WELFARE ANALYSIS OF HOUSEHOLD DEMAND FOR VEHICLE FUEL

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ABSTRACT

Title of Dissertation	Welfare Analysis of Household Demand for Vehicle Fuel
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Thailand has adopted policies that promote the use of biofuel produced from local crops to reduce the country's dependence on imported fossil fuel. The pricing policy was designed to encourage greater use in the transportation sector of gasohol, which is a blend of gasoline and ethanol. It consists of two measures, namely, a subsidy on gasohol and a tax on gasoline. Their effect was to make gasohol price lower than that of gasoline so that motorists might use more gasohol, which is a substitute to gasoline. However, the economic impact of the measures was welfare loss and inefficiency, which was the result of the increasing difference between the MRS and MRT of both products as gasohol consumption increased. In this regard, the influence of households' socio-economic characteristics and other factors on vehicle fuel consumption and the impacts of the existing pricing policy were examined so that an alternative pricing policy that should lead to the highest efficiency of both fuels and increase gasohol consumption with the least cost could be proposed in this study. To address these two research questions the study was divided into two parts: first, a micro-analytic empirical approach was used to investigate vehicle fuel demand patterns of households, which cannot be revealed by macro-data. The complete demand analysis based on micro level data was then carried out to assess the effects of price and non-price factors, deriving results of demand elasticities for each vehicle fuel items, particularly E10-gasohol and gasoline. Second, the demand elasticities, both uncompensated and compensated, were used to determine the alternative pricing policy to support the use of gasohol as a gasoline substitute. The welfare measure used to examine the highest efficiency of pricing policy is the compensating valuation.

The results found that the consumption pattern of households for vehicle fuels is determined by their total vehicle fuel expenditure, the prices they pay for the fuels, and by the gender, age and educational attainment of the household head. The analysis also revealed that, based on the 2009 prices of gasoline and gasohol which were influenced by the pricing policy, a welfare loss of THB 115,158.59 million was incurred. This was approximately 15% of the expenditure on vehicle fuel consumption in 2009. From these findings, the short term a retail price structure of gasoline and gasohol should be based on economic efficiency to reduce the welfare loss. For the long term, the efficient retail price structure of both fuels should be incorporated with the program to increase the efficiency of ethanol production and a higher ethanol blending. These measures would increase gasohol consumption at the least cost.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The rapidly increasing demand for energy in emerging markets, such as China and India, the world's dependence of oil supply from usually politically volatile areas, and the ageing wells and decreasing reserves of oil, have contributed to a growing global energy insecurity. In addition, mitigation of climate change impacts includes in large measure having to use less fossil fuel-based energy to reduce greenhouse gas (GHG) emissions. This goal of energy security has led to the development of, among various alternative energy sources, biofuels such as ethanol and biodiesel. As biofuels come from crops that many countries - with or without oil reserves - can grow or have been growing, they have begun to assume an important role in national energy security policy. (It is as yet a debatable point but the production and consumption of biofuels are seen to have a lesser carbon footprint than fossil fuel). Countries that have adopted this policy have set production and/or consumption targets for biofuels. The strategy to achieve the targets usually consists of producing a given quantity of biofuel or establishing minimum blending percentages with fossil fuels particularly gasoline and diesel.

Governments worldwide recognize that it will require significant assistance and support in the form of tax exemptions, grants, subsidies and other schemes to implement their biofuel plans. An example is the European Commission (EC) directive issued in 2003 to promote the use of biofuels and other renewables for transport by setting a target of 2 percent biofuel penetration by December 2005 and 5.75 percent by December 2010 (International Energy Agency, 2004: 34-35). The USA has several policies promoting production and use of biofuels, one of which is the Renewable Fuel Standard (RFS) calling for the increased blending of biofuels with conventional motor fuels, a federal tax credit (subsidy) of 46 cents-per-gallon of

10 percent ethanol blended gasoline for blenders and retailers as well as a 54 cents-per-gallon duty imposed on all imported ethanol to protect the ethanol industry from foreign competition (Gorter, Just and Tan, 2009: 65-67). China has selected several provinces for trial blends of 10 percent ethanol, refunded value-added taxes for ethanol production and exempted a five percent consumption tax on ethanol (Koizumi and Ohga, 2007: 2-8). Malaysia has mandated blending to stimulate the use of biodiesel. It is not mandatory in Indonesia but the government had a plan to increase biodiesel blend to 10 percent in 2010 (Tisdell, 2009: 15-16).

Thailand depends heavily on fuel imports. In 2010 its energy imports was about THB 950 billion, approximately 9.4 percent of GDP, of which 79 percent was in the form of crude oil (Energy Policy and Planning Office, 2011: 3-5). In 2010, petroleum products accounted for 56.5 percent of the final commercial energy consumption and were mainly consumed in the transport sector approximately by 71.6 percent (Department of Alternative Energy Development and Efficiency, 2010b: 9). The petroleum products used in this sector comprise diesel (46.8%), which includes palm diesel, gasoline (22.2%), which also includes gasohol, jet fuel (15.7%), fuel oil (5.6%), and LPG (3.2%) (Department of Alternative Energy Development and Efficiency, 2010b: 11). As the main user of petroleum products, Thailand's transport sector is also the major source of air pollutant emissions particularly carbon dioxide (CO_2) from fossil fuel combustion (Department of Alternative Energy Development and Efficiency, 2010b: 30). Thailand has tried to alleviate its heavy reliance on imported fossil fuel by producing biofuels and promoting their use. Energy plants have been established that use feedstock to produce ethanol or biodiesel from sugarcane, cassava, corn, sweet sorghum, and oil palm and policies have been issued to increase the use of ethanol and biodiesel in the transport sector. One policy outcome is E10-gasohol which is a blend of gasoline and 10 percent ethanol, and B5 which is a biodiesel blend containing 5 percent biofuel. Other important policies are those aimed at encouraging the consumption of these blends by vehicle-owning households. These are discussed in the next section.

The main raw materials for ethanol production are molasses and cassava. In 2010, molasses-based ethanol accounted for 60-70 percent of total ethanol production. Meanwhile, cassava-based ethanol production has increased significantly to account for 20-30 percent of total ethanol production (Global Agricultural Information Network, 2010: 7). In 2008, the Ministry of Energy launched the 15-Year Renewable Energy Development Plan (REDP) 2008-2022. Its goal is to increase the share of alternative energy mix, with a target of fulfilling 20 percent of the country's total energy demand by 2022. Under this plan, the targets of ethanol production have been set at 3.0 million litres/day for the short term (by 2011), 6.2 for the medium term (by 2016) and 9.0 for the long term (by 2022) (Department of Alternative Energy Development and Efficiency, 2008: 8-10). To reach these targets, the government has implemented a pricing policy on E10-gasohol and gasoline that relies on excise tax and oil fund levy. These tools lead to a lower gasohol price relative to that of fossil fuels, resulting in the substitution of gasohol for gasoline. Janthanee Homchuen (2006: 81-87) found that, in the case of Thailand, gasohol increasingly became a substitute for gasoline as a result of the highly positive cross price elasticity of demand for gasohol with respect to gasoline. The higher gasohol consumption has thus resulted in a higher ethanol consumption, which has driven the increase in its production.

The retail price structure of petroleum products in Thailand (Table 1.1) can be categorized into three main parts, namely, ex-refinery price, wholesale price and retail price. Ex-refinery price is the price set by the refineries by referring to the world market price, which is the Singapore Oil Market Price. Wholesale price comprises the ex-refinery price plus the excise tax, municipality tax (10% of excise tax), contribution to the Oil Fund, contribution to the Energy Conservation Promotion Fund (ENCON Fund), and value added tax (VAT) of the wholesale price. The retail price comprises the wholesale price, the marketing margin and the VAT of the marketing margin. In line with Thiraphong Vikitset (2008: 3-8), this price structure has two parts: the economic cost and transfer payment. The economic cost comprises the opportunity cost and the externality cost. For petroleum products, the economic cost can be reflected by ex-refinery price, conservation fund and marketing margin (Thiraphong Vikitset, 2008: 3-8). The opportunity cost of refinery is represented by the ex-refinery price, which reflects the distribution cost and profit of the oil traders (Thiraphong Vikitset, 2008: 3-8), the refining cost and profit of the oil refiners, and the marketing margin component. Currently, there are no retail price components that reflect the externality cost in the existing retail price structure of petroleum products. The conservation fund item in this structure price is the money contributed to the Energy Conservation Promotion Fund (ENCON Fund). This Fund finances the promotion of renewable energy and energy efficiency, resulting in mitigating of environmental problem that generated by the usage of energy. Thus this item can be considered as an externality cost. The transfer payment comprises the excise tax, municipal tax, oil fund and value added tax.

Table 1.1 Price Structure of Petroleum Products in Bangkok, August 2, 2010

	ULG 91	GASOHOL 91
1. Ex-Refinery Price	16.95	17.87
2. Excise Tax	7.00	6.30
3. Municipal Tax	0.70	0.63
4. Oil Fund	6.70	1.40
5. Conservation Fund	0.25	0.25
6. Wholesale Price (WSP) [1+2+3+4+5]	31.60	26.45
7. Value Added Tax (VAT)	2.21	1.85
8. WSP&VAT [6+7]	33.81	28.30
9. Marketing Margin	1.71	1.90
10. Value Added Tax (VAT)	0.12	0.13
11. Retail Price [8+9+10]	35.64	30.34
12. Economic Cost [1+5+9]*	**18.91**	**20.02**
13. Retail Price/Economic Cost*	**1.88**	**1.52**

Source: Energy Policy and Planning Office, 2012b.

Note: *Calculated by Author.

In neoclassical economics based on perfectly competitive markets, the marginal rate of substitution (MRS) is equal to the marginal rate of transformation (MRT), leading to economic efficiency (Pindyck and Rubinfeld, 1992: 594-596). The marginal rate of substitution (MRS) for both gasoline and gasohol is the ratio of the retail gasoline price to gasohol, while the ratio of the economic cost of gasoline to gasohol is the marginal rate of transformation (MRT). Thus, the ratio of the retail price to the economic cost for gasoline equals the ratio of the retail price to the economic cost for gasohol, resulting in an efficient market for both fuels. However, the effect of pricing policy to encourage the usage of gasohol leads to a retail price higher than the economic cost, as shown in Table 1.1, and the difference between MRS and MRT of both fuels, as shown in Figure 1.2. When the gasohol consumption is higher than the gasoline consumption, the difference between MRS and MRT is larger, as shown in Figure 1.1 and 1.2. Therefore, this policy has resulted in economic inefficiency and welfare loss. This study aims to measure the effects on welfare of specific government policies that promote the usage of gasohol and to propose an alternative pricing policy that should lead to the highest efficiency of both fuels.

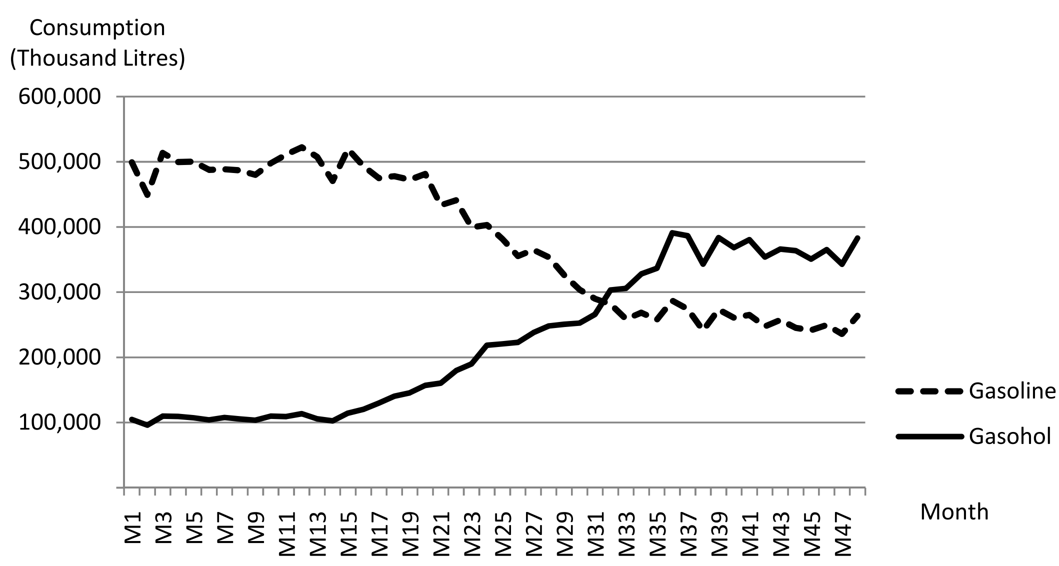

Figure 1.1 Consumption of Gasoline and Gasohol, January 2006- December 2009

Source: Department of Energy Business, 2012.

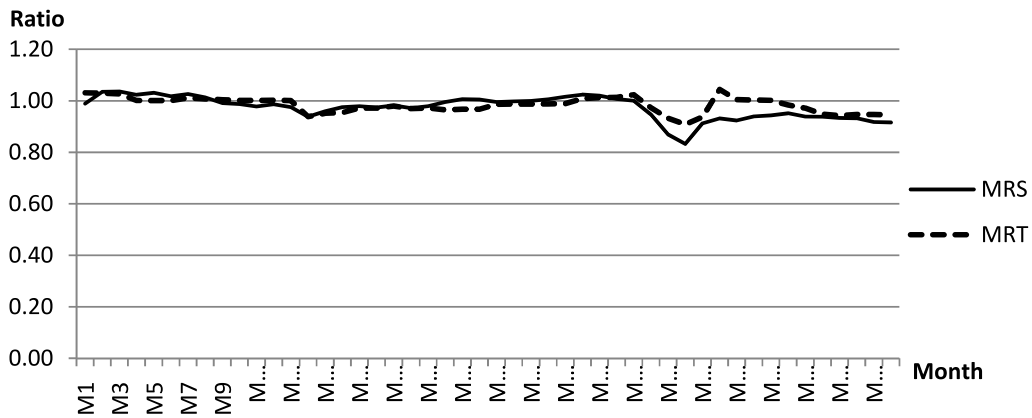

Figure 1.2 Marginal Rate of Substitution (MRS) and Marginal Rate of Transformation (MRT) for Gasoline and Gasohol, January 2006-December 2009

Source: Energy Policy and Planning Office, 2012a.

Note: Calculated by Author.

1.2 Research Questions

Besides its effect on welfare, which is the key determinant of an efficient policy, the consumption pattern of households for vehicle fuel is also an important information to the policymaker. A pricing policy to encourage the use of gasohol should lead to the substitution of gasohol for gasoline, which then increases gasohol consumption. Price, however, may not be the sole factor that influences the consumptions of both products. There could be other factors that influence their consumption. In this regard, the study attempts to answer these questions:

1) What is the consumer behavior toward the use of vehicle fuel?

2) Which pricing policy that supports the use of gasohol as a substitute to gasoline incurs the least cost?

1.3 Research Objectives

In order to answer the research questions, this study shall:

1) Examine the influence of households' socio-economic characteristics and other factors on vehicle fuel consumption by estimating the household demand for vehicle fuel.

2) Examine the impact of pricing policy to support the usage of gasohol as a gasoline substitute by using consumer welfare.

3) Propose an alternative pricing policy that should lead to the highest efficiency in both fuels.

1.4 Contribution of the Study

The results from the study will provide an understanding of vehicle fuel consumption patterns of households and reveal the factors that influence household demand for vehicle fuel. This information would also provide a basis for an efficient energy policy, which would raise social welfare.

1.5 Scope of the Study

This study will focus on the impact of the pricing policy that encourages the demand for gasohol. Consumption of these two types of fuel, gasoline and gasohol, is closely related to the car- and motorcycle-owning households, particularly of vehicles that are gasoline powered. The study will take a micro-analytic empirical approach to investigate vehicle fuel demand patterns of households that cannot be revealed by macro-data.

In line with the objectives, the scope of the study shall comprise two major areas of work: Firstly, the complete demand analysis based on micro level data shall investigate the effects of price and non-price factors, deriving results of demand elasticities for each vehicle fuel items, particularly E10-gasohol and gasoline. Secondly, the demand elasticities, both uncompensated and compensated, shall be used to find an alternative pricing policy to support the use of gasohol as a gasoline substitute. The welfare measure used to examine the highest efficiency of pricing policy is the compensating valuation.

CHAPTER 2

BIOFUEL IN THAILAND

2.1 Overview of Energy in Thailand

Thailand relies heavily on energy imports because of its limited energy resources. As would be expected of a country that is modernizing, economic growth is tightly linked with energy consumption. Figure 2.1 shows a high positive relationship between final energy consumption and GDP, at 1988 price, during 1991-2010. As can be seen in Figure 2.2, Thailand's economy grew at an average of 8.6 percent a year between 1991 and 1995, with the annual average final energy consumption growing at the same pace. The same relation was seen when growth slowed down, in 1996-1999; economic growth reached a low of -l0.5 percent and final energy a low of -9.3 percent in 1998. This was largely an effect of the 1997 Asian Financial Crisis. In the 2000s, the economic and final energy growth rates fluctuated but registered almost similar growth rates of 4.4 and 4.1 percent, respectively.

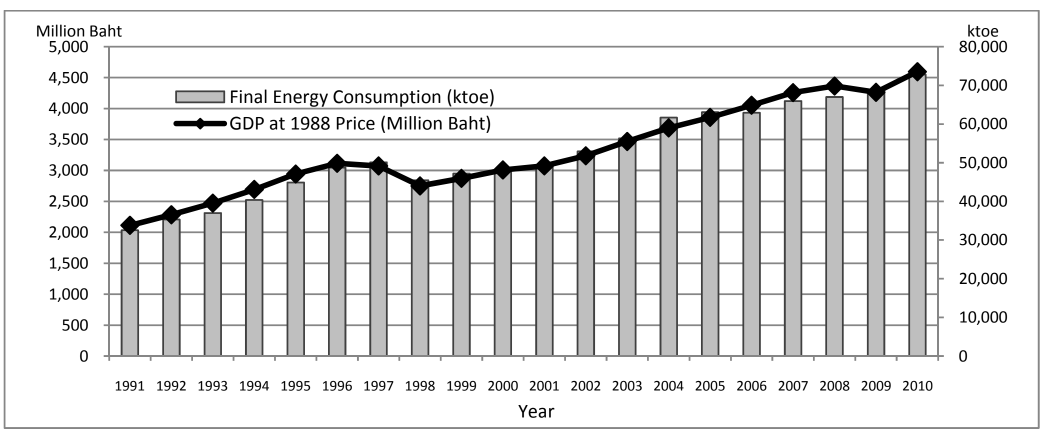

Figure 2.1 Relations of Final Energy Consumption and GDP at 1988 Price, 1991-2010

Source: Energy Policy and Planning Office, 2012a.

Note: ktoe means kilo ton oil equivalent.

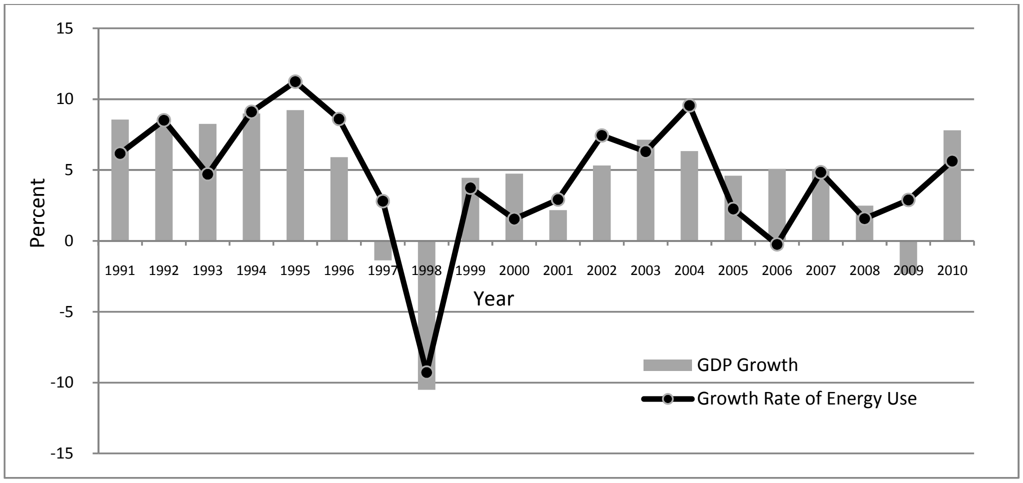

Figure 2.2 Economic Growth and Growth Rate of Energy Use, 1991-2010
Source: Energy Policy and Planning Office, 2012a.

Thailand's total primary energy supply in 2010 was about 124,301 ktoe, of which 72,143 ktoe (58.0 %) was from domestic production and 65,113ktoe (52.4 %) from imports (Table 2.1). Natural gas was the main contributor to domestic production at 31,407 ktoe (43.5%), while renewable energy sources contributed 30.4 percent. Crude oil was the largest form of net import at 40,734 ktoe (62.6%), while 11,385 ktoe of natural gas was still imported from Myanmar to feed power plants. Transforming primary energy to final energy incurred a net loss of around 46,075 ktoe, approximately 37.1 percent of total primary energy supply. Therefore, Thailand's total final energy supply in 2010 was 78,226 ktoe and the total final energy consumed was 70,247 ktoe. Of this amount, the share of industry was 36.4 percent, transportation 35.0, residential 15.6, commercial 8.0, and agriculture 5.0 percent. Petroleum products had the highest share (45.7%) of the final energy consumption. The shares of renewable energy, electricity, and coal in final energy consumed were 19.1, 18.1 and 11.7 percent, respectively, while that of natural gas was 5.4 percent.

