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Gasoline and High Speed Diesel Consumption in Thailand: A Case Study in Welfare*

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This article examines the retail pricing policy of gasoline, high speed diesel, and the vehicle tax policy in Thailand between January 2002 and August 2005. The pricing policy of gasoline and high speed diesel is characterized by cross price subsidy from the gasoline consumers to the high speed diesel consumers. The vehicle tax policy is characterized by heavy tax rates that are higher for the gasoline engine vehicles relative to the diesel engine vehicles. The vehicle tax policy caused considerably greater welfare losses than the pricing policy of gasoline and high speed diesel. The efficient pricing criterion is proposed as a package to correct the welfare losses. The package includes replacements of all the transfer payments items in the price structure of gasoline and high speed diesel by their global pollution components, and the removal of the existing vehicle taxes. The efficient policy package will generate less tax revenue and the short falls can be offset by the charges designed to correct other externalities that cannot be effectively internalized by the fuel tax.

Keywords: Thailand, gasoline, high speed diesel, vehicles, externalities, welfare

Introduction

The transportation sector in Thailand is the largest consumer of petroleum products. Before the year 2005, gasoline and diesel are the two major petroleum products that are consumed in this sector. Gasoline is sold as gasoline 91 (gasoline with octane 91) and gasoline 95 (gasoline with octane 95). Diesel is sold almost entirely as high speed diesel and a small amount of low speed diesel. High speed diesel is the dominant fuel in the transportation sector as its consumption is more than twice the gasoline consumption.

There was a cabinet resolution on December 9, 2003 to eventually replace gasoline 95 with gasohol, a mixture of gasoline and ethanol (The Energy Policy and Planning Office, 2006). After the cabinet resolution, the consumption share of gasohol in the total fuel consumption is still insignificant but its consumption share began to increase sharply towards the end of 2005. Eventually, the consumption of gasohol exceeded the gasoline 95 consumption for the first time in April 2007.

Following the gasohol plan, the cabinet also approved the National Energy Council Committee's energy policy on November 21, 2006 to promote the consumption of biodiesel B5 as a substitute for high speed diesel

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by expanding the acreage of palm oil and the distribution channels. Before the endorsement of this policy, the consumption share of biodiesel in the total diesel consumption is less than 1 percent. But from February 2007 onwards, the consumption share of biodiesel in the total diesel consumption increased markedly to 7 percent in December 2007.

The fuel consumption patterns in the transportation sector depend on the behavior of the vehicle operators that can be influenced by the government fuel pricing policy and the vehicle tax policy. The effect of the government's fuel pricing policy and the vehicle tax policy on the fuel consumption pattern leads to the objectives of this article.

The first objective is to review the Thai government's retail pricing policy of petroleum products and the vehicle tax policy. The scope of the review is limited to the pricing policy of gasoline and high speed diesel and the vehicle tax policy before the emergence of gasohol and biodiesel towards the end of 2005. The second objective is to quantify the effects that these two policies have on welfare and economic costs in Thailand. The third objective is to propose an alternative pricing package for gasoline, high speed diesel, and vehicles for the country.

The article is organized into seven parts. The second part reviews the existing retail price structure of gasoline, high speed diesel, and the vehicle tax structure. The third part reviews the theoretical frame work that links the fuel demand to the vehicle demand. The fourth part presents the model designed to simulate the welfare losses from the fuel pricing policy and the vehicle tax policy. The fifth part presents the results of the welfare losses estimations and proposes an alternative policy package for gasoline, high speed diesel, and vehicles. The sixth part considers the revenue consequence of the proposed policy package. Finally, summary, conclusions, and recommendations are presented in part seven of the article.

Review of Retail Price Structure and Existing Vehicle Tax Structure

Price Structure of Gasoline and High Speed Diesel

The wholesale prices of gasoline, high speed diesel, and other petroleum products, have the same following structure:

wholesale price = ex-refinery price + excise tax + municipal tax + oil fund 1 + oil fund 2
+energy conservation fund + value added tax

The retail price of each product is then determined by adding the marketing margin and the value added tax to its wholesale price so that:

retail price = wholesale price + marketing margin + value added tax

Before the deregulation of oil prices in August 1991, the government controls all components of the retail price structure. After 1991, the government no longer controls the ex-refinery price and the marketing margin components. Their rates are allowed to be determined by the "market mechanism".

Even after the oil price deregulation in 1991, the price structure still allows the government to manipulate the wholesale and retail prices of gasoline and high speed diesel by setting the rates of all the tax items, oil fund 1, oil fund 2, and the energy conservation fund components at the desired levels. The rates for all the taxes and the energy conservation fund components are left unchanged for many years and the retail prices are manipulated through the oil fund components.

The retail price structure of gasoline 95, gasoline 91, and high speed diesel on March 31, 2005 is presented in Table 1 to illustrate the nature of the fuel pricing policy. The government collects the oil fund 1 component from the gasoline and high speed diesel consumers and then uses the oil fund 2 component to subsidize the high speed diesel consumers. In effect, the pricing policy provides the cross price subsidy from the gasoline consumers to the high speed diesel consumers.

Table 1

Retail Price Structure of Gasoline and High Speed Diesel in Thailand, March 31, 2005 (baht/liter)

	Gasoline 95	Percent	Gasoline 91	Percent	High speed diesel	Percent
ex-refinery price	15.14	68.52	14.65	68.82	16.32	89.70
excise tax	3.69	16.68	3.69	17.31	2.31	12.67
municipal tax	0.37	1.67	0.37	1.73	0.23	1.27
oil fund 1	0.50	2.26	0.30	1.41	0.50	2.75
oil fund 2	0.00	0.00	0.00	0.00	-3.34	-18.37
conservation fund	0.04	0.18	0.04	0.19	0.04	0.22
wholesale price	19.73	89.32	19.04	89.45	16.05	88.24
value added tax	1.38	6.25	1.33	6.26	1.12	6.18
wsp + vat*	21.11	95.57	20.38	95.71	17.17	94.41
marketing margin	0.92	4.14	0.85	4.00	0.95	5.22
value added tax	0.06	0.29	0.06	0.28	0.07	0.37
retail price	22.09	100.00	21.29	100.00	18.19	100.00

Notes. * wsp + vat = wholesale price + value added tax; Source: Energy Policy and Planning Office, 2006.

Fleet Structure

Vehicles in Thailand are classified into vehicles under the Motor Vehicle Act, vehicles under the Land Transport Act, and vehicles under the non-Motorized Vehicle Act. The total number of vehicles under the Motor Vehicle Act constitutes 96.3 percent of the total stock of vehicles in Thailand compared to 3.6 percent for the vehicles under the Land Transportation Act and 0.11 percent for the vehicles under the non-Motorized Vehicle Act on December 31, 2001. Vehicles under the Non Motorized Vehicle Act are vehicles powered by human or animal power. The new vehicles under the Motor Vehicle Act constitutes between 97 percent and 98 percent of the total new vehicles between January 2002 and August 2005.

The high proportion of the vehicles under the Motor Vehicle Act is due to the inclusion of motor cycles whose number constitutes about 68 percent of the total number of vehicles in the country. If motor cycles are removed from the list, the vehicles under the Motor Vehicle Act would constitute about 89 percent of the total vehicles compared to about 11 percent for the vehicles under the Land Transportation Act.

Vehicles under the Motor Vehicle Act are further classified into 16 subgroups. Table 2 presents the total stock of all vehicles under this category on December 31, 2001. The number of motor cycles comprises over 70 percent of the total number of all vehicles under this category. If the number of motorcycles is excluded from the list, sedans, vans and pickups become the two major groups of vehicles comprising about 35 percent and 51 percent, respectively, of the total number of vehicles under the Motor Vehicle Act.

Approximately 75 percent of the sedan fleet is powered by gasoline while over ninety percent of the van and pick up fleet are powered by high speed diesel. Almost all of the motorcycles in the country are powered by gasoline. In addition to gasoline and high speed diesel, LPG (Liquefied Petroleum Gas) is used by the majority of motor tricycles but their number constitutes only 0.22 percent of the total number of vehicles under the Motor Vehicle Act.

Buses and trucks are classified under the Land Transportation Act and the distribution of their stock by vehicle types on December 31, 2001 is presented in Table 3. Trucks constitute over eighty percent of the vehicles under this group. The vehicles under the Land Transportation Act are predominantly powered by high speed diesel.

