer products compared to the U.S. market. Thus, we adopt the same nest structure of Klier and Linn (2010b). As a result, the error term ε_{ij} is decomposed in the same fashion as (2.5), the market shares are derived similar to (2.6), (2.7), (2.8) and (2.9), and the regression model for the market share of product j becomes:

$$\ln s_j - \ln s_0 = \sigma \ln s_{j|c} + \alpha p_j + \beta_d dpm_j + \beta_m \ln mpg_j + \boldsymbol{B}\boldsymbol{X_j} + \xi_j \qquad (2.13)$$

To conduct the estimation, Gramlich (2010) also uses the IV approach, and the estimates for the coefficients of regressors are constructed by the moment that specifies the orthogonality condition of unobservable characteristics ξ_j and information that is uncorrelated to ξ_j.

III. Data
Our data for automobile sales are from the Taiwan Transportation Automobile Manufacturers Association (TTVMA). The data include monthly sales starting from June 1997 to December 2010. The characteristics of automobiles within the same time period are from Automobile Guide and Automobile News. Those characteristics include the class of product (small automobile, middle automobile, large automobile, small recreation automobile (RV), and middle RV), engine displacement, product length, product width, product height, product weight, wheelbase, horsepower, torque, cylinder numbers, and fuel efficiency, as shown in **Table III.1**. We get the automobile price data from Automobile Guide since those based on transactions are unavailable. The gasoline price data, on the other hand, are from the CPC Corporation, Taiwan. The data for consumer price index (CPI) are from the Directorate-General of Budget, Accounting, and Statistics (DGBAS). All prices are in 2006 price. Other variables not listed in Table III.1 are presented in **Table III.2**.

The data include 740 observations from 1997 to 2010. **Table III.3** shows that the number of products increases from around 50 in late '90s to 78 in 2008, and then drop

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[2] In Gramlich's original setting, consumer first decides what automobile type he wants, including automobile, utility automobile, truck/van, and the outside option (not purchasing a new automobile), then chooses a segment such as small automobile or sport utility automobile within a given automobile type, and then determines the sub-segment such as low or high-end products within a segment, and finally chooses a specific product within a sub-segment.

to 62 in 2010.[3] The average automobile price, with some fluctuations, increases from 590.6 thousand NT$ (around US$19,687) in 1997 to 764.3 thousand NT$ (around US$25,476) in 2011. The automobile sales peak in 2005 at a level of over 364 thousand automobiles, then drop to around 150 thousand units in 2008 when the average fuel expenditure (NT$ per kilometer traveled) peaks, and then increase mildly later. In addition, the average fuel efficiency drops by 8.51% from 1997 to 2005, a sharp contrast to characteristics such as displacement, horsepower, and weight, which increase by 18.32%, 24.02%, and 23.25% during the same period, respectively. While after 2005, products continue to become bigger, heavier, and more powerful, the average fuel efficiency improves. This may reflect that automobile manufacturers begin to emphasize fuel efficiency in response to market demand and regulation.

Table III.1 Automobile characteristics and corresponding variable names

Characteristics	Variable name	Description
Automobile price	price	Prices listed on Automobile Guide (2006 New Taiwanese Dollars)
Automobile Sales	sales	Monthly sales from TTVMA
Automobile length	length	Millimeters (mm)
Automobile width	width	Millimeters (mm)
Automobile height	height	Millimeters (mm)
Displacement	dis	Cubic centimeters (c.c.); engines with larger displacement tend to be more powerful and consume more gasoline
Wheelbase	wheelbase	Millimeters (mm); automobiles with larger wheelbase tend to be more spacious and stable
Horsepower	hp	Horsepower; engines with higher horsepower are more powerful
Torque	kgm	Kilogram-meter (kgm); at a given revolutions per minute (rpm), higher torque means higher horsepower. Engines with higher torque at lower rpm tend to deliver better low-speed acceleration and are more fuel efficient
Distance traveled per unit of gasoline	mpg	Kilometer per liter (km/l)
Engine cylinder number	cylin	More cylinders tend to have a higher displacement and a lower fuel efficiency level

[3] The decrease in the number of automobile products after 2008 may due to several factors, including the global economic downturn, more stringent fuel efficiency requirement that is in place from 2010 onward, etc. But these are beyond the scope of our study.

