Vehicle Controls and Petrol Demand in Hong Kong

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Abstract

The demand for automotive petrol in Hong Kong is derived entirely from the demand for personal vehicular transportation. Because the stock of vehicles adjusts over time slowly to changes in the cost of ownership and usage, the demand for petrol also adjusts gradually in response to changes in the cost of owning and operating a vehicle. This study estimates and simulates the demand for petrol in Hong Kong using an empirical model which explicitly accounts for adjustment in the stock of vehicles. The point estimates of short-run price and income elasticities of petrol demand are $-0.25$ and $0.23$, respectively. The long-run price and income elasticities are estimated to be $-1.17$ and $1.71$, respectively.
1 Introduction

The primary purposes of this study are 1) to obtain precise estimates of the short-run and long-run price and income elasticities of demand for petrol in Hong Kong, and 2) to examine the quantitative impact of vehicle controls on the demand for petrol. The interest in Asian energy demand has been growing in step with the importance of Asian economies in the world marketplace. This study focuses on one important component of energy demand—the demand for petrol. McRae (1993) provides the first comprehensive analysis of petrol demand in Asian economies, noting that most prior work on energy demand had focused exclusively on industrialized nations. The present study focuses exclusively on Hong Kong and extends McRae’s earlier study in two ways: the study uses more accurate data, and the study estimates and simulates a two-equation econometric model to show how changes in petrol prices and vehicle fees impact the demand for petrol through adjustments in the stock of vehicles.\footnote{McRae’s (1994) demand model had a poor statistical fit for Hong Kong compared to most of the other countries in his study. McRae attributed the poor fit to anomalies in the gasoline price series for Hong Kong that he obtained from the Asian Development Bank (1989). My study uses petrol prices that were obtained from the Shell company of Hong Kong; it is important to note that these prices differ from those reported by the Asian Development Bank and, presumably, are more accurate.}

The demand for petrol in Hong Kong is derived almost exclusively from the demand for personal transportation by private car. This is so because nearly all petrol consumed in Hong Kong is used by private cars; nearly all taxis, buses and goods vehicles use diesel fuel (Rusco and Walls, 1995a; Rusco and Walls, 1995c). For this reason, it is possible in the context of Hong Kong to analyze structurally the demand for petrol and the demand for private cars. Petrol usage in other countries is frequently the aggregate of many dissimilar components. Because the demand for petrol in Hong Kong consists only of a single component, private car usage, we are able to obtain precise estimates of price and income elasticities.
Because petrol demand in Hong Kong is derived exclusively from personal car transportation, it is possible to examine the effect of vehicle control policies on the demand for petrol. Vehicle control policies—policies designed to increase the cost to an individual of owning and operating a car—have been used by the government of Hong Kong in an effort to alleviate traffic congestion. Vehicle taxes and registration fees are the instruments through which the government discourages vehicle ownership and usage. These vehicle control policies have had a substantial impact on the size and composition of the fleet of private cars (Rusco and Walls, 1995b).

Through their effects on the vehicle fleet, vehicle control policies shift the demand curve for petrol. The aggregate demand for petrol depends on the size of the vehicle fleet in addition to its own price and other factors, while the size of the vehicle fleet depends on the cost of owning and operating a car in addition to other factors. Thus, the demand for petrol is indirectly changed by variables which affect the vehicle stock such as the price of petrol and vehicle fees. The price of petrol, then, affects demand both directly and indirectly; moreover, the indirect changes may occur gradually due to the time lags required for the vehicle stock to adjust fully.

The paper continues as follows. The two-equation empirical model of petrol demand and vehicle fleet size is described in the next section. In the third section the data are described and the econometric estimates are reported; the estimates are used to calculate short-run and long-run elasticities of petrol demand with respect to petrol price and income. The estimated model is also simulated to show how exogenous changes in petrol prices and vehicle fees impact the demand for petrol over time. Conclusions are made in the fourth section.
The empirical model employed in this paper is based entirely on the earlier works of Wheaton (1982), Baltagi and Griffin (1983), Wasserfallen and Güntensperger (1988), and Berkowitz et al. (1990). The model begins with the standard engineering identity relating the amount of petrol consumed by each vehicle at time $t$ to the distance that it travels and its fuel efficiency.