Table 2

Stock of Vehicles Under the Motor Vehicle Act on December 31, 2001

	Number	Percent	Percent[a]	% gasoline[b]	% diesel[b]
Vehicles under Motor Vehicle Act[c]	21,760,467	100	100	77.1	21.41
1. Sedan (not more than 7 pass.)	2,280,676	10.48	34.96	74.97	15.07
2. Microbus and passenger van	583,299	2.68	8.94	10.8	84.04
3. Van and pickup	3,341,448	15.36	51.21	5.75	91.85
4. Motor tricycle	2,147	0.01	0.03	57.32	3.29
5. Interprovincial taxi	388	0	0.01	63.45	17.24
6. Urban taxi	69,037	0.32	1.06	6.23	0.60
7. Fixed route taxi	9,128	0.04	0.14	83.02	0.28
8. Motor tricycle taxi (Tuk Tuk)	46,821	0.22	0.72	23.13	1.24
9. Hotel taxi	2,221	0.01	0.03	67.94	9.38
10. Tour taxi	498	0	0.01	48.34	8.73
11. Car for hire	538	0	0.01	40.38	43.02
12. Motorcycle	15,236,081	70.02	-	99.96	0.04
13. Tractor	99,449	0.46	1.52	0.80	96.02
14. Road roller	8,612	0.04	0.13	0.53	98.11
15. Farm vehicle	77,899	0.36	1.19	3.47	92.44
16. Automobile trailer	2,225	0.01	0.03	0	0

Notes. [a] Percent of total number of vehicles without motorcycle; [b] Based on averages between March 2006 and December 2008 data; [c] See source for definition of each category. Total percent of gasoline and diesel engine vehicles do not add up to 100 due to the small amount of other fuel consumption. Source: Compiled from Statistics Sub-Division, Technical and Planning Group, Land Transport Management Bureau, Department of Land Transport.

Table 3

Total Stock of Vehicles Under the Land Transportation Act, December 31, 2001

Vehicles under Land Transport Act	Number	Percent	% gasoline[a]	% diesel[a]
Bus: Total	107,622	13.39	5.15	94.27
Fixed route bus	77,944	9.70	2.44	97.19
Non fixed route bus	20,885	2.60	15.14	83.53
Private bus	8,793	1.09	0.43	99.31
Truck: Total	673,599	83.79	0.05	88.04
Non fixed route truck	90,181	11.22	0.02	66.36
Private truck	583,418	72.58	0.05	92.50
Small rural bus	22,648	2.82	14.05	85.71
Total	803,869	100.00	1.03	88.83

Notes. [a] based on averages between March 2006 and December 2008 data. Total percent of gasoline and diesel engine vehicles do not add up to 100 due to the small amount of other fuel consumption. Source: Compiled from Statistics Sub-Division, Technical and Planning Group, Land Transport Management Bureau, Department of Land Transport.

Vehicle Tax Structure

Taxes are collected on the imported vehicles as well as on the locally assembled vehicles. An import tax of mP baht is collected on an imported vehicle with a c.i.f. price of P baht, where m is the import tax rate. An excise tax of $P(1+m)e/(1\text{-}1.1e)$ is then collected on this vehicle, where e is the excise tax rate. The interior tax is collected at 10 percent of the excise tax and this tax is remitted to the Ministry of Interior. Finally, the value added tax is collected at 7 percent of the c.i.f. price plus import tax, excise tax, and interior tax. The retail price of an imported vehicle with the c.i.f. price of *P* baht, inclusive of all taxes, but not including dealers' profits, is then equal to $1.07P(1+m)/(1-1.1e)$.

The import tax rates are highest for passenger cars at 80 percent and lowest for buses at 40 percent. A major change in the import tax rates occurs in July 2003 when the import tax rate of 60 percent is removed for all trucks. The excise tax rates for diesel engine vehicles are considerably lower than the rates for gasoline engine vehicles. For example, the lowest excise tax rate for a 2,000 cc gasoline engine passenger car is 30 percent compared with the rate of 4 percent for a pickup which is predominantly powered by diesel engine.

The excise tax rate is progressive as the rate increases with the engine capacity. In addition, buses with more than 10 seats and trucks in excess of 4,000 kilograms are exempted from the excise tax collections. Table 4 presents the import tax and the excise tax structure for the gasoline engine vehicles and diesel engine vehicles.

Table 4

Imports and Excise Tax Rates for Vehicles, January 2002-August 2005

Import tax	January 2002-June 2003	July 2003-August 2005
All passengers_(diesel)	80	80
Van and pickup_(diesel)	80	80
All passengers_(gasoline)	80	80
All buses	40	40
All trucks	60	0
All motor cycles	60	60
Excise tax	January 2002-July 2004	August 2004-August 2005
Passenger cars		
≤ 2,000cc & ≤ 220 hp	35	35
2,000 < *x* < 2,500 & ≤ 220 hp	35	35
2,500 < *x* < 3,000 & ≤ 220 hp	41	40
> 3,000 & > 220 hp	48	50
Pickup	3	3
PPV		
≤ 3,250 cc	18	20
> 3,250 cc	18	50
Double cab		
≤ 3,250 cc	12	12
>3,250 cc	20	50
Modified		
≤ 3250 cc	n.a.	3
> 3250 cc	50	50
Buses < 10 seats		
≤ 2,000cc & ≤ 220 hp	35	30
2,000 < *x* < 2,500 & ≤ 220 hp	35	35
2,500 <*x* < 3,000 & ≤ 220 hp	41	40
> 3,000 & > 220 hp	41	50
Trucks < 4,000 kilogram		
≤ 3250 cc	3	3
≤ 3250 cc	18	18
> 3250 cc	18	50
Motor cycles		
2 strokes	5	5
4 strokes	3	3

Note. Source: Customs Department, Excise Department.

The effect of the vehicle tax structure is to increase the prices of the gasoline engine vehicles relative to the prices of the diesel engine vehicles and also encourages the purchase of smaller engine vehicles. As an illustration, a gasoline engine passenger car and a pickup truck with the same c.i.f. price of *P* baht will have different retail prices. The retail price of gasoline engine passenger vehicle, before adding dealers' profit, is 2.87*P* compared with the retail price of 2.01*P* for the pickup truck.

The vehicle tax structure is the same for the locally assembled vehicles. However, import tax is not collected for vehicles that have no import contents. The import tax is collected on the locally assembled vehicles in the case where there are import contents but the rates are lower than the rates for imported vehicles.

Some Observations

Reviews of the vehicle tax policy and the retail pricing policy of gasoline and high speed diesel suggest that these two policies can influence the consumption patterns of gasoline and high speed diesel through the vehicle purchasing decisions and through the patterns of their utilizations.

The vehicle tax policy which lowers the prices of diesel engine vehicles relative to the prices of gasoline engine vehicles provides incentives for potential new vehicle purchasers to purchase new diesel engine vehicles. The purchase of new diesel engine vehicles is expected to be a contributing factor to the relative increase in the high speed diesel consumption.

A similar observation was made for the case of Sri Lanka (Clean Air Initiative for Asian Cities, n.d.). It is reported that the retail price of gasoline was three times the retail price of diesel in a given period, a result of heavy gasoline tax. The gasoline/diesel price ratio offers incentive for the automobile consumers to use the diesel engine vehicles rather than the gasoline engine vehicles.

During the reported period, the sales volume of diesel engine vehicles is five times the sales volume of gasoline engine vehicles. This is not surprising since the operating cost of a diesel engine vehicle, at this relative price, operating more than 4,000 km per year, is substantially lower than the operating cost of a gasoline engine vehicle.

Theoretical Framework

Link Between Fuel Demand and Vehicle Demand

Discussions in the last section suggest that the demand for gasoline and high speed diesel are linked to the demand for vehicles. A survey of gasoline demand studies (Espey, 1998) provides some formal evidence of a link between the demand for fuels and the demand for vehicles by using meta-analysis to compare several gasoline demand studies published between 1966 and 1997 that cover the period of analysis between 1929 and 1996.

Gasoline prices and income are the two common variables in the reviewed gasoline demand studies. Apart from these two common explanatory variables, the reviewed studies differ by the inclusions and exclusions of other variables, the model specifications, data characteristics, and the estimation methods.

One important conclusion from the reviewed studies is that some measure of vehicle ownership is a variable that significantly explains the demand for gasoline. The exclusion of this variable would be expected to bias the results of the demand studies. Another interesting conclusion is that the linear models yield results that are not significantly different from the log linear models.

On the other side of the coin, there are studies on demand for vehicles that provide some evidence of the links to gasoline demand. Similar to the gasoline demand studies, these vehicle demand studies differ by model specifications, data characteristics, and estimation methods.