Table 2.1 Thailand's Energy Balance, 2010

Unit: kilo ton oil equivalent (ktoe)

Supply and Consumption	Coal&coal Products	Crude Oil	Natural Gas	Condensate & NGL	Petroleum Products	Electricity	Renewable Energy	Other*	Total
Domestic Production	4,966	7,641	31,407	4,368	-	-	21,964	1,797	72,143
	(6.9%)	(10.6%)	(43.5%)	(6.1%)			(30.4%)	(2.5%)	(100.0%)
Imports	10,669	40,734	11,385	1,482	161	621	61	-	65,113
	(16.4%)	(62.6%)	(17.5%)	(2.3%)	(0.2%)	(1.0%)	(0.1%)		(100.0%)
Exports	-13	-1,471	-	-103	-10,327	-138	-45	-	-12,097
Stock Changes	-626	863	-	-810	-307	-	22	-	-858
Total Primary Energy Supply	**14,996**	**47,767**	**42,792**	**4,937**	**-10,473**	**483**	**22,002**	**1,797**	**124,301**
	(12.1%)	**(38.4%)**	**(34.4%)**	**(4.0%)**	**(-8.4%)**	**(0.4%)**	**(17.7%)**	**(1.4%)**	**(100.0%)**
Total Transformation, Own Uses and Losses	-6,756	-47,767	-37,785	262	44,111	12,241	-8,584	-1,797	-46,075
Total Final Energy Output	**8,240**	**-**	**5,007**	**5,199**	**33,638**	**12,724**	**13,418**	**-**	**78,226**
	(10.5%)		**(6.4%)**	**(6.6%)**	**(43.0%)**	**(16.3%)**	**(17.2%)**		**(100.0%)**
Non - Energy Uses	-	-	1,238	5,199	1,542	-	-	-	7,979

Table 2.1 (Continued)

Supply and Consumption	**Coal&coal Products**	**Crude Oil**	**Natural Gas**	**Condensate & NGL**	**Petroleum Products**	**Electricity**	**Renewable Energy**	**Other***	**Total**
Final Energy Consumption	**8,240** (**11.7%**)	**-**	**3,769** (**5.4%**)	**-**	**32,096** (**45.7%**)	**12,724** (**18.1%**)	**13,418** (**19.1%**)	**-**	**70,247** (**100.0%**)
- Agriculture	-	-	-	-	3,470	29	-	-	3,499
- Industry**	8,240	-	2,171	-	2,790	5,422	6,948	-	25,571
- Residential	-	-	-	-	1,652	2,841	6,470	-	10,963
- Commercial	-	-	1	-	1,193	4,426	-	-	5,620
- Transportation	-	-	1,597	-	22,991	6	-	-	24,594

Source: Department of Alternative Energy Development and Efficiency, 2010: 6-17.

Note: ***** Other is the summation of Hydro, Black Liquor & Residual Gas and other forms.

****** Industry Sector is the summation of the Manufacturing, Mining and Construction sectors.

The major portion (75%) of the total transport energy consumption is in road transport (Department of Alternative Energy Development and Efficiency, 2010a: 21). Of all the vehicles registered under the Motor Vehicle Act in 2010, motorcycles accounted for as much as 63.0 percent, while passenger cars (sedans) including microbuses, passenger pickups, vans and pickups altogether accounted for another 34.9 percent (Department of Land Transport, 2012). In this sector, most of the energy demand in 2010 was for petroleum products (93.5%), comprising diesel (including palm diesel) 46.8 percent, gasoline (including gasohol blends) 22.2 percent, jet fuel 15.7 percent, fuel oil 5.6 percent, liquefied petroleum gas (LPG) 3.2 percent, and a tiny fraction in electricity (Table 2.2).

Table 2.2 Energy Consumption for Transportation by Type, 2010

Fuel Type	Quantity (ktoe)	Share (%)
Petroleum Product	**22,991**	**93.48**
LPG	794	3.23
Gasoline-91(Regular)	2,147	8.73
Gasoline-95 (Premium)	57	0.23
Gasohol-91	1,156	4.70
Gasohol-95	2,001	8.14
Gasohol E20	101	0.41
Gasohol E85	1	0.00
Jet Fuel	3,852	15.66
Standard Diesel	7,054	28.68
B5 including palm diesel	4,462	18.14
Fuel Oil	1,366	5.55
Processed Natural Gas	**1,597**	**6.49**
Electricity	**6**	**0.02**
Total	**24,594**	**100.00**

Source: Department of Alternative Energy Development and Efficiency, 2010: 20.

2.2 Biofuel Production and Consumption

The above figures establish that Thailand's transport sector is the major consumer of energy. It is heavily dependent on imported oil so that a rise in world crude oil price would have a great impact on it and the economy as a whole. This is largely the reason the Ministry of Energy had, beginning in 2005, strongly promoted the use of biofuel in the transport sector to reduce oil consumption and dependence on imported forms of energy. In Thailand, ethanol and biodiesel have the potential to displace a substantial amount of petroleum because they can be made from raw materials that are abundant such as cassava, sugar, maize and palm oil. Sugarcane and cassava are the major crops for ethanol production, and palm oil for biodiesel production. About 45.2 kg of molasses, a by-product of sugar manufacture, can be extracted from 1 ton of sugarcane, which can be converted to 10 litres of ethanol (Gonsalves, 2006: 6). The conversion rate of cassava to ethanol is 170 litres per ton or 10 litres of ethanol from 58.8 kg of cassava (Suthiporn Chirapanda, Sudarat Techasriprasert, Somjate Pratummin, Samai Jain and Prapon Wongtarua, 2009: 6).

Ethanol can be used as a substitute for conventional gasoline (CG) in passenger vehicles. However, it is most commonly used as an additive with gasoline in a blend called gasohol, which can come as E10, 10 percent ethanol with gasoline, E20, 20 percent ethanol with gasoline, or E85, 85 percent ethanol with gasoline. E10 is used in modern vehicles without modifications to the fuel system and engine while specially designed flex-fuel vehicles can run on E85 (Global Agricultural Information Network, 2010: 3). A mixture of 5 percent biodiesel and 95 percent diesel is called B5 and diesel mixed with 2 percent biodiesel is called B2 (Global Agricultural Information Network, 2010: 3). B2 was phased out and replaced by B5 in 2012 (Global Agricultural Information Network, 2012: 11).

2.2.1 Biofuel Production

As can be seen in Table 2.3, the entire biofuel production including ethanol and biodiesel was produced locally. During 2006-2010, the volume increased from 128 million litres to 1,012 million litres. The growth rate was rapid in 2006-2008, after which it slowed down. The volume of ethanol exported was small. In 2010, there were 19 ethanol plants with a total production capacity of 2.9 million litres/day, of which nearly half were flexible feedstock-based ethanol plants (Global Agricultural Information Network, 2011: 8). However, actual output was only about 1.45 million litres/day of which 1.17 litres was from molasses and 0.28 million litres from cassava (Global Agricultural Information Network, 2011: 8). For biodiesel, there were 14 plants operating in 2010 with a total production capacity of 6 million litres/day but their output was only 1.8-2.0 million litres (Global Agricultural Information Network, 2011: 13).

Table 2.3 Biofuel Primary Supply, 2006-2010

Unit: Million Litres

Supply	**2006**	**2007**	**2008**	**2009**	**2010**
Ethanol					
Domestic Production	103	192	322	401	425
Imports	-	-	-	-	-
Exports	-	-14	-66	-16	-48
Stock Changes	23	-4	83	64	70
Total Primary Supply	**126**	**174**	**339**	**449**	**447**
Biodiesel					
Domestic Production	2	70	448	560	600
Imports	-	-			
Exports	-	-			
Stock Changes	-	-	-43	-23	-35
Total Primary Supply	**2**	**70**	**405**	**537**	**565**
Total Biofuel Supply	**128**	**244**	**744**	**986**	**1,012**

Source: Department of Alternative Energy Development and Efficiency, 2011: 7.

2.2.2 Biofuel Consumption

The entire biofuel production is allocated for the transportation sector, in the form of gasohol and B5. The consumption of gasohol in Thailand has been steadily increasing since it was introduced in 2004. In 2008-2010, gasohol consumption increased at a high annual average growth of 40 percent. Over the same period gasoline consumption decreased continuously so that by the end of 2010, gasohol consumption had surpassed gasoline consumption (Figure 2.3). Similarly the consumption of biodiesel in the form of B2 considerably increased from 47 million litres to 7,053 million litres while the consumption of conventional diesel decreased from 18,273 million litres to 11,427 million litres between 2006 and 2010 (Figure 2.4). These were driven by the government policy - prompted by the rise in oil price - to promote biofuel consumption through price incentives accompanied by an intensive education campaign to increase consumer confidence in biofuel use (Wanida Norasethasopon, 2010: 104-107). With biodiesel, the policy requiring compulsory production of B2 was the main reason for the rapid growth in its consumption (Gonsalves, 2006: 20).

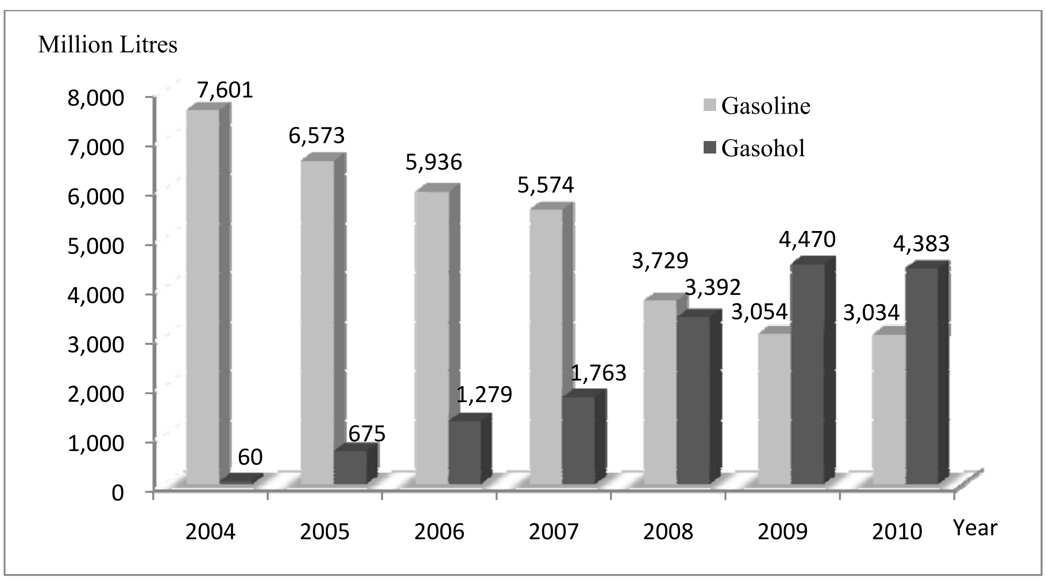

Figure 2.3 Gasoline and Gasohol Consumption, 2004-2010

Source: Department of Energy Business, 2012.

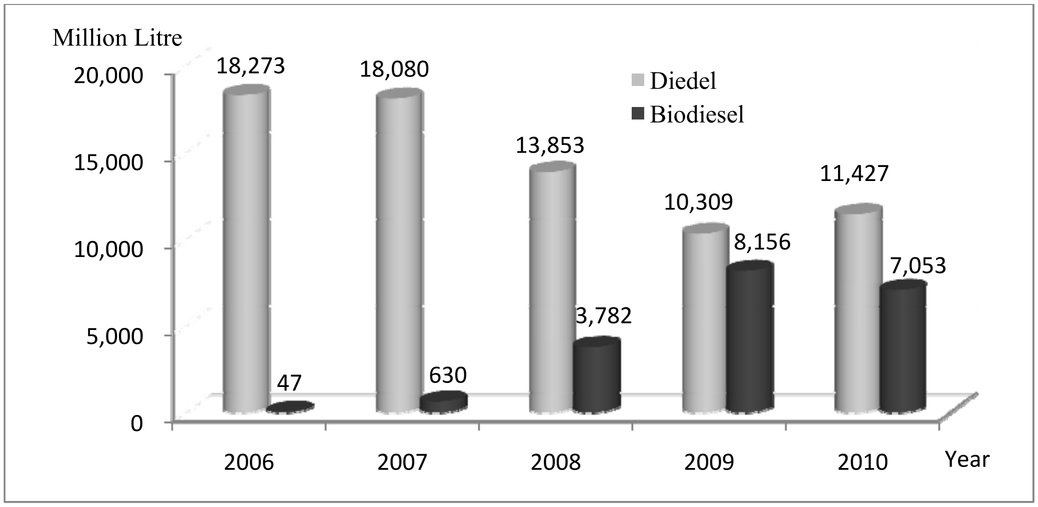

Figure 2.4 Diesel and Biodiesel Consumption, 2006-2010
Source: Department of Energy Business, 2012.

2.3 Analysis of Life Cycle on the Energy and Environment of Biofuel Production

The Government's objectives in supporting and promoting the use of biofuel as a fossil fuel substitute in the transport sector are to enhance energy security and reduce environmental impact. Achievement of the first can be easily measured. An increasing volume of biofuel has been produced from the country's abundant feedstock resulting in the significant replacement of imported oil in the transport sector and diversification of energy resources. Measuring the latter objective however, is more difficult. Theoretically, biofuel is carbon neutral. It means that the CO_2 emitted on combustion has previously been sequestered through photosynthesis during plant growth resulting in a net zero GHG emission (Rajagopal and Zilberman, 2008: 5). In fact, the production of biofuel requires energy for cultivation, transportation and conversion of feedstock, leading to a net positive GHG emission (Rajagopal and Zilberman, 2008: 5). Thus, the relevant question is whether biofuel emits less overall GHG than fossil fuel.

Life Cycle Assessment (LCA) is a tool that can be applied for estimating the latter to quantify how much biofuel reduces GHG emission and how energy efficient it is (Rajagopal and Zilberman, 2008: 5). This tool accounts for all stages of the production and consumption of biofuel, including the GHG emissions and energy efficiencies associated with the resources required for its production (Seksan Papong, Tassaneewan Chom-In, Soottiwan Noksa-nga and Pomthong Malakul, 2010: S112-S113). There have been many studies on the application of LCA to assess the potentials of biofuel for promoting energy security and reducing environmental impact in comparison with fossil fuels. Pomthong Malakul, Seksan Papong, Tassaneewan Chom-In and Soottiwan Noksa-nga (2011: 25-40) used a life cycle approach to analyze the energy and environmental performance of biofuel production in Thailand. This study considered the creation of pure biofuel and did not include its final combustion in vehicles. The findings revealed that GHG emission of cassava-based ethanol production is higher than that of palm oil biodiesel i.e. 2.86 kg CO_2 eq. per litre of anhydrous ethanol and 1.42 kg CO_2 eq. per litre of palm oil methyl ester. Nguyen, Gheewala and Garivait (2007: 4585–4596) also used a life cycle approach to evaluate fuel ethanol produced from cassava in Thailand. They found that cassava-based ethanol systems can have a lower GHG emission than system based on conventional gasoline. With the same approach, Nguyen and Gheewala (2008: 1589–1599) compared the environmental and cost performance of molasses-based E10 with those of conventional gasoline. The findings showed that molasses-based E10 reduces CO_2 and nitrogen oxides (NO_x) emissions more than conventional gasoline. However its total social costs were higher than those of gasoline due to a higher direct production cost and the external costs for other air emissions, e.g. sulfur dioxide (SO_2), nitrous oxide (N_2O) and carbon monoxide (CO). In summary, the LCAs of biofuels have varying impacts on net greenhouse gas balances compared to fossil fuels, depending on the feedstock and conversion technology, but also on other factors, including methodological assumptions.

2.4 Biofuel Policy

Thailand’s biofuel programme and policy were formulated only after the world oil price increased sharply in 2003. The government began to seriously push the production and consumption of biofuel. In 2008, the Ministry of Energy launched a 15-Year Renewable Energy Development Plan (REDP) 2008-2022 to increase alternative energy use to 20 percent of the total national energy consumption. Under the Plan, biofuel target including ethanol and biodiesel is divided into three stages. The short-term target for ethanol production and consumption is 3.0 million litres/day, 6.2 million litres/day in the medium term and 9.0 million litres/day in the long term. For biodiesel, the short term target is also 3.0 million litres/day while the medium and long term targets are lower than that for ethanol, which are 3.64 and 4.5 million litres/day, respectively (Table 2.4).

Table 2.4 Biofuel Target for Thailand's 15-year Renewable Energy Development Plan

Biofuels	Short Term 2008-2011		Medium Term 2012-2016		Long Term 2017-2022	
	ML/D	ktoe	ML/D	ktoe	ML/D	ktoe
Ethanol	3	816	6.2	1,686	9	2,447
Biodiesel	3	944	3.64	1,145	4.5	1,416
Total Alternative Energy Demand (ktoe)	10,456		17,556		22,819	
Proportion of Alternative Energy Use (%)	14.4		19.9		20.4	

Source: Department of Alternative Energy Development and Efficiency, 2008: 8-10.
Note: ML/D is Million Litres per Day.

To help meet this ambitious biofuel consumption target, the REDP 2008-2022 includes a biofuel strategic plan that includes measures on the supply and demand sides. The measures discussed in this section focus on ethanol because of its high relevance to the objectives of this study. As can be seen in Table 2.5, the supply side measures aim to increase the yields of both sugarcane and cassava and find ways, through research, to produce ethanol from other crops or raw materials. This is meant to avoid shortage of feedstock for ethanol production, which could happen at the 2022 target consumption level of 9 million litres/day. On the demand side, the government provides a mix of tax incentives and subsidies to ethanol producers, gasohol refineries and automobile manufacturers. In the case of gasohol refineries, the subsidy from the oil fund applied to gasohol sales at the pump has led to gasohol price lower than gasoline. Besides subsidizing gasohol prices, the government has plans to discontinue gasoline use in transportation in order to force vehicle owners to use E10 gasohol instead (Suthin Wianwiwat, 2011: 18-19). As the gasoline market is relatively small in Thailand compared to diesel, promoting flexible fuel vehicles with tax incentives was seen as an effective way to expand the domestic market for gasohol in the later years of the REDP (Food and Agriculture Organization of the United Nations, 2010: 6-8). The persistent information campaign to convince people that vehicles could use gasohol without causing any damage to the engines has led to an increase in consumer confidence on gasohol use (Suthin Wianwiwat, 2011: 18-19).

Currently, the lower retail price of gasohol compared to gasoline, which is the result of subsidizing gasohol prices with the oil fund, has not significantly increased gasohol consumption, at least not as much as should have. Praipol Koomsup, Puree Sirasoontorn and Napon Suksai (2012: 3.11-3.12) suggest that the government use this measure to generate the difference in the retail price between gasoline and gasohol: the retail price of gasoline 91 should be at least THB 5-6/litre higher than E10-gasohol 91; the retail price of gasoline 91 should be at least THB 3/litre higher than E10-gasohol 95; and the retail price of E10-gasohol 95 should be at least THB 2-3/litre higher than E10-gasohol 91. These would lead to proportionate quantities in the sale of gasoline, E10-gasohol 95and E10-gasohol 91 at 40 percent, 35 percent and 25 percent, respectively.

Table 2.5 Ethanol Promotion Measures

Measures	**Detail**
<u>Supply Side</u>	
Improvement of Energy Crop	
• Sugarcane	Raise average yield to 15 tons/rai with total production of 95 million tons/year by 2011
• Cassava	Raise average yield to 5 tons/rai with total production of 30 million tons/year by 2011
• Other Alternative Crops	Research and development of technology to produce ethanol from other crops
<u>Demand Side</u>	
Tax Incentive and Subsidies	
• Ethanol Producers	An excise tax exemption on ethanol at 7.0 baht/litre on sale of ethanol for gasohol production in the domestic market
• Gasohol Refineries	A subsidy of 13.5 baht/litre for E85 gasohol production from the Oil Fund applied at gasohol sales at the pump
• Automobile Manufacturers	Reduced excise tax to 22-32 percent on vehicles compatible with E85 Reduced import duties for flex fuel vehicles (FFV) from 80 percent to 60 percent by 2010
Enforcement	Discontinued use of gasoline-91
Public information	TV and radio advertising spots at 100 times/year to win the confidence of motorists

Source: Global Agricultural Information Network, 2010: 3.

2.5 Oil Fund and Energy Conservation Promotion Fund

According to REDP 2008-2022, there are the two funds under this plan, namely, the Thailand Oil Fund and Thailand Energy Conservation Promotion Fund (ENCON Fund). The objectives and role of each fund are discussed below.

2.5.1 Thailand Oil Fund

The oil fund was established in March 1979 by the Thai Government to protect the economy from the global oil crisis (Economic and Social Commission for Asia and the Pacific, 2012). The fund consists of a monetary reserve that will be used to maintain domestic retail price level at a set ceiling in times when world petroleum prices increase by subsidizing domestic oil producers and importers. The oil fund receives regular income from the tax levied on gasoline, diesel, kerosene, and fuel oil. Each oil type is levied a different rate according to its role and impact on the economy. The fund was used to subsidize the price of transportation fuel when oil price was regulated in 1979-1990 and when it was deregulated in 1991, which continues to the present. For instance, it was used to subsidize gasoline and diesel during 2004 -2005 and non-automotive diesel in 2008.

Additionally, the subsidy from the oil fund also led to the complete phase out of leaded gasoline in 1996 (Economic and Social Commission for Asia and the Pacific, 2012). The lower oil fund levy imposed on unleaded gasoline made the retail price of leaded gasoline more expensive than unleaded gasoline. Due to this effective measure, the oil fund has been used to subsidize biofuel to encourage its consumption. In case of gasohol, the oil fund levy for conventional gasoline was gradually increased to a level substantially higher than the levy on gasohol, resulting in the lower price of gasohol compared with gasoline. However, gasohol consumption did not increase as much as expected, likely because of other barriers such as the lack of confidence on using gasohol products in terms of its mileage performance and the effect of gasohol on the engine.

Although the oil fund was introduced to stabilize the domestic oil price, it was subjected to political interference from various interest groups. As a result, oil prices were often dictated by reasons other than solving economic problems, which further increased the debt burden of the oil fund. To deal with this problem, Praipol Koomsup, et al. (2012: 4.18-4.19) suggest that the oil fund should be divided into two parts. One part should be the cross price subsidy to encourage the use of biofuels, the other to stabilize the retail prices of oil. To ensure that the oil fund is used for the proper purposes, the deficit or surplus of the fund should not be higher than the set level of approximately 1 billion baht.