Because data on the individual vehicles are not observed, we must aggregate the individual observations to the level for which the quantities can be observed. The aggregate form of the fuel demand identity is obtained by summing over all vehicles in the economy $i = 1 \ldots N$,

$$ \text{Petrol Demand}_t = \frac{\text{Distance}_t}{\text{Efficiency}_t} $$

(1)

where the aggregate efficiency is the distance-weighted average efficiency of the vehicle fleet (Wasserfallen and Güntensperger, 1988, p. 277). We now focus on the determinants of the numerator and the denominator of this equation since distance and efficiency are in fact unobserved quantities.

The demand for petrol itself is derived from the demand for private car transportation. The demand for private car transportation is defined to be the distance traveled by private cars and it can be modeled as a function of the price of petrol ($P$), the price of other goods ($O$), income ($Y$), and the number of cars that have been brought forward from the preceding time period ($N_{t-1}$).\(^2\)

The efficiency of the fleet of automobiles depends on the composition of the vehicle fleet at each point in time. Efficiency is a complex function which structurally depends on the history of prices, incomes, and other factors.

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\(^2\)The distance traveled can also be modeled as a function of the current vehicle stock rather than the stock brought forward from the previous period. The model is developed here using the lagged vehicle stock so that we need not be concerned with simultaneity problems. However, in practice simultaneity would not be an issue as long as the price for petrol is exogenous because, for example, it is determined by world markets and fuel taxes.
Because efficiency is such a complex function, the empirical analysis will use a reduced form equation to model the average efficiency of the vehicle fleet. Following Wasserfallen and Güntensperger (1988), efficiency is assumed to depend upon the price of petrol ($P$) and the level of income ($Y$).

The relationships for the distance traveled and efficiency can be substituted into the aggregate fuel demand equation (eqn. 1) to obtain an estimable equation for petrol demand:

\[
\text{Petrol Demand}_t = f(P_t, O_t, Y_t, N_{t-1}).
\] (2)

This results in an equation for the endogenous fuel consumption which depends only upon observable magnitudes.

We now turn to modeling the other endogenous variable, the stock of vehicles ($N$), through the use of a second equation. It is assumed that the desired stock of vehicles ($N^*$) is a function of a vector of variables $X$ which includes income ($Y$), and variables that reflect the cost of owning and operating a car such as the petroleum price ($P$), the price of a car ($C$), and annual license fees ($F$).

However, due to adjustment costs, the stock of cars adjusts only partially between time periods. The vehicle stock is postulated to adjust at the rate of $(1 - \lambda)$ where $\lambda$ is a parameter to be estimated; $\lambda$ must lie in the unit interval for the partial adjustment equation to be economically meaningful. This yields the estimable equation for the endogenous stock of vehicles:

\[
N = \beta' X + \lambda N_{t-1} + \mu_t.
\] (3)

Equations (2) and (3) form a recursive system and thus can be estimated jointly as a seemingly unrelated regressions model.\(^3\) We will now proceed to estimate the two equations and to simulate (using both equations) the

\(^3\)Because the system is recursive or triangular, the seemingly unrelated regressions estimator does not suffer from simultaneous equations bias in this situation. The model could also be estimated by this method even if the current stock of vehicles were used rather than the lagged stock: Simultaneity would not be a problem to the extent that the price of petrol is exogenous and determined in world markets.
effects of exogenous changes in petrol price and vehicle fees on the demand for petrol.

3 Data, Estimation and Simulation

The data used in the estimation of equations (2) and (3) come from several sources published by the government of Hong Kong. The data are annual observations from 1976–1992, inclusive. The quantity of petrol consumed, population, income, and a price deflator were drawn from various issues of the Hong Kong Monthly Digest of Statistics. Data on the stock of cars and vehicle fees were drawn from the Traffic and Transport Digest and The Annual Traffic Census. Petrol prices were provided by the Shell petroleum company of Hong Kong. The nominal values for the data are shown in Table 1 for the years 1980, 1985, and 1990. It is evident from the table that there has been substantial variation in each series during the sample period.