Income and vehicle prices are the two common variables that determine the demand for vehicles. In addition to these two common variables, the rising gasoline prices were also found to significantly affect the automobile demand by causing a shift in demand for automobile towards vehicles with better fuel economy (Carlson & Umble, 1980; Tishler, 1983; McManus, 2007; Beresteanu & Li, 2007; Miller & Ashley, 2008). The link between the demand for fuel and demand for vehicles may be examined by the identity equation (Sweeney, 1978; Griffin, 1979; Batalgi & Griffin, 1983; Batalgi, Bresson, Griffin & Pirotte, 2003):

$$QG_t = U_t.E_t.TV_t \quad (t = 1, 2, \dots, T) \tag{1}$$

where QG_t = gasoline consumption in period t; TV_t = stock of vehicles in period t; U_t = average utilization rate of vehicles in kilometer/vehicle in period t; E_t = average fuel economy of vehicles in liter/kilometer in period t.

The identity in equation (1) may be expressed in log linear form:

$$LogQGPERTV_t = LogU_t + LogE_t \quad (t = 1, 2, \dots, T) \tag{2}$$

where $QGPERTV_t$ = consumption of gasoline per vehicle.

The vehicle utilization rate is determined by the equation:

$$LogU_t = con_u + a_u LogRY_t + b_u LogRPG_t + c_u LogTV_t \quad (t = 1, 2, \dots, T) \tag{3}$$

where RY_t = real per capita income; RPG_t = real gasoline price; TV_t = per capita stock of vehicles.

The fuel economy in identity (1) is a function of the same variables that determine the utilization rate. The difference between these two equations is in the distribute lags of these variables to allow for the long gestation period of the vehicle stock. The fuel economy equation is represented by the equation:

$$LogE_t = con_e + a_e LogRY_t + a_{e1} LogRY_{t-1} + \cdots + b_e LogRPG_t + b_{e1} LogRPG_{t-1} + \dots + c_e LogTV_t + c_{e1} LogTV_{t-1} + \cdots \ (t = 1, 2, \dots, T) \tag{4}$$

Equations (3) and (4) are substituted into equation (2) to bypass the unavailable data on fuel economies and utilization rates. One model used to estimate the gasoline consumption per vehicle is a first order autoregressive equation (Batalgi, 1983)

$$LogQGPERTV_t = con_g + b_g LogRY_t + c_g LogRPG_t + d_g LogTV_t + e_g LogQGPERTV_{t-1} \quad (t = 1, 2, \dots, T) \tag{5}$$

where all the coefficients are appropriately defined.

The identity equation (1) was modified (Pock, 2007) by disaggregating the per capita stock of vehicles into the per passenger stock of gasoline engine vehicles and the per passenger stock of diesel engine vehicles to study the gasoline demand and the diesel demand in Europe. The modified demand equation for gasoline is now represented by the equation

$$LogQGPERTVG_t = \alpha_g + \beta_g LogRY_t + \gamma_g LogRPG_t + \delta_g LogTVG_t + \varepsilon_g LogTVD_t + \epsilon_g LogQGPERTVG_{t-1} \quad (t = 1, 2, \dots, T) \tag{6}$$

where $QGPERTVG_t$ = consumption of gasoline per gasoline engine vehicle; TVG_t = per passenger stock of gasoline engine vehicles; TVD_t = per passenger stock of diesel engine vehicles.

Effects of Fuel Pricing Policy and Vehicle Tax Policy on Fuel Consumption

The link between the fuel demand and vehicle demand specified by the Pock model, represented by equation (6), is modified and expanded to study the effects of the fuel pricing policy and the vehicle tax policy on fuel consumption in Thailand. The fuel pricing policy can affect the utilization rates of the existing vehicle owners and the purchasing decisions of the potential new vehicle owners.

It is possible for an existing vehicle owner to own both a gasoline engine vehicle and a diesel engine vehicle. In this case, he can react to a fall (rise) in the high speed diesel price by increasing (reducing) the utilization rate of his diesel engine vehicle and reducing (increasing) the utilization rate of his gasoline engine vehicle. In order to account for this possibility, the real price of high speed diesel (gasoline) is included as another explanatory variable in the utilization rate equation of the gasoline (diesel) engine vehicle.

The utilization rate of an existing owner of a gasoline engine vehicle is now explained by the equation

$$LogUG_t = con_{gu} + a_{gu}LogRY_t + b_{gu}LogRPG_t + c_{gu}LogTVG_t$$
$$+d_{gu}LogTVD_t + e_{gu}LogRPD_t \quad (t = 1, 2, \ldots, T) \tag{7}$$

where UG_t = utilization rate of gasoline engine vehicle; RPD_t = real high speed diesel price.

The fuel economy equation of the gasoline engine vehicles then becomes:

$$LogEG_t = con_{ge} + a_{ge1}LogRY_t + a_{ge2}LogRY_{t-1} + \cdots + \ b_{ge1}LogRPG_t + b_{ge2}LogRPG_{t-1} + \cdots$$
$$+c_{ge1}LogTVG_t + c_{ge2}LogTVG_{t-1} + d_{ge1}LogRPD_t + d_{ge2}LogRPD_{t-1} + \cdots$$
$$+e_{ge1}LogT\ VD_t + e_{ge2}LogTVD_{t-1} + \cdots \tag{8}$$

Using equations (7), (8), and (2), the consumption per gasoline vehicle equation becomes a first order autoregressive equation:

$$LogQGPERTVG_t = con_G + \alpha_{G1}LogRY_t + \beta_{G1}LogRPG_t + \gamma_{G1}LogTVG_t$$
$$+\delta_{G1}LogRPD_t + \epsilon_{G1}LogTVD_t + \eta_{G1}LogQGPERTVG_{t-1} \tag{9}$$

Similarly, the high speed diesel consumption per diesel engine vehicle is explained by the equation:

$$LogQGPERTVD_t = con_D + \alpha_{D1}LogRY_t + \beta_{D1}LogRPG_t + \gamma_{D1}LogTVG_t$$
$$+\delta_{D1}LogRPD_t + \epsilon_{D1}LogTVD_t + \eta_{D1}LogQGPERTVD_{t-1} \tag{10}$$

where $QGPERTVD_t$ = consumption of high speed diesel per diesel engine vehicle.

Equations (9) and (10) capture the effect of the fuel pricing policy on the gasoline and high speed diesel consumption through the price variables *RPG* and *RPD*. These two equations do not, however, capture the effects that the vehicle tax policy has on the gasoline and high speed diesel consumption. The model must be expanded to capture the effects of the vehicle tax policy on the gasoline and high speed diesel consumption.

The first step is to disaggregate the vehicles into categories classified by the Motor Vehicle Act and the Land Transportation Act. The per capita stock of gasoline engine vehicles is disaggregated into four major categories as shown by the linear identity equation:

$$TVG_t = PASSGT_t + MTAG_t + MVAG12_t + MVAGOTHER_t \tag{11}$$

where $PASSG_t$ = per capita stock of gasoline engine passenger vehicles; $MTAG_t$ = per capital stock of gasoline engine buses and trucks under Land Transportation Act; $MVAG12_t$ = per capita stock of motor cycles; $MVATOTHG_t$ = remaining per capita stock of gasoline engine vehicles.

The per capita stock of the passenger gasoline engine vehicles is further disaggregated into vehicle types classified under the Motor Vehicle Act listed in Table 2 by the linear identity equation:

$$PASSG_t = MVAG1_t + MVAG2_t + MVAG3_t + MVAG4_t + MVAG5_t + MVAG6_t$$
$$+MVAG7_t + MVAG9_t + MVAG10_t + MVAG11_t \tag{12}$$

where $MVAG_{it}$ = per capita stock of gasoline engine vehicles in category *i* under the Motor Vehicle Act listed in Table 2, *i* = 1, 2, 3, 4, 5, 6, 7, 9, 10, 11.

Similarly, the disaggregation of the per capita stock of diesel engine vehicles is explained by the linear identity equation:

$$TVD_t = PASSD_t + MTAD_t + MVADOTHD_t \tag{13}$$

where $PASSD_t$ = per capita stock of diesel engine passenger vehicles; $MTAD_t$ = per capita stock of diesel engine buses and trucks under Land Transportation Act; $MVADOTHD_t$ = remaining per capita stock of diesel engine vehicles.