Table III.2 Other variables

Variable name	Description	Variable name	Description
s_j	Market share of j	mpgm_1	Last period's average mpg level of a class
s_{jc}	Market share of j within class c	CAC	Manufacturer 1
rprice	Automobile price (base year = 2006)	CMC	Manufacturer 2
rpgas	Gasoline price (base year = 2006)	Ford	Manufacturer 3
dpm	Fuel expenditure (=rpgas/mpg)	Formosa	Manufacturer 4
year	Year	Honda	Manufacturer 5
ptw	Power to weight ratio (=hp/weight)	Kuozui	Manufacturer 6
cft	Comfortableness (=length*width)	Mazda	Manufacturer 7
dism_1	Last period's average displacement of a class	Prince	Manufacturer 8
hpm_1	Last period's average horsepower of a class	San	Manufacturer 9
weightm_1	Last period's average weight of a class	Ta	Manufacturer 10
kgmm_1	Last period's average torque of a class	Yulon	Manufacturer 11

Table III.3 Averages of automobile characteristics

year	# of j	price	sales	mpg	dpm	hp	weight	length	wheel-base	width	dis
*1997	47	59.06	138919	13.87	1.29	111.64	1101.20	4325.92	2523.13	1678.79	1680.19
1998	53	58.41	289171	13.86	1.36	112.95	1129.09	4342.60	2529.09	1689.53	1681.72
1999	41	61.18	250598	13.89	1.29	114.79	1153.49	4342.56	2530.78	1687.12	1701.49
2000	42	68.53	248619	13.63	1.50	126.40	1210.37	4422.19	2553.55	1703.45	1828.67
2001	45	71.84	194955	13.47	1.55	131.89	1243.67	4459.82	2579.31	1711.02	1875.33
2002	49	73.34	248002	13.11	1.55	136.44	1304.08	4433.17	2577.63	1716.76	1933.12
2003	57	73.72	287836	12.87	1.72	137.60	1302.74	4426.40	2587.16	1725.47	1939.86
2004	61	73.69	335357	12.70	1.86	139.13	1345.82	4441.42	2607.10	1738.80	1983.07
2005	58	71.68	364851	12.69	1.98	138.46	1357.25	4417.97	2609.88	1741.32	1987.97
2006	61	72.68	237265	12.82	2.16	141.54	1352.55	4423.24	2613.78	1745.03	1996.82
2007	73	71.25	231683	12.95	2.19	139.93	1364.50	4406.47	2611.89	1745.23	1973.55
2008	78	72.78	150056	13.12	2.30	142.61	1372.25	4408.79	2620.39	1753.58	1997.41
2009	66	76.44	194320	13.35	2.02	148.21	1424.58	4463.53	2652.68	1755.28	2062.80
2010	62	76.43	216632	13.43	2.16	148.58	1441.68	4498.90	2663.93	1779.66	2058.36

* The time period covered for 1997 data is from June, 1997 (the earliest month with all data available) to December, 1997.

IV. Results

We explore how demand for automobile is determined by variables including fuel expenditure (NT$ per kilometer traveled) (dpm), automobile performance (ptw), weight, automobile price ($rprice$), and other macroeconomic variables. We present results based on the model settings of Klier and Linn (2010b) and Gramlich (2010). These settings can be found in **Table IV.1** and **Table IV.2**, respectively. The two tables also present the expected sign of each regressor's coefficient. Note that in Table IV.2, the expected sign for the coefficient of $\ln mpg_j$ is negative since $\ln mpg_j$ is negatively associated to other observable characteristics of "quality" (see II.3). For each setting, we consider the following estimation strategies: 1) ordinary least square (OLS); 2) IV estimation of Berry et al. (1995) (IV-BLP); 3) IV estimation of Gramlich (2010) (IV-JG); and 4) IV estimation derived from both Klier and Linn (2010b) and Gramlich (2010) (IV-KLG).