All nominal Hong Kong dollar values were converted to inflation-adjusted real dollar values for use in the empirical analysis. Because the nominal dollar values are deflated to obtain real dollar values, the ‘other prices’ variable is indirectly included in the model and need not be included directly. Population was included in the model indirectly by transforming vehicle stock, income, and petrol consumption into per capita quantities. The two equations (eqns. 2 and 3) were estimated jointly as a seemingly unrelated regressions model in levels and in logarithms. The logarithmic form was preferred since it gave a much better fit and resulted in homoscedastic residuals; the logarithmic form also has the convenience that the estimates can be interpreted directly as elasticities.

Table 2 contains the econometric estimates of the petrol demand equation in the first column. The coefficients on income, petrol price and the

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4 Nominal values were converted to real using the consumer price index A. The model was also estimated using the consumer price index B to obtain real dollar values and this did not qualitatively affect the results.
vehicle stock are all of the expected signs and statistically significant; the coefficient on the constant term is not significant. We could not reject the null hypothesis of no first-order serial correlation using the Durbin-Watson test. Since all of the variables are in logarithms, the point estimates of the price and income elasticities of demand are the coefficients on petrol price and income, respectively. The price elasticity is $-0.2333$ and the income elasticity is $0.2518$. The point estimates seem appropriate, especially in the context of Hong Kong. The short-run demand for petrol is price inelastic and the magnitude is comparable to other countries. The short-run income elasticity of demand is somewhat smaller than the estimates for other countries. The lower income elasticity in Hong Kong appears to reflect the low ratio of roads to cars. As incomes rise, the short-run demand for additional car travel (and the demand for fuel) is largely choked-off by the large amount of time required to consume additional transportation by private car. The user-supplied time required to consume petrol is particularly important when one considers that in Hong Kong most cars are owned and used by persons with relatively high incomes who can be expected to have high marginal values of time. The coefficient on the stock of cars is $0.7617$ and this is also consistent with the capacity-constrained road network: a one percent increase in cars would lead to a three-fourths of a percent increase in the quantity of petrol demanded.

The second column of Table 2 shows the estimates of the vehicle stock adjustment equation. All of the parameter estimates have the expected sign and, with the exception of the constant term and the petrol price, were

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5My point estimate of the income elasticity of demand (0.2518) is fairly close to McRae’s (1994) estimate (0.220).

6For example, in papers based on all of the major studies of gasoline demand, Dahl (1986, p. 73) reports the overall short-run price elasticity of demand to be $-0.29$ and Dahl and Sterner (1991, p. 208) report the average price elasticity to be $-0.31$.

7Dahl (1986, p. 73) reports the overall short-run income elasticity of demand to be 0.47 and Dahl and Sterner (1991, p. 208) report the average income elasticity to be 0.52.

8Barron and Leung (1991, p. 63, footnote 4) report that if all of Hong Kong’s cars, buses, and trucks were placed on the existing roadways at one time, they would cover over 64% of the length of roadways.
The elasticity of the vehicle stock with respect to the price of petrol is \(-0.2081\) and the income elasticity is \(0.3243\). It is interesting to note that the results indicate that the rate of adjustment between the actual and desired stock of vehicles is about 20%. However, our primary interest in estimating the vehicle stock equation is to show how the stock of vehicles affects the demand for petrol. For example, it is clear that an increase in the price of petrol will immediately reduce the quantity demanded of petrol and, by reducing the stock of vehicles, reduce the demand for petrol in subsequent time periods. In a similar fashion, increasing the cost of vehicle ownership through higher vehicle fees also reduces the demand for petrol gradually as the vehicle stock adjusts from the actual to the desired level.