Finally, the disaggregation of the per capita stock of diesel engine passenger vehicles is represented by the linear identity equation

$$PASSD_t = MVAD1_t + MVAD2_t + MVAD3_t + MVAD4_t + MVAD5_t$$
$$+MVAD6_t + MVAD7_t + MVAD9_t + MVAD10_t + MVAD11_t \quad (14)$$

where $MVAD_{it}$ = per capita stock of diesel engine vehicles in category i under the Motor Vehicle Act listed in Table 2, i = 1, 2, 3, 4, 5, 6, 7, 9, 10, 11.

The linear identity equations (11) and (13) must be transformed into the log linear share equations to provide compatible links to equations (9) and (10). The share equation of TVG is:

$$LogTVG_t = a_{VG}Log\ PASSG_t + b_{VG}Log\ MTAG_t + c_{VG}LogMVA1G12_t + d_{VG}LogMVAOTHG_t \quad (15)$$

with the constraints:

$$a_{VG} + b_{VG} + c_{VG} + d_{VG} = 1 \quad (16)$$

Euler's theorem may be applied to equation (11) to justify equation (15):

$$TVG_t = PASSG_t.\frac{dTVG_t}{dPASSG_t} + MTAG_t.\frac{dTVG_t}{dMTAG_t} + MVA1G12_t.\frac{dTVG_t}{dMVAG12G_t} + MVAOTHG_t.\frac{dTVG_t}{dMVAOTHG_t} \quad (17)$$

which may be shown to be equivalent to the coefficient restrictions in equation (16).

Similarly, the linear identity (13) is transformed into the per capita diesel engine vehicle share equation:

$$LogTVD_t = \ a_{VD}LogPASSD_t + b_{VD}LogMTAD_t + c_{VD}LogMVAOTHD_t \quad (18)$$

with the constraints:

$$a_{VD} + b_{VD} + c_{VD} = 1 \quad (19)$$

The government vehicle tax policy in period t does not affect the existing vehicle stock purchased in previous periods but it influences the number and types of new vehicles purchased in period t. The vehicle stock in period t consists of the vehicle stock in the previous period plus the number of new vehicles purchased in period t. The per capita stock of vehicles in period t is then the sum of the new per capita stock of vehicles purchased in previous periods so that:

$$LogTVG_t = \sum_{t=1}^{T} LogNTVG_t \quad (20)$$

where $NTVG_t$ = new per capita stock of gasoline engine vehicles in period t.

A potential new vehicle owner planning to purchase a vehicle in period t can factor the fuel options into his purchasing decision. For a given price of a gasoline engine vehicle relative to the price of a diesel engine vehicle, an increase in the relative price of gasoline to high speed diesel provides additional incentive to purchase the diesel engine vehicle.

The number of new gasoline engine passenger vehicles purchased in period t is specified by the first order autoregressive equation:

$$LogNPASSG_t = con_{pg} + a_{pg}LogPMVAG_t + b_{pg}LogPMVADt + c_{pg}LogRPG_t$$
$$+d_{pg}LogRPD_t + e_{pg}LogRY_t + f_{pg}LogPASSG_{t-1} \quad (21)$$

where $NPASSG_t$ = new per capita stock of gasoline engine passenger vehicles purchased in period t; $PMVAG_t$ = price of gasoline engine passenger vehicles; $PMVAD_t$ = price of diesel engine passenger vehicles.

Using equation (20) the per capita stock of gasoline engine passenger vehicles in period t is then a general distributed lag autoregressive equation:

$$LogPASSG_t = \sum_{t=1}^{T} LogNPASSG_t = con_{pgT} + \sum_{i=0}^{T} a_{pgi}LogPMVAG_{t-i} + \sum_{i=0}^{T} b_{pgi}LogPMVAD_{t-i} +$$
$$\sum_{i=0}^{T} c_{pgi}LogRPG_{t-i} + \sum_{i=0}^{T} d_{pgi}LogRPD_{t-i} + \sum_{i=0}^{T} e_{pgi}LogRY_{t-i} + \sum_{i=1}^{T} f_{pgi}LogPASSG_{t-i} \quad (22)$$

Over 99 percent of the motor cycles are powered by gasoline engine and its per capita stock in period t is represented by the equation:

$$LogMVAG12_t = \sum_{t=1}^{T} LogNMVAG12_t = con_{pm} + \sum_{i=0}^{T} a_{pmi} LogPMVAG12_{t-i} + \sum_{i=0}^{T} b_{pmi} LogRPG_{t-i} + \sum_{i=0}^{T} c_{pmi} LogRY_{t-i} + \sum_{i=0}^{T} d_{pmi} LogMVAG12_{t-i} \quad (23)$$

where $NMVAG12_t$= new per capita stock of motorcycles purchased in period t.

The per capita stock of gasoline engine buses and trucks are less than 2 percent of the total per capita stock of buses and trucks and is represented by the equation:

$$LogMTAG_t = \sum_{t=1}^{T} LogNMTAG_t = Logc_{tbg} + \sum_{i=0}^{T} a_{bgi} LogRY_{t-i} + \sum_{i=0}^{T} b_{bgi} LogPMTA_{t-i} + \sum_{i=0}^{T} c_{bgi} LogRPG_{t-i} + \sum_{i=1}^{T} d_{bgi} LogMTAG_{t-i} \quad (24)$$

where $NMTAG_t$ = new per capita stock of gasoline engine buses and trucks purchased in period t; $PMTAG_t$= price of gasoline engine buses and trucks.

The per capita stock of the remaining gasoline engine vehicles is represented by the equation:

$$LogMVAGOTHG_t = \sum_{t=1}^{T} LogNMVAGOTG_t = c_{got} + \sum_{i=0}^{T} a_{goi} LogRY_{t-i} \quad (25)$$

The per capita stock of diesel engine passenger vehicles is represented by the equation

$$LogPASSD_t = \sum_{t=1}^{T} LogNPASSD_t = con_{pdT} + \sum_{i=0}^{T} a_{pdi} LogPMVAG_{t-i} + \sum_{i=0}^{T} b_{pdi} LogPMVAD_{t-i} + \sum_{i=0}^{T} c_{pdi} LogRPT_{t-i} + \sum_{i=0}^{T} d_{pdi} LogRPD_{t-i} + \sum_{i=0}^{T} e_{pdi} LogRY_{t-i} + \sum_{i=1}^{T} f_{pgi} LogPASSD_{t-i} \quad (26)$$

where $NPASSD_t$ = new per capita stock of diesel engine passenger cars purchased in period t.

About 98% of trucks and buses are powered by diesel engine and the per capita stock of this group is represented by

$$LogMTAD_t = \sum_{t=1}^{T} LogNMTAD_t = c_{tbd} + \sum_{i=0}^{T} a_{bdi} LogRY_{t-i} + \sum_{i=0}^{T} b_{bdi} LogPMTA_{t-i} + \sum_{i=0}^{T} c_{bdi} LogRPD_{t-i} + \sum_{i=1}^{T} d_{bdi} LogMTAD_{t-i} \quad (27)$$

where $NMTAD_t$ = new per capita stock of diesel engine buses and trucks purchased in period t; $PMTAD_t$= price of diesel engine buses and trucks.

Finally, the remaining per capita stock of other diesel engine vehicles is represented by:

$$LogMVADOTHD_t = \sum_{t=1}^{T} LogNMVADOTHD_t = Logc_{dot} + \sum_{i=0}^{T} a_{doi} LogRY_{t-i} \quad (28)$$

Equations (9), (10), (15), (18), (22), (23), (24), (25), (26), (27), and (28) form a system of simultaneous equations that can be used to simulate the effects that the fuel pricing policy and the vehicle tax policy have on the gasoline and high speed diesel consumption.

Model Estimations

Data Availability

Monthly data between the period January 2002 and August 2005 are used to estimate the model. Data for gasoline and high speed diesel consumption are published monthly by the National Energy and Policy Office. The price structure of gasoline and high speed diesel are also published by the National Energy and Policy Office on a daily basis and are used to construct their monthly prices.

The gasoline 95 retail prices are slightly higher than the gasoline 91 retail prices and the two prices exhibit perfect correlation during the period of analysis, which is not surprising, since they are the same product that differs only in the number of octane content. The consumption of gasoline 95 and gasoline 91 is aggregated into single gasoline consumption and its retail prices are presented as the average prices of gasoline 95 and gasoline 91 weighted by their consumption.

The data on the stock of vehicles by categories and by fuel types are published on an annual basis by the

Land Transport Department of the Transportation Ministry. The monthly stock of vehicles on January 2002 is obtained by adding the number of the new vehicles purchased in January 2002 to the vehicle stock on December 31, 2001. The monthly stock in successive months is similarly obtained by adding the number of new vehicles purchased in the given month to the stock in the previous month.

