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The Social Cost of Thailand's Transportation Fuel Pricing Policy

by

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Abstract

The price structure of Thailand's transportation fuels has always been heavily distorted by the government. The prices of diesel and biofuels are consistently subsidized, while the prices of other fuels are raised above their competitive level in order to provide cross-subsidies to diesel and biofuels. Price distortion in this fashion leads to over-/under-consumption of transportation fuels relative to the socially optimal level. This study estimates the economic and social cost of the price distortions within Thailand's transportation fuel market that stem from inefficient price structure and cross subsidies.

1 Introduction

Thailand's transportation sector depends heavily on the imported petroleum products, and thus is highly vulnerable to the fluctuations in the world's crude oil price. In response to this vulnerability, the Thai government has made consistent efforts to stabilize the price and relieving consumers' burden from the increased in transportation cost, as well as to promote the use of domestically-produced biofuels to replace imported oil. These two major economic

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and political priorities were achieved mainly by creating distortions in the price structure of Thailand's petroleum products. "Distortions" in this context refers to the deviations of the retail from the social costs (private costs of importing and refining, plus the external cost of pollution, accidents, security, congestion, and so on). These distortions are mainly in the form of excessive taxes on some products and implicit/explicit subsidies on other products.

Generally, the government utilizes the petroleum excise taxes and the oil fund as the main tools to manipulate the price structure. To achieve the first objective of alleviating consumers' burden during the last episode of the crude price hike between 2011 and 2014, the government used a combination of excise tax cut and higher oil fund subsidy to cap the price of diesel at around 30 THB per liter. To achieve the second objective of encouraging automobile users to switch from the regular unleaded gasoline to the ethanol-blended gasoline (gasohol), the government collected high excise tax and oil fund fee from the regular unleaded gasoline users; this tax revenue went to subsidizing the price of gasohol as a cross subsidy.

Although existing price distortions through taxes and subsidies are created to fulfill important policy objectives, they come at the costs of increasing economic inefficiencies and fiscal constraints. Price distortions induce over-consumption of some fuels and under-consumption for other fuels. These over- and under-consumption means that the marginal cost does not equate the marginal benefit for the last unit of consumption, leading to the deadweight loss (i.e. economic inefficiency) in the respective market. The size of the deadweight loss should be of tremendous interest to policy makers since if defines the cost-effectiveness of the price instrument. If the efficiency cost is large, using price instrument in this manner should be avoided since it is a costly way to achieve policy objectives. Indeed, many prior studies indicate that the economic cost of fuel subsidies might outweighs its benefit to energy consumers (International Institute for Sustainable Development, 2013; Davis, 2013)

Apart from creating the deadweight loss, price distortions created by taxes and subsidies may impose constraints on the government's budget. The fiscal constraints would be especially important if the subsidy expense in the gasoline market exceeds the tax revenue collected. The constraint will trigger the need to raise taxes in other markets or restrict public expenditure on development priorities such as education, health, and infrastructure.

Over the past few years, the Thai government has had limited success in reforming the petroleum price structure until the crude oil prices crashed in 2015. The oil price crash eased the subsidy burden, allowed the government to adjust tax rates to the appropriate level, and eliminated most of the unnecessary subsidies (except for LPG). It remains to be seen if Thailand will be able to secure these gains and take steps to prevent subsidies from returning once world oil prices rise in the future.

This study analyzes the economic impacts of the recent price distortions that exist in Thailand's petroleum markets between 2011 and 2015 and address three main questions. First, how much are the economic costs associated with these distortions? Second, how much do these taxes and subsidies affect the government's fiscal constraints and its ability to finance other public projects? Third, what could be the alternative policies that can achieve the same objectives with minimal impacts on economic efficiency and government's budget?

The study considers two types of price distortions. First, the *within-market* distortion, which occurs when each petroleum product is either priced above or below its social cost. Second, the *cross-market* distortion, which is the spillover of distortions to the related markets due to the ability of consumers to substitute across various products. To quantify the economic inefficiency, we first estimate price elasticity of demand, which captures the own- and cross-price substitution patterns between various types of petroleum products. We then construct the efficient price structure that reflects both the private cost (the cost of the petroleum import and refining) and the social cost (cost of global and local pollutants, the cost of congestion, and the cost of accidents) of each petroleum product. Using the estimated price elasticity, we simulate the efficient consumption level under the efficient pricing scheme. Lastly, we use the simulated consumption to calculate the deadweight loss associated with over- or under-consumption of each petroleum product under the status quo price structure.