The estimated equations can be solved analytically to obtain the long-run price and income elasticities of petrol demand. The long-run response of petrol demand to a change in petrol price or income would be the summation of the initial response and the subsequent responses as the vehicle stock is adjusted. Let \(\alpha_p\), \(\alpha_y\), and \(\alpha_c\) represent the coefficients on price, income, and lagged vehicle stock in the petrol equation. Also, let \(\beta_p\), \(\beta_y\), and \(\beta_c\) represent the coefficients on price, income, and lagged vehicle stock in the vehicle stock equation. The long-run price and income elasticities can then be expressed as

\[
\epsilon_p = \alpha_p + \beta_p \alpha_c \left( 1 + \frac{1}{1 - \beta_c} \right) = -1.167
\]

\[
\epsilon_y = \alpha_y + \beta_y \alpha_c \left( 1 + \frac{1}{1 - \beta_c} \right) = 1.707
\]

Because the vehicle stock equation contains a lagged dependent variable, serial correlation would cause the seemingly unrelated regressions estimator to be biased. Also, due to the lagged dependent variable, it is not appropriate to apply the Durbin-Watson test. However, the Breusch (1978)-Godfrey (1978) Lagrange multiplier test may be applied in this situation and the results showed no evidence of serial correlation.

Recall that the coefficient on the variable \(\text{Cars}_{t-1}\) is an estimate of \(\lambda\) and the rate of adjustment is defined to be \((1 - \lambda)\).
The long-run price elasticity appears to be somewhat larger (absolutely) than the average values reported in other studies; however, the estimate of −1.167 is within the range of estimates reported in Dahl (1986) and Dahl and Sterner (1991). The long-run income elasticity is also within the range of values reported in the literature; furthermore, it is also somewhat larger than the average values reported in Dahl (1986) and Dahl and Sterner (1991).

It is important to note that the long-run elasticities are very sensitive to the coefficient of the lagged vehicle stock ($\beta_c$) in the vehicle stock equation. A small overestimate of $\beta_c$ could lead to very large overestimates of the long-run price and income elasticities. Therefore, these estimates should be interpreted with caution. However, since the same factor of $(1/(1 - \beta_c))$ affects both long-run elasticities, we can be reasonably certain that the long-run demand for petrol is more elastic with respect to income than with respect to price.

To make clear the relative impact of increases in the petrol price and vehicle fees, the estimated equations were simulated for the fuel demand which would result from changing the petrol price and vehicle fees. The petrol demand and vehicle stock adjustment equations were solved initially using the historical data for a baseline representation of the demand for petrol over the sample period; this baseline historical demand for petrol is shown as the solid line in Figure 1. The econometric model was then dynamically simulated to show the demand for petrol under four counterfactual scenarios pertaining to the exogenous petrol price and vehicle fees.

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11Dahl (1986) reports the average long-run price elasticity of gasoline demand to be −1.02. Dahl and Sterner (1991) report the average long-run price elasticity to be −0.80.

12The average values of the long-run income elasticity reported in Dahl (1986) and Dahl and Sterner (1991) are 1.38 and 1.31, respectively.

13The econometric model was estimated and simulated in logarithms of per capita values. However, the results of the simulation analysis were exponentiated and transformed into aggregate values so that they could be interpreted in meaningful units.

14In the simulations, the values for the endogenous petrol demand and vehicle stock are computed by applying the regression coefficients to the independent variables. In the second and all subsequent periods, the previously calculated values of the vehicle stock are used rather than the actual historical values. Thus, the simulation analysis is truly dynamic because there is feedback within the vehicle stock equation, and from the vehicle...
In the first scenario, the real price of petrol is increased by 10% over historical values beginning in 1984. In the second scenario, the real price of petrol is increased by 50% in 1984, and the price of petrol remains constant at this level. For the third scenario, the real vehicle fees were increased by 10% over historical values beginning in 1984. Finally, in the last scenario, the real vehicle fees were increased by 100% in 1984, and the real vehicle fees were held constant at this level. Figure 1 plots the response of petrol demand over time to each of the four counter-factual scenarios.