The data on retail vehicle price index of each vehicle category is not available so its proxy is constructed from the available monthly c.i.f. price index. As an example, the proxy for the retail price index of the passenger vehicle category is constructed by adjusting its c.i.f. price index by the given tax rates.

There are also no direct data on the monthly GDP, so a proxy variable that is highly correlated with GDP is required. The money supply is a candidate for a possible proxy variable for the monthly GDP. The relationship between money supply and GDP has been studied extensively for many countries with varying results.

In the United States, a high correlation between the money supply and GDP was observed in the seventies. However, the changes over time in banking accounts, the proliferation of financing companies, and more widespread investment among consumers (stock and bond investments which are not captured in M1 and M2 aggregates) break down the high correlation between money supply and GDP (Barnes, n.d.). Outside of the United States, correlation between the money supply and GDP was also observed in the Euro area (Polleit, 2005). In the case of Japan, a positive correlation between money supply and income was observed until after the mid nineties, when the correlation began to break down (Miyao, 2004).

Past studies suggest that the correlation between these two variables may not hold for all periods. For estimation purpose, the qualification of the monthly money supply as a proxy variable for the monthly GDP in the model depends upon the robustness of their correlation during the period of analysis.

Endogeneity in Model

The eleven equations simultaneous system raises the issue of endogeneity unless the gasoline price variable, the high speed diesel price variable, and the vehicle price variable can be shown to be exogenous to the model. For the case of Thailand, it can be argued that the supply of gasoline and high speed diesel are perfectly elastic.

Before the oil price deregulation in 1991, the government determined all components of the retail prices. The ex-refinery price component determination is based on the import parity principle. According to this principle, if no refineries exist in Thailand, gasoline, high speed diesel, and other petroleum products must be imported into the country to satisfy the local demand.

The Singapore market is the closest market to Thailand and may be considered as the country’s supply source. The import price of gasoline or high speed diesel then equals the corresponding Singapore ex-refinery price plus transportation costs, insurance costs, and quality adjustment costs to match the local product specifications. Thailand, as a relatively small country, is a price taker and can import all of the required gasoline and high speed diesel at these prices with negligible effects on the international prices.

Under the import parity principle, the government sets the local ex-refinery prices of gasoline and high speed diesel equal to their corresponding import prices. The import parity principle allows the local ex-refinery prices to be higher than the corresponding Singapore ex-refinery prices by the amount of the transportation costs, the insurance costs, and the quality adjustment costs. If the local refining costs are the same as the Singapore refining costs, a typical refinery in Thailand would earn “wind fall” profit from the differences between the local and the Singapore ex-refinery prices.

As a consequence of the local ex-refinery price determination, the supply of gasoline and high speed diesel at the local refineries are perfectly elastic at their local ex-refinery prices. If the local refineries were to sell their products above these prices, they cannot compete with the imported products.

On the other hand, they have no incentive to sell their products at lower prices since they can sell all of their products at these prices. When the marketing margin, which is also set by the government, and the other transfer payment items are added, the supply of these two products for the final consumers become perfectly elastic at their retail prices. Given the nature of the perfectly elastic supply, the consumption of gasoline and high speed diesel in the country are determined by their demand.

Similarly, the vehicle price index can be argued to be exogenously determined outside the model. As a relatively small importing country, Thailand is a price taker and can import vehicles at their c.i.f. prices that are exogenously determined outside the model. The vehicle retail price index of each vehicle category is constructed from its corresponding tax rates that are determined exogenously by the government so the proxy vehicle price index can be regarded as an exogenous variable.

Model Estimations

The M1 money supply is tested for its correlation with GDP during the estimation period to justify its role as a proxy variable. When the unit root test is performed on the annual real per capita M1(RM1) and real per capita GDP (RGDP) between 1992 through 2005, the null hypothesis that each variable has a unit root cannot be rejected. The results of the unit root test imply that the relationship between real M1 and real GDP must be further tested for their cointegration to avoid possible spurious correlation.

The VAR method is used to test for cointegration between the annual real per capita M1 and the annual real per capita GDP between the period 1992 and 2005. The relationship between the two variables derived from the Johansen cointegration test and their unrestricted cointegration rank test (trace) are presented in Table 5.

Table 5
Unrestricted Cointegration Rank Test (Trace) for Relationship Between Per Capital Real M1 and Per Capita Real GDP

	LogRGDP		
Coefficient	1.09		
Standard error	0.02		
T-statistics	59.34		
Hypothesized No. of CE(s)	Trace Statistic	0.05 Critical Value	Prob.**
None *	29.40	12.32	0.0000

Notes. * denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-aug-Michelis (1999) *p*-values.

The tests provide evidence that there is a robust relationship between the real per capita M1 and the real per capita GDP. The real monthly money supply M1 is then used as a proxy variable for the monthly real GDP between January 2002 and August 2005 in the model estimations.

The equations in the model, with the exception of the share equations, are characterized by the distributed lag and autoregressive forms. The number of lags and the order of the autoregressive equations cannot be determined, a priori, and are determined empirically from the available data. The share equations are estimated by the simple OLS method and the remaining nine equations are estimated by the VAR method.

Table 6

Estimation Results

Equations	Log (RPG)	Log (RM1)	Log (TVG)	Log (TVD)	Log (RPD)
9. Log (QGPERTVG)	-0.43	0.38	0.65	-2.76	0.09
standard error	-0.05	0.09	0.11	-0.14	0.04
t-statistics	-8.64	4.10	5.65	-19.21	2.59
	Log (RPD)	Log (RM1)	Log (TVD)	Log (TVG)	C
10. Log (QDPERTVD)	-0.31	0.37	3.37	-1.97	14.17
standard error	-0.06	0.23	1.43	-1.14	
t-statistics	-4.79	1.63	2.36	-1.73	
	C	Log (PASSG)	Log (MTAG)	Log (MVAG12)	
15. Log TVG	0.37	0.11	0.00	0.88	
	R^2_{adj} = 1.00	Pr = 0.00	Pr = 0.13	Pr = 0.00	
	C	Log (PASSD)	Log (MTAD)	LogMVAOTHD	
18. Log TVD	0.57	0.82	0.14	0.04	
	R^2_{adj} = 1.00	Pr = 0.00	Pr = 0.00	Pr = 0.00	
	Log (PMVAG/PMVAD)	Log (RM1)	C		
22. Log(PASSG)	-0.09	1.09	1.79		
standard error	-0.03	0.06			
t-statistics	-2.95	17.77			
	Log (PMVAD/PMVAG)	Log (RM1)	Log (RPG)	C	
23. Log(PASSD)	-0.05	0.22	0.38	-2.71	
standard error	-0.02	0.05	0.03		
t-statistics	-3.13	4.61	10.97		
	Log (RM1)	C			
24. Log(MVAG12)	1.03	3.47			
standard error	0.06				
t-statistics	17.33				
	Log (RM1)	Log (PMTA)	C		
25. Log(MTAG)	0.96	-0.93	-0.37		
standard error	0.18	-0.21			
t-statistics	5.43	-4.52			
	Log (RM1)	Log (PMTA)	C		
26. Log(MTAD)	3.05	-2.67	23.77		
standard error	0.58	-0.56			
t-statistics	5.22	-4.80			
	Log(RM1)	C			
27. LogMVAGOTH	0.05	-8.29			
standard error	0.02				
t-statistics	2.38				
	LogPCRM1T	C			
28. Log (MVADOTH)	0.30	-4.68			
standard error	0.04				
t-statistics	6.93				

The Akaike information criterion and the Schwarz criterion are used to determine the “best” number of lags and the order of the autoregression in the vector autoregression estimation stage of the VAR estimation method. The possible seasonal effects from the monthly data are taken into account at this estimation stage by including eleven monthly dummy variables in the given equations.

The Johansen normalized cointegrating coefficients are then derived from the "best" vector autoregression estimates and are presented in Table 6. Their unrestricted cointegration rank tests are presented in Table 7. All the variables in the equations have expected and significant signs. The own price elasticity of gasoline and high speed diesel from the gasoline and high speed diesel consumption equations are found to be rather inelastic at -0.45 and -0.31 respectively. The estimated price inelasticities of gasoline and high speed diesel are compatible with the estimates in the reviewed demand studies.