2.5.2 The Energy Conservation Fund

The Energy Conservation Promotion Act, B.E. 2535 (1992) has been in effect since April 3, 1992 as a tool for determining regulatory measures and promoting efficient use of energy (Asia Pacific Energy Research Centre, 2010: 9). Under the Act, the Energy Conservation Promotion Fund (ENCON Fund) was established to provide financial support to stimulate private investments in renewable energy and energy efficiency aiming to reduce reliance on fossil fuels and environmental pollution (Food and Agriculture Organization of the United Nations, 2009: 293). The capital and assets of the ENCON Fund were from the oil fund, levies imposed on petroleum product and additional sources such as surcharges on power consumption, government subsidies and remittances from the private sector (Irawan and Heikens, 2012: 5). The National Energy Policy Council (NEPC) is responsible for the promotion of energy conservation pursuant to the provisions specified in the ENCON Act and the management of the ENCON Fund (Chavalit Pichalai, 2007: 126). The Energy Conservation Program (ENCON Program) was established to set guidelines, criteria, conditions and priorities on the ENCON Fund allocation (Chavalit Pichalai, 2007: 126). The ENCON program is divided into three applications: (i) the Compulsory Program, for large energy consumers such as manufacturing plants, (ii) the Voluntary Program, for pre-selected industrial branches with an identified energy efficiency potential, and (iii) the Complementary Program, focusing on public relations and market training for the public and private sectors. Renewable energy development is one of the three subprograms of the ENCON Program. It is a key implementation approach to achieve the government’s target to increase the share of renewable energy in the total national fuel supply (Chavalit Pichalai, 2007: 130).

There are several measures financed by the ENCON Fund. For instance, all government vehicles are required to use gasohol only, and the temperature in air conditioned government offices is set at 25 degrees Celsius or higher. Low-energy light bulbs are sold nationwide at a low price. And the consumption of the different gasohol blend, E10, E20 and E85 is promoted through a direct subsidy from the ENCON Fund.

CHAPTER 3

LITERATURE REVIEW

This chapter consists of two sets of reviews: (i) demand and consumer welfare and (ii) energy demand consumption and welfare impact of energy policy change.

3.1 Demand Analysis and Consumer Welfare Analysis

3.1.1 Consumer Demand Theory

Assumptions about consumer behavior are introduced into the theory of demand through the specification of a utility function. The utility function measures the level of satisfaction an individual experiences as a result of consuming a particular bundle of commodities per unit of time (Johnson, Hassan and Green, 1984: 20-48). The basics of utility maximization are built on the assumption that a consumer purchases commodities with limited income (Taljaard, 2003: 8-11). To determine the quantities that will be purchased, it is assumed that the consumer has certain preferences, which can be represented by a utility function. A rational consumer will then allocate his limited income among goods in order to maximize utility (Taljaard, 2003: 8-11). The utility function is denoted by $u = u(q_1,\ldots.q_n)$ where q is consumption bundle consisting of n goods, subjected to a linear budget constraint (m). This utility maximization problem is known as primal problem. Mathematically, the consumer demand for a good derived from primal problem can be presented by

$$\text{Maximize } u(q_1,\ldots.q_n) \qquad \text{subject to } m = \sum_{i=1}^{n} p_i q_i \tag{3.1}$$

The solution of the first-order conditions of utility maximization problem is a Marshallian or uncompensated demand function, as in the form of

$$q_i = q_i\,(p_1, p_2, \ldots, p_n, m) \qquad i = 1, 2, \ldots, n \tag{3.2}$$

If Marshallian demand function (3.2) is substituted into the utility function called direct utility $u(q_1,....q_n)$ (3.1), it yields the indirect utility function which expresses utility maximization in term of income and prices, as the following

$$u^* = v(p_1,....p_n,m) \tag{3.3}$$

Moreover, Marshallian demand function can be derived from the indirect utility function by using Roy's identity (Deaton and Muellbauer, 1980b: 40-41),

$$q_i = \frac{\partial v/\partial p_i}{\partial v/\partial m} \qquad \text{for } i = 1, 2, \ldots, n \tag{3.4}$$

The dual utility maximization is the expenditure or cost minimization. The consumer is to choose the consumption bundle, q_i, in order to minimize the total expenditure at the certain level of utility. The objective function is shown as:

$$\text{Minimize } m = \sum_{i=1}^{n} p_i q_i \qquad \text{subject to } u(q_1,....q_n) = \bar{u} \tag{3.5}$$

The solution of the first-order conditions of problem (3.5) is the Hicksian or compensated demand function, as in the form of

$$q_i = h_i\,(p_1, p_2, \ldots, p_n, u) \qquad i = 1, 2, \ldots, n \tag{3.6}$$

Same as Marshallian demand, if the Hicksian demand function is substituted into the objective function, the result is the expenditure function that presents the minimize expenditure needed to attain the certain level of utility at given prices.

$$m^* = m\,(p_1,....p_n, \bar{u}) \tag{3.7}$$

Hicksian demand function can be derived from the expenditure function by using Shepard's lemma (Deaton and Muellbauer, 1980b: 40-41)

$$q_i = \frac{\partial m}{\partial p_i} \qquad \text{for } i = 1, 2, \ldots, n \tag{3.8}$$

Deaton and Muellbauer (1980b: 43-46) restated the properties of consumer demand to provide a reasonable characterization of demand model. These are adding up property, homogeneity, symmetry and negativity. Firstly, the adding up property expresses the notion that the total value of both the Hicksian and Marshallian demands is the total expenditure. In other words, the expenditure on individual commodities must sum up to the total expenditure. Furthermore, the adding up restriction of the Engle aggregation condition states that the sum of income elasticity weighted by its expenditure share is equal to one ($\sum_{i=1}^{n} w_i e_{iy} = 1$).

Secondly, the homogeneity implies that if all prices and total expenditures are changed by the same proportion, the quantities demanded remain unchanged. This is called "no money illusion". Moreover, the homogeneity restriction is expressed in terms of elasticities as $\sum_j e_{ij} + e_{iy} = 0$. This states that the sum of own and cross price elasticities and income elasticity of a commodity is zero.

Thirdly, the symmetry restriction implies that the cross-price derivatives of Hicksian demands (compensated demands) are symmetric. That is $\partial h_i(p,u)/\partial p_i = \partial h_j(p,u)/\partial p_j$ for all $\neq j$.

Lastly, negativity property implies the downward sloping compensated demand function. Thus, this restriction indicates that an increase in price with utility held constant must cause demand for that good to fall or at least remain unchanged. If these properties are fulfilled, the dimensionality of parameter space can be reduced and the estimated elasticities are consistent with the neoclassical demand theory.

3.1.2 Demand Analysis

1) Single Equation Approach and Complete System Approach

There are two basic approaches to estimate energy demand equations. These are the single equation approach and the complete systems approach. Since the former models the consumption of one commodity at a time without reference to the interrelationship among the goods, it is simple to estimate and has been used in empirical analyses for energy by Hsing (1994: 4-7), Kayser (2000: 331-348), Filippini and Pachauri (2002: 1-10), Liao and Lee (2009: 1-15) and Wadud, Graham and Noland (2010: 47-74). The single equation approach may produce results inconsistent with demand theory due to its inability to incorporate cross commodity effects and to verify symmetry, adding-up and other relevant properties of a theoretically relevant demand function (Wohl, 1992: 32-35). The complete systems approach was developed to address these inadequacies of the single equation approach. In this approach, the postulates of consumer theory are directly testable and the generation of empirical results is consistent with theory of consumer behavior (Chambwera, 2004: 72-73). Due to these advantages, complete system approach has been given considerable attention in energy demand analysis by many economists, for instance, Nicol (2003: 201–214), Oladosu (2003: 1-21), Chambwera (2004: 1-222), Slavík (2004: 202-233), Labandeira, Labeaga and Rodríguez (2006: 87-112), Gundimeda and Köhlin (2008: 517-546) and Iootty, Jr. and Ebeling (2009: 5326-5333).

2) Functional Form

There are four different forms of systems of demand equations which satisfy theoretical plausibility for driving the system of demand equations from primal problem. These four systems are the Linear Expenditure System (LES), the Rotterdam model, the Translog demand system and the Almost Ideal Demand System (AIDS).

The Linear Expenditure System (LES) was proposed by Stone (1954: 511-527) and derived from the stone-Geary utility function. It was a general linear formulation of demand and imposed theoretical parameter restrictions of adding up, homogeneity and symmetry. LES was quite restrictive because it did not allow inferior good, as all goods must be gross complements (Deaton and Muellbauer, 1980b: 64-67). Such a fixed preference structure may be only reasonable for demands of highly aggregated commodity groups, among which inferiority or complementarity is not expected. Besides, the LES assumes linear Engel curves. This implies that marginal budget shares are constant with the change in income, thus it can be used only for short-term prediction (Ecker, 2008: 58). However, the LES is better applied to large categories of expenditure than to individual commodities (Deaton and Muellbauer, 1980b: 64-67).

The Rotterdam model was proposed by Theil (1965: 67-87) and Barten (1969: 7–73). The Rotterdam model was directly derived from consumer demand theory and the model's parameters could be directly related to underlying theoretical restrictions. Moreover, the Rotterdam model allowed the separability of preferences, a desirable and useful property in demand analysis. If separability holds, total expenditure can be partitioned into groups of goods, making it possible to analyze the preferences in one group independent of the quantities in other groups (Ecker, 2008: 58-60). However, the Rotterdam model had a strong disadvantage, like the LES model, i.e., constant marginal shares. This could lead to counterintuitive results in terms of changes in income, particularly when this model is applied with cross sectional data (Ecker, 2008: 58-60).

The Translog demand system was introduced by Christensen, Jorgenson and Lau (1975: 367-383). The functional form of the basic Translog (BTL) demand system is derived from the indirect Translog utility function. Applying the logarithmic form of Roy's identity yields the Translog demand system in budget share form. Furthermore, the additivity, homogeneity and symmetry restrictions for this functional form can be found. However, the disadvantages of the Translog model are that its coefficients have no simple economic interpretation and the testing of homogeneity of degree zero of budget shares, which means that the hypothesis to determine the validity of the demand theory is questionable (Kim, 1984: 28-30).

One of the most widely used flexible demand specifications in recent decades is the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980a: 312-326). The AIDS is based on the Working-Leser model for Engle curve. The Working-Leser model has been proposed by Working (1943: 43-56) and Leser (1963: 694-703) provide a more detailed discussion of this functional form. In the Working-Leser model, each share of the goods and services item is simply a linear function of the log of total expenditure on all the goods and services items under consideration. According to Zhang (2010: 49-50), this model can be extended to include household demographic characteristics and household location which have an influence on all goods and services items in the model. The advantage of the extended model is that the price information is not necessary. This can be expressed as:

$$w_i = \alpha_0 + \beta_i logX + \sum_k \gamma_{ik} Z_k + \varepsilon_i \tag{3.9}$$

where w_i is the share of the total goods and services budget expenditure on a specific commodity, *X* is the log of total expenditure of household, *Z* are set of household characteristics that may influence demand and ε_i is random disturbances assumed with zero mean and constant variance. β *and* γ are coefficients from estimating with regression analysis. The effect of changes in income on specific goods item consumption is measured by the β coefficient. If $\beta>0$, the expenditure share increases within higher income and it is considered as luxury. If $\beta<0$, the expenditure share decreases within higher income and it is considered a necessity. If $\beta=0$, the budget share is constant across income levels. Additionally, the expenditure elasticity of a specific commodity demand for the average household is presented by

$$e_i = 1 + \frac{\beta_i}{w_i} \tag{3.10}$$

For the AIDS model, Deaton and Muellbauer (1980a: 312-326) have started from a specific class of preferences. These preferences, known as the Price Independent Generalized Logarithmic (PIGLOG) class, are represented via the cost or expenditure function, which defines the minimum expenditure necessary to attain a specific utility level at given prices. The PIGLOG class is defined by

$$\log c(u,p) = (1-u)\log\{a(p)\} + u\log\{b(p)\} \tag{3.11}$$

where *u* denotes the utility lines between 0 (subsistence) and 1 (bliss). The function *a(p)* and *b(p)* are the cost of subsistence and bliss, respectively. These are specified as:

$$\log a(p) = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}^* \log p_i \log p_j \tag{3.12}$$

$$\log b(p) = \log a(p) + \beta_0 \prod_i p_i^{\beta_i} \tag{3.13}$$

Substituting the function of log *a(p)* and log *b(p)* into equation 3.11, the AIDS cost function is expressed as equation 3.14

$$\log c(u,p) = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}^* \log p_i \log p_j + u\beta_0 \prod_i p_i^{\beta_i} \quad (3.14)$$

The fundamental property of cost function is used to derive the demand functions from equation 3.14. This property states that its derivatives are the quantities demand, i.e., $\frac{\partial c(u,p)}{\partial p_i} = q_i$. Multiplying both sides by $p_i/c(u,p)$ yields

$$\frac{\partial \log c(u,p)}{\partial \log p_i} = \frac{p_i q_i}{c(u,p)} = w_i \qquad (3.15)$$

where w_i is the budget share of goods *i* .

As a result, the logarithmic differentiation 3.14 yields the budget share as a function of price and utility. This is the Hicksian demand that expresses, in terms of the budget share, as:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i u \beta_0 \prod_i p_i^{\beta_i} \qquad (3.16)$$

For any two goods *i* and *j*

$$\gamma_{ij} = \frac{1}{2}\left(\gamma_{ij}^* + \gamma_{ij}^*\right) = \gamma_{ji} \qquad (3.17)$$

Under the assumption of a utility maximizing consumer, *c(u,p)* is equal to total expenditure, *m*. Thus equation 3.16 can be solved for utility (*u*) in terms of price (*p*) and expenditure (*m*). By applying the Shepherd Lemma approach, the AIDS demand function or the Marshallian demand function in the budget share form as follows

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log\left(\frac{m}{P}\right) \tag{3.18}$$

where P is a price index defined by

$$\log P = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}^* \log p_i \log p_j \tag{3.19}$$

The restriction of adding up, homogeneity and symmetry are imposed in the system by setting

$$\sum_{i=1}^{n} \alpha_i = 1, \sum_{i=1}^{n} \beta_i = 0, \sum_{i=1}^{n} \gamma_i = 0, \sum_j \gamma_{ij} = 0 \text{ and } \gamma_{ij} = \gamma_{ji} .$$

The AIDS is widely chosen for energy demand analysis for several reasons. Firstly, the equations are consistent with economic theory as the demand equation can be derived from a well-behaved utility function. Secondly, it can be used to test the restrictions of homogeneity and symmetry through linear restrictions on fixed parameters. Lastly, it is easy to approximate in linear terms without observing significant differences between parameters obtained from the AIDS and the Linear Approximation of Almost Ideal Demand System (LA/AIDS) model (Deaton and Muellbauer, 1980a: 312).

While the AIDS possesses many desirable properties, it may be difficult to estimate it. In order to avoid the non-linearity of parameters, the price index (P) is usually approximated by Stone's price index (Deaton and Muellbauer, 1980a: 317). Thus, the Linear Approximate Almost Ideal Demand System (LA/AIDS) is the AIDS specification that is commonly linearized by applying the Stone's price index. However, the Stone index does not satisfy the fundamental property of index number because it is variant to changes in units of price measurement (Alston, Foster and Green, 1994: 351; Asche and Wessells, 1997: 1183; Moschini, 1995: 63-68) Following Moschini (1995: 63-68), the Laspeyres price index is the preferred choice to correct the units of measurement error. The Laspeyres price index can be defined as:

$$\ln P^L = \sum_{i}^{k} w_i^0 \ln p_i \tag{3.20}$$

where w_i^0 is the mean budget share of vehicle fuel item *i.*

3) Incorporation of Household Characteristics

Demographic variables have traditionally played a major role in the analysis of household budget data. This study will investigate whether household characteristics (demographic and socioeconomic) affect the household consumption patterns on the vehicle fuels.

As the differences in the demand for different goods can vary across households due to differences in preferences, the demographic translation suggested by Pollak and Wales (1981: 1533-1551) is incorporated into the LA/AIDS model. The demographic translation is defined as:

$$\alpha_i = \alpha_i^* + \sum_{r}^{n} \theta_{ir} d_r \tag{3.21}$$

where the θ coefficients are associated parameters and d_r are households characteristics (demographic and socio-economic), with $r = 1, 2, \ldots, n$. The above translation assumes that differences in preference are mainly determined by differences in household characteristics.

The demand system incorporated by the demographic translation and the Laspeyres price index takes the form of:

$$w_i = \alpha_i^* + \sum_{j}^{k} \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{m}{P^L}\right) + \sum_{r}^{n} \theta_{ir} d_r \qquad i = 1, 2, \ldots k \tag{3.22}$$

To preserve the adding up property, the following restrictions should be added:

$$\sum_{i}^{k} \theta_{ir} = 0 \quad \forall\, r \tag{3.23}$$

Moreover, the restriction $\sum_i^k \alpha_i = 1$ should be replaced by:

$$\sum_{i}^{k} \alpha_i^* = 1 \tag{3.24}$$

The household characteristics included in this study and their hypothesized effects on household vehicle fuel (or energy) expenditure are based on a combination of practical considerations and on past demand studies such as Archibald and Gillingham (1980: 622-628), Jorgenson, Slesnick and Stoker (1988: 313-325), Kayser (2000: 331-348), Oladosu (2003: 1-21), Shittu, Idowu, Otunaiya and Ismail (2004: 38-51), Slavík (2004: 202-233), Labandeira, et al. (2006: 87-112), Romero-Jordán, del Río, Jorge-García and Burguillo (2010: 3898-3909) and Wadud, et al. (2010: 47-74).

Household expenditure is a key determinant in energy demand, according to Romero-Jordán, et al. (2010: 3898-3909). Household expenditure is used as an indicator of income in this study. Several energy demand studies indicate that energy consumption increases with income (Slavík, 2004: 202-233; Wadud, et al., 2010: 47-74). Furthermore increased incomes also provide households flexibility to choose between different alternative fuels for different uses. The specification of the AIDS model uses total expenditure rather than income. Total expenditure data is also easy to obtain from household surveys with more reliability than income data.

Household size is an important demographic demand factor that affects household consumption in general as shown by previous studies including Jorgenson, et al. (1988: 313-325), Oladosu (2003: 1-21), and Wadud, et al. (2010: 47-74). These studies found that household size has a significant positive effect on car fuel or energy consumption. The higher household members tend to increase the expenditure share for car fuels or energy.

The gender of the household head is included in the model, as in several studies. Archibald and Gillingham (1980: 622-628), Kayser (2000: 331-348) and Wadud, et al. (2010: 47-74) found that gasoline consumption is lower if the household head is a female.

As to the age of household head, Archibald and Gillingham (1980: 622-628), Kayser (2000: 331-348), Shittu, et al. (2004: 48-49) and Wadud, et al. (2010: 47-74) reported that the households with younger heads tend to increase the expenditure share for vehicle fuels (gasoline and diesel).

The level of education in a household measured by that of the household head is a measure of social status. Archibald and Gillingham (1980: 622-628), Romero-Jordán, et al. (2010: 3898-3909) and Wadud, et al. (2010: 47-74) shown that households whose heads have a higher level of education tend to use less fuel.

Regarding the presence of children in households, Slavík (2004: 217) and Wadud, et al. (2010: 47-74) reported lower gasoline consumption in households with several children. For the presence of elder in households, Jorgenson, et al. (1988: 321) and Labandeira, et al. (2006: 87-112) reported that the elder group lowers the expenditure share of energy or private transport as they have less transport needs and senior citizens' tend to stay more at home.

The location of households is hypothesized that it may influence vehicle fuel consumption. Archibald and Gillingham (1980: 622-628), Kayser (2000: 331-348), Labandeira, et al. (2006: 87-112) and Wadud, et al. (2010: 47-74) reported that households located in different regions consume different amounts of gasoline. For instance, Archibald and Gillingham (1980: 622-628) found that households located in a rural setting and households with no public transportation available for travel to work tend to spend more on gasoline than similar households in an urban setting and with access to public transportation.

As to the work status of the household head, Romero-Jordán, et al. (2010: 3898-3909) found that household head with employer status spends more on vehicle fuels than employee. In addition, Wadud, et al. (2010: 47-74) reported that having more wage earners in a household increase gasoline consumption.

The number of vehicles owned by a household is hypothesized that it would highly influence vehicle fuel consumption. The findings of Archibald and Gillingham (1980: 622-628), Romero-Jordán, et al. (2010: 3898-3909) and Wadud, et al. (2010: 47-74) confirm the hypothesis.

4) Two-stage Budgeting Approach and Separability Assumption

The fundamental problem of demand system estimation that concerns all commodities entering a consumer's budget is the large number of parameters to be estimated. Additionally, such estimation would be time consuming, in the low degrees of freedom and might exhibit multicollinearity among the price series (Manaloor, 1995: 34-36). To overcome this problem, aggregation of commodities into groups is necessary. The multi-stage budgeting approach and separability assumption can be employed to aggregate commodities into distinct groups. The multi-stage budgeting approach occurs when the consumer or household allocates its total expenditures in sequential stages. The simplest form of this approach is the two-stage budgeting which was first proposed in terms of a utility tree by Strotz (1957: 269-280). The example of a utility tree provided by Deaton and Muellbauer (1980b: 122-136) is as follows:

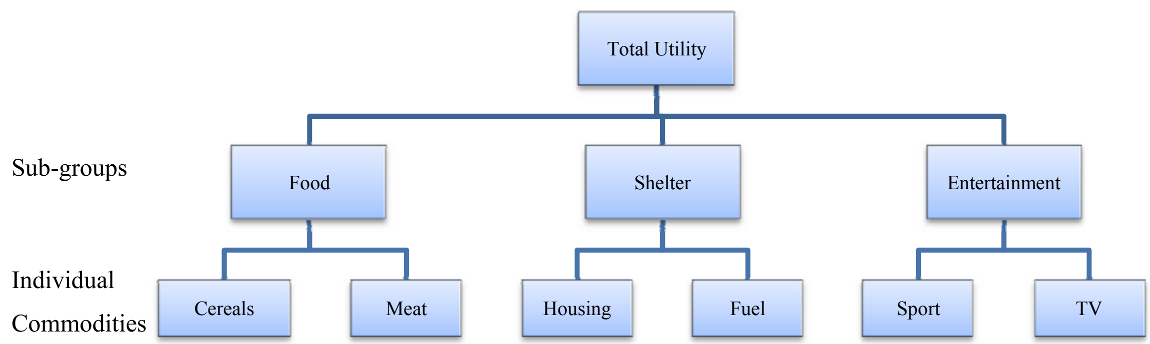

Figure 3.1 Utility Tree
Source: Deaton and Muellbauer, 1980b: 123.