It is apparent from Figure 1 that fuel demand is much more responsive to changes in its price than to changes in vehicle fees. Increasing the historical prices of petrol by 10% in 1984 would have caused the actual consumption in 1992 to have fallen from about 412,000 liters to only about 372,000 liters. The distance between the simulated demand and the baseline demand increases each year, until 1991, due to the effect of petrol price on the stock of vehicles. In the second petrol price simulation, the price of petrol in 1984 was increased by 50% over the historical level and was held constant at this level through 1992. Again, as is seen in Figure 1, petrol demand adjusted gradually as the stock of vehicles adjusted to the new price level. By 1992, petrol demand had fallen to about 244,000 liters per year. It is clear from these simulations of petrol price that the effect of a price is revealed over a period of several years due to partial adjustment between the actual and stock equation to the petrol demand equation. The particular simulations performed vary only with respect to the time path of the exogenous petrol price and vehicle fees.

In particular, the real price of petrol is increased by 10%, which is equivalent to adding the logarithm of 1.1 to the logarithm of the petrol price. The remaining scenarios also pertain to the variables in levels and not in logarithms.

In principle it would be possible to calculate and to compare the welfare effects of the four scenarios used in the simulation analysis. However, the results of such an analysis would ignore the potentially large welfare effects resulting from changes in the level of traffic congestion. For example, if the government increased the tax on petrol this would directly decrease consumer surplus due to two factors: the move up the petrol demand curve, and the reduction of petrol demand as the vehicle stock adjusted over time. The fuel tax would also serve as a crude form of road pricing, thereby eliminating some of the deadweight loss resulting from the congestion externality. If the deadweight loss due to unpriced traffic congestion is very large, the increase in fuel taxes could lead to a net increase in total surplus.
desired stock of cars.

Vehicle fees also affect the demand for petrol through their effect on the stock of vehicles. Increasing the historical vehicle fees by 10% beginning in 1984 causes the quantity of petrol demanded in 1992 to fall to about 388,000 liters. The effect of vehicle fees on petrol demand is much smaller than the effect of the petrol price. This can also be seen directly from the estimates of vehicle stock adjustment in column (2) of Table 2: Petrol price increases lower the quantity demanded directly in addition to lowering demand through a diminished vehicle stock; vehicle fees reduce petrol demand in an indirect way only. Moreover, the elasticity of the vehicle stock with respect to petrol price is four times as large as the elasticity of the vehicle stock with respect to vehicle fees. In the final simulation of vehicle fee increases, the real fees in 1984 were doubled and held constant at this level through 1992. In this case the quantity of petrol demanded fell to about 260,000 liters by 1992. ¹⁷

4 Summary and Conclusion

This paper has presented econometric estimates of the short-run and long-run price and income elasticities of petrol demand in Hong Kong. It was found that the short-run price elasticity of demand for petrol is highly inelastic and that the point estimate does not differ from the average short-run price elasticities reported in the literature. The short-run income elasticity was somewhat smaller than the average reported in the literature; this, however, appears to be consistent with the attributes of Hong Kong’s vehicle users and the capacity constraints of the road network. The long-run price and income elasticities were somewhat larger than the average values reported in the literature; however, the long-run demand appeared to be more income-elastic than price-elastic.

¹⁷The long period of adjustment in the simulation is consistent with the finding that the rate of adjustment between actual and desired vehicle stock was quite small.
Simulations of the two-equation econometric model have shown how changes in vehicle fees and the price of petrol impact the demand for petrol. Changes in the price of petrol can affect demand both directly and indirectly: the direct change occurs as a move is made along a given demand curve; the indirect change occurs as the size of the vehicle fleet adjusts to the new petrol price. As the size of the fleet adjusts, the demand curve for petrol shifts. The empirical results have shown that the long-run effects of petrol price changes are much larger than proportionate changes in vehicle fees since they act through direct and indirect channels.