Table 7

Unrestricted Cointegration Rank Test (Trace)

	Hypothesized No. of CE(s)	Trace statistic	0.05 Critical value	Prob.**
1. LOGQGPERVAG	None *	211.06	83.94	0.0000
2. LOGQDPERVAD	None *	143.09	76.97	0.0000
3. LOGPASSG	None *	41.44	35.19	0.0093
4. LOGPASSD	None *	67.61	54.08	0.0020
5. LOGMVAG12	None *	32.02	20.26	0.0008
6. LOGMTADT	None *	48.23	35.19	0.0012
7. LOGMTAGT	None *	68.68	35.19	0.0000
8. LOGMVAGOTH	None *	25.35	20.26	0.0091
9. LOGMVADOTH	None *	23.21	20.26	0.0191

Notes. * denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-aug-Michelis (1999) *p*-values.

The significant vehicle stock variables in the gasoline and high speed diesel equations are also compatible with the reviewed demand studies that some measures of vehicle ownership significantly affect the gasoline demand and also, in this case, the high speed diesel demand.

The gasoline price variable has no significant effect on the high speed diesel consumption but the high speed diesel price has a small but significant effect on the gasoline consumption with a 0.09 cross price elasticity. The gasoline and the high speed diesel price variables have no significant effects on the per capita stock of gasoline engine vehicles but the gasoline price variable has a significant effect on the per capita stock of diesel engine vehicles.

The relative prices of gasoline engine and diesel engine passenger vehicles have rather small effects on the per capita stock of gasoline engine passenger vehicles and the per capita stock of diesel engine passenger vehicles. In contrast, the per capita stock of buses and trucks is relatively more price and income elastic than the per capita stock of passenger vehicles.

Table 8

Simulation Equations for Fuel Consumption

	C	Log (RPG)	Log (RPD)	Log (PMVAG/PMVAD)	Log (PMTA)	Log (RM1)
1. Log (QGPERTVG)	-1.65	-1.29	0.09	-0.13	1.02	-0.64
	C	Log (RPG)	Log (RPD)	Log (PMVAD/PMVAG)	Log (PMTA)	Log (RM1)
2. Log (QDPERTVD)	11.89	0.98	-0.31	-0.13	-1.24	0.41

The per capita stock of vehicles equations and the share equations are used to substitute for the variables TVG and TVD in equations (9) and (10). The resulting equations shown in Table 8 then capture the effects of the fuel pricing policy and the vehicle tax policy on the gasoline and high speed diesel consumption.

Figure 1 compares the actual consumption of gasoline with its estimated consumption from equation 9 in Table 6 and with the estimated gasoline consumption from equation 1 in Table 8. The coefficient of variation is 0.12 for the gasoline consumption estimates from equation (9) and 0.14 for the gasoline consumption estimates from equation 1. The closeness between the two estimated series of gasoline consumption and its actual consumption indicates that the model can capture the effects of the government's vehicle tax policy on gasoline consumption.

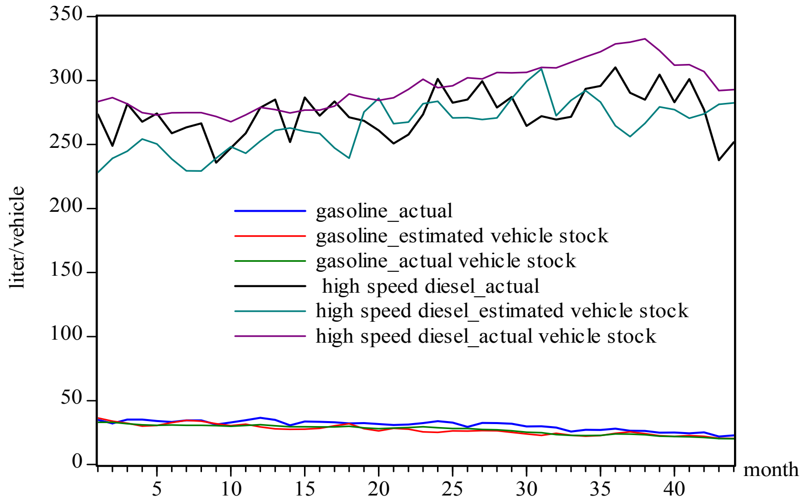

Figure 1. Actual and simulated fuel consumption, January 2002-August 2005.

Figure 1 also compares the actual consumption of high speed diesel with its estimated consumption from equation (10) in Table 6 and the estimated consumption from equation (2) in Table 8. The coefficient of variation is 0.095 for the high speed diesel consumption estimates from equation (10) and 0.088 for the estimates from equation (2). As in the case of gasoline, the estimated model can capture the effects of the government's vehicle tax policy on high speed diesel consumption.

Government's Policy and Welfare Losses

The welfare losses caused by the government's fuel pricing policy and the vehicle tax policy depend on the divergence between the actual gasoline and the high speed diesel consumption from their efficient consumption. The efficient gasoline and high speed diesel consumption are achieved when the two fuels and all vehicles are priced at their social marginal costs.

The social marginal cost pricing requires identifications of the automobile externalities. The sources of automobile externalities are identified as global pollutions, local air pollutions, traffic congestions, traffic accidents, and other externalities (Parry, Walls, & Harrington, 2007). If these externalities are not internalized they would cause over consumption of gasoline and high speed diesel. The effective instruments required to correct these externalities depend on the nature of their effects on fuel consumption. The identity in equation (1) is helpful in considering the effectiveness of the instruments designed to internalize these externalities.

Global pollution is caused by the emission of carbon dioxide, the major greenhouse gas that causes global warming. These emissions occur whenever a liter of gasoline or high speed diesel is used to start a vehicle engine. The global pollution is thus related to the amount of fuel consumption rather than the distance travelled by vehicles.

Since the global pollutions are related to fuel consumption, the instrument used to internalize its social costs must be able to reduce fuel consumption to its optimum level. A simple fuel tax equivalent to the costs of global pollution per liter of fuel is an effective instrument to internalize the global pollution costs. The higher fuel prices are expected to discourage driving by reducing the vehicle utilization rates for the existing vehicle owners and provide incentives for the potential new vehicle owners to purchase the fuel efficient cars which will improve the overall vehicle fuel economy and, hence, reduce the fuel consumption.

The local pollution costs are caused by the tail pipe emissions of vehicles which contain particulate matter (PM) or fine particles, sulfur dioxide (SO_2), nitrogen oxide (NO_2), volatile organic compound (VOC), and carbon monoxide (CO). These pollutants are detrimental to health but the fine particles are reported to be the major cause of health problems. Unlike the case of global pollutions, the local pollutions are related to the distance travelled by the vehicles rather than the fuel consumption.

A fuel tax may not be an effective instrument to internalize the local pollution costs as in the case of the global pollution. The degree of the effectiveness of the fuel tax depends on the behavioral responses of the vehicle owners to higher fuel prices that can be disaggregated into two parts. The first part concerns the existing vehicle owners' response to increasing fuel prices by reducing their vehicle utilization rates which will reduce the local pollution costs. The second part concerns the potential new vehicle owners' response to increasing fuel prices by increasing their demand towards more fuel efficient vehicles. It is this latter part of response to the fuel tax that fails to reduce the local pollutions costs.

The existing import vehicle tax, the vehicle excise, and the interior tax in Thailand are ineffective in reducing the local pollutions externality since they fail to reduce the vehicle utilization rate. Other vehicle taxes such as the luxury car tax are also ineffective in correcting the externalities that are related to the distance travelled by vehicles (Clark & Prentice, 2009). A vehicle tax such as the gas guzzler tax (United States Environment Protection Agency, 2010) implemented in the United States provides incentive to potential new owners to purchase fuel efficient vehicles. Although the gas guzzler tax provides incentive to improve the vehicle fuel economy it fails to influence the vehicle utilization rates.

Other externalities are also related to the distance travelled or the vehicle utilization rates as in the case of local pollutions, so other instruments rather than the fuel tax are required to correct their externalities. The congestion charge is an example of the instrument used to reduce the congestion externality by reducing the vehicle utilization rates. The internalization of these externalities lies outside the scope of this paper. Some discussions and reference on this issue may be found in other studies (Parry, Walls, & Harrington, 2007; Clark & Prentice, 2009).

Reference for Efficient Pricing of Fuel and Vehicles

The existing price structure of gasoline and high speed diesel can be modified to accommodate the fuel tax to internalize the global pollution costs. All of the transfer payments items in the existing price structure are unrelated to the correction of externalities and are removed from the price structure. The efficient price structure now consists of the ex-refinery price, the marketing margin, and the fuel tax that reflect the global pollution costs.