In the first stage, the consumer allocates total expenditures across the different groups and then, in a second stage, group expenditures are allocated to the individual commodities within that group. The closely related assumption with two-stage budgeting is separability of preferences. If separability of preferences holds, commodities can be partitioned into groups so that preferences within the same group can be described independently of the quantities in the other groups. Thus, the utility function can be expressed as

$$U = u(q_1, q_1, \dots, q_n)$$
$$= f[u_1(q_{11}, q_{12}, \dots q_{1k}), u_2(q_{21}, q_{22}, \dots q_{2k}), \dots, u_m(q_{m1}, q_{m2}, \dots q_{mk})] \quad (3.25)$$

where $q_1, q_1, \dots, q_n$ = commodity vectors,

$f[.]$ = some increasing function,

$u_1, u_2, \dots, u_m$ = sub-utilities functions associated with their respective commodity or commodities in their subgroup,

n = the number of commodities,

k = number of commodities in a subgroup,

m = partition of all consumption goods into groups or subgroups,

$n > k$.

Each u_1 can be regarded as a utility function for broad commodity groupings such as food, shelter or entertainment, while q_{mk} are the quantities of individual goods consumed within the group. If the marginal rate of substitution between any two goods from the same group is independent of the quantity of goods consumed in the other groups, this separability is known as weak separability. It is both necessary and sufficient for the second stage of two-stage budgeting (Deaton and Muellbauer, 1980b: 124). The result of linking the two is to avoid the impact of individual commodities prices and quantities from all other subgroup. However, price change in commodities of one group can impact indirectly on the demand for commodities in another group through expenditure allocation in sequential stages (Coleman and Thigpen, 1991: 12-14). In other words, the price change affects the expenditure allocation in the first stage and then alters the budget constraints in the second. The two-stage budgeting approach based on weak separability assumption reduces the number of independent variables required in estimation (Manaloor, 1995: 34-36). Therefore, the first stage requires information only on group prices or a price index for each group while, in the second stage, the only information needed for making a decision for any given group is the total expenditure allocated to that group in the first stage, plus the prices for each item in that group (Taljaard, 2003: 11-12).

5) Censor data

The data set used for this study had some missing observations. More specifically, there were no data available on LPG and gasohol. These non-purchases could be due to no preference, but they could also be caused by infrequent vehicle fuel purchases by consumers or because the survey may not have taken place at the time that the consumers buy those fuel items. The fact that the observed expenditure shares could not take on negative values meant that the dependent variables were censored (Heien and Wessells, 1990: 368).

Estimation techniques that fail to accommodate the censoring of the dependent variables lead to biased estimates (Park, Holcomb, Raper and Oral Capps, 1996: 294-295). In order to account for zero budget shares, one of the most common approaches is two-step estimation of a censored system of equations. The two-step approaches are widely used in previous empirical estimations, as in Heckman Two-step Procedure (Heckman, 1979: 153-161), Heien and Wessells Two-step Procedure (Heien and Wessells, 1990: 365-371) and Shonkwiler and Yen Two-step Procedure (Shonkwiler and Yen, 1999: 972-982).

The Heckman two-step estimation procedure is based on the Tobit model. In the first step, a probit model is used to calculate the inverse Mills ratio (IMR) separately for each equation in the system. In the second step, the equations are augmented by the IMRs as selectivity regressors. However, the Heckman two-step procedure only includes the participating households in the second step of the model. This may cause concerns with the efficiency of the method and the estimated results might only suit the households that participated (Nawata, 1993: 15-24).

Heien and Wessells Two-step Procedure is based on the Heckman's approach but the Heien and Wessells estimation procedure uses the whole data sample (both limit and non-limit variables) observations in the second step. This approach can improve the results based on the goodness-of-fit and elasticity values. Moreover, this procedure is not only computationally simple to apply in the demand analysis but is also consistent and more efficient than other two-step estimators (Heien and Wessells, 1990: 365-371).

Shonkwiler and Yen (1999: 972-982) based the estimation procedure on the Heien and Wessells. A general probit mechanism was adopted in first step to calculate the cumulative distribution function (cdf) and probability density function (pdf) from the binary choice model. The probability was then used as an instrument that incorporated the censoring latent variables in the second step estimation. Shonkwiler and Yen (1999: 972-982) argued that Heien and Wessells' procedure might have inconsistent estimators and they proposed an alternative estimation procedure for a system of equations with limited dependent variables. Nevertheless Heien and Wessells Two-step Procedure has been a favorite choice for empirical analysis in demand analysis due to the large zero consumption percentage in the data set and its simple computation for the demand analysis (Shonkwiler and Yen, 1999: 972-982).

3.1.3 Welfare Analysis

1) Welfare Measures

There are three measures which are widely used to evaluate the welfare implications of a policy change. Typically, consumer welfare can be measured by Consumer Surplus (CS) for which uncompensated flexibility is used, and by Equivalent Variation (EV) or Compensating Variation (CV) for which compensated flexibility is used.

CS is Marshallian consumer surplus that measures the change in welfare resulting from a price change in monetary terms. It equals the total price that a household would pay minus the amount that it actually pays for the quantity bought. In other words, CS is the area to the left of the Marshallian demand curve between two prices. It should be noted that CS – a measure of welfare consumer‘s welfare – is only valid consistently when the marginal utility of income is constant (Hausman, 1981: 662). This condition is only fulfilled by the homothetic utility function and when there is no income effect in which the price of a commodity changes (Samuelson, 1942 quoted in Niklitschek, 1985: 10-11).

Equivalent variation (EV) and compensating variation (CV) were introduced by Hicks (1942: 126-137). These are money metric of gain or loss in consumer's welfare, following an economic change. The economic change may be introduced by government, e.g., pricing policy to promote gasohol usage. Equivalent variation (EV) is defined as the amount of income that must be given to a consumer (possibly negative) in the place of price and income changes to leave the consumer well off with the change. Compensating variation (CV) is defined as the amount of income that must be taken away from a consumer (positive or negative) after an economic change to restore him/her to the original welfare level. In other words, the

CV is the income adjustment required to maintain the consumer at the utility level that occurred before price and income changes.

2) Compensating Variation for AIDS model

The main reason for estimating demand systems is to facilitate welfare analysis. The measurement of welfare change namely the compensating variation (CV) and the equivalent variation (EV) are based on demand parameter estimates and, these parameter estimates differ depending on the choice of the demand model. The AIDS model derived from cost function can be used more reliably in calculating welfare measures because this model provides the expenditure function that can measure the household willingness to pay to reach a certain utility level at a given good's price level (Bopape, 2006: 123-124). Therefore, in this study, the compensating variation derived from the demand parameter estimated in AIDS model is used to measure the impact of pricing policy to support the gasohol usage as a gasoline substitute and to propose an alternative pricing policy for the highest efficiency of both fuels. Several studies have measured the policy impacts with the compensating or equivalent variation incorporated with AIDS model. Such are Janthanee Homchuen (2006: 1-146) and Barros and Prieto-Rodriguez (2008: 659-672).

From the definition above, the compensating variation can be expressed as

$$CV = c(u^0, p^1) - c(u^0, p^0) = c(u^0, p^1) - m_0 \tag{3.26}$$

Recall the AIDS cost function expressed as equation 3.14

$$\log c(u,p) = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}^* \log p_i \log p_j + u^0 \beta_0 \prod_i p_i^{\beta_i}$$

From equation 3.14, indirect utility revised for after period (denoted by one) and utility for reference period (denoted by zero) is expressed as

$$\log c(u^0, p^1) = \alpha_0 + \sum_i \alpha_i \log p_i^1 + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log p_i^1 \log p_j^1 + u^0 \beta_0 \prod_i (p_i^1)^{\beta_i} \tag{3.27}$$

Indirect utility solved from AIDS cost function is represented as

$$v(p,m) = u^0 = \frac{1}{\beta_0 \prod_{i=1}^{n} p_i^{\beta_i}} \left[\ln m - \alpha_0 - \sum_i \alpha_i \ln p_i - \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j \right] \quad (3.28)$$

Combining u^0 with equation 3.27, this becomes:

$$\ln c(u^0, p^1) = \alpha_0 + \sum_i \alpha_i \ln p_i^1 + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i^1 \ln p_j^1 + \prod_{i=1}^{n} (p_i^1 / p_i^0)^{\beta_i} \left[\ln m_0 - \alpha_0 - \sum_i \alpha_i \ln p_i^0 - \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i^0 \ln p_j^0 \right] \quad (3.29)$$

Equation 3.29 is equivalent income as the following

$$\ln \mathrm{c}\,(\mathrm{u}^0, \mathrm{p}^1) = \ln \mathrm{m}_1$$

$$\mathrm{c}(u^0, p^1) = \mathrm{m}_1 \quad (3.30)$$

Combining 3.26 and 3.30, the compensating variation equation is,

$$CV = m_1 - m_0 \quad (3.31)$$

3.2 Economic Efficiency and Price Policy

Gasohol first appeared on the market in 2001 and has been gradually promoted to replace gasoline. The Thai government has adopted the retail pricing policy to lower gasohol price relative to gasoline, leading to the continuously increasing consumption of gasohol. Moreover, Janthanee Homchuen (2006: 81-87) investigates that gasohol and gasoline are substitutes in Thailand. Due to the substitution between both fuels, this policy affects their consumption pattern, welfare of consumer and producers as well as economic efficiency. The effect of pricing policy on economic efficiency is illustrated in Figure 3.2.

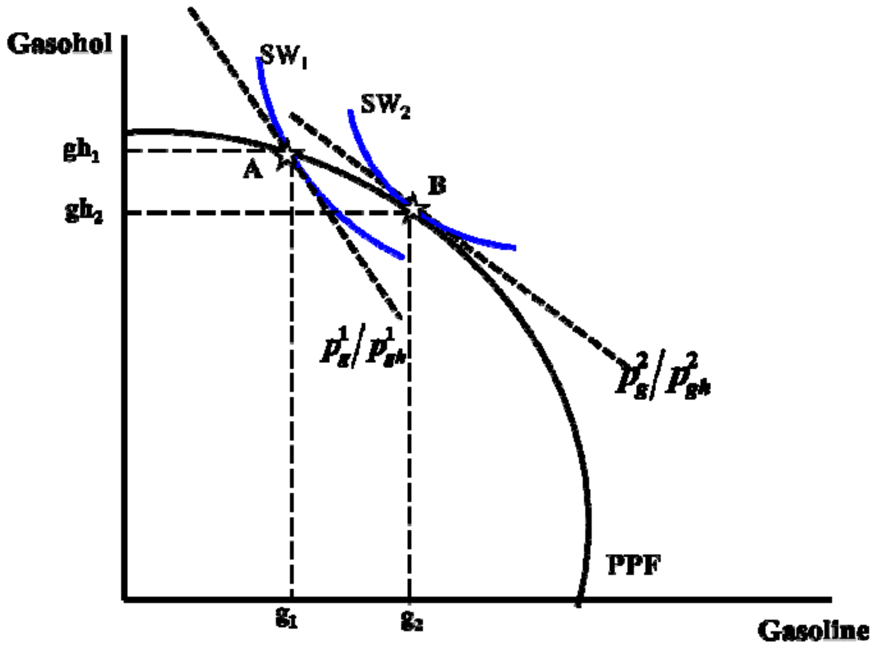

Figure 3.2 Efficiency of Gasoline and Gasohol Production and Consumption
Source: Adapted from Thiraphong Vikitset, 2008: 11. and Jirath Chenphuengpawn, 2011: 35.

As shown in Figure 3.2, the production possibility frontier (PPF) presents the efficient combinations of gasohol and gasoline. PPF is downward sloping because to produce more gasoline efficiently, one must switch input to it from the gasohol production, resulting in a lower gasohol production level. The slope of the PPF at each point is defined by the marginal rate of transformation of gasoline for gasohol (MRT). The MRT measures how much gasohol must be given up to produce one additional unit of gasoline. Let the retail prices of gasoline and gasohol induced by pricing policy are P_g^1 and P_{gh}^1, respectively. This policy leads to the consumption of both fuels at point A. This point consists of gh_1 litre of gasohol consumption and g_1 litre of gasoline consumption on the SW_1 indifference curve. At the same time, the refiners produce both fuels at point A in response to the demand. Consequently, there is the difference between MRS and MRT of gasoline and gasohol resulting from the pricing policy, which in turn results in welfare loss and an increase in economic cost

(Pindyck and Rubinfeld, 1992: 594-596). As long as there is a difference between MRS and MRT of gasoline and gasohol, the economic cost of these fuels can be decreased by shifting the consumption and production from gasohol to gasoline until the indifference between MRS and MRT at point B. At this point, the efficient production and consumption of gasoline and gasohol can be induced by the pricing policy which sets each fuel price equal to its marginal economic cost. Moreover, the indifference curve (SW_2) at point B is higher than one at point A.

3.3 Related Energy Demand and Welfare Analysis

3.3.1 Energy Demand Analysis

The relevant literature on energy demand analysis is summarized in this section. The majority of the studies on energy demand analysis aim to estimate the elasticities of energy in different types of time series, cross sectional and panel data. The two approaches of modeling the demand for energy are the complete system and the single equation approach. The information on elasticities is used to examine the impact of the energy price change from an intervention of government.

For the single equation approach, Archibald and Gillingham (1980: 622-628) used the individual household data from the 1972-73 Consumer Expenditure Survey (CES) of the Bureau of Labor Statistics (BLS) to analyze the short-run consumer demand for gasoline for non-business automobile use. The short-run is defined by household's automobile stock and demographic profile being fixed. The results show that the location of household, the automobile stock as well as the characteristics of the head of the household such as gender, age, race and education appear to affect gasoline consumption. Moreover, households with low total expenditure levels have a high price elasticity and high total expenditure elasticity while households with high total expenditure levels have the opposite. Likewise, Kayser (2000: 331-348) estimates household demand for gasoline and the corresponding price and income demand elasticities using household-level data. The results reveal that higher gasoline prices do not lead to a substantial reduction in the amount of gasoline consumed by households in the short-run. Households living in a rural setting and households with no public transportation available for travel to work are on average affected more strongly by higher gasoline prices than similar households in an urban setting and with access to public transportation. Moreover, the working poor who have to travel to work by car and have no access to public transportation is affected more by rising prices than the non-working poor who have access to public transportation. Slavík (2004: 202-233) estimates car fuel demand using micro-data with the Almost Ideal and Linear Expenditure model. The elasticities from demand estimation are used to find the impact of the increase of the excise tax rate on fuel. The results reveal that the price elasticity of lower and higher income households is different, thus a tax rate change could have more negative consequences to the poorest group. Furthermore, Wadud, et al. (2010: 47-74) estimate price and income elasticities of the demand for gasoline with the simple Translog model including different demographic and geographic characteristics using household level survey data in the USA. The findings indicate that a household's price and income elasticity depends on the number of vehicles owned, the number of wage earners and the location of the household.

Many studies have estimated the energy demand with the complete demand system. For example, Jorgenson, et al. (1988: 313-325) used the panel data to obtain more accurate estimates of the effects of demographic characteristics and total expenditure on aggregate expenditure allocation. This study is based on a two-stage allocation process that results in two systems of individual demand functions. Total energy expenditure is allocated among individual types of energy in the second stage, namely electricity, natural gas, gasoline and fuel oil. The results show that gasoline is the least price elastic while electricity is the most price elastic form of energy. In addition, the price elasticities of demand for all energy types fluctuate with changes in family size, age of household head and region. Decoster (1995: 133-156) used the AIDS model with household data to estimate the behavioral parameters for simulation model namely expenditure and own-price elasticities for 32 commodities. The results reveal that the expenditure elasticities for public and private transport are 0.69 and 0.78, respectively. Moreover, the own-price elasticities for the different motor fuels are rather similar (around -0.6). Shittu, et al. (2004: 38-51) examined the influence of households' socio-economic characteristics on household demand for six energy commodities by estimating a system of energy demand equations and elasticities with a households cross-sectional data. The study reveals that education of household head and household size are an insignificant influence on the household demand of the seven energy commodities, whereas income, ownership of vehicles and age of household heads have a significant influence. Additionally, Tiezzi (2005: 1597–1612) estimated the demand for six consumption goods such as gasoline (transport fuels), public transports and services, natural gas (domestic fuels) and food using the Almost Ideal Demand system with household data. The findings reveal that the own-price elasticity for natural gas and gasoline turns out to be significantly elastic (-1.057 and -1.282). For cross price elasticity, the demand for natural gas appears to be complementary to gasoline. Moreover, in terms of the income elasticities of demand, natural gas turns out to be a luxury good (1.523), whereas the demand for gasoline increases less proportionally with respect to the increase in income, indicating it is a necessary good. Oladosu (2003: 1-21) used data from household surveys in 1988, 1991 and 1994 and estimates the AIDS model augmented with household and vehicle characteristics. Results show that own price elasticities for all vehicle are close to 1 and all vehicles are substitutes for one another. Vehicle 1 which is the newest vehicle is expenditure inelastic, while the second newest to fourth newest vehicles are expenditure elastic. These results imply that efficiency effects on total fuel usage may be a net decrease or increase depending on the efficiency mixture of vehicle holding, fuel prices and effects on real expenditures.

In the case of energy demand in Spain, Labandeira, et al. (2006: 87-112) estimated an energy demand system for Spain using AIDS model with household micro-data for a long term period. They find that food, electricity and LPG are normal goods, while natural gas, car fuels and public transport are luxuries. Romero-Jordán, et al. (2010: 3898-3909) applied the AIDS model on household data to calculate price and income elasticities of demand for transport fuel in Spain. The results show that, although income elasticities are elastic, price elasticities are lower than 0.4 and inelastic. This implies a greater responsiveness of fuel consumption to fuel price changes and suggests that fuel taxes can play a significant role in reducing fuel consumption.

Besides energy demand analysis with household data or micro data, aggregate time series data is widely applied with energy demand analysis. For example, Hu (2004: 1-6) applied a Translog demand system with annual data from 1985 to 2000 to estimate demand for five energy types, namely coal, crude oil, electricity, natural gas and petroleum products in four sectors – chemical, metal, non-metal material and residence. The results find that substitution of coal took place in three of the four sectors. The most significant substitutions are in the metal and residential sectors, with petroleum products being the coal substitute for the former and electricity for the latter. The findings suggest that changes in the relative prices of the fuels lead to substitution away from coal to less CO_2-intensive fuels and therefore an overall reduction of CO2 emission. Iootty, et al. (2009: 5326-5333) used time series data in the period 1970–2005 to estimate the price and income elasticities for all the available fuels in the automotive sector in Brazil, namely gasoline, compressed natural gas (CNG), ethanol and diesel. The results show that gasoline, ethanol and diesel are normal goods, and with the exception of ethanol, they are expenditure elastic. CNG was estimated as an inferior good. Furthermore, the substitutability between gasoline and ethanol is higher than the one between gasoline and CNG. Likewise, Mehrara and Ahmadi (2011: 72-77) applied the AIDS model to estimate price and income elasticities for all the available fuels in the automotive sector such as gasoline, automotive gas oil and Liquefied Petroleum Gas (LPG). The results indicate the highest own-price elasticity is LPG and own-price elasticity for gas oil and gasoline is estimated by about -0.22 and -1.01. In addition, gasoline and gas oil are normal goods, while LPG is an inferior good. Moreover, Broadstock and Chen (2012: 1-11) applied the AIDS model with The UK annual data set covering the period 1960-2009 to examine the policy options that encourage substitution between gasoline and diesel so as to reduce the emission-based externalities from road transport. They found that own price elasticities for gasoline and diesel are negative and all cross price elasticites are positive, confirming that the fuels are substitutes. Moreover, the own-price and cross-price elasticities for gasoline are much lower than for diesel.

3.3.2 Welfare Analysis

This section summarizes the relevant literature on welfare analysis incorporating the energy demand analysis to examine the impact of policy. Tiezzi (2005: 1597–1612) evaluated the welfare effects of Carbon taxation on Italian households and the distribution of the welfare change across different types of households and different expenditures levels. The income and price elasticities estimated by the AIDS model are used to examine True cost of living index numbers and the compensating variation. The results indicate that the Carbon tax generates welfare loss on Italian households. The distribution of welfare losses across different levels of total monthly expenditures does not allow sustaining the regressiveness of Carbon taxation, as the cost of living of households in the highest income groups is most adversely affected by the tax increases. This might be because the tax lies mainly on transport fuels. Thus the higher-income Italian households with car owner were less responsive to higher prices. Barros and Prieto-Rodriguez (2008: 659-672) examined the welfare effects of environmental policy, which consists of an increment of the indirect taxes on fuels to finance the elimination of VAT on the public means of transport. They estimate an Almost Ideal Demand System for 16 different groups of goods in the Spanish economy, resulting in expenditure and price elasticities. This information is used to examine the impact of policy, i.e., the elimination of VAT on public transport services and a simultaneous increment on fuel taxes. The results show a small loss in social welfare. Consequently, this policy can be enforced in Spain. Additionally, Wadud, et al. (2010: 47-74) assessed consumer surplus using price and income elasticities of the demand for gasoline. The effect of a gasoline tax on distributional burden which can have impacts on policy design is determined by the consumer surplus (CS). For distributional burden, the result reveals that the tax is progressive across the lower income groups and regressive across the higher income groups.

In case of Thailand, Janthanee Homchuen (2006: 1-146) estimated the impacts of gasohol substitution to unleaded gasoline toward consumer welfare (EV) by using the linear Approximated Almost Ideal Demand System (LA/AIDS) with time series data between Oct 2003 – Feb 2007. The results indicate that the own price elasticity of gasohol is negative and elastic. In addition, cross price elasticity of demand for gasohol with respect to gasoline price is high. Moreover, the impacts on substitution of gasohol increase net consumer welfare, even after considering the government and private loss of subsidy to subsidize gasohol price.

Several studies in Thailand determine the efficient policy for vehicle fuel with deadweight loss that is obtained from demand and supply analysis. Thiraphong

Vikitset (2008: 1-40) quantified the effects that gasoline and high speed diesel pricing policy have on welfare and economic cost in Thailand. To find the deadweight loss and social welfare, the demand and supply structural equations for the gasoline and high speed diesel are estimated by monthly data between January 2002 and August 2005. The results obtain not only own price and cross price elasticities for gasoline and high speed diesel but also the pricing policy that economically efficient and minimizes deadweight loss. Jirath Chenphuengpawn (2011: 1-116) estimated the variation of demand and supply in the market of high speed diesel and biodiesel B5 by using monthly data from February 2007 to January 2011 and then calculates deadweight loss resulting from cross price subsidy to promote the usage of biodiesel B5 in Thailand. From this model, the simulation of the pricing policy obtains the finding for the highest efficiency of both fuels.

CHAPTER 4

METHODOLOGY

This chapter describes the methodology used for the empirical analysis of vehicle fuel consumption in Thailand. The first section presents a two-stage demand system, incorporating demographic variables and employing a two-step estimator to deal with zero consumption problems. Sections 4.2 and 4.3 provide the computation of elasticities of demand and consumer welfare analysis, respectively.