In particular, for IV-BLP, the focus is to eliminate the correlation between the automobile price and unobserved characteristics (i.e., price endogeneity), and the instrumental variables include observed characteristics, number of products produced by the same manufacturer, and number of same-class-products produced by all other manufacturers. These variables are correlated to the automobile own price and are assumed to be orthogonal to unobserved characteristics of automobile ξ_j. For IV-JG, in addition to dealing with the aforementioned price endogeneity issue, it also takes into account the potential correlation between the observed characteristics (such as ptw) and the unobserved characteristics ξ_j. In IV-JG, observed characteristics are instrumented by the following variables, including torque, length, number of cylinders, wheelbase, and the one-period-lag gasoline price.[4] Lastly, since unlike Klier and Linn (2010b), our data do not allow us to instrument observed automobile characteristics by information from another automobile of different class but with the same engine platform, we propose the IV-KLG approach where the instrumental variables for the observed characteristics include the one-period lagged values of the following variables: displacement, horsepower, torque, fuel efficiency, weight, number of cylinders, and gasoline price.

Table IV.1 Model setting based on Klier and Linn and Expected Signs of Coefficients

Regressand: $\ln sales$	
Regressors	Expected coefficient sign
$\ln s_{jc}$	+; between 0 and 1
$\ln rprice$	–
dpm	–
ptw	+
$weight$	+
$Year \cdot manfacturer$	n/a

Table IV.2 Model setting based on Gramlich and Expected Sign of Coefficients

Regressand: $\ln sales$	
Regressors	Expected coefficient sign
$\ln s_{jc}$	+; between 0 and 1
$rprice$	–
dpm	–
$\ln mpg$	–
$Year \cdot manfacturer$	n/a

We compare results from different model settings and estimation strategies, and investigate the price elasticity of the automobile market in Taiwan. **Table IV.3** presents results based on the model setting of Klier and Linn (2010b). We find in general, the signs of coefficients are consistent to our expectation presented in Table IV.1. The only exception is the negative but insignificant estimate for the coefficient of ptw based on OLS regression. Note that with OLS regression, the own price

[4] Gramlich (2010) assumes that torque, length, number of cylinders, and wheelbase are orthogonal to the demand shock of the current period.

elasticity of automobile is –2.11 (see the coefficient for $\ln rprice$). While this estimate is significant, it is much lower than estimates based on other IV approaches, which could reflect that OLS fails to account for the positive correlation between automobile price and observed characteristics.

The following columns in Table IV.3 present results based on various IV estimations. When using IV-BLP, we find the estimate for the coefficient of ptw becomes positive and significant, which reveals a preference for higher power, other things being equal. Also, the estimate for own price elasticity is higher than the OLS case, which is reasonable since IV-BLP has accounted for the positive correlation between unobserved characteristics and the automobile's own price. The estimation of IV-JG further controls for the potential correlations between observed and unobserved characteristics. While the results are similar to those based on IV-BLP, we find that under IV-JG, the estimates for coefficients of ptw and $weight$ increase relative to IV-BLP, and the negative impact of a higher fuel expenditure becomes more obvious. However, since IV-JG requires that the length of automobile, number of cylinder, torque, and wheelbase should be orthogonal to the unobserved characteristics, which could be questionable, IV-JG may not be able to avoid the endogeneity issues completely. Therefore, we present results based on IV-KLG, and conduct the estimation by GMM, which allows us to choose the lagged regressors as the instrumental variables. Among our findings are: 1) when the price of automobile increases by 1%, there will be 4.12% decrease in automobile sales, i.e., the own-price elasticity of automobile demand is –4.12; 2) when the fuel expenditure increases by 1NT$ (0.033US$) per kilometer, the automobile sales will decrease by 3.31%, which confirms that consumers prefer more fuel efficient automobiles since they lower fuel expenditures; 3) although the coefficient of ptw is positive, it is insignificant even at 10% significance level; and 4) when the automobile weight increases by 1 kilogram, the automobile sales will increase by 0.0092%. The last finding shows that, after controlling for other regressors, consumers prefer heavier automobiles, which may have better ride quality and safety features.