The paper proceeds as follows. Section 2 reviews prior studies on gasoline demand and pricing policies. Section 3 explain the empirical methodology used to estimate price elasticity of demand and calculate the deadweight loss. Section 4 lists data sources and provides important summary statistics. Section 5 reports the estimation results for price elasticity, the simulated quantity under efficient pricing, and the associated deadweight loss in each market. Section 6 recommends alternative pricing policies that achieve the government's objectives with lower economics cost. Lastly, Section 7 concludes.

2 Literature Review

This section reviews prior studies related to each step of our methodology: estimating the price elasticity of gasoline demand, setting the efficient price, and calculating the deadweight loss from fuel price distortions.

There exists a number of studies that estimate price elasticity of demand for petroleum products. These prior studies use a variety of estimation methods, which results in seemingly large differences in findings. The first main approach to estimating price elasticity of demand is multiple regression analysis for each petroleum product. The first drawback from this multiple regression approach is that it assumes uncorrelated error terms between the demand of different petroleum products. If there are common unobserved shocks that affect demand or substitution between petroleum products, the estimated coefficients might not be efficient. The second drawback from this approach is that it only captures a reduced-form relationship between the price and quantity of petroleum products, which does not necessarily reflect the causal impact of price change on consumption behavior.

A more preferred approach to estimate demand elasticity is an Almost Ideal Demand System (AIDS) proposed by Deaton and Muellbauer (1980). We argue that the Almost Ideal Demand System in expenditure function form is a better choice to model consumer's demand for gasoline. Since the AIDS model is derived from the consumer utility maximization problem, it captures the structural relationship between product price and optimal consumption.

Furthermore, since the AIDS model estimates a complete demand system, it can account for the cross-equation correlations and produce more efficient estimates.

In Thailand's context Koomsup et al. (2014) estimate the demand elasticity of four petroleum products using both the multiple regression analyses and the AIDS model. The authors find the own-price elasticity estimates from the multiple regression analyses to have wrong direction and not statistically different from zero. Nonetheless, their AIDS estimation produces sensible estimates of the own-price elasticity that range from -0.5 to -1.2.

With respect to the efficient price structure, all of the prior studies suggest that the efficient pricing should at least account for the social cost of air pollution (Davis, 2013; Lin and Prince, 2009; Coady et al., 2015; Whitley and Burg, 2015; Kansuntisukmongkol and Tangkitvanich, 2007). The inclusion of other external costs such as accident, congestion, or scarcity costs depends on the definition in each study. Indeed, Parry et al. (2014) provides a comprehensive quantification of the social cost of carbon, local air pollutants (SO_2, NO_x), congestion, and accidents. Following Davis (2013), we make use of information provided in Parry et al. (2014) and define our efficient pricing to consist of the private cost and the social cost of carbon, local pollutants, accident, and congestion. We decide to include the social cost of accident and congestion since neither of the external costs is reflected elsewhere in the Thailand's transportation sector. We decide to exclude the scarcity cost from the analysis because there does not exist a credible measure of the external cost of petroleum scarcity for Thailand. In fact, a few studies point out that ignoring the scarcity issue in the carbon policy design will lead to sub-optimal outcomes, and thus efficient pricing should contain the social cost from fuels shortage (Germain-mertens and Pessleux, 2013; Joëts, 2015).[1] Thus, we interpret our results with this caveat in mind.

Davis (2013) proposes a simple framework measures the effect of global fuel subsidies for gasoline and diesel. The study assumes a constant elasticity of demand and a perfectly elastic supply for each fuel in each country. From assumptions about supply and demand

[1] To quantify scarcity cost, they use the assumption that fuel scarcity will increase the cost of transportation, resulting in high inflation rate and lower purchasing power.

elasticity, the author quantifies a relatively large economics cost from overconsumption as a result of the subsidies. In the context of Thailand, Chenphuengpawn (2012, 2014) quantifies the deadweight loss associated with cross-subsidies for biofuels using a similar approach as Davis (2013).