4.1 Demand System

This study assumes a two budgeting model of household consumption decisions, as presented in Figure 4.1. This implies that the consumer's utility maximization decision can be decomposed into two stages. In the first stage, total expenditure is allocated to broad groups, such as food, public transport, private transport, durable goods, non-durable goods as well as other services and non consumption. In the second stage, the budget for private transport (called "vehicle fuel expenditure" in this stage) is allocated to specific items such as gasoline, gasohol, diesel and LPG. The core assumption of this stage is weak separability. This implies that the demand for vehicle fuel does not depend on the price of other goods in the household's budget. The estimation of demand system is divided into two parts, as illustrated in the following section.

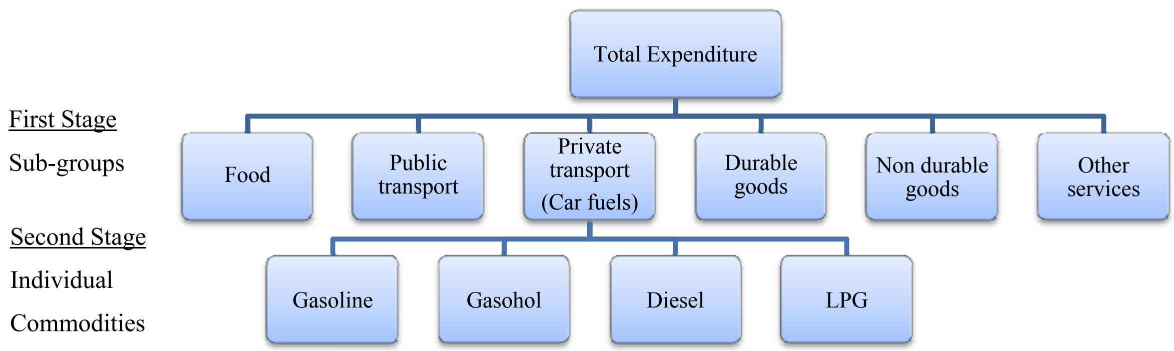

Figure 4.1 Utility Tree and Two Stage Budgeting

Source: Adapted from Deaton and Muellbauer, 1980b: 123.

4.1.1 First Budgeting Stage Analysis

At the first stage of household budgeting, households decide the shares of their total expenditure to allocate to broad group (g). An extended Working-Leser Model is applied to derive group expenditure elasticities in the absence of price information, as in equation 4.1

$$w_{gh} = \alpha_i^* + \beta_g lnX_h + \sum_{r=2}^{5} \theta_{ir}\mathrm{dage}_{rh} + \sum_{r=2}^{3} \theta_{i(4+r)}\mathrm{dsize}_{rh} + \sum_{r=2}^{4} \theta_{i(6+r)}\mathrm{dwkst1}_{rh}$$
$$+ \sum_{r=2}^{3} \theta_{i(9+r)}\mathrm{dedu1}_{h} + \sum_{r=2}^{5} \theta_{i(11+r)}\mathrm{dreg1}_{h}$$
$$+ \sum_{r=2}^{5} \theta_{i(15+r)}\mathrm{dyear}_{h} \qquad (4.1)$$

where g is denoted as broad group; food (*f*), public transport (*pbt*), private transport (*pvt*), durable goods (*dg*), non-durable goods (*ndg*), other service and non consumption (*os*). In addition, index h is denoted as individual households, whereas r is the number of the included household's characteristic variables. Table 4.1 summarizes all the variables used in first stage analysis.

Table 4.1 All Variables Used in First Stage Analysis

Variables	Description
lnX	Natural log of total expenditures per month
w_f	The budget share of food
w_pbt	The budget share of public transport
w_pvt	The budget share of private transport
w_dg	The budget share of durable goods
w_ndg	The budget share of non-durable goods
w_os	The budget share of other service and non consumption
	Dummy variable
	Age of household head
dage_1	Under 25 (base)
dage_2	25-35
dage_3	36-55
dage_4	56-65
dage_5	Over 65
	Household size
dsize_1	1-2 (base)
dsize_2	3-5
dsize_3	Over 5
	Work Status of household head
dwkst1_1	Economically inactive (base)
dwkst1_2	Worker
dwkst1_3	Employee
dwkst1_4	Employer
	Level of Education of head
dedu1_1	Primary education or lower (base)
dedu1_2	Secondary or higher education
dedu1_3	University or higher education

Table 4.1 (Continued)

Variables	Description
	Region
dreg1_1	HH is located in the Bangkok and 3 provinces included Samut Prakarn, Nonthaburi and Pathum Thani (base)
dreg1_2	HH is located in the Central excluded Bangkok and 3 provinces
dreg1_3	HH is located in the North
dreg1_4	HH is located in the Northeast
dreg1_5	HH is located in the South
	Year
dyear_1	2006 (base)
dyear_2	2007
dyear_3	2008
dyear_4	2009

4.1.2 Second Budgeting Stage Analysis

The second stage of household decision making involves allocating the total vehicle fuel expenditure to individual fuels such as gasoline, gasohol, diesel and LPG. This is estimated as a system of equations to determine the share of each fuel in the household total vehicle fuel expenditure, the relative prices of the fuels paid by different households, and other household characteristics. The Linear Approximation of Almost Ideal Demand System (LA/AIDS) is employed to estimate the expenditure and the own and cross elasticities for each fuel. The Heien and Wessells Two-step Procedure (Heien and Wessells, 1990: 365-371) is employed to deal with the zero consumption problems. In the first step, the probability that a given household would purchase vehicle fuel item is determined using a probit analysis. In this study, the probit regression is used for each vehicle fuel item:

$$Z_{ih} = g(\mathbf{x}_{ih}, \mathbf{a}) + \mu_{ih} \tag{4.2}$$

All available observations in second budgeting stage are used for the probit analysis, where the dependent variable (Z_{ih}) equals one if the vehicle fuel expenditure is nonzero, and zero otherwise. Vector **x** represents socio-demographic variables, vector **a** represents the corresponding coefficients, and μ_{ih} represents the error term. The specific form of g is:

$$
\begin{aligned}
g(\mathbf{x}_{ih}, \mathbf{a}) = a_0 + a_1 \,\text{ln\_y\_2}_{ih} + a_2\text{dgend\_1}_{ih} + a_3\text{age}_{ih} + a_4\text{age2}_{ih} + \text{a}_5\text{size}_{ih} \\
+ a_6\text{earn}_{ih} + a_7\text{dage05}_{ih} + a_8\text{elder65}_{ih} + a_9\text{darea}_{ih} \\
+ \sum_{j=2}^{4} a_{9+j}\,\text{dwkst2}_{jih} + \sum_{j=2}^{3} a_{12+j}\,\text{dedu2}_{jih} + \sum_{j=2}^{5} a_{14+j}\text{dexplv}_{jih} \\
+ \sum_{j=2}^{5} a_{18+j}\text{dnveh}_{jih} \qquad (4.3)
\end{aligned}
$$

This probability is used to compute the Inverse Mills Ratio (IMR) for each household *h* and each commodity *i* as follows:

$$IMR_{ih} = \frac{\varphi(\widehat{g_\iota})}{\Phi(\widehat{g_\iota})} \quad \text{if } Z_{ih} = 1 \qquad (4.4)$$

$$IMR_{ih} = \frac{\varphi(\widehat{g_\iota})}{1 - \Phi(\widehat{g_\iota})} \quad \text{if } Z_{ih} = 0 \qquad (4.5)$$

Where φ and Φ represent the density and cumulative-probability functions, respectively.

In the second step, the inverse Mills ratio is used as an instrument that incorporates the censoring latent variable in estimation of LA/AIDS. All observations are used for the second step estimation. Therefore, the LA/AIDS in this study will take the following form:

$$w_{ih} = \alpha_i^* + \sum_{j=1}^{3} \gamma_{ij} \ln p_{jh} + \beta_i \ln\left(\frac{m_h}{P_h^L}\right) + \theta_{i1}\text{age}_h + \theta_{i2} size_h + \sum_{r=1}^{4} \theta_{i(2+r)}\text{owv}_{rh}$$
$$+ \theta_{i7}\text{dgend\_1}_h + \theta_{i8}\text{dage05}_h + \theta_{i9}\text{elder65}_h + \theta_{i10}\text{dmulvh}_h$$
$$+ \sum_{r=2}^{3} \theta_{i(10+r)}\text{dedu2}_h + \sum_{r=2}^{5} \theta_{i(12+r)}\text{dreg2}_h + \sum_{r=2}^{5} \theta_{i(16+r)}\text{explv}_h$$
$$+ \rho_i IMR_{ih} \qquad (4.6)$$

Details for each variable in equation 4.3 and 4.6 can be found in Table 4.2.

Table 4.2 All Variables Used in Second Stage Analysis

Variable	Description
m_h	Expenditures for vehicle fuels per month (Baht)
lnm_h	Natural log of expenditures for vehicle fuels per month
lnP_h^L	Natural log of expenditures for vehicle fuels per month weighted by Laspeyres price index
w_1	The budget share of gasoline
w_2	The budget share of gasohol
w_3	The budget share of diesel
w_4	The budget share of LPG
p1	Gasoline price (Baht/litre)
p2	Gasohol price (Baht/litre)
p3	Diesel price (Baht/litre)
p4	LPG price (Baht/litre)
ln_p1	Natural log of the gasoline price
ln_p2	Natural log of the gasohol price
ln_p3	Natural log of the diesel price
ln_p4	Natural log of the LPG price
age	Age of household head
age2	Square age of household head

Table 4.2 (Continued)

Variable	Description
size	Household size
earn	Number of earners
owv_1	Number of Motorcycle owned by HH
owv_2	Number of Automobile owned by HH
owv_3	Number of Pick- up (mini truck), van owned by HH
owv_4	Number of Other mini- truck owned by HH
	Dummy variable
dgend_1	Male head of household
dage05	Household has at least 1 child less than 6 years of age (no child=0)
delder65	Household has at least 1 elder more than 65 years of age (no elder =0)
darea	Household is located in municipal areas (non- municipal areas=0)
dmulvh	Household has multiple type of vehicles (no =0)
	Work Status of household head
dwkst2_1	Economically inactive (base)
dwkst2_2	Worker
dwkst2_3	Employee
dwkst2_4	Employer
	Level of Education of head
dedu2_1	Primary education or lower (base)
dedu2_2	Secondary or higher education
dedu2_3	University or higher education
	Total household monthly Expenditure category (Baht)
dexplv_1	Less than 5,000 (base)
dexplv_2	5,000-8,999
dexplv_3	9,000-12,999
dexplv_4	13,000-19,999
dexplv_5	Over 20,000

Table 4.2 (Continued)

Variable	Description
	Number of Vehicles owned
dnveh_1	1 (base)
dnveh_2	2
dnveh_3	3
dnveh_4	4
dnveh_5	More than 4
	Region
dreg2_1	HH is located in the Bangkok and 3 provinces included Samut Prakarn, Nonthaburi and Pathum Thani (base)
dreg2_2	HH is located in the Central excluded Bangkok and 3 provinces
dreg2_3	HH is located in the North
dreg2_4	HH is located in the Northeast
dreg2_5	HH is located in the South
IMR	Inverse Mills Ratio

The resulting model, referred to as the LA/AIDS, is estimated using Zellner's Iterative Seemingly Unrelated Regression (ITSUR) procedure (Zellner, 1962: 348-368). To be consistent with consumer theory, the model has been estimated with homogeneity and symmetry. Because the conditional demand system is expressed as a budget share, one equation has to be dropped from the system. Excluding one equation automatically implies the adding-up restriction. Thus, in this study, three equations in the model are included, consisting of the four vehicle fuel categories. Parameters in the omitted LPG equations can be recovered from the adding-up conditions.

4.2 Computation of Elasticities of Demand

All elasticity estimates are evaluated at the sample mean and are calculated as follows (Green and Alston, 1990: 442-445):

Expenditure elasticity : $e_i = 1 + \frac{\beta_i}{w_i}$ (4.7)

Marshallian own-price elasticity : $e_{ii} = -1 + \frac{\gamma_{ii}}{w_i} - \beta_i$ (4.8)

Marshallian cross-price elasticity : $e_{ij} = \frac{\gamma_{ij}}{w_i} - \beta_i \frac{w_j}{w_i}$ (4.9)

Hicksian own-price elasticity : $\eta_{ii} = -1 + \frac{\gamma_{ii}}{w_i} + w_i$ (4.10)

Hicksian cross-price elasticity : $\eta_{ij} = \frac{\gamma_{ij}}{w_i} + w_j$ (4.11)

4.3 Consumer Welfare Analysis

This section describes the methodology used to examine the result on consumer welfare of a pricing policy that promotes gasohol consumption. Static simulations are carried out to measure consumer welfare under different pricing scenario to propose an alternative pricing policy for the highest efficiency of both fuels. The Compensating Variation (CV) is used to determine the welfare impact of vehicle fuel price changes on households because it allows the conduct of an ex-ante analysis of welfare change (Suharno, 2010: 56-59). The concept of CV was introduced by Hicks (1942: 126-137) and developed later by Deaton and Muellbauer (1980b: 184-189). CV measures the change in money income or expenditure, c (·), which is needed to maintain a constant utility level after a change in prices. Hence the CV is expressed as:

$$CV = \Delta c = c(u^0, \boldsymbol{P}^1) - c(u^0, \boldsymbol{P}^0) \tag{4.12}$$

where $\boldsymbol{P}$ and u represent the vector of prices facing the household and the utility level, respectively. $c(u^0, \boldsymbol{P}^0)$ is the cost of achieving the utility level u^0, given the initial price vector $\boldsymbol{P}^0$, whereas $c(u^0, \boldsymbol{P}^1)$ is the cost of achieving the same utility at the new price level $\boldsymbol{P}^1$. Assume that prices change from $\boldsymbol{P}^0$ to $\boldsymbol{P}^1$ as a result of a subsidy on gasohol or tax on gasoline.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter describes the characteristics of households in the sample, discusses the results of the empirical models described in the previous chapter, and presents the simulation on pricing policy to find an alternative policy that would result in the highest efficiency of both fuels.

5.1 Data Description

This study utilizes the data from the household socio-economic survey (SES) 2006-2009, conducted by the National Statistical Office (NSO). The SES provides detailed information about household vehicle fuel expenditures, socio-economic and demographic characteristics of households, and ownership of durable goods. The survey collected data from 44,918 households in 2006, 43,055 in 2007, 44,969 in 2008, and 43,844 in 2009 throughout Thailand. To avoid multicollinearity problems and enhance heterogeneity of data set, all data in 4 years are pooled to form one large data base, combining micro-data for a sufficiently long term period. For estimation purposes, households that reported null total expenditures and null expenditures of vehicle fuels are excluded. As a result, the total observations consist of 175,692 households for the first budgeting stage and 142,445 for the second stage.

The problem associated with this type of survey is that only data on household expenditure has been collected. Therefore, price data cannot be calculated by dividing expenditure by corresponding quantities, as with other studies. Price data is obtained from Energy Policy and Planning Office (EPPO), Ministry of Energy in the form of the pump price of vehicle fuels in Bangkok. Vehicle fuels prices in a district outside Bangkok had been determined as Bangkok price plus transport cost issued by EPPO. These prices are averaged by month and used to determine prices of vehicle fuels each household would have to pay over the month in which it was surveyed.

In line with the methodology described in Chapter 4, the two budgeting models of household consumption decisions are examined in this study. The allocation of total expenditure among private transport groups and the other 5 board groups is considered at the first budgeting stage of the two-stage budgeting model. In the second budgeting stage, the expenditure on private transport is further disaggregated into the expenditure on gasoline, gasohol, diesel, and LPG. The summary statistics of socio-economic and demographic characteristics of households in Thailand are presented in Table 5.1. The mean total monthly household expenditure is 13,558.35 Baht. The consumption patterns of the group of goods and services to which households allocate their budget at the first stage are reflected by the budget share. The average budget shares of food, other services and non-consumption, non-durable goods, and durable goods are 0.4243 0.2610 0.1564 and 0.0718, respectively. The average budget share of private transport is 0.0747 while that of public transport is 0.0118, which means households on average spend more on private transport than public transport. The dominant age of the head of the household is 36-55 years (48.49%) while household size for the sample is 3-5 members (54.02%). The majority of household heads have no more than primary school education (64.94%), and are mostly workers (39.41%).

Table 5.1 Means and Standard Deviations of Data of First Budgeting Stage

Variables	Description	Mean	Std. Dev.
X	Total expenditures per month (Baht)	13,558.3500	14,259.0500
lnX	Natural log of total expenditures per month	9.1340	0.9121
w_f	The budget share of food	0.4243	0.1746
w_pbt	The budget share of public transport	0.0118	0.0313
w_pvt	The budget share of private transport	0.0747	0.0678
w_dg	The budget share of durable goods	0.0718	0.1216
w_ndg	The budget share of non-durable goods	0.1564	0.0864
w_os	The budget share of other service and non-consumption	0.2610	0.1635

Table 5.1 (Continued)

Variables	Description	Mean	Std. Dev.
	<u>Dummy variable</u>		
	Age of household head		
dage_1	Under 25 (base)	0.0252	0.1568
dage_2	25-35	0.1291	0.3354
dage_3	36-55	0.4849	0.4998
dage_4	56-65	0.1832	0.3869
dage_5	Over 65	0.1775	0.3821
	Household size		
dsize_1	1-2 (base)	0.3733	0.4837
dsize_2	3-5	0.5402	0.4984
dsize_3	Over 5	0.0865	0.2812
	Work status of household head		
dwkst_1	Economically inactive (base)	0.2024	0.4018
dwkst_2	Worker	0.3941	0.4887
dwkst_3	Employee	0.3349	0.4720
dwkst_4	Employer	0.0686	0.2528
	Level of education of head		
dedu_1	Primary education or lower (base)	0.6494	0.4772
dedu_2	Secondary or higher education	0.2415	0.4280
dedu_3	University or higher education	0.1091	0.3118
	Region		
dreg_1	HH is located in the Bangkok and 3 provinces included Samut Prakarn, Nonthaburi and Pathum Thani (base)	0.1038	0.3050
dreg_2	HH is located in the Central excluded Bangkok and 3 provinces	0.2468	0.4311
dreg_3	HH is located in the North	0.2469	0.4312

Table 5.1 (Continued)

Variables	Description	Mean	Std. Dev.
dreg_4	HH is located in the Northeast	0.2613	0.4394
dreg_5	HH is located in the South	0.1412	0.3482
	Year		
dyear_1	2006 (base)	0.2535	0.4350
dyear_2	2007	0.2435	0.4292
dyear_3	2008	0.2546	0.4357
dyear_4	2009	0.2483	0.4320

Source: Calculated from SES in 2006-2009.

Table 5.2 presents the socio-economic and demographic characteristics of households at second budgeting stage. The mean total monthly household expenditure for vehicle fuel is 1,334.03 Baht. The shares of the different vehicle fuels in total private transport expenditure show that, on average, households allocate most of their private transport budget for gasoline. The households spend the rest of their private transport budget on diesel (0.1994), gasohol (0.0647) and LPG (0.0045). The average size of households in the sample is 3.4. The average age of household heads is 49 years and the dominant household head is male (69.91%). The majority of household heads have no more than primary school education (61.67%) and are workers (41.15%). As many as 40.56 percent of the sample households own one vehicle, 34.19 percent own two vehicles, and less than 1 percent own more than four vehicles.

Table 5.2 Means and Standard Deviations of Data of Second Budgeting Stage

Variable	**Description**	**Mean**	**Std. Dev.**
m_h	Expenditures for vehicle fuels per month (Baht)	1,334.0320	1,598.3460
$\ln m_h$	Natural log of expenditures for vehicle fuels per month	6.6929	0.9976
$\ln P_h^L$	Natural log of expenditures for vehicle fuels per month weighted by Laspeyres price index	3.2994	0.9958
w_1	The budget share of gasoline	0.7314	0.3905
w_2	The budget share of gasohol	0.0647	0.2306
w_3	The budget share of diesel	0.1994	0.3417
w_4	The budget share of LPG	0.0045	0.0582
p1	Gasoline price (Baht/litre)	31.4369	4.6584
p2	Gasohol price (Baht/litre)	27.4418	3.9000
p3	Diesel price (Baht/litre)	27.1399	4.6438
p4	LPG price (Baht/litre)	9.8553	0.4219
ln_p1	Natural log of the gasoline price	3.4373	0.1452
ln_p2	Natural log of the gasohol price	3.3015	0.1472
ln_p3	Natural log of the diesel price	3.2877	0.1603
ln_p4	Natural log of the LPG price	2.2871	0.0429
age	Age of household head	49.7694	13.7937
age2	Square age of household head	2,667.2550	1,446.4870
size	Household size	3.4444	1.6038
earn	Number of earners	1.9719	1.0161
owv_1	Number of Motorcycle owned by HH	1.3481	0.7621
owv_2	Number of Automobile owned by HH	0.1794	0.4571

Table 5.2 (Continued)

Variable	**Description**	**Mean**	**Std. Dev.**
owv_3	Number of Pick- up (mini truck), van owned by HH	0.3298	0.5668
owv_4	Number of Other mini- truck owned by HH	0.1287	0.3899
	Dummy variable		
dgend_1	Male head of household	0.6991	0.4587
dage05	Household has at least 1 child less than 6 years of age (no child=0)	0.2273	0.4191
delder65	Household has at least 1 elderly more than 65 years of age (no elderly member =0)	0.2064	0.4047
darea	Household is located in municipal areas (non- municipal areas=0)	1.9720	1.0160
dmulvh	Household has multiple type of vehicles (no =0)	0.4278	0.4948
	Work status of household head		
dwkst_1	Economically inactive (base)	0.1683	0.3741
dwkst_2	Worker	0.4115	0.4921
dwkst_3	Employee	0.3412	0.4741
dwkst_4	Employer	0.0791	0.2699
	Level of education of head		
dedu_1	Primary education or lower (base)	0.6167	0.4862
dedu_2	Secondary or higher education	0.2589	0.4380
dedu_3	University or higher education	0.1244	0.3301

Table 5.2 (Continued)

Variable	Description	Mean	Std. Dev.
	Total household monthly Expenditure category (Baht)		
dexplv_1	Less than 5,000 (base)	0.1497	0.3568
dexplv_2	5,000-8,999	0.2545	0.4356
dexplv_3	9,000-12,999	0.1871	0.3900
dexplv_4	13,000-19,999	0.1851	0.3883
dexplv_5	Over 20,000	0.2236	0.4167
	Number of vehicles owned		
dnveh_1	1 (base)	0.4056	0.4910
dnveh_2	2	0.3419	0.4743
dnveh_3	3	0.1621	0.3686
dnveh_4	4	0.0604	0.2382
dnveh_5	More than 4	0.0300	0.1706
	Region		
dreg_1	HH is located in the Bangkok and 3 provinces included Samut Prakarn, Nonthaburi and Pathum Thani (base)	0.0765	0.2658
dreg_2	HH is located in the Central excluded Bangkok and 3 provinces	0.2475	0.4315
dreg_3	HH is located in the North	0.2546	0.4356
dreg_4	HH is located in the Northeast	0.2710	0.4445
dreg_5	HH is located in the South	0.1504	0.3575

Source: Calculated from SES in 2006-2009.