Note that our estimate for the own-price elasticity of automobile demand is much higher than the U.S. case. For instance, Klier and Linn (2010b) reports estimates for this elasticity within the range between –0.43 and –1.86, depending on model settings and estimation strategies. This discrepancy could be explained by the fact that for an average consumer in Taiwan, purchasing an automobile constitutes a higher expenditure share than that of an average U.S. consumer. Based on the IV-KLG approach presented in Table **IV.3**, **Table A1** in the appendix presents the own-price elasticities of products by different car manufacturers, and **Table A2** and **Table A3** present the elasticities for the top-selling cars and RVs, respectively. In short, while we find variations in estimates for different manufacturers, time periods, and classes, these estimates are large. In particular, we find that small cars or RVs tend to have higher own-price elasticities, reflecting that these markets are more competitive, which is consistent to anecdotal evidence.

Besides, an insignificant estimate for the coefficient of ptw in Table IV.3 reveals that for a small and crowded country with strict speed limits, having a high-performance automobile is less attractive—a very different result compared to those of existing studies, which are mostly focused on the U.S. market. Lastly, we also perform the hypothesis test based on Hansen's J statistics where the null hypothesis is that all instrumental variables are uncorrelated to the error term (unobserved characteristics). Since the null is not rejected with a pretty high p-value (0.4935), we are more confident with results based on IV-KLG.

Table IV.3 Results based on Klier and Linn's Setting

	OLS	IV-BLP	IV-JG	IV-KLG
Constant	23.3017***	40.4233***	36.9978***	23.2453***
$\ln s_{jc}$	0.9534***	0.9342***	0.9439***	0.7243***
$\ln rprice$	-2.1099***	-7.8826***	-8.1450***	-4.1205***
dpm	-1.0659***	-1.5111***	-4.4716***	-3.3105***
ptw	-20.0090	16.4005***	27.1085**	13.4250
$weight$	0.0012***	0.0079***	0.0099**	0.0092**
Sample size	740	740	740	571
R^2	0.9099	0.8521		
$\bar{R}^2$	0.9078	0.8487		
Hansen's J			Just identified	0.4689
p-value				0.4935

***,**, and * means 1%, 5%, and 10% significance levels, respectively.

Let us now consider the model setting of Gramlich (2010), which uses $\ln mpg$ as the proxy for the observable "quality" characteristics that is negatively associated with $\ln mpg$ due to the underlying technological tradeoff. To validate this application, we need to verify our data provide evidence that supports this tradeoff argument. The empirical evidence of technology tradeoff is presented in **Table IV.4**. We find when all automobiles are considered in the regression, the coefficients for the log of horsepower and the log of weight are both negative with 1% significance levels, and the regression yields a relatively high R-square value, which confirms the existence of technology tradeoffs between fuel efficiency and weight, and also between fuel efficiency and horsepower, respectively. Table V.4 also shows that in general, regressions including only each sub category of automobiles also reveal similar patterns as the case when all automobiles are included. Therefore, we will present results with Gramlich's setting, as shown in **Table IV.5**.