This paper offers several contributions to existing literature. First, the market for transportation fuels in Thailand offers a unique case study for the demand for gasoline. In contrast to most other countries where there are at most 3–4 options for transportation fuels, Thailand has seven types of transportation fuels for consumers to choose from: (i) Unleaded Regular Gasoline Octane 91 (ULG91R), (ii) Gasohol 91, (iii) Unleaded Regular Gasoline Octane 95 (ULG95R), (iv) Gasohol 95 E10, (v) Gasohol 95 E20, (vi) Gasohol 95 E85, and (vii) Diesel. The wide variety of gasoline types makes modeling substitution patterns more interesting. Furthermore, instead of letting the gasoline prices be determined by the market mechanism, the prices of all fuels have been set by the government (the National Energy Policy Committee, NEPC) to fulfill government's policy objectives. Therefore, in contrast to prices in other countries, transportation fuel prices in Thailand are largely exogenous and are not affected by domestic supply or demand.

Our second contribution is that we estimate substitution patterns and quantify economic inefficiencies in all major transportation fuel markets: Octane 91 (ULG91R, Gasohol 91), Octane 95 (ULG95R, Gasohol 95 E10, Gasohol 95 E20, Gasohol 95 E85), and Diesel. In particular, since 2011 was the year when the markets for Gasohol E20 and E85 really took off, the data allows us to estimate demand for ethanol-blended gasoline versus all other alternatives.

Lastly, while existing studies of gasoline demand in Thailand use data prior to 2011, we use more recent data to provide the updated elasticity estimates that more accurately reflect the recent change in technology, preference, and policies in Thailand.

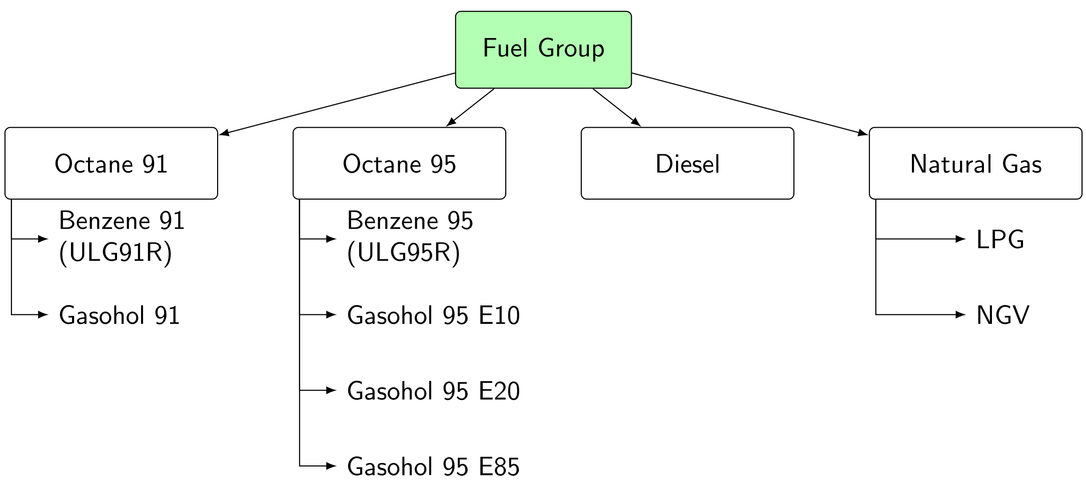
3 Empirical Strategy

This section describes the empirical strategies we use to estimate the price elasticity of demand, construct efficient price structure, and calculate the deadweight loss from the status quo price structure.

3.1 Estimating demand elasticity

To estimate demand for each type of fuel, we adopt the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980). To minimize the number of parameters being estimated, we first group fuels into two levels. The *top level* defines the four fuel segment that are difficult to substitute since it require engine modification: Octane 91, Octane 95, Diesel, and Natural Gas. The *bottom level* lists specific fuel types. Specifically, the Octane 91 segment (top level) contains Benzene 91 (ULG91R) and Gasohol 91 at the bottom level. The Octane 95 segment contains Benzene 95 (ULG95R), Gasohol 95 E10, Gasohol 95 E20, and Gasohol 95 E85 at the bottom level. The Natural Gas segment contains Liquified Petroleum Gas (LPG) and Natural Gas for Vehicle (NGV) at the bottom level. Figure 1 displays this grouping.

Figure 1: Transportation fuel hierarchy



We decide not to estimate demand separately for ULG91R and Gasohol 91 due to the fact that ULG91R was discontinued in 2013. Thus, practically there is no bottom level estimation for the Octane 91 segment. Further, we exclude Natural Gas segment (LPG and NGV) from the estimation for several reasons. First, due to a short time period of the analysis, we have too few observations to estimate a 4-equation AIDS with precision. Second, the retail prices of LPG and NGV have been heavily regulated and hardly changed over the sample period. The lack of price variation in the data prevents us from reliably identifying consumers' price response.