5.2 Empirical Results

5.2.1 First Budgeting Stage Analysis

The Working-Leser Model is employed to derive expenditure elasticity when price is missing, as shown in Table 5.3. The discussion of results in this section will focus on two board groups, namely, public and private transport due to their close relation to the second budgeting stage analysis. Total household monthly expenditure, in natural logarithmic form, is statistically significant for all board groups. Additionally, the negative sign of the coefficient for food, public transport and non-durable goods implies that the expenditure share falls as the total household monthly expenditure increases. This means that these goods are necessity goods. On the other hand, the positive sign of the coefficient for private transport and durable goods implies that the expenditure share rises with an increase in total household monthly expenditure. This means that these goods are luxury goods.

Size of household dummy results indicates that there is a difference in consumption demand for different goods and service items among households of different sizes (with 1-2 members as base). Other things being equal, the household that has 3-5 members and over 5 members spends more for both public and private transport than the household with 1-2 members.

The age of the household head, measured by dummy variables, is significant in all of the budget shares of private and public transport. Other things remaining the same, the budget shares of public transport for households whose head is 25-35 years, 36-55 years, 56-65 years and older than 65 years old are lower than those whose head is younger than 25 years. On the other hand, the budget shares of private transport for household head in the age category of 25 years to older than 65 year are higher than the age younger than 25 years old.

The dummy variables of education of household head are statistically significant for all board groups. Other things being equal, a household head with secondary or higher school and university education spends more on private transport than one with no more than a primary education. Conversely, a household head with secondary or higher school and university education spends less on public transport than household head with no more than a primary education.

The coefficients of household head who is a worker and an employee are significantly negative with the budget share on public transport and positive with the budget share on private transport. A worker and an employee spend less for public transport and more for private transport than households with an economically inactive head, other things remaining the same. However, households with an employer head do not appear to significantly affect the budget share on both groups.

Household location dummy is statistically significant for all board groups. All other things held constant, the budget share of public transport of households located in Central, North, Northeast and South regions is lower than that of households located in Bangkok and three provinces including Samut Prakarn, Nonthaburi and Pathum Thani (base category). Conversely, the budget shares of private transport of households located in Central, North, Northeast and South regions are higher than the base category.

Table 5.3 Demand Estimation for Broad Group Expenditure (Working-Leser Model)

Variable	**Food**	**Public Transport**	**Private Transport**	**Durable Goods**	**Non-Durable Goods**	**Other Service and Non Consumption**
Natural log of total household monthly Expenditure (ln)	-0.112291***	-0.002424***	0.007526***	0.059338***	-0.031227***	0.079078
	(0.000884)	(0.000106)	(0.000227)	(0.000543)	(0.000480)	
Household size						
1-2 (base)						
3-5	0.061977***	0.003918***	0.017477***	-0.001077*	0.012546***	-0.094841
	(0.000775)	(0.000158)	(0.000364)	(0.000622)	(0.000445)	
Over 5	0.100517***	0.004238***	0.023934***	-0.009460***	0.023500***	-0.142729
	(0.001328)	(0.000268)	(0.000631)	(0.001135)	(0.000745)	
Age of household head						
Under 25 (base)						
25-35	-0.002777	-0.006179***	0.006864***	0.012215***	0.016356***	-0.026479
	(0.002388)	(0.000644)	(0.000982)	(0.001652)	(0.001321)	
36-55	-0.016288***	-0.004301***	0.015489***	-0.005402***	0.024436***	-0.013934
	(0.002336)	(0.000630)	(0.000947)	(0.001541)	(0.001292)	
56-65	-0.014930***	-0.005312***	0.017001***	-0.018143***	0.031970***	-0.010586
	(0.002423)	(0.000650)	(0.001013)	(0.001614)	(0.001347)	

Table 5.3 (Continued)

Variable	Food	Public Transport	Private Transport	Durable Goods	Non-Durable Goods	Other Service and Non Consumption
Over 65	-0.023489***	-0.005214***	0.006444***	-0.010774***	0.035903***	-0.002870
	(0.002527)	(0.000672)	(0.001036)	(0.001614)	(0.001410)	
Education of head						
Primary education or lower (base)						
Secondary or higher education	-0.019530***	-0.001471***	0.007928***	-0.010195***	0.012250***	0.011018
	(0.000931)	(0.000190)	(0.000423)	(0.000765)	(0.000518)	
University or higher education	-0.047396***	-0.002414***	0.019364***	-0.022728***	0.029027***	0.024147
	(0.001355)	(0.000265)	(0.000619)	(0.001199)	(0.000797)	
Work status of household head						
Economically inactive (base)						
Worker	-0.017674***	-0.001530***	0.008435***	0.005363***	-0.011358***	0.016764
	(0.001163)	(0.000233)	(0.000502)	(0.000744)	(0.000680)	
Employee	0.012788***	0.000025	-0.00014	-0.002572***	-0.021931***	0.011830
	(0.001215)	(0.000264)	(0.000541)	(0.000839)	(0.000706)	

Table 5.3 (Continued)

Variable	Food	Public Transport	Private Transport	Durable Goods	Non-Durable Goods	Other Service and Non Consumption
Employer	-0.033862***	-0.003525***	0.011743***	0.003044**	-0.004729***	0.027339
	(0.001512)	(0.000294)	(0.000772)	(0.001377)	(0.000907)	
Region						
Bangkok and 3 provinces (base)						
Central	-0.013511***	-0.032354***	0.026344***	0.037934***	-0.004522***	-0.013891
	(0.001187)	(0.000410)	(0.000564)	(0.000925)	(0.000663)	
North	-0.060877***	-0.037750***	0.029135***	0.062936***	-0.011339***	0.017895
	(0.001288)	(0.000409)	(0.000575)	(0.001028)	(0.000733)	
Northeast	-0.054916***	-0.038540***	0.028992***	0.067815***	-0.009656***	0.006305
	(0.001287)	(0.000407)	(0.000574)	(0.001036)	(0.000722)	
South	-0.015017***	-0.035014***	0.031444***	0.047429***	-0.014331***	-0.014511
	(0.001323)	(0.000420)	(0.000628)	(0.001062)	(0.000741)	
Year						
2006 (base)						
2007	0.005285***	0.000328*	-0.000031	-0.003501***	0.000623	-0.002704
	(0.000950)	(0.000199)	(0.000433)	(0.000768)	(0.000556)	
2008	0.024957***	0.000394**	0.011141***	-0.010289***	-0.005294***	-0.020909
	(0.000961)	(0.000199)	(0.000451)	(0.000751)	(0.000548)	

Table 5.3 (Continued)

Variable	**Food**	**Public Transport**	**Private Transport**	**Durable Goods**	**Non-Durable Goods**	**Other Service and Non Consumption**
2009	0.035886***	-0.000738***	0.001023**	-0.012555***	-0.008065***	-0.015551
	(0.000968)	(0.000193)	(0.000431)	(0.000760)	(0.000557)	
Constant	1.456155***	0.070052***	-0.055135***	-0.501729***	0.424272***	-0.393615
	(0.008363)	(0.001287)	(0.002286)	(0.005048)	(0.004556)	
R^2	0.335732	0.126102	0.082675	0.170741	0.111232	
Adjust R^2	0.335660	0.126008	0.082576	0.170651	0.111136	
Number of Observations	175692	175692	175692	175692	175692	

Note: *, **, *** Estimates are significant at the 10 percent, 5 percent and 1 percent levels, respectively.

Coefficient of non-food group is calculated from the adding-up restrictions.

Numbers in parentheses are standard errors.

5.2.2 Demand for Vehicle Fuel (Second Budgeting Stage)

In this section, the focus is on private transport expenditure disaggregated by type of vehicle fuel. The demand parameters for each fuel type are estimated at second stage using the LA/AIDS model. However, the analysis started with The Heien and Wessells Two-step Procedure (Heien and Wessells, 1990: 365-371), which is used to deal with the zero consumption problems. A probit regression is computed to determine the probability that a given household will consume the vehicle fuels. The result of probit analysis is presented in Appendix Table 1. This regression is subsequently used to compute the Inverse Mills ratio for each household. This ratio is used as an instrument that incorporates the censoring latent variables in the second stage estimation of the demand system (equation 3.6). The parameters from the LA/AIDS model are shown in Table 5.4. To avoid singularity problem, the expenditure share on LPG equation is excluded from the system. Therefore, the parameters of this equation are obtained from the homogeneity restriction imposed on each share equation and from the adding up restriction imposed across equations.

The coefficients of expenditure on vehicle fuel (in natural logarithmic form) are statistically significant for all vehicle fuel types. The budget shares of gasoline and gasohol decrease as total energy expenditure increases, while the budget shares of diesel and LPG increase. In all cases for this variable, diesel is the most sensitive to changes in vehicle fuel expenditure, followed by gasoline.

Own-price and cross price coefficients for all types of vehicle fuels are statistically significant. An increase in the price of gasoline decreases own share in total vehicle fuel expenditure while increasing the budget shares of gasohol, diesel and LPG. A greater portion of the expenditure saved from reduced gasoline expenditure is reallocated to the other vehicle fuel types. An increase in the price of gasohol decreases its own share of the budget including the share of diesel and LPG while increasing the share of gasoline in total vehicle fuel expenditure. Households reduce the budget share of gasohol, diesel and LPG in total vehicle fuel expenditure and reallocate the savings to gasoline. An increase in the price of diesel results in the decrease in the budget share of gasohol and LPG and an increase in the budget share of diesel and gasoline. Households reallocate expenditures saved from gasohol and LPG to diesel and gasoline. The higher LPG price leads to an increase of the budget share of gasoline and a decline in the budget share of gasohol, diesel and LPG. However, the estimated parameters of the LA/AIDS equation do not offer a straightforward economic interpretation but form the basis of elasticity because the dependent variable is the budget share rather than quantity (Wadud, 2006: 32).

The selected characteristics of household head, namely, gender, age and education are statistically significant in all vehicle fuel types. Other things being equal, households with a male head spend more gasohol and diesel while households with a female spend more gasoline and LPG. Households with younger heads have a significantly higher budgetary allocation for gasoline, gasohol and LPG, and significantly lower budgetary allocation for diesel. In case of gasoline and diesel, Shittu, et al. (2004: 47-51) also found that households with an older head consume more diesel than those with a younger head while Wadud, et al. (2010: 60-62) found that those with a younger head consume more gasoline. Educational level of household head has a negative relation on budget share of gasoline and gasohol. Compared to the group with no more than a primary education (base), the groups with secondary or higher school and university education exhibit a lower budget share for gasoline and gasohol. This result is consistent with the findings of Archibald and Gillingham (1980: 624-626). Additionally, Wadud, et al. (2010: 60-62) opined that households with higher education tend to use less fuel because they are more environmentally of the effects of fuel consumption on the environment. While the heads of the household with secondary or high school education allocate more of the budget share on diesel than do the heads of the household with primary or lower education, the heads of household with university education, allocate the least of the budget share on diesel.

Household size is positively related with budget shares for gasoline and gasohol but negatively related with budget shares for diesel and LPG. Budget share for gasoline and gasohol increases with an increase in household size but decreases for diesel and LPG. The case for gasoline is consistent with Wadud, et al. (2010: 59-63).

Households with children spend less for gasoline and more for diesel but do not significantly alter budget shares for gasohol. The case for gasoline is likewise consistent with Wadud, et al. (2010: 59-63) and Slavík (2004: 217). Households with elderly members spend less on gasohol but do not significantly alter their budget shares for gasoline and diesel.

The number of vehicles owned by a household has a positive relation with the budget share allocated to each type of fuel type depending on the type of vehicle. For instance, an increase in the number of motorcycles leads to more consumption of gasoline because motorcycle engines operate best on gasoline. Although motorcycle engines can run on gasohol, households prefer not to use it. This is the lack of consumer confidence on the use of gasohol. Likewise, an increase in the number of automobiles leads to a higher consumption of gasoline and gasohol and an increase in the number of pick- up trucks and vans leads to consuming more diesel. Finally, households that own different types of vehicle spend less on gasoline and gasohol and more on diesel. This finding on gasoline case is similar to Wadud, et al. (2010: 59-63).

Regional characteristics have a significant influence on households' vehicle fuel consumption behavior. The budget share of gasoline and gasohol of households located in Central, North, Northeast and South region is lower than those in Bangkok including Samut Prakan, Nonthaburi and Pathum Thani (base category). In contrast, the budget share of diesel of households located in Central, North, Northeast and South region is higher than the base category.

The IMRs are all significant in all the equations. This implies the usefulness of including this variable in the LA/AIDS model in order to correct for sampling bias brought about by zero purchase of some households for vehicle fuels.

Table 5.4 Parameter Estimates of Demand System (LA/AIDS Model)

Variable	Gasoline	Gasohol	Diesel	LPG
Natural log of expenditures for vehicle fuels per month weighted by Laspeyres price index	-0.099542***	-0.009240***	0.102413***	0.006369
	(0.001252)	(0.000476)	(0.001514)	
Natural log of the gasoline price	-0.311913***	0.091712***	0.064131***	0.15607
	(0.007246)	(0.002918)	(0.004918)	
Natural log of the gasohol price	0.091712***	-0.049176***	-0.015749***	-0.026787
	(0.002918)	(0.005006)	(0.003702)	
Natural log of the diesel price	0.064131***	-0.015749***	0.023181***	-0.071563
	(0.004918)	(0.003702)	(0.005523)	
Natural log of the LPG price	0.156069***	-0.026788***	-0.071563***	-0.057718
	(0.003991)	(0.002366)	(0.003048)	
Age of household head	-0.000122**	-0.000187***	0.000360***	-0.000051
	(0.000052)	(0.000026)	(0.000054)	
Household size	0.007607***	0.002158***	-0.009596***	-0.000169
	(0.000499)	(0.000186)	(0.000508)	

Table 5.4 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Number of Motorcycle owned by HH	0.037278***	-0.008322***	-0.075691***	0.046735
	(0.001024)	(0.000453)	(0.001207)	
Number of Automobile owned by HH	0.069748***	0.025657***	-0.171403***	0.075998
	(0.002708)	(0.001235)	(0.003415)	
Number of Pick- up (mini truck), van owned by HH	-0.198015***	-0.022742***	0.262822***	-0.042065
	(0.003282)	(0.000901)	(0.003904)	
Number of Other mini- truck owned by HH	0.078301***	0.009354***	-0.058117***	-0.029538
	(0.002683)	(0.000851)	(0.002733)	
Male head of household	-0.008398***	0.002605***	0.010748***	-0.004955
	(0.001421)	(0.000523)	(0.001335)	
Dummy for the presence of children < 5 years (no child=0)	-0.010858***	0.000944	0.008462***	0.001452
	(0.001589)	(0.000585)	(0.001508)	
Dummy for the presence of elder > 65 years (no elder =0)	-0.000847	-0.003000***	0.001423	0.002424
	(0.001724)	(0.000879)	(0.001498)	
Dummy for the presence of multi type of vehicles (no =0)	-0.177935***	-0.012658***	0.112642***	0.077951
	(0.003092)	(0.001174)	(0.003308)	

Table 5.4 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Education of head				
Primary education or lower (base)				
Secondary or higher education	-0.004917***	-0.013350***	0.002748*	0.015519
	(0.001648)	(0.000639)	(0.001580)	
University or higher education	-0.010544***	-0.015182***	-0.011957***	0.037683
	(0.002708)	(0.001507)	(0.002464)	
Region				
Bangkok and 3 provinces (base)				
Central	-0.007454**	-0.018022***	0.029607***	-0.004131
	(0.003134)	(0.001695)	(0.002893)	
North	-0.043707***	-0.019244***	0.053151***	0.0098
	(0.003464)	(0.001702)	(0.003119)	
Northeast	-0.026203***	-0.021405***	0.055774***	-0.008166
	(0.003083)	(0.001684)	(0.003215)	

Table 5.4 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
South	-0.002822	-0.025000***	0.048402***	-0.02058
	(0.003436)	(0.001712)	(0.003308)	
Total household monthly Expenditure category				
Less than 5,000 (base)				
5,000-8,999	0.013445***	-0.004275***	-0.012838***	0.003668
	(0.001050)	(0.000464)	(0.001010)	
9,000-12,999	0.008060***	-0.009663***	-0.005790***	0.007393
	(0.001658)	(0.000714)	(0.001512)	
13,000-19,999	-0.004498*	-0.018069***	0.018082***	0.004485
	(0.002410)	(0.000884)	(0.002119)	
Over 20,000	-0.012636***	-0.030199***	0.031909***	0.010926
	(0.002997)	(0.001037)	(0.002763)	
Inverse Mill's ratio (IMR)	-0.347168***	0.417890***	0.089822***	-0.160544
	(0.002020)	(0.001851)	(0.001671)	

Table 5.4 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Constant	1.445009***	-0.008448**	-0.294008***	-0.142553
	(0.006828)	(0.003409)	(0.006295)	
Chi-squared	364280.61	640416.74	250315.92	
R-squared	0.6943	0.8225	0.6351	
Number of Observations	142445	142445	142445	

Note: *, **, *** Estimates are significant at the 10 percent, 5 percent and 1 percent level, respectively.
Numbers in parentheses are standard errors.

5.2.3 Price and Expenditure Elasticities

Based on coefficients in Table 5.3, Equation 4.7 is calculated at sample mean, leading to the expenditure elasticities for six broad groups at the first budgeting stage. The results are presented in Table 5.5. Private transport and durable goods turn out to be luxury goods. Barros and Prieto-Rodriguez (2008: 663-664), Labandeira, et al. (2006: 101-103) and Decoster (1995: 146) also report that the expenditure elasticity for private transport is greater than one, indicating they are luxury goods. Conversely, consumers tend to spend proportionately less on the rest of the groups as the total expenditure increases. This implies that food, public transport, non-durable goods as well as other services and non consumption are necessary goods. The result of public transport is consistent with Decoster (1995: 146). On the other hand , the finding of Labandeira, et al. (2006: 101-103) indicates that public transport is luxury goods.

Expenditure elasticities of demand for the different fuel categories are given in Table 5.6. The elasticities obtained from the LA/AIDS model are with respect to the expenditures only on vehicle fuels. The results indicate that, as households' expenditure on vehicle fuel increases, the proportion of expenditure on diesel and LPG is much higher than on gasoline and gasohol. The higher expenditure elasticity of diesel and LPG could be an effect of the policy and technology shift in favor of diesel and LPG cars. The comparison of expenditure elasticity with previous studies is shown in Table 5.7. The expenditure elasticity of demand for gasoline is quite similar to the finding of Tiezzi (2005: 1606-1607), Janthanee Homchuen (2006: 79-80) and Broadstock and Chen (2012: 9) but is consistently high compared to the results of Iootty, et al. (2009: 5329-5330) and consistently low compared to the results of Shittu, et al. (2004: 49) and Mehrara and Ahmadi (2011: 75-76). The expenditure elasticities of demand for gasohol is higher than Janthanee Homchuen's (2006: 79-80) finding and lower than Iootty, et al. (2009: 5329-5330). In case of diesel, it is higher than the results of Iootty, et al. (2009: 5329-5330), Janthanee Homchuen (2006: 79-80) and Broadstock and Chen (2012: 9) and lower than that of Shittu, et al. (2004: 49). Janthanee Homchuen (2006: 79-80) and Labandeira, et al. (2006: 102-103) found that expenditure elasticity of LPG is 0.1293 and 0.343, respectively, which are very much lower than the result of this study.

Table 5.5 Expenditure Elasticity for Broad Groups at the First Budgeting Stage

Group	Expenditure Elasticities
Food	0.735365
Public Transport	0.795172
Private Transport (Vehicle fuels)	1.100775
Durable Goods	1.826048
Non-Durable Goods	0.800301
Other Service and Non Consumption	0.696968

Source: Own computations based on household socio-economic survey 2006-2009, NSO.

Table 5.6 Estimated Expenditure Elasticities of Vehicle Fuels

Vehicle Fuels	Expenditure Elasticities
Gasoline	0.863902
Gasohol	0.857153
Diesel	1.513679
LPG	2.401536

Source: Own computations based on household socio-economic survey 2006-2009, NSO.