In the case of Hong Kong, vehicle controls appear to have had a significant impact on the demand for petrol in the last decade. However, the empirical results in this paper make clear that both the vehicle stock and the demand for petrol are far more responsive to changes in the price of petrol than to changes in vehicle fees and taxes. Furthermore, the long-run demand for petrol was found to be far more responsive to income than to the price of petrol. Given the current trend of rising real income in Hong Kong, the demand for petrol can be expected to rise significantly in the next decade, especially as the existing system of roads and highways is expanded to improve the accessibility to points in southern China and beyond. The empirical results lead to the conclusion that a fuel tax would be the most effective policy instrument due to the immediate short-term impact on petrol demand in addition to the long-term impact resulting from adjustment in the stock of vehicles. In light of this finding, policy makers may find it beneficial to re-think the extant policy measures—based primarily on vehicle controls—in their efforts to control petrol consumption, vehicular pollution, and traffic congestion.
References


Hong Kong Government. (various issues). *Annual Traffic Census.* Government Printer, Hong Kong.


### Table 1: Nominal Data for Selected Years

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>1980</th>
<th>1985</th>
<th>1990</th>
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<tbody>
<tr>
<td>Petrol Consumption</td>
<td>liters per year</td>
<td>289,388</td>
<td>269,212</td>
<td>353,556</td>
</tr>
<tr>
<td>Petrol Price</td>
<td>HK$ per liter</td>
<td>2.27</td>
<td>4.75</td>
<td>6.39</td>
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<tr>
<td>Cars</td>
<td>vehicle stock</td>
<td>190,146</td>
<td>144,723</td>
<td>197,852</td>
</tr>
<tr>
<td>Income</td>
<td>GDP in HK$ millions</td>
<td>137,081</td>
<td>261,070</td>
<td>558,859</td>
</tr>
<tr>
<td>Vehicle Fees</td>
<td>HK$ per year</td>
<td>900</td>
<td>3,750</td>
<td>5160</td>
</tr>
<tr>
<td>Population</td>
<td>residents</td>
<td>5,145,100</td>
<td>5,500,400</td>
<td>5,752,000</td>
</tr>
</tbody>
</table>

Table 2: Parameter Estimates

<table>
<thead>
<tr>
<th>Regressand</th>
<th>(1) Regressors</th>
<th>(2) Regressors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Stock Consumption of Cars</td>
<td>Constant: $-2.1889$ (8.918)</td>
<td>Constant: $-0.3627$ (1.119)</td>
</tr>
<tr>
<td></td>
<td>Income: $0.2518$ (0.098)</td>
<td>Income: $0.3243$ (0.049)</td>
</tr>
<tr>
<td></td>
<td>Petrol Price: $-0.2333$ (0.064)</td>
<td>Petrol Price: $-0.2081$ (0.140)</td>
</tr>
<tr>
<td></td>
<td>Vehicle Fees: $-$</td>
<td>Vehicle Fees: $-0.1534$ (0.039)</td>
</tr>
<tr>
<td></td>
<td>Vehicle Price: $-$</td>
<td>Vehicle Price: $-0.0069$ (0.142)</td>
</tr>
<tr>
<td></td>
<td>Cars$_{t-1}$: $0.7617$ (0.028)</td>
<td>Cars$_{t-1}$: $0.7955$ (0.089)</td>
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<tr>
<td></td>
<td>$R^2$: $0.989$</td>
<td>$R^2$: $0.937$</td>
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<tr>
<td></td>
<td>Durbin-Watson: $2.13$</td>
<td>Durbin-Watson: $1.92$</td>
</tr>
</tbody>
</table>

Notes—Estimated standard errors are in parentheses. The equations were estimated jointly as a seemingly unrelated regressions model. The correlation of the residuals across equations was 0.71.
Figure 1: Dynamic Simulations of Petrol Consumption

Price +10% increase historical petrol prices by 10% beginning in 1984.
Price +50% increase 1984 petrol price by 50% and hold constant at this level.
Fees +10% increase historical vehicle fees by 10% beginning in 1984.
Fees +100% increase 1984 vehicle fees by 100% and hold constant at this level.