Our estimation strategy follows the two-stage budgeting model for AIDS as used in Hausman et al. (1994). The first stage captures consumers' decision to allocate budget among the top level fuel segment. The second stage captures consumers' decision to allocate budget among the bottom level of fuels, conditional on the fixed group budget from the first stage.

For each bottom-level fuel within the top-level segment, we specify budget share as:

$$s_{it} = \alpha_i + \beta_i \ln(Y_{Gt}/\pi_{Gt}) + \sum_{k=1}^{J_G} \ln(p_{kt}) + \epsilon_{it}, \tag{1}$$

where i denotes specific fuel in the bottom category, G denotes the top-level fuel segment, t denotes time (monthly). s_{it} is the expenditure share of fuel i out of the total expenditure of segment G, Y_{Gt} is the total expenditure, π_{Gt} is the price index for the segment, and p_{kt} is the price of individual fuel in the bottom category. Segment-level price index takes the form of the Stone price index:

$$\ln(\pi_{Gt}) = \sum_{k=1}^{J_G} s_{kt} \ln(p_{kt}). \tag{2}$$

The budget share for the top-level fuels is modeled in a similar manner.

With the estimated parameters, we can calculate the uncompensated elasticity as

$$\epsilon_{ij} = -\delta_{ij} + \{\gamma_{ij} - \beta_i \frac{d \ln \pi}{d \ln p_j}\}/s_i, \tag{3}$$

where $\delta_{ij} = 1$ for $i = j$ and $\delta_{ij} = 0$ otherwise. Finally, for welfare analysis, we compute the compensated elasticity ϵ^*_{ij} as

$$\epsilon^*_{ij} = \epsilon_{ij} + s_j(1 + \frac{\beta_i}{s_i}). \quad (4)$$

3.2 Constructing efficient price structure

We define the efficient price as the sum of the private cost (cost of importing and refining) and the social cost. The social cost in this study includes the social cost of carbon, the social cost of local pollutants (SO_2 and NO_x), the social cost of congestion and accidents (details of the calculations is available upon request).

The social cost of carbon (in THB/liter) is calculated using carbon emission factor of each fuel stated in and the assumption of the social cost of carbon of $31.8 per ton (U.S. Environmental Protection Agency , EPA).

To calculate the social cost of local pollutants (SO_2 and NO_x, in THB/liter), we use local pollutants emission factor in 91, 95 and diesel group from Kansuntisukmongkol and Tangkitvanich (2007) study and in NGV, LPG group from The International Energy Agency (IEA). Also the assumption of the social cost of SO_2 of 2013 dollar/ton and the social cost of NO_x of 423 dollar/ton (Parry et al., 2014)

Accidents and congestion cost (in THB/liter) can be obtained by using the external cost per kilometer driven calculated in Parry et al. (2014) (external cost per kilometer is different in accidents and congestion cost). We also use average fuel efficiency of each types of fuel (kilometer per liter) from The Petroleum Institute of Thailand (PTIT).

3.3 Calculating deadweight loss from suboptimal pricing

To calculate the deadweight loss in the market of each fuel, we make two assumptions regarding the demand and supply. First, we assume a constant-elasticity demand following Davis (2013). Our fuel-specific demand is adapted from Davis (2013) to allow for substitutions between fuels within the same level. For example, we have three fuel segments at the top level, thus the demand for the first segment is specified as