Table 5.7 The Comparison of Expenditure Elasticity with the Other Studies

Vehicle Fuels	Estimated Results from This Study	Results from Previous Studies	Authors/Year
Gasoline	0.863902	0.880	Tiezzi (2005: 1606-1607)
		0.905	Janthanee Homchuen (2006: 79-80)
		0.963	Broadstock and Chen (2012: 9)
		0.591	Iootty, et al. (2009: 5329-5330)
		1.140	Mehrara and Ahmadi (2011: 75-76)
		5.420	Shittu, et al. (2004: 49)
Gasohol	0.857153	0.477	Janthanee Homchuen (2006: 79-80)
		2.013	Iootty, et al. (2009: 5329-5330)
Diesel	1.513679	1.080	Mehrara and Ahmadi (2011: 75-76)
		1.166	Iootty, et al. (2009: 5329-5330)
		1.192	Janthanee Homchuen (2006: 79-80)
		1.730	Shittu, et al. (2004: 49)
LPG	2.401536	0.343	Labandeira, et al. (2006: 102-103)
		0.129	Janthanee Homchuen (2006: 79-80)

Behavioral characteristics of the consumer demand systems are measured by elasticity; consumer response to price change is summarized in terms of own price elasticity and cross-price elasticity. Both compensated and uncompensated price elasticities are computed. The uncompensated elasticity of demand represents changes in the quantity demanded as a result of changes in prices, capturing both price effect and income effect. Compensated elasticity of demand refers to the portion of change in the quantity of demand, which captures only the price effect. The uncompensated own-price elasticities are all negative with absolute magnitudes of greater than one (elastic), excluding diesel, as shown in Table 5.8. The uncompensated own-price elasticity with the other studies is shown in Table 5.9. The result for gasoline is quite similar to the result of Tiezzi (2005: 1606-1607) and Broadstock and Chen (2012: 9) while it is higher than that of Thiraphong Vikitset (2008: 30-35), Iootty, et al. (2009: 5329-5330) as well as Mehrara and Ahmadi (2011: 75-76). Additionally, this result is lower than Janthanee Homchuen's (2006: 79-80). The own-price elasticity for gasohol is consistently very low compared to the results of Janthanee Homchuen (2006: 79-80) and consistently high compared to the results of Iootty, et al. (2009: 5329-5330). Although the own-price elasticity for diesel is greater than the finding of Thiraphong Vikitset (2008: 30-35) and Iootty, et al. (2009: 5329-5330) as well as lower than Broadstock and Chen (2012: 9), these results are similar to Janthanee Homchuen (2006: 79-80). The own-price and cross price elasticities of LPG are very large in absolute value. These may be the influence of two factors: 1) the price of LPG that has for a long time been intervened by the Thai government and 2) the small share of LPG expenditure in the total vehicle fuel expenditure which is about 0.0045 (Hu, 2004: 4-5). The cross price elasticities are all statistically significant. The uncompensated cross price elasticities show that mainly gasohol exerts a strong competition to gasoline, with a cross price elasticity of 1.522312. Furthermore, LPG is extremely sensitive to a price change in gasoline. To be able to use LPG in general, the cars have to be technically modified to allow the using of gasoline and LPG. The cost of modification is high, which is probably the reason the sample size of households using LPG is small. The average of budget share for LPG is remarkably small at only 0.0045. The households that own vehicles that can run on LPG and gasoline exhibit extreme response to the gasoline price change. Because LPG price is much lower than gasoline resulting from the government subsidy. The other cross price elasticities are small, even though all of them are significantly different from zero.

The compensated price elasticity estimates are shown in Table 5.10. Since the compensated price elasticity takes into account the substitution effect, it is smaller than the uncompensated elasticity in absolute value terms particularly the own price elasticities. The compensated own price elasticities are all negative, as expected. Any positive sign of compensated cross price elasticity indicates the substitution relationship between pairs of goods whereas a negative sign indicates the complementary relationship among goods. Gasohol, LPG and diesel are substitutes to gasoline. Conversely, the result shows weaker substitution relations of gasoline among gasohol, LPG and diesel. In the case of diesel, it is similar to the result of Broadstock and Chen (2012: 9), indicating the substitution between gasoline and diesel. This may result from a household having more than one type of vehicle, such as a motorcycle or automobile and a diesel car (pick-up truck), which use different fuel types. When the price of gasoline increases, the household may use the diesel car more often or for longer trips, resulting in higher diesel consumption. These results of elasticities play an important role in policy. They are used to analyze the impact of simulation policies.

Table 5.8 Estimated Uncompensated Elasticities (Marshallian) of Vehicle Fuels

	Gasoline	**Gasohol**	**Diesel**	**LPG**
Gasoline	**-1.326919**	0.134196	0.114817	0.214003
Gasohol	1.522312	**-1.751003**	-0.214994	-0.413483
Diesel	-0.054039	-0.112220	**-0.986143**	-0.361277
LPG	33.319041	-5.985295	-16.027287	**-13.707555**

Source: Own computations based on household socio-economic survey 2006-2009, NSO.

Table 5.9 The Comparison of Uncompensated Own Price Elasticity with the Other Studies

Vehicle Fuels	Estimated Results from This Study	Results from Previous Studies	Authors/Year
Gasoline	-1.326919	-1.282	Tiezzi (2005: 1606-1607)
		-1.258	Broadstock and Chen (2012: 9)
		-2.682	Janthanee Homchuen (2006: 79-80)
		-1.01	Mehrara and Ahmadi (2011: 75-76)
		-0.826	Iootty, et al. (2009: 5329-5330)
		-0.430	Thiraphong Vikitset (2008: 30-35)
Gasohol	-1.751003	-1.263	Iootty, et al. (2009: 5329-5330)
		-11.145	Janthanee Homchuen (2006: 79-80)
Diesel	-0.684358	-0.644	Janthanee Homchuen (2006: 79-80)
		-0.324	Iootty, et al. (2009: 5329-5330)
		-0.350	Thiraphong Vikitset (2008: 30-35)
		-1.641	Broadstock and Chen (2012: 9)
LPG	-13.696642	-0.367	Labandeira, et al. (2006: 102-103)
		-0.072	Janthanee Homchuen (2006: 79-80)
		-3.580	Mehrara and Ahmadi (2011: 75-76)

Table 5.10 Estimated Compensated Elasticities (Hicksian) of Vehicle Fuels

	Gasoline	Gasohol	Diesel	LPG
Gasoline	**-0.695061**	0.190077	0.287054	0.217928
Gasohol	2.149233	**-1.695558**	-0.044102	-0.409588
Diesel	1.053065	-0.014309	**-0.684358**	-0.354398
LPG	35.075523	-5.829953	-15.548488	**-13.696642**

Source: Own computations based on household socio-economic survey 2006-2009, NSO.

5.3 Simulations

The alternative pricing policies are simulated to attain the second and third objectives. The simulations incorporated the estimated price elasticities from the previous section and the analysis of consumer welfare (the compensating variation) are used to examine the impact of pricing policy to support the use of gasohol as a gasoline substitute and to propose an alternative pricing policy that promotes the highest efficiency of gasoline and gasohol. There are two assumptions set in this simulation. Firstly, the market of vehicle fuels is perfectly competitive. Therefore, if the MRS of gasoline and gasohol equals the MRT of both, the production and consumption of both products is efficient. The second assumption is that the supply of vehicle fuels is perfectly elastic. This implies that the pricing policy has no effect on the producer surplus.

Additionally, the optimal pricing policy to encourage the use of gasohol is derived from the minimized welfare loss with the same total amount of revenue constraint (in base year 2009). This constraint is defined as

$$\text{Total revenue} = [(P_{gasoline} - MC_{gasoline}) * Q_{gasoline}] + [(P_{gasohol} - MC_{gasohol}) * Q_{gasohol}]$$

$P_{gasoline}$ = the retail price of gasoline

$P_{gasohol}$ = the retail price of gasohol

$Q_{gasoline}$ = the consumption of gasoline

$Q_{gasohol}$ = the consumption of gasohol

$MC_{gasoline}$ = the marginal economic cost of gasoline

$MC_{gasohol}$ = the marginal economic cost of gasohol

Furthermore, the social cost is calculated in this simulation to reflect the externality cost that is not included in the retail price structure. The Social Cost of Carbon (SCC) is used to calculate the social cost in this study. According to Jirath Chenphuengpawn (2011: 54), the SCC from the previous studies is adjusted to the value in 2009 (base year) and then calculated into average. Thus, the SCC is equal to USD 14.06 /ton of CO_2. The CO_2 emissions by one litre of gasoline and gasohol are 2.34 and 2.11 kilograms CO_2, respectively. Therefore the social costs for gasoline and gasohol are approximately THB 1.13 and THB 1.02 /litre, respectively.

The retail price structure of gasoline and gasohol in 2009 resulting from the pricing policy to encourage the use of gasohol is shown in Table 5.11. This retail price structure is baseline case in the simulation. The consequence of this policy is that the ratio of the retail price to marginal economic cost for gasoline is greater than gasohol, resulting in welfare loss.

Table 5.11 Price Structure of Gasoline and Gasohol in Thailand, 2009

Average on 2009	Gasoline	Gasohol
1. Ex-Refinery Price	14.65	15.62
2. Excise Tax	5.89	4.75
3. Municipal Tax	0.59	0.48
4. Oil Fund	5.94	1.78
5. Conservation Fund	0.60	0.25
6. Wholesale Price (WSP) [1+2+3+4+5]	27.67	22.88

Table 5.11 (Continued)

Average on 2009	Gasoline	Gasohol
7. Value Added Tax (VAT)	1.94	1.60
8. WSP&VAT [6+7]	29.61	24.48
9. Marketing Margin	4.07	2.09
10. Value Added Tax (VAT)	0.28	0.14
11. Retail Price [8+9+10]	33.96	26.71
12. Economic Cost [1+5+9]	19.32	17.96
13. Retail Price/Economic Cost [11/12]	**1.76**	**1.49**

Source: Energy Policy and Planning Office, Ministry of Energy, 2009. and Calculated by Author.

5.3.1 The Scenarios

Five scenarios (S1-S5) were simulated to attain the second and third objectives of this study.

S1 is the ideal pricing policy. Gasoline and gasohol are priced at their marginal economic cost leading to an economic efficiency. Transfer payment including the excise tax, oil fund levy and VAT are phased out from the retail price structures of both fuels. The difference of the compensating variation (welfare) between baseline case and S1 is the impact of pricing policy to support the use of gasohol as a gasoline substitute.

It is not possible for the government to implement the ideal scenario because there is no revenue to stabilize the price of petroleum products. Therefore, scenarios S2-S5 allow for collecting and adjusting the transfer payment components, namely, the excise tax, oil fund levy and VAT to generate revenue for the government. In these scenarios, gasoline and gasohol are priced at an economic efficient level which is MRS equal to MRT and imposes a total amount of revenue that is equal to baseline case (2009 situation).

S2: In this scenario, the retail price of both fuels is imposed at economic efficient level (MRS=MRT) under the same total amount of revenue as the baseline, allowing for distortion. This implies that the economic cost of each fuel is fixed at the same level as baseline while each item of transfer payment of both fuels is adjusted to find the retail price of both fuels at economic efficient level under the same total amount of revenue.

Besides the decrease in the economic inefficiency of the existing pricing policy, an increase the use of gasohol without the higher distortion is a concern in scenarios S3-S5. The lower gasohol price without the higher distortion is the reduction of gasohol economic cost, implying a decrease in ex-refinery gasohol price. Thus, an increase of ethanol production efficiency and increase of ethanol blending are the main concerns in scenarios S3-S5.

S3: In this scenario, price of each fuel is imposed at economic efficient level (MRS=MRT) under the same amount of revenue as the baseline including the 10 percent reduction in ethanol price. This leads to the decrease of the ex-refinery price of gasohol to about 1 percent or THB 0.16/litre. The ex-refinery price of gasohol consists of the 90 percent of the gasoline price and 10 percent of the ethanol price.

S4: In this scenario, the price of each fuel is imposed equal to its marginal economic cost under the same amount of revenue as the baseline including the 20 percent ethanol price decreases. This leads to the decrease in the ex-refinery price of gasohol to about 2 percent or THB 0.31/litre.

S5: In this scenario, the price of each fuel is imposed that is equal to its marginal economic cost under the same amount of revenue as the baseline. Moreover, the ex-refinery price of gasohol is lowered to about 4 percent or THB 0.62/litre, due to the higher proportion of ethanol in the blend (20% to 80% gasoline), which is called E20-gasohol and the lower ethanol price by 20 percent.

All the scenarios are summarized in Table 5.12.

Table 5.12 Summary of The Scenarios

Scenario	MRS = MRT	The Equal Revenue Constraint	The Lower Ethanol Price	The Higher Ethanol Blending
S1	✓	-	-	-
S2	✓	✓	-	-
S3	✓	✓	10%	-
S4	✓	✓	20%	-
S5	✓	✓	20%	20%

5.3.2 The Results of the Simulation

As can be seen in Table 5.13, the baseline case has created the highest welfare loss which is 115,158.59 million baht per year or approximately 15 percent of the expenditure on vehicle fuel consumption in 2009. Conversely, there is no welfare loss in S1, in which there is no distortion or interference by the government. However, the government would have no revenue to manage the petroleum price situation. Compared to baseline, there is a considerable increase in gasoline consumption because of the substantial decrease in gasoline price; the lower consumption of gasohol results from the domination of the cross price effect. Furthermore, the higher consumption leads to higher social cost and economic cost. This scenario may generate more environmental impacts because the lower fuel price may induce behavior that uses fuel less efficiently.

The S2 is efficient pricing policy with the equal revenue constraint. It can reduce the welfare loss created by the existing pricing policy by approximately 102.15 million baht per year by the removal of the gasohol subsidy, which is causing the welfare loss in the baseline. In minimizing welfare loss with the same total amount of revenue constraint, the retail price structure in the simulation allows the gasohol consumers to pay back the subsidy received from the gasoline consumers under the baseline price structure. Although, there remains a high welfare loss, the economic cost and social cost are lower than in the ideal case. However, S2 can generate revenue for vehicle fuel price stabilization. Unfortunately, this policy (S2) reduces gasohol consumption due to the higher gasohol price and the lower gasoline price compared to S1. In S1, when the gasoline price decreases, gasohol consumption is impeded by the cross price effect of gasoline. This indicates that a policy based on S2 scenario cannot increase the use of gasohol as a gasoline substitute nor achieve the production target of ethanol in the 15-year renewable energy development plan.

The S3, S4 and S5 scenarios present the alternative policies that can increase the use of gasohol without the higher distortion, resulting in the achievement of the ethanol target in a 15-year plan with the least cost. Instead of decreasing the gasohol price with the subsidy, increasing ethanol production efficiency and proportion of ethanol in the blend (from E10 to E20), which leads to a lower ex-refinery price of gasohol, can reduce the retail price of gasohol without generating welfare loss. This is confirmed by the higher gasohol consumption with the lower welfare loss from S2 to S5 scenario.

In the short term, the proposed policy would be S2 because the development of a more efficient ethanol production or the higher ethanol blending could take a long time. The welfare loss created by baseline pricing policy is reduced by the implementation of S2 policy, which results in economic efficiency and allows the collection of revenue to cover the social cost. The scenarios S3, S4 and S5 can encourage gasohol consumption with the least cost in the long run.

Table 5.13 The Impact of the Simulations of Pricing Policy

Scenario	Welfare Loss (M.THB)	Gasoline Price (THB/L)	Gasohol Price (THB/L)	MRS	MRT	Government Revenue (M.THB)	Social Cost (M.THB)	Economic Cost (M.THB)	Gasoline Consumption (M.Litre)	Gasohol Consumption (M. Litre)
Baseline 2009	115,158.59	33.96	26.71	1.27	1.08	62,456.86	5,382.25	92,870.49	3,292.44	1,629.21
S1 Idea Case	**-**	**19.32**	**17.96**	**1.08**	**1.08**	**0.00**	**7,209.58**	**124,042.98**	**5,031.08**	**1,494.57**
S2	115,056.44	33.15	30.81	1.08	1.08	62,456.86	5,069.76	87,268.84	3,464.67	1,132.04
S3	114,450.41	33.08	30.49	1.09	1.09	62,456.86	5,103.50	87,679.56	3,468.11	1,161.31
S4	113,880.69	33.02	30.16	1.09	1.09	62,456.86	5,137.48	88,085.55	3,470.54	1,191.93
S5	112,793.28	32.91	29.53	1.11	1.11	62,456.86	5,202.07	88,811.34	3,474.09	1,251.32

Note: Prices are in Baht per Litre (THB/L); Consumption is in Million litres per Year (M.Litre/Y); Values are in Million Baht per Year (M.THB/Y).

CHAPTER 6

CONCLUSION AND POLICY IMPLICATIONS

6.1 Conclusion

The rapid economic development of Thailand had been, as expected and as research has shown, accompanied by a corresponding rise in the use of energy. A large proportion of the energy source was and still is imported fossil fuel. In order to avoid over-reliance on imported fossil fuel, as well as to reduce GHG and other emissions from the combustion of oil, Thailand turned to its abundant agricultural resources for alternative fuel, in particular biofuel. It adopted policies that promote the production and consumption of biofuel, namely ethanol and biodiesel, in the transport sector - the heaviest consumer of oil-based energy - to achieve the two objectives of reduced dependence on imports and less environmental impact from energy use. In 2008, the Ministry of Energy launched a 15-year alternative energy plan 2008–2022 that set some ambitious targets: by the end of 2022, ethanol production will be 9.0 ML/day and biodiesel 4.5 ML/day (Department of Alternative Energy Development and Efficiency, 2008: 8-10). To attain the target for ethanol, the government implemented a pricing policy for gasohol (or ethanol) comprising two measures, namely, a subsidy on gasohol and a tax on gasoline. The policy was meant to encourage people to use more gasohol by having its price lower than that of gasoline. The consequence of this policy was negative: the more gasohol was consumed, the wider the difference between MRS and MRT of both products became, which resulted in welfare loss and economic inefficiency.

This study examined the influence of households' socio-economic characteristics and other factors on vehicle fuel consumption by estimating the household demand for vehicle fuel. The study also examined the impact of the existing pricing policy and proposes an alternative pricing policy that should lead to the highest efficiency of both fuels. Due to the data limitation, this study focused on the impact of policy only on the demand side by using a micro-analytic empirical approach. The complete demand analysis based on micro level data was carried out to investigate the effects of price and non-price factors, deriving results of demand elasticities for each vehicle fuel items, particularly E10-gasohol and gasoline. The demand elasticities, both uncompensated and compensated, were then used to examine the impact of the existing policy and to find the alternative pricing policy to support the use of gasohol as a gasoline substitute. The welfare measurement used to examine the highest efficiency of pricing policy is the compensating valuation.

The results reveal that the pattern consumption of households for vehicle fuels is determined by the household's total vehicle fuel expenditure, the prices of the fuels paid by households, and other household characteristics. The characteristics of household head, namely, gender, age and education are statistically significant in all vehicle fuel types. For instance, all other things held constant, households with a male head allocate more for gasohol and diesel than gasoline and LPG, and more so than households headed by a woman. Households with younger heads have a significantly higher budgetary allocation for gasoline, gasohol and LPG, and significantly lower budgetary allocation for diesel. Households whose head has higher education tend to use less gasoline and gasohol. Budget share for gasoline and gasohol increases with an increase in household size but decreases for diesel and LPG. The number of vehicles owned by a household has a positive correlation on the budget share allocated to each vehicle fuel type depending on the type of vehicle. For instance, an increase in the number of motorcycles leads to more consumption of gasoline because motorcycle engines are built to run on gasoline. Although motorcycle engines can also operate on gasohol, its use has been low among motorcyclists likely because of their lack of the confidence on gasohol. Likewise, an increase in the number of automobiles has led to higher consumption of gasoline and gasohol while the increase in the number of pick- up trucks and vans has led to more consumption of diesel.

The expenditure elasticities obtained from the LA/AIDS model for gasoline, gasohol, diesel and LPG are 0.863902, 0.857153, 1.513679 and 2.401536, respectively. These imply that as households' expenditure on vehicle fuel increases, the proportion of expenditure on diesel and LPG is much greater than on gasoline and gasohol. Although the own price elasticities of all type of vehicle fuels are statistically significant with a negative sign and consistent with economic theory, the absolute magnitudes are greater than the findings of previous papers on Thailand due to the different data types. For instance, the own price elasticites of demand for gasoline and gasohol are -1.326919 and -1.751003. The uncompensated and compensated cross price elasticities show that gasohol exerts a strong competition to gasoline. The uncompensated cross-price elasticity for gasohol with respect to gasoline price is 1.522312 while cross-price elasticity for gasoline with respect to gasohol price is 0.134196. This implies that the responsiveness of gasohol consumption with regard to gasoline price is greater than the responsiveness of gasoline consumption with regard to gasohol price.

To answer the second research question of this study, five scenarios (S1-S5) are simulated that incorporated the estimated price elasticities from the LA/AIDS model and the analysis of consumer welfare. Two assumptions set in this simulation are 1) that the market of vehicle fuels is perfectly competitive and 2) that the supply of vehicle fuels is perfectly elastic. The pricing policy that influenced the existing retail prices of gasoline and gasohol in 2009 created a welfare loss of THB 115,158.59 million per year or approximately 15 percent of the expenditure on vehicle fuel consumption in 2009. In the short term, the proposed retail price structure of gasoline and gasohol should be based on economic efficiency in order to reduce the welfare loss created by the existing pricing policy. In the long run, the efficient retail price structure of both fuels should be incorporated with the increase in ethanol production efficiency and the higher ethanol blending. This would increase gasohol consumption with the least cost.

6.2 Policy Implications

Because the existing retail prices of gasoline and gasohol induced by the pricing policy has generated economic inefficiency and caused welfare loss (because of the difference between MRS and MRT of gasoline and gasohol), this study proposes a pricing policy that supports the use of gasohol as substitute for gasoline that incurs the least cost. The results suggest that gasoline and gasohol should be priced at their efficient level (MRS=MRT) to reduce the economic inefficiency and welfare loss that have been created by the existing retail prices of gasoline and gasohol. Unfortunately, this policy would lead to a lower gasohol consumption as a result of the higher gasohol price and lower gasoline price. The reason is that the efficient retail prices structure allow the gasohol consumer to pay back the subsidy received from the gasoline consumer under the baseline price structure in 2009 (Thiraphong Vikitset, 2008: 39). The results of the cross price elasticities reveal that gasoline and gasohol are close substitutes. Therefore the lower gasohol consumption is caused by the own price effect and the cross price effect between gasoline and gasohol. This suggests that phasing out gasoline from the market would support an increase in gasohol consumption and result in an efficient pricing policy. However, phasing out of gasoline from the market should proceed slowly to give time for people whose vehicles are not compatible with gasohol to adjust to the measure. It takes time for vehicles which can only use gasoline to reach obsolescence.

According to the simulation results the efficient pricing policy, including the increase in efficiency of ethanol production and the higher blending of ethanol from E10 to E20 to E85, leads to a higher gasohol consumption; these two measures lead to a lower retail price of gasohol. Reducing the cost of ethanol production, particularly the cost of the feedstock, which is more than 50 percent of total ethanol cost, can enhance ethanol production efficiency and the competitiveness of ethanol with gasoline (Suthamma Yoosin and Chumnong Sorapipatana, 2007: 74). The efforts to improve the efficiency of producing ethanol should be financed by the excise tax revenue or other financial instruments.

A 10 percent decrease in ethanol price leads to a 1 percent decrease in the ex-refinery price of gasohol. This is a slight influence on gasohol price and on gasohol consumption. Therefore, the higher ethanol blending should be incorporated with the programme to increase ethanol production efficiency. However, this policy, which focuses on increasing gasohol consumption, may take a longer time to achieve the ethanol target of 9 ML a day set by REDP 2008-2022.