There are several studies that provide estimates of the global warming costs. One well-known study (Nordhaus, 2006) estimated the discounted costs of carbon dioxide emissions over their expected atmospheric life of 100 years at $20 per ton of carbon in 2005 prices. The Nordhaus estimates are compatible with the price of the EU allowances for carbon dioxide emissions between January 2007 to January 2009 that varies between \$5 and \$30 per ton of carbon dioxide equivalent with an average price of approximately \$20 per ton.

It is reported that the carbon dioxide emissions from diesel fuel are higher than emissions from gasoline fuel (United States Environmental Protection Agency, 2005). The carbon dioxide emissions from diesel fuel were found to be 2,778 grams per gallon of diesel compared to 2,441 grams per ton of gasoline. This translates into emissions of 644.9 grams of carbon dioxide per liter of gasoline and 733.9 gram per liter of diesel. Using the average carbon dioxide emissions costs of \$20 per ton of carbon, and the exchange rate of 35 baht per dollar, the carbon dioxide emissions costs are approximately 0.45 baht/liter for gasoline and 0.51 baht/liter for diesel.

The import tax, the interior tax, and the excise tax are removed from the vehicle retail prices so the vehicles' border prices or c.i.f. prices represent their efficient prices. The retail prices of gasoline, high speed diesel, and vehicles with their corresponding efficient prices are presented in Table 9.

Table 9

Average Retail and Efficient Prices of Fuels and Vehicles, January 2002-August 2005

	Gasoline	High speed diesel	GE vehicles	DE vehicles	Buses & Trucks
Retail	16.84	14.26	322.76	156.3	205.73
Border	11.64	11.69	95.8	95.8	98.2
Global pollution cost	0.45	0.51	-	-	-
Efficient	12.09	12.11	95.8	95.8	98.2
Transfer payments	5.2	2.57	226.96	60.5	107.53

Notes. GE = gasoline engine; DE = diesel engine; fuel prices and global pollution costs are in baht/liter; and vehicle prices are in index form.

The average gasoline retail price is about 39.3 percent higher than its efficient price while the high speed diesel retail price is about 17.8 percent higher than its efficient price. The distortions in the vehicle retail prices are considerably larger than the retail fuel price distortions. The vehicle tax policy results in the largest price distortions for gasoline engine vehicles as their retail price index is about 3.4 times their efficient price index. The ratio of retail price to efficient price is lower for buses and trucks at 2.1 and the diesel engine vehicles have the smallest ratio of 1.63.

The retail pricing policy of gasoline and high speed diesel has implications on their economic costs. The ratio of Pg to Pd, the marginal rate of substitution, is 1.19 which is greater than the ratio of Pge to Pde, the marginal rate of transformation, which is approximately 1 between January 2002 and August 2005.

From the point of view of the utility maximizing consumer, a liter of high speed diesel can be exchanged for 0.84 liter of high gasoline. If there is a marginal decrease of 1 liter in the refining of high speed diesel, there would be an increase in the gasoline output of 1 liter. There is thus an extra 0.16 liter of gasoline in the country which is worth (0.16) (12.09) or 1.93 baht. This is the economic cost or the opportunity cost for each liter of high speed diesel that is refined and consumed over the efficient level.

Framework for Measuring Welfare Losses

There are several past studies that investigate the welfare losses in terms of losses in consumer surplus and producer surplus from given government energy policies. The welfare losses in many studies are estimated by assuming a range of price elasticity for demand and supply of the energy source under investigation.

There are numerous studies that estimate the welfare losses by assuming a range of price elasticity.

Examples are the study on the effects of world fossil price subsidies and global carbon emissions on welfare (Larsen & Shah, 1995); the study on the welfare effects of raising household prices of district heat, electricity and gas in Poland (Freund & Wallich, 1996); the study on the welfare losses in the gasoline market after hurricanes Katarina and Rita caused damages to the energy infra structure of the Gulf Coast in the United States (Montgomery, Baron, & Weisskopf, 2007).

Welfare losses are also estimated from the demand and supply models. An example is the study on the welfare effects of raising the prices of gasoline in Iran after a period of low regulated prices (Ahmadian, Chitnis, & Hunt, 2007). The authors of this study did not assume the values for the demand and supply price elasticity but estimated the welfare effects from the demand and supply models.

The welfare losses from the fuel price policy and the vehicle tax policy in Thailand are estimated in three scenarios. The first scenario considers the effects of the fuel pricing policy on fuel consumption when this policy is implemented in isolation. Similarly, the second scenario considers the effects of the vehicle tax policy on fuel consumption when it is implemented in isolation. Finally, the third scenario considers the effects of the fuel pricing policy and the vehicle tax policy as a policy package on fuel consumption.

Figure 2 illustrates the conceptual framework for the estimation of welfare losses for gasoline when the fuel pricing policy is implemented in isolation. The demand for gasoline Dg (Pde) is the reference for the efficient demand when high speed diesel and all vehicles are priced at their efficient levels. Dg (Pd) is the demand for gasoline when high speed diesel is priced at its actual retail level Pd and all vehicles are priced at their efficient levels. The difference between Dg (Pde) and Dg (Pd) are then caused by the high speed diesel pricing policy. In this illustration, it is assumed that the oil fund is used to set the actual price of high speed diesel lower than its efficient price.

For a perfectly elastic gasoline supply, the efficient supply of gasoline is determined by the efficient price Pge so the efficient gasoline consumption is Qge. When the government sets the actual price of diesel at Pd and the actual price of gasoline at Pg the actual consumption of gasoline is Qg liter/vehicle which is less than Qge, its efficient consumption.

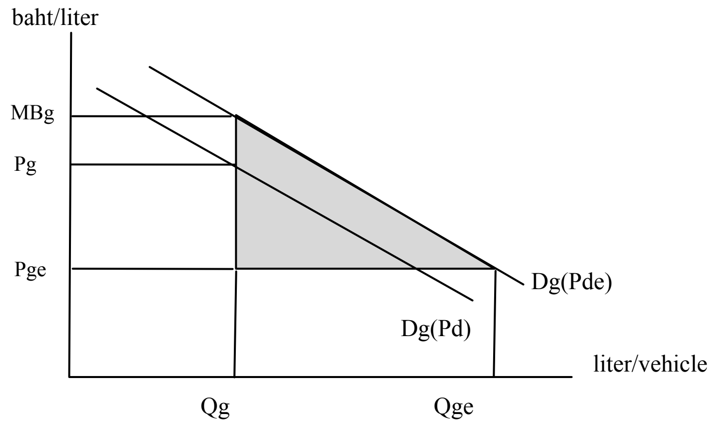

Figure 2. Welfare losses from gasoline pricing policy.

The marginal benefit, MBg, of the actual gasoline consumption Qg is greater than its social marginal social cost Pge so the gasoline and high speed diesel pricing policy results in welfare losses equal to the shaded area of the triangle in Figure 2. The welfare losses for high speed diesel from the fuel pricing policy can be estimated by using the same analytical framework.

The welfare losses from the vehicle tax policy in isolation are also estimated from the difference between the actual fuel consumption and the efficient consumption. The efficient demand for gasoline is the same as in the first scenario but the actual gasoline demand is now determined by setting the gasoline price and the high speed diesel price equal to their efficient levels and the vehicle prices equal to their actual levels. The difference between the efficient and the actual gasoline demand is then attributable to the vehicle tax policy.

The welfare losses from the fuel pricing policy and the vehicle tax policy as a package are also estimated from the difference between the actual fuel consumption and the efficient consumption. The actual gasoline demand under the policy package is determined by setting the gasoline price, the high speed diesel price, and the vehicle price equal to their actual levels.

Estimations of Welfare Losses

The efficient and actual prices of gasoline, high speed diesel, and vehicles in Table 8 are used to estimate the efficient and actual gasoline and high speed diesel consumption. The welfare losses are estimated from the actual consumption, the efficient consumption, and the relevant elasticities estimated from the model.

The model estimation results in Table 6 provide some previews of the relative effects that the policy variables have on fuel consumption and, hence, the welfare losses. Gasoline and high speed diesel are rather price inelastic so the prices of these two fuels would have relatively small effects on their consumption. The small cross price elasticity of high speed diesel of 0.09 is not likely to have a significant effect on the gasoline consumption.