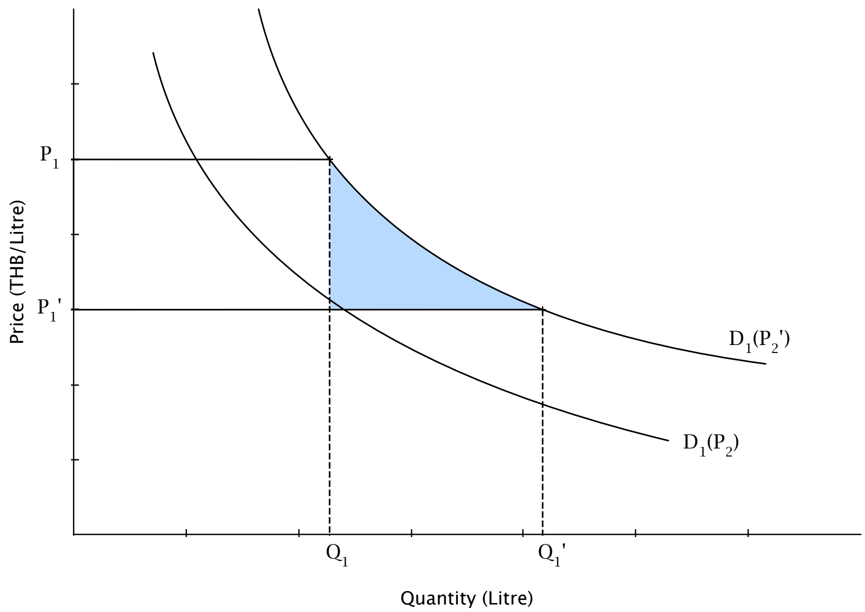
$$q_{1t} = A_{1t} p_1^{e_{11}} p_2^{e_{12}} p_3^{e_{13}}, \tag{5}$$

where q_{1t} is demand for the first segment at time t, A_{1t} is time- and segment-specific constant, p_i is the price for fuel in segment i, e_{ij} is the price elasticity of demand for segment $i$with respect to p_j. Second, we assume that supply for each fuel is perfectly elastic. This is a reasonable assumption given that Thailand import most of its transportation fuel to serve domestic demand.

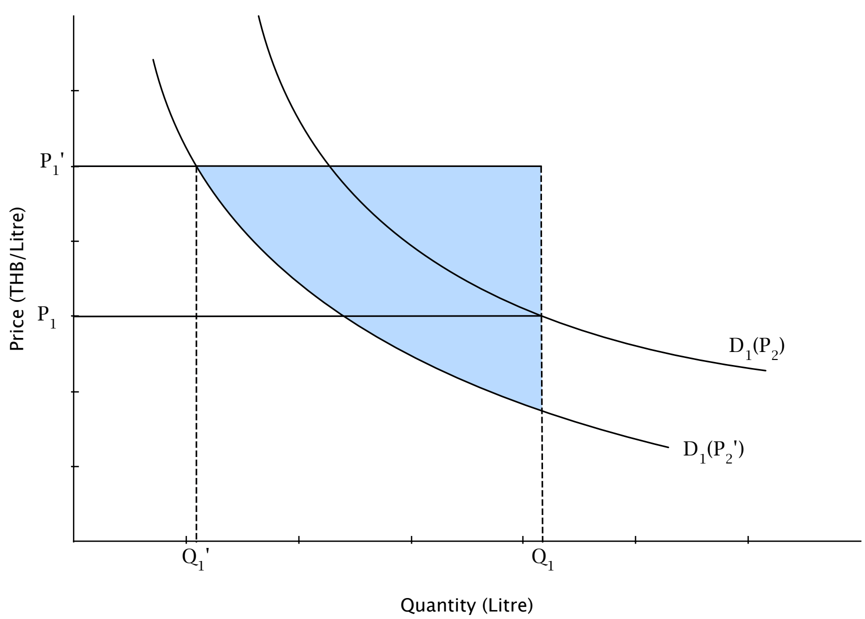
With a properly defined supply and demand, we next demonstrate how to calculate the deadweight loss. Figure 2 illustrates the impact of suboptimal price in each market. Let $D_1(P_2)$ denote the demand function of fuel 1 as a function of the price of fuel 2 (its substitute). Let P_1 be the status quo price and Q_1 be the status quo equilibrium quantity. Now suppose the government imposes efficient prices $P_1' < P_1$ and $P_2' > P_2$ as shown in figure 2a. Increasing price of fuel 2 to P_2' will shift demand for fuel 1 to the right since fuel 2 is a substitute for fuel 1. Denote this new demand curve as $D_1(P_2')$. Given the new demand, the efficient level of consumption becomes Q_1'. In this situation $Q_1' > Q_1$ means that the market *underconsumes* fuel 1 under the status quo pricing. For every unit between Q_1 and Q_1', the marginal benefit (willingness to pay) exceeds the marginal cost (P_1'). Thus, the deadweight loss in this case is the shaded area under the demand curve and above P_1'.

In another scenario, shown in figure 2b the efficient prices are $P_1' > P_1, P_2' < P_2$. In this case, the demand for fuel 1 shift to the left because the price of fuel 2 decreased. Equilibrium quantity under the efficient price is $Q_1' < Q_1$, which means the market *overconsumes* fuel 1 under the status quo pricing. The deadweight loss in this case is the shaded area under P_1' and above the new demand curve $D_1(P_2')$.