Even if the proposed pricing policy reduces economic inefficiency, the ethanol target may not be attained within the timeframe of 15 years. In this regard, an alternative energy development plan might be needed that reconsiders the ethanol target and re-examines whether it is achievable or not, and whether it is compatible with consumers' behaviors. It should also be aligned with Thailand's economic structure. It is, therefore, necessary to lower the target to a realistic and attainable level. Resetting the target should be guided by the findings on consumer behavior.

BIBLIOGRAPHY

Alston, Julian M; Foster, Kenneth A and Green, Richard D. 1994. Estimating Elasticities with the Linear Approximate Almost Ideal Demand System: Some Monte Carlo Results. **The Review of Economics and Statistics.** 76 (May): 351-356.

Archibald, Robert and Gillingham, Robert. 1980. An Analysis of the Short-Run Consumer Demand for Gasoline Using Household Survey Data. **The Review of Economics and Statistics.** 62 (November): 622-628.

Asche, Frank and Wessells, Cathy R. 1997. On Price Indices in the Almost Ideal Demand System. **American Journal of Agricultural Economics.** 79 (November): 1182-1185.

Asia Pacific Energy Research Centre. 2010. **Peer Review of Energy Efficiency in Thailand.** Japan: Asia Pacific Energy Research Centre, The Institute of Energy Economics.

Barros, Carlos Pestana and Prieto-Rodriguez, Juan. 2008. A Revenue-Neutral Tax Reform to Increase Demand for Public Transport Services. **Transportation Research Part A: Policy and Practice.** 42 (May): 659-672.

Barten, A.P. 1969. Maximum Likelihood Estimation of a Complete System of Demand Equations. **European Economic Review.** 1 (Autumn): 7–73.

Bopape, Lesiba Elias. 2006. **The Influence of Demand Model Selection on Household Welfare Estimates: An Application to South African Food Expenditures.** Doctoral Degree, Michigan State University.

Broadstock, David C and Chen, Xun. 2012. **A Possible Role for Discriminatory Fuel Duty in Reducing the Emissions from Road Transport: Some UK Evidence.** Surrey Energy Economics Centre (SEEC), School of Economics Discussion Papers (SEEDS), University of Surrey.

Chambwera, Muyeye. 2004. **Economic Analysis of Urban Fuelwood Demand the Case of Harare in Zimbabwe.** Doctoral Degree, Wageningen University.

Chavalit Pichalai. 2007. Thailand's Energy Conservation Program and the Role of New and Renewable Energy in Energy Conservation. **The Journal of the Royal Institute of Thailand.** 32 (January-March): 125-133.

Christensen, Laurits R.; Jorgenson, Dale W. and Lau, Lawrence J. 1975. Transcendental Logarithmic Utility Functions. **The American Economic Review.** 65 (June): 367-383.

Coleman, Jonathan and Thigpen, M. Elton. 1991. **An Econometric Model of the World Cotton and Non-Cellulosic Fibers Markets.** World Bank Staff Commodity Working Paper Number 24. Washington, D.C.: World Bank.

Deaton, Angus and Muellbauer, John. 1980a. An Almost Ideal Demand System. **The American Economic Review.** 70 (June): 312-326.

Deaton, Angus and Muellbauer, John. 1980b. **Economics and Consumer Behaviour.** New York: Cambridge University Press.

Decoster, André. 1995. A Microsimulation Model for Belgian Indirect Taxes with a Carbon / Energy Tax Illustration for Belgium. **Tijdschrift voor Economie en Management.** 40 (June): 133-156.

Department of Alternative Energy Development and Efficiency. 2008. **Renewable Energy Development Plan : REDP.** Bangkok: Department of Alternative Energy Development and Efficiency, Ministry of Energy. (In Thai)

Department of Alternative Energy Development and Efficiency. 2010a. **Thailand Alternative Energy Situation 2010.** Bangkok: Department of Alternative Energy Development and Efficiency, Ministry of Energy. (In Thai)

Department of Alternative Energy Development and Efficiency. 2010b. **Thailand Energy Situation 2010.** Bangkok: Department of Alternative Energy Development and Efficiency, Ministry of Energy. (In Thai)

Department of Energy Business. 2012. **Statistics.** Retrieved October 18, 2012 from http://www.doeb.go.th/info/info_procure.php

Department of Land Transport. 2012. **Transport Statistics.** Retrieved October 18, 2012 from http://www.dlt.go.th/th/index.php?option=com_wrapper&view=wrapper&Itemid=66

Ecker, Olivier. 2008. **Economics of Micronutrient Malnutrition: The Demand for Nutrients in Sub-Saharan Africa.** Doctoral Degree, University of Hohenheim.

Economic and Social Commission for Asia and the Pacific. 2012. **The Oil Fund.** Retrieved October 18, 2012 from http://www.unescap.org/drpad/vc/conference/ex_th_14_tof.htm

Energy Policy and Planning Office. 2011. **Energy Situation of Thailand 2010.** Bangkok: Energy Forecast and Information Technology Center, Energy Policy and Planning Office, Ministry of Energy. (In Thai)

Energy Policy and Planning Office. 2012a. **Energy Statistics.** Retrieved October 18, 2012 from http://www.eppo.go.th/info/index-statistics.html

Energy Policy and Planning Office. 2012b. **Price Structure of Petroleum Products in Bangkok.** Retrieved October 18, 2012 from http://www.eppo.go.th/petro/price/index.html

Filippini, Massimo and Pachauri, Shonali. 2002. **Elasticities of Electricity Demand in Urban Indian Households.** CEPE Working Paper Series. Zürich, Switzerland: Center for Energy Policy and Economics, Swiss Federal Institute of Technology.

Food and Agriculture Organization of the United Nations. 2009. **Case Studies on Bioenergy Policy and Law: Options for Sustainability.** Rome, Italy: FAO Legislative Studies.

Food and Agriculture Organization of the United Nations. 2010. **BEFS Thailand: Key Results and Policy Recommendations for Future Bioenergy Development.** Rome, Italy: Food and Agriculture Organization of the United Nations.

Global Agricultural Information Network. 2010. **Thailand Biofuels Annual.** Retrieved June 12, 2012 from http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_7-7-2010.pdf

Global Agricultural Information Network. 2011. **Thailand Biofuels Annual.** Retrieved June 12, 2012 from http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_7-7-2011.pdf

Global Agricultural Information Network. 2012. **Thailand Biofuels Annual.** Retrieved August 20, 2012 from http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_7-7-2011.pdf

Gonsalves, Joseph B. 2006. **An Assessment of the Biofuels Industry in Thailand.** Geneva, Switzerland: United Nations Conference on Trade and Development (UNCTAD).

Gorter, Harry de; Just, David R. and Tan, Qinwen. 2009. The Socially Optimal Import Tariff and Tax Credit for Ethanol with Farm Subsidies. **Agricultural and Resource Economics Review.** 38 (April): 65-77.

Green, Richard and Alston, Julian M. 1990. Elasticities in AIDS Models. **American Journal of Agricultural Economics.** 72 (May): 442-445.

Gundimeda, Haripriya and Köhlin, Gunnar. 2008. Fuel Demand Elasticities for Energy and Environmental Policies: Indian Sample Survey Evidence. **Energy Economics.** 30 (March): 517-546.

Hausman, Jerry A. 1981. Exact Consumer's Surplus and Deadweight Loss. **American Economic Review.** 71 (September): 662-676.

Heckman, James J. 1979. Sample Selection Bias as a Specification Error. **Econometrica.** 47 (January): 153-161.

Heien, Dale and Wessells, Cathy Roheim. 1990. Demand Systems Estimation with Microdata: A Censored Regression Approach. **Journal of Business & Economic Statistics.** 8 (July): 365-371.

Hicks, J. R. 1942. Consumers' Surplus and Index-Numbers. **The Review of Economic Studies.** 9 (Summer): 126-137.

Hsing, Yu. 1994. Estimating the Impact of the Higher Fuel Tax on US Gasoline Consumption and Policy Implications. **Applied Economics Letters.** 1 (January): 4-7.

Hu, Baiding. 2004. **An Analysis of Fuel Demand and Carbon Emissions in China.** Retrieved June 12, 2012 from http://www.researchgate.net/publication/2946660_An_Analysis_of_Fuel_Demand_and_Carbon_Emissions_in_China

International Energy Agency. 2004. **Biofuels for Transport: An International Perspective.** Paris France: The Organisation for Economic Co-operation and Development (OECD).

Iootty, Mariana; Jr., Helder Pinto and Ebeling, Francisco. 2009. Automotive Fuel Consumption in Brazil: Applying Static and Dynamic Systems of Demand Equations. **Energy Policy.** 37 (December): 5326-5333.

Irawan, Silvia and Heikens, Alex. 2012. **Case Study Report: Thailand Energy Conservation Fund.** A UNDP Working Paper. New York: United Nations Development Programme (UNDP).

Janthanee Homchuen. 2006. **Analysis of Impacts of Gasohol Substitution for Unleaded Gasoline on Consumer Welfare.** Master Degree, Chulalongkorn University.

Jirath Chenphuengpawn. 2011. **Dead-Weight Loss of Alternative Energy Pricing Policy: A Case of High Speed Diesel (B0, B2, B3) and Biodiesel B5.** Master Degree, School of Development Econnomics, National Institute of Development Administration.

Johnson, Stanley R.; Hassan, Zuhair A. and Green, Richard Dale. 1984. **Demand Systems Estimation: Methods and Applications.** Iowa: Iowa State University Press.

Jorgenson, Dale W.; Slesnick, Daniel T. and Stoker, Thomas M. 1988. Two-Stage Budgeting and Exact Aggregation. **Journal of Business & Economic Statistics.** 6 (July): 313-325.

Kayser, Hilke A. 2000. Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information. **Energy Economics.** 22 (June): 331-348.

Kim, Won-Nyon. 1984. **A System-Wide Approach to Demand Analysis for Rental Housing Characteristics in Honolulu SMSA and Effects of Demographic Variables on Housing Characteristics.** Doctoral Degree University of Hawaii.

Koizumi, Tatsuji and Ohga, Keiji. 2007. Biofuels Policies in Asian Countries: Impact of the Expanded Biofuels Programs on World Agricultural Markets. **Journal of Agricultural & Food Industrial Organization.** 5 (December): 1-20.

Labandeira, Xavier; Labeaga, Jose M. and Rodríguez, Miguel. 2006. A Residential Energy Demand System for Spain. **The Energy Journal.** 27 (2): 87-112.

Leser, C. E. V. 1963. Forms of Engel Functions. **Econometrica.** 31 (October): 694-703.

Liao, Huei-Chu and Lee, Yi-Huey. 2009. **Chinese Gasoline and Diesel Demand.** 32nd IAEE International Conference. San Francisco, California, US: United States Association for Energy Economics. 1-15.

Manaloor, Varghese Abraham. 1995. **Food Demand and Policy Analysis for Lesotho : An Application of the Almost Ideal Demand System.** Doctoral Degree, University of Saskatchewan.

Mehrara, Mohsen and Ahmadi, Saeedeh. 2011. The Estimation of the Automotive Fuel Demand in Iran: Almost Ideal Demand System Approach. **Australian Journal of Business and Management Research.** 1 (October): 72-77.

Moschini, Giancarlo. 1995. Units of Measurement and the Stone Index in Demand System Estimation. **American Journal of Agricultural Economics.** 77 (February): 63-68.

Nawata, Kazumitsu. 1993. A Note on the Estimation of Models with Sample-Selection Biases. **Economics Letters.** 42 (1): 15-24.

Nguyen, Thu Lan T. and Gheewala, Shabbir H. 2008. Fuel Ethanol from Cane Molasses in Thailand: Environmental and Cost Performance. **Energy Policy.** 36 (May): 1589–1599.

Nguyen, Thu Lan Thi; Gheewala, Shabbir H. and Garivait, Savitri. 2007. Energy Balance and GHG-Abatement Cost of Cassava Utilization for Fuel Ethanol in Thailand. **Energy Policy.** 35 (September): 4585–4596.

Nicol, C.J. 2003. Elasticities of Demand for Gasoline in Canada and the United State. **Energy Economics.** 25 (March): 201–214.

Niklitschek, Mario E. 1985. **Exact Welfare Measurement: Theory and Application to Recreation Economics.** Master Degree, Oregon State University.

Oladosu, Gbadebo. 2003. An Almost Ideal Demand System Model of Household Vehicle Fuel Expenditure Allocation in the United States. **Energy Journal.** 24 (January): 1-21.

Park, John L.; Holcomb, Rodney B.; Raper, Kellie Curry and Oral Capps, Jr. 1996. A Demand Systems Analysis of Food Commodities by U.S. Households Segmented by Income. **American Journal of Agricultural Economics.** 78 (May): 290-300.

Pindyck, Robert S. and Rubinfeld, Daniel L. 1992. **Microeconomics.** 2nd edition. New York: Macmillan.

Pollak, Robert A. and Wales, Terence J. 1981. Demographic Variables in Demand Analysis. **Econometrica.** 49 (November): 1533-1551.

Pomthong Malakul; Seksan Papong; Tassaneewan Chom-In and Soottiwan Noksa-nga. 2011. Life-Cycle Energy and Environmental Analysis of Biofuels Production in Thailand. **Kasetsart Engineering Journal.** 24 (January-March): 25-40.

Praipol Koomsup; Puree Sirasoontorn and Napon Suksai. 2012. **The Study on the Restructuring of the Oil Fuel Price.** Working Paper. Bangkok: Energy Policy and Planning Office, Ministry of Energy. (In Thai)

Rajagopal, Deepak and Zilberman, David. 2008. The Use of Environmental Life-Cycle Analysis for Evaluating Biofuels. **Agricultural and Resource Economics Update.** 11 (January-February): 5-8.

Romero-Jordán, Desiderio; del Río, Pablo; Jorge-García, Marta and Burguillo, Mercedes. 2010. Price and Income Elasticities of Demand for Passenger Transport Fuels in Spain. Implications for Public Policies. **Energy Policy.** 38 (August): 3898-3909.

Samuelson, Paul A. 1942. Constancy of the Marginal Utility of Income. In **Studies in Mathematical Economics and Econometrics: In Memory of Henry Schultz.** O. R. Lange, F. McIntyre and T. O. Yntema. Chicago: University of Chicago Press. 75–91.

Seksan Papong; Tassaneewan Chom-In; Soottiwan Noksa-nga and Pomthong Malakul. 2010. Life Cycle Energy Efficiency and Potentials of Biodiesel Production from Palm Oil in Thailand. **Energy Policy.** 38 (January): 226-233.

Shittu, A.M.; Idowu, A.O.; Otunaiya, A.O. and Ismail, A.K. 2004. Demand for Energy among Households in Ijebu Division, Ogun State, Nigeria. **Agrekon.** 43 (March): 38-51.

Shonkwiler, J. Scott and Yen, Steven T. 1999. Two-Step Estimation of a Censored System of Equations. **American Journal of Agricultural Economics.** 81 (November): 972-982.

Slavík, Michal. 2004. Demand for Fuel and its Consequences for Indirect Taxation: A Microeconomic View. **Czech Journal of Economics and Finance.** 54 (5-6): 202-233.

Stone, Richard. 1954. Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand. **The Economic Journal.** 64 (September): 511-527.

Strotz, Robert H. 1957. The Empirical Implications of a Utility Tree. **Econometrica.** 25 (April): 269-280.

Suharno, vorgelegt von. 2010. **An Almost Ideal Demand System for Food based on Cross Section Data: Rural and Urban East Java.** Doctoral Degree, Georg-August University Göttingen.

Suthamma Yoosin and Chumnong Sorapipatana. 2007. A Study of Ethanol Production Cost for Gasoline Substitution in Thailand and Its Competitiveness. **Thammasat International Journal of Science and Technology.** 12 (January-March): 69-80.

Suthin Wianwiwat. 2011. **A Computable General Equilibrium Analysis of Biofuel Promotion Policy in Thailand.** Doctoral Degree, The University of Queensland.

Suthiporn Chirapanda; Sudarat Techasriprasert; Somjate Pratummin; Samai Jain and Prapon Wongtarua. 2009. **Status and Potential for the Development of Biofuels and Rural Renewable Energy: Thailand.** Mandaluyong City, Philippines: Asian Development Bank.

Taljaard, Pieter R. 2003. **Econometric Estimation of the Demand for Meat in South Africa.** Master Degree, University of the Free State.

Theil, Henri. 1965. The Information Approach to Demand Analysis. **Econometrica.** 33 (January): 67-87.

Thiraphong Vikitset. 2008. **An Alternative Retail Pricing Policy for Petroleum Products: A Case Study of Gasoline and High Speed Diesel in Thailand.** A Research Report, School of Development Economics, National Institute of Development Administration.

Tiezzi, Silvia. 2005. The Welfare Effects and the Distributive Impact of Carbon Taxation on Italian Households. **Energy Policy.** 33 (August): 1597–1612.

Tisdell, Clem. 2009. **The Production of Biofuels: Welfare and Environmental Consequences for Asia.** Working Paper No. 159. Queensland: University of Queensland.

Wadud, Md Abdul. 2006. An Analysis of Meat Demand in Bangladesh Using the Almost Ideal Demand System. **The Empirical Economics Letters.** 5 (January): 29-35.

Wadud, Zia; Graham, Daniel J. and Noland, Robert B. 2010. Gasoline Demand with Heterogeneity in Household Responses. **The Energy Journal.** 31 (January): 47-74.

Wanida Norasethasopon. 2010. Effect of Gasohol Production on the Sugarcane Industry in Thailand. **Journal of Asia Pacific Studies.** 1 (May): 101-131.

Wohl, Jennifer Bard. 1992. **A Regional Analysis of the Effects of Food Subsidy Policies on Household Consumption Patterns in Morocco.** Master Degree, Michigan State University.

Working, Holbrook. 1943. Statistical Laws of Family Expenditure. **Journal of the American Statistical Association.** 38 (March): 43-56.

Zellner, Arnold. 1962. An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. **Journal of the American Statistical Association.** 57 (June): 348-368.

Zhang, Xu. 2010. **Analysis of Value Added Meat Product Choice Behaviour by Canadian Households.** Master Degree, University of Alberta.

APPENDIX

Table 1 Probit Estimates of the Decision to Purchase the Vehicle Fuels of Thailand Households

Variable	Gasoline	Gasohol	Diesel	LPG
Natural log of expenditures for	-0.283708***	0.120682***	0.868054***	0.239781***
car petrol per month (ln)	(0.007557)	(0.007101)	(0.007702)	(0.018430)
Male head of household	-0.076622***	-0.043457***	0.234296***	0.028158
	(0.011219)	(0.011277)	(0.010586)	(0.029533)
Age of household head	-0.009333***	0.000989	0.010834***	0.008826
	(0.002400)	(0.002381)	(0.002389)	(0.006632)
Square age of household head	0.000083***	-0.000004	-0.000108***	-0.000063
	(0.000025)	(0.000024)	(0.000024)	(0.000067)
Household size	0.079445***	-0.055519***	-0.094081***	-0.039013***
	(0.005109)	(0.005033)	(0.004461)	(0.012481)
Number of earners	-0.018207**	0.036070***	-0.075285***	-0.033894*
	(0.007649)	(0.007483)	(0.006445)	(0.019138)
Dummy for the presence of	-0.001828	-0.008114	0.132587***	0.049656
children < 5 years (no child=0)	(0.014288)	(0.014241)	(0.011977)	(0.036094)

Table 1 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Dummy for the presence of elder	-0.031348*	0.025539	0.076654***	0.011147
> 65 years (no elder =0)	(0.017260)	(0.017025)	(0.015239)	(0.041607)
Dummy for municipal areas(non-	-0.120876***	0.222397***	-0.047949***	0.093344***
municipal areas=0)	(0.011320)	(0.011663)	(0.009602)	(0.031820)
Status of household head				
Economically inactive (base)				
Worker	0.007154	-0.181962***	0.364859***	-0.061251
	(0.019378)	(0.019569)	(0.018487)	(0.052916)
Employee	0.162694***	-0.089837***	-0.062142***	-0.077618
	(0.019911)	(0.019922)	(0.019358)	(0.050204)
Employer	-0.049844**	-0.164431***	0.396232***	-0.250566***
	(0.024010)	(0.024515)	(0.022537)	(0.062370)

Table 1 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Education of head				
Primary education or lower (base)				
Secondary or higher education	-0.120021***	0.192200***	0.001141	0.186258***
	(0.013077)	(0.013353)	(0.011832)	(0.035082)
University or higher education	-0.144592***	0.309648***	-0.274543***	0.331591***
	(0.017076)	(0.016922)	(0.016923)	(0.040441)
Total household monthly				
Expenditure category				
Less than 5,000 (base)				
5,000-8,999	-0.195041***	0.123602***	0.177828***	0.519057***
	(0.020713)	(0.021583)	(0.020375)	(0.187064)
9,000-12,999	-0.387149***	0.240373***	0.344833***	0.706788***
	(0.021784)	(0.022627)	(0.021073)	(0.185343)

Table 1 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
13,000-19,999	-0.591995***	0.332703***	0.539247***	0.897694***
	(0.022546)	(0.023219)	(0.021871)	(0.184932)
Over 20,000	-0.731376***	0.481174***	0.479906***	1.078779***
	(0.024792)	(0.024722)	(0.023852)	(0.186220)
Number of Vehicles owned				
1 (base)				
2	0.616066***	-0.014873	0.626266***	0.036546
	(0.013355)	(0.012907)	(0.012008)	(0.036605)
3	0.893301***	-0.010288	0.888072***	0.096912**
	(0.018497)	(0.016341)	(0.014215)	(0.041261)
4	1.057269***	0.039584*	1.050140***	0.166952***
	(0.027121)	(0.022221)	(0.019570)	(0.049826)
More than 4	1.116849***	0.097472***	1.155832***	0.218527***
	(0.035263)	(0.028494)	(0.027106)	(0.060917)

Table 1 (Continued)

Variable	Gasoline	Gasohol	Diesel	LPG
Constant	3.429087***	-2.531267***	-7.654053***	-5.351514***
	(0.072718)	(0.071152)	(0.075370)	(0.249287)
Chi-squared	7780	5810	35400	1460
Pseudo-R-squared	0.121954	0.077512	0.376724	0.149889
Log likelihood	-39800	-38000	-52100	-5110
Number of Observations	142445	142445	142445	142445

Note: *, **, *** Estimates are significant at the 10%, 5% and 1% level, respectively.
Numbers in parentheses are standard errors.

BIOGRAPHY

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