Table IV.4 Technology Tradeoffs between Fuel Efficiency and Other Automobile Characteristics

Regressand:	$\ln mpg$					
	All-variables	Small-automobile	Middle-automobile	Large-automobile	Small-RV	Middle-RV
constant	6.343***	5.165***	7.281***	2.184	3.831***	6.158***
$\ln hp$	–0.129***	–0.036	–0.441***	–0.066	–0.150*	–0.167*
$\ln weight$	–0.555***	–0.504***	–0.655***	–0.130	–0.310***	–0.276
year	0.009***	0.007***	0.013***	0.012***	0.019***	–0.010***
Sample size	740	258	196	56	172	58
R^2	0.693	0.601	0.589	0.339	0.441	0.553
$\bar{R}^2$	0.691	0.595	0.580	0.291	0.427	0.514

***,**, and * means 1%, 5%, and 10% significance levels, respectively.

We find that, as shown in Table IV.5, all estimates have signs consistent to our prediction (see Table IV.2). In particular, $\ln mpg$ is expected to have a negative coefficient because of the technological trade-off. The stories for the comparison of different estimation approaches are similar to the previous model setting. For instance, we find that compared to the OLS case, when the automobile's own price is instrumented, the coefficient of $rprice$ will become higher. Note that, however, even for IV-KLG, the null hypothesis that all instruments are uncorrelated to the unobserved characteristics is rejected at a 5% significance level. As a result, we find that Klier and Linn's model setting with IV-KLG estimation is more appropriate for our study.

Table IV.5 Results based on Gramlich's Setting

	OLS	IV-BLP	IV-JG	IV-KLG
Constant	17.0558***	20.3912***	23.4064***	15.7625***
$\ln s_{jc}$	0.9577***	0.9637***	0.9334***	0.7729***
$rprice$	-0.0377***	-0.0513***	-0.0568***	-0.0395***
dpm	-0.8122***	-0.7803***	-2.1633***	-1.4271***
$\ln mpg$	-0.3541	-1.6450***	-6.4498***	-1.1642*
Sample size	740	740	740	571
R^2	0.9069	0.9026		
$\bar{R}^2$	0.9050	0.9006		
Hansen's J				4.7388
p-value				0.0935

***,**, and * means 1%, 5%, and 10% significance levels, respectively.

VI. Conclusions

In this study, we investigate consumers' preferences over various product characteristics of automobiles, and examine their responses to increasing fuel expenditures. Our empirical findings reveal that while consumers prefer more fuel efficient automobiles, the preference for higher power is insignificant based on the model setting and estimation strategy that can fully account for the endogeneity issues. This suggests that for Taiwan, a small and crowded country with strict speed limits, having a high-performance automobile is less attractive, which is a very different observation compared to those of current studies focused mostly on the U.S. market. We also find that while automobile weight is negatively associated with fuel efficiency level (kilometer per liter), after controlling for all other factors, consumers prefer heavier automobiles, which may have better ride quality and safety features not directly observable in our data. Lastly, we find that in Taiwan's car market, the own-price elasticity of automobile is lower than estimates for the U.S. market. Since for an average Taiwanese consumer, purchasing an automobile constitutes a higher expenditure share than that of an average U.S. consumer, anecdotal stories suggest that consumers in Taiwan might be more sensitive in changes in automobile prices, and our finding provides empirical evidence for that.

The contribution of this paper is to provide demand side analyses for the automobile markets based on a country with quite different policy and environment backgrounds compared to those in the existing studies. Future research may also work on the supply side model and investigate issues such as automakers' responses to fuel efficiency regulation and the relevant enforcement costs. Although existing studies have done these for the U.S. market, examples from other countries will also be informative.