FIGURE 2: Deadweight loss calculation



(A) Deadweight loss in the case of underconsumption



(B) Deadweight loss in the case of overconsumption

Mathematically, we calculate the deadweight loss in each market as:

$$DWL = \left| \int_{Q_i}^{Q'_i} D(q)\, dq - P'_i(Q'_i - Q_i) \right|. \tag{6}$$

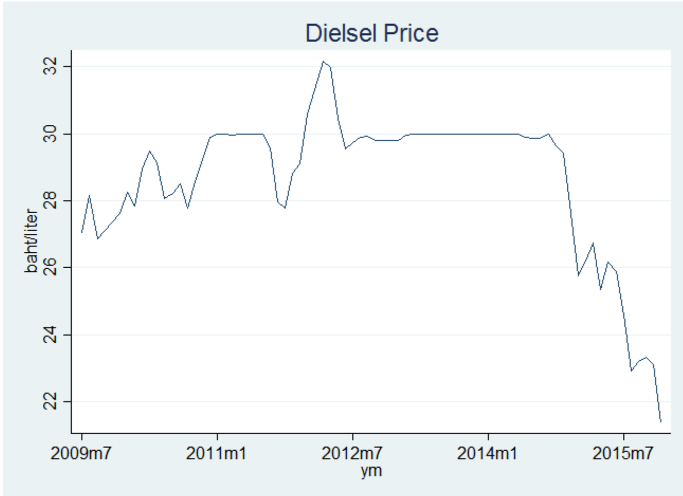
Note that, $\int_{Q_i}^{Q_i'} D(q)\,dq - P_i'(Q_i' - Q_i) > 0$ indicates underconsumption and $\int_{Q_i}^{Q_i'} D(q)\,dq - P_i'(Q_i' - Q_i) < 0$ indicates overconsumption. In general, and also in the case of Thailand, overconsumption is pervasive. It happens when there are negative externalities and the market participants do not bear the full social cost of their production and consumption decisions.

4 Data

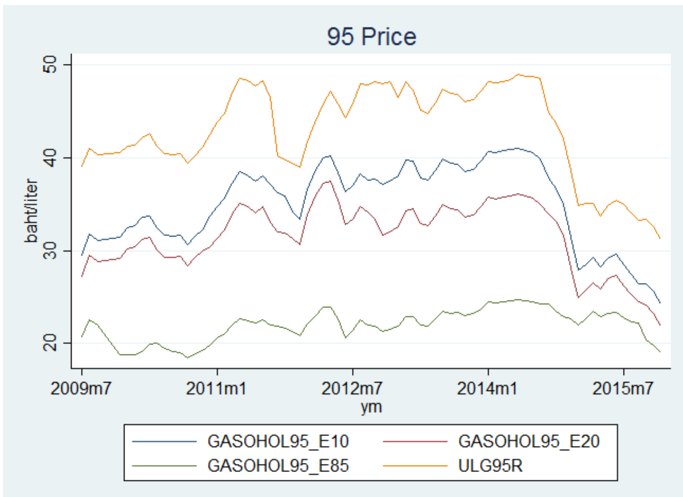
The monthly-level data on fuel price and consumption are provided by the Energy Policy and Planning Office (EPPO), Ministry of Energy. Additional data on the number of Gasohol 95 E20 and E85 were collected from the Department of Energy Business (DOEB), Ministry of Energy.

Figure 3 shows average price for all major fuels between 2011 and 2015. There are a few notable features of the pricing pattern. First, the price of Diesel has been highly stable and almost never exceed 30 THB/liter. Since Diesel accounts for the largest share of transportation fuel consumption, this price pattern reflects the government's priority to protect consumers from rising cost of crude oil. Second, among the Octane 95 and Octane 91, the price of gasohol are consistently lower than the price of their non-ethanol counterparts. Indeed, the more ethanol contents there is, the cheaper the retail price (i.e. Gasohol 95 E85 is cheaper than Gasohol 95 E20, which is cheaper than Gasohol 95 E10). This pattern reflects the government's priority to encourage consumers to switch to gasohol. The price data for ULG91R ends in 2013 due to the government's decision to discontinued the use of ULG91R after January 2013