Table 10
Simulation Results of Welfare Losses

Reference for efficiency	*Gasoline*	*High speed diesel*
efficient price (baht/liter)	12.09	12.11
efficient consumption (liter/vehicle)	21.94	434.40
efficient per capita stock of vehicles	0.36	0.10
Effect of fuel pricing policy: efficient vehicle prices, actual fuel prices		
“actual” per capita stock of vehicles	0.36	0.11
“actual” consumption (liter/vehicle)	14.22	585.74
welfare losses (baht/vehicle)	1.14	1.02
percent of retail price	6.77	7.16
Effect of vehicle tax policy: efficient fuel prices, actual vehicle prices		
“actual” per capita stock of vehicles	0.36	0.08
“actual” consumption (liter/vehicle)	41.89	196.78
welfare losses (baht/vehicle)	3.51	1.06
welfare losses (baht/vehicle)	20.85	7.45
Effect of vehicle/fuel price policy: actual fuel prices, actual vehicle prices		
“actual” per capita stock of vehicles	0.36	0.09
“actual” consumption (liter/vehicle)	27.17	264.79
welfare losses (baht/vehicle)	1.28	1.03
welfare losses (baht/vehicle)	7.59	7.24

In contrast, the elasticities and cross elasticities of the per capita stock of vehicles in equation 9 and equation 10 are rather large so their changes are expected to have relatively large impacts on the gasoline and the high speed diesel consumption. The per capita stock of diesel engine vehicles has larger elasticities and cross elasticities than the per capita stock of gasoline engine vehicles so the changes in its per capita stock will have relatively greater effects on the fuel consumption. The results of the welfare losses estimations are presented in Table 10.

Welfare Losses From Fuel Pricing Policy

The fuel pricing policy causes under consumption of gasoline and over consumption of high speed diesel. The gasoline under consumption is caused by the gasoline and high speed diesel prices that tend to directly decrease the gasoline consumption. The gasoline price also affects the gasoline consumption indirectly through its effect on the per capita stock of diesel engine vehicles. The high gasoline price increases the per capita stock of per capita stock of diesel engine passenger vehicles over its efficient level which decreases the total per capita stock of diesel engine vehicles and, hence, the gasoline consumption.

In contrast, the over consumption of high speed diesel is caused by the gasoline and high speed diesel prices that tend to directly increase the high speed diesel consumption. In addition, the increase in the per capita stock of diesel engine vehicles caused by the gasoline price reinforces the increase in high speed diesel consumption.

The welfare losses from the fuel pricing policy are thus caused by the over consumption of high speed diesel and under consumption of gasoline. The welfare losses for high speed diesel are about 1.02 baht/liter which are slightly less than the welfare losses in gasoline consumption of 1.14 baht/liter.

Welfare Losses From Vehicle Tax Policy

In contrast to the fuel pricing policy, the vehicle tax policy, when implemented in isolation, causes under consumption of high speed diesel and over consumption of gasoline. This result can be explained by the effects that the vehicle tax policy has on the per capita stock of vehicles. The vehicle tax policy causes a decrease in the efficient per capita stock of diesel engine vehicles from 0.1 to 0.08. This is mainly attributable to the decrease in the per capita stock of the diesel engine buses and trucks group that has rather large price elasticity.

The actual per capita stock of gasoline engine vehicles is approximately the same as its efficient per capita stock even though the vehicle prices are increased to their actual levels. This is explained by the low price inelasticity of the per capita stock of gasoline engine vehicles. The decrease in the total per capita stock of diesel engine vehicles tends to increase the gasoline consumption and to decrease the high speed diesel consumption.

The welfare losses from the vehicle tax policy are caused by the over consumption of gasoline and under consumption of high speed diesel. The welfare losses in gasoline are more than twice the welfare losses from the fuel pricing policy but the welfare losses in high speed diesel are slightly higher than the welfare losses from the fuel pricing policy. The vehicle tax policy causes greater welfare losses than the fuel pricing policy because of the larger effect on the per capita stock of diesel engine vehicles.

Welfare Losses From Fuel Pricing Policy and Vehicle Tax Policy

The fuel pricing policy and the vehicle tax policy as a policy package also cause the over consumption of gasoline and the under consumption of high speed diesel. Similar to the case when the vehicle tax policy is implemented in isolation, the effect of the policy package is to decrease the per capita stock of diesel engine vehicles but to a lesser extent.

The smaller decrease in the per capita stock of diesel vehicles is explained by the gasoline price that tends to increase the per capita stock of diesel engine passenger vehicles. The increase in the per capita stock of diesel engine passenger vehicles partially offset some of the decrease in the per capita stock of buses and trucks.

The welfare losses from the policy package are then less than the welfare losses under the vehicle policy, but greater than the welfare losses under the fuel pricing policy.

Revenue Consideration

The implementation of efficient pricings for gasoline, high speed diesel, and vehicles in place of the existing policy inevitably affects the government tax revenue. It can be seen from Table 8 that the tax on gasoline and high speed diesel will decrease by 4.75 baht/liter and 2.06 baht/liter respectively. In addition, the government will lose the tax revenue from vehicles.

Table 11 presents the comparison between the simulated actual revenue from all transfer payments items and the simulated revenue under the efficient pricing policy. The tax revenue from gasoline and high speed diesel are estimated from the global pollution tax of 0.45 baht/liter for gasoline and 0.51 baht/liter for high speed diesel. The tax revenue from gasoline and high speed diesel consumers under the efficient pricing policy will decrease by about 2.9 billion baht/month and 2.4 billion baht/month respectively.

Table 11
Average Tax Revenue Under Actual and Efficient Pricing, January 2002-August 2005

	Simulated actual (million baht/month)	Simulated efficient (million baht/month)	Difference (million baht/month)
Gasoline	3,177.46	223.88	-2,953.58
High Speed Diesel	3,843.48	1,434.12	-2,409.35
Passenger Vehicles	2,138.30	-	-2,138.30
Buses and Trucks	679.34	-	-679.34
Total	9,838.57	1,658.00	-8,180.57

The import tax and excise tax for vehicles are combined as an effective tax rate to estimate the losses in revenue. The tax rate for passenger vehicles are the average rates between the gasoline engine vehicles and diesel engine vehicles weighted by their numbers. The tax rates for buses and trucks are similarly estimated. The tax rates are then applied to the import value of passenger vehicles and buses and trucks. If there are no taxes collected from vehicles, the government will have to forego about 2.8 billion baht from the vehicle tax revenue so the total revenue deficit will be approximately 8.18 million baht/month.

The revenue deficit can be financed from the charges designed to correct the other externalities. One potential source of revenue for Thailand that should be seriously considered is the collection of congestion charges to correct the congestion externality and the local pollution externality. The congestion charge policy has never been implemented in Thailand and its implementation can raise revenue to help offset the loss in revenue from the inefficient vehicle taxes. Example of a country that is following this policy direction is the Netherlands where its government is planning to replace the MRB vehicle tax and the vehicle sales tax by the congestion charge (Victoria Transport Institute, 2010).

In the case where the revenue generated from the externality correcting charges fails to offset the revenue loss, the government needs to consider the available options to raise revenue. It is inevitable that raising revenue by charges unrelated to externality costs imposes some inefficiency costs. In this respect, the excise tax has an advantage over other taxes in raising revenue (Clark & Prentice, 2009). If the excise taxes are to be levied on gasoline and high speed diesel, the inefficiency costs are not expected to be high since the two fuels are rather price inelastic.

Summary, Conclusions, and Recommendations

The consumption of gasoline and high speed diesel in Thailand are influenced by their pricing policy and the vehicle tax policy. The fuel pricing policy results in the cross price subsidy from the gasoline consumers to the high speed diesel consumers. The vehicle tax policy results in a tax structure that biases the purchase of vehicles towards the diesel engine vehicles.

The fuel pricing policy and the vehicle tax policy result in welfare losses by distorting the actual consumption of gasoline and high speed diesel from their efficient levels. The efficient consumption is achieved by pricing gasoline, high speed diesel, and vehicles at their social marginal economic costs. The existing price structure of gasoline and high speed diesel allows only the global pollution externality to be internalized effectively by the fuel tax.

Other externality costs that are related to the vehicle utilization rates cannot be internalized effectively through the existing price structure and require other charges to internalize their costs. It is recommended that the government gives high priority to the collection of congestion charges to correct the congestion externality and to help finance the revenue deficit from the proposed price structure.

A trial basis of collecting the congestion charge for some parts of Bangkok has been suggested (Vikitset, 2011). A thorough study on the "optimum" options of implementing the congestion charges for Thailand that are compatible with the overall transport system is urgently required. Its implementation will complement the efficiency of the proposed fuel price structure.

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