Table A.1 Average Own-price Elasticities

					Car	makers					
year	CAC	CMC	Ford	Formosa	Honda	Kuozui	Mazda	Prince	San	Ta	Yulon
1997	-4.11	-3.26	-3.98			-3.84	-4.09	-4.12	-3.98	-4.10	-3.31
1998	-4.10	-3.64	-4.01			-3.86	-4.11	-4.12	-3.98	-3.93	-3.48
1999	-4.11	-3.74	-3.93			-3.69	-4.07	-4.12	-3.67	-3.98	-3.59
2000	-4.12	-3.80	-3.87			-3.82	-4.02	-2.38	-3.62	-3.88	-3.76
2001		-3.67	-3.81	-3.99		-3.88	-4.01	-2.75	-3.85	-4.10	-3.72
2002		-3.47	-3.97	-4.01		-3.53	-4.01	-3.86	-4.06	-4.11	-3.88
2003		-3.66	-3.48	-4.04	-3.80	-3.59	-3.88	-4.04	-4.08	-4.12	-3.79
2004		-3.84	-3.67	-4.08	-3.74	-3.28	-3.99	-4.05	-4.03		-3.82
2005		-3.86	-3.90	-4.10	-3.75	-3.27	-3.92	-4.07	-4.04		-3.73
2006		-3.93	-3.90	-4.10	-3.84	-3.43	-3.88	-4.03	-4.03		-3.80
2007		-3.98	-3.94	-4.11	-3.89	-3.37	-3.53	-4.07	-4.09		-3.95
2008		-3.93	-4.00		-3.91	-3.44	-4.00	-4.09	-4.04		-3.81
2009		-3.91	-4.00		-3.94	-3.51	-3.98	-4.10	-4.05		-3.75
2010		-3.95	-3.97		-3.96	-3.50	-3.92	-4.10	-3.97		-3.77

Table A.2 Elasticity of the Top-selling Car in Each Class

	Car maker	Model	Real Price: NT$	Elasticity
		Small	Automobile	
2006	Kuozui	Corolla	63.45 (52.41)	-3.36 (-3.97)
2007	Kuozui	Corolla	62.33 (50.79)	-3.41 (-3.98)
2008	Kuozui	Corolla	69.12 (49.96)	-3.23 (-3.99)
2009	Kuozui	Corolla	61.64 (57.08)	-3.31 (-3.91)
2010	Kuozui	Corolla	61.05 (55.78)	-3.15 (-3.85)
		Median	Automobile	
2006	Kuozui	Camry-L	85.90 (77.10)	-2.76 (-3.86)
2007	Kuozui	Camry-L	85.36 (76.44)	-2.98 (-3.91)
2008	Kuozui	Camry-L	91.04 (78.48)	-2.92 (-3.94)
2009	Kuozui	Camry-L	77.25 (81.76)	-3.31 (-3.94)
2010	Mazda	Mazda 3	70.53 (78.76)	-3.36 (-3.96)
		Large	Automobile	
2006	Kuozui	Camry-L	116.40 (111.25)	-2.84 (-3.62)
2007	Kuozui	Camry-L	129.67 (108.47)	-1.92 (-3.52)
2008	Kuozui	Camry-L	124.30 (108.48)	-2.20 (-3.62)
2009	Yulon	Teana	92.18 (118.52)	-2.15 (-3.52)
2010	Yulon	Teana	92.72 (117.72)	-2.63 (-3.37)

Numbers in parentheses are class averages.

Table A.3 Elasticity of the Top-selling SUV in Each Class

	car maker	model	Real Price: NT$	elasticity
		Small	RV	
2006	Kuozui	Wish	80.05 (76.64)	-3.36 (-3.88)
2007	Kuozui	Wish	78.63 (75.38)	-3.49 (-3.96)
2008	Kuozui	Wish	75.24 (72.54)	-3.69 (-3.96)
2009	Kuozui	Wish	75.91 (73.25)	-3.53 (-3.97)
2010	Kuozui	Wish	75.56 (73.79)	-3.57 (-3.98)
		Middle	RV	
2006	Yulon	X-Trail	90.65 (93.75)	-2.64 (-3.62)
2007	Mazda	Tribute	105.60 (94.18)	-1.92 (-3.69)
2008	Yulon	Serena	81.60 (90.67)	-2.21 (-3.69)
2009	Yulon	Serena	82.75 (93.69)	-2.17 (-3.62)
2010	San	Santa Fe	98.03 (91.69)	-2.59 (-3.52)

Numbers in parentheses are class averages.

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