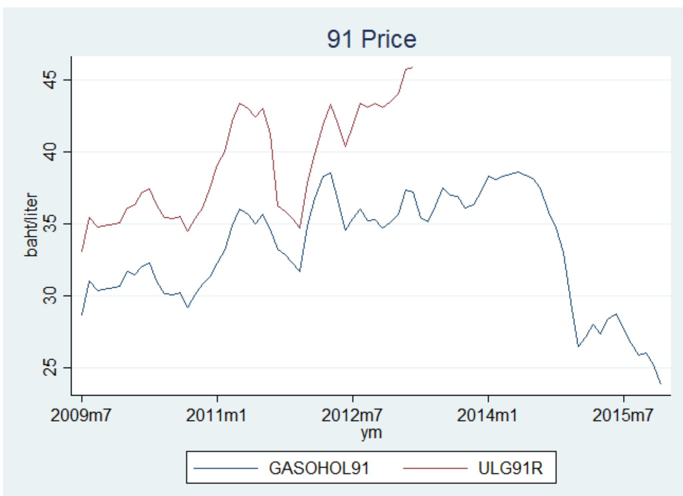
Figure 3: Average retail price



(a) Retail price of Diesel



(b) Retail price of Octane 95 group



(c) Retail price of Octane 91 group

Apart from the average retail price, the EPPO also collects detailed data on the price structure of each fuel. In other words, we know exactly what the retail price is consists of. Figure 4 shows the average price structure of each fuel between 2011 and 2015. It is apparent that all the fuels have similar post-refinery price, which captures the cost of importing and refining. However, the government imposes different level of tax and oil fund fee so that the final retail prices reflect the government's policy. Unleaded gasoline with no ethanol contents, ULG95R and ULG91R, were levied a high tax rate and oil fund fee. Ethanol-blended gasoline, on the other hand, were not subject to as much tax and fees. In fact, Gasohol 95 E20 and E85 even received subsidies from the oil fund to make them more attractive to consumers. Similar to ethanol-blended gasoline, Diesel was also subject to minimal tax and fees.

FIGURE 4: Status quo price structure, average 2011–2015

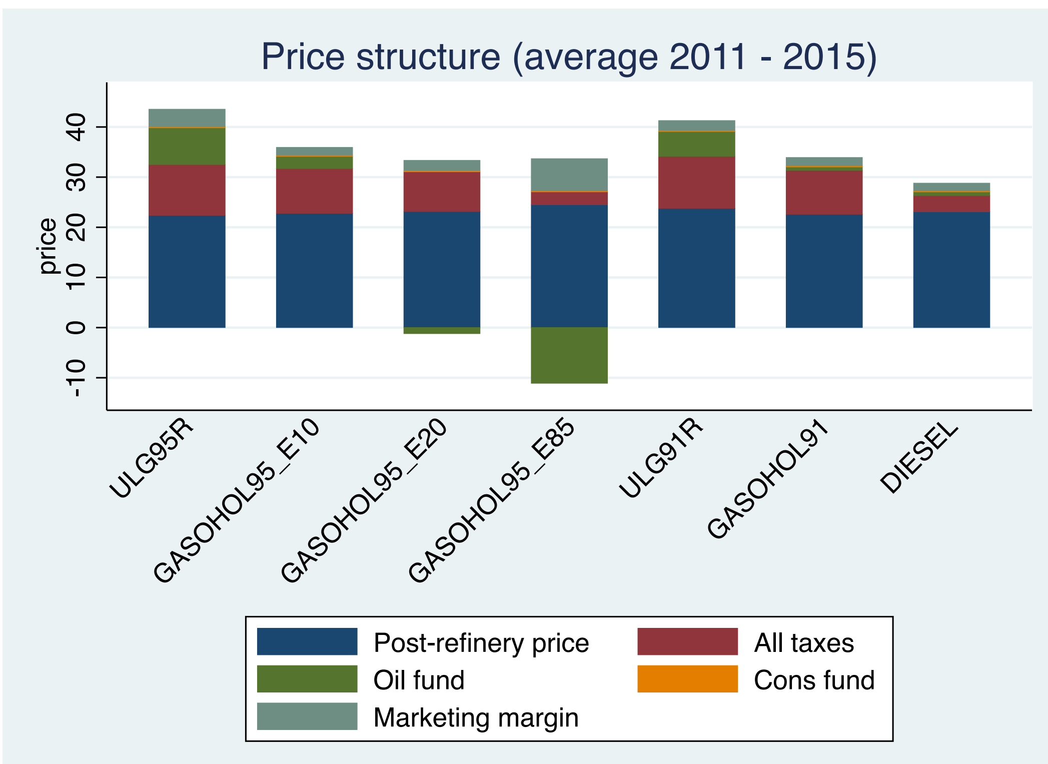
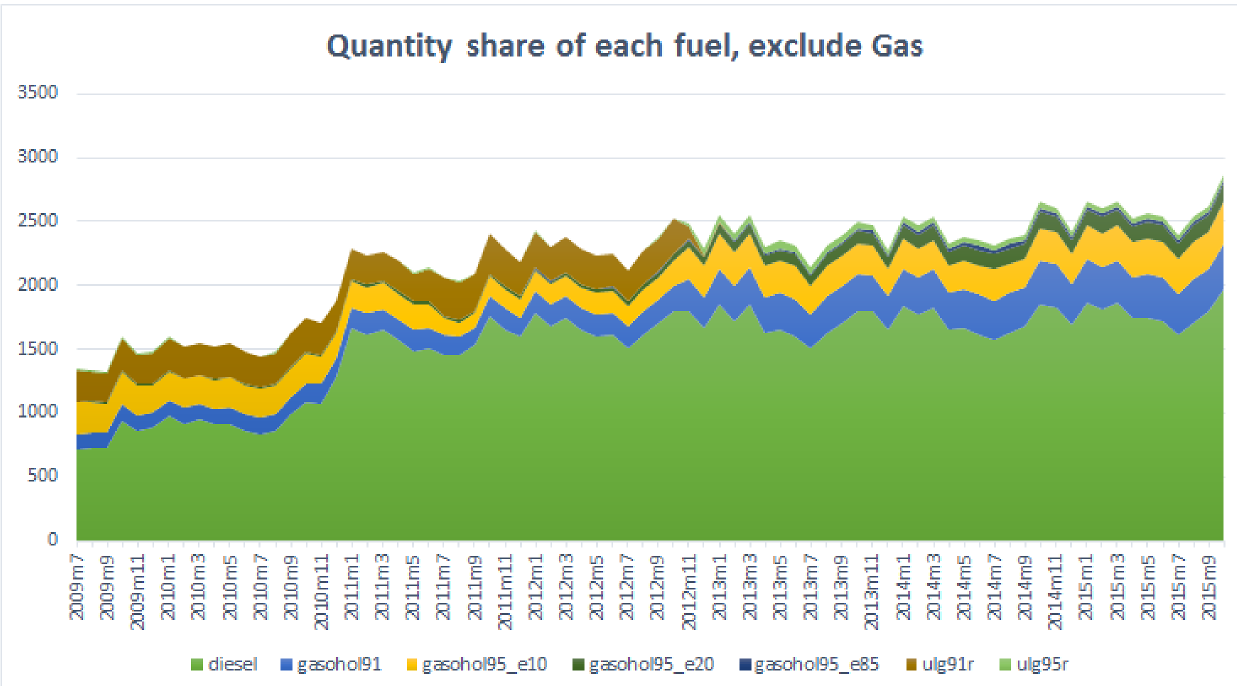


Figure 5 shows the consumption share of each type of fuel. As mentioned earlier, Diesel accounts for the largest portion of transportation fuel, followed by Octane 91 and Octane 95. The fact that diesel is widely used in manufacturing, logistic, and public transportation forces the government to put a price ceiling on this fuel.

A distinct drop in consumption of ULG91R in 2013 is due to the government's decision to discontinued the use of ULG91R after January 2013. Figure 5 indicates that consumers of ULG91R may have switched to Gasohol91, ULG95R, and Gasohol95 E10.[2]

FIGURE 5: Consumption of each fuel, 2011–2015



5 Results

5.1 Demand Elasticities

Table 1 reports the price elasticity of demand for Octane 95 gasoline group as estimated from the AIDS model. Note that we group Gasohol95 E20 and Gasohol95 E85 together because their individual expenditure share is too small for a reliable estimation. Own-price elasticities range from -1.6 (Gasohol95 E10) to -2.2 (ULG95R). The cross-price elasticities suggest that the Regular 95 are a close substitute to Gasohol 95 E10, but not to the E20/E85. Gasohol

[2]In fact, we also see a sharp increase in consumption of LPG and NGV during this period.

95 E10, on the other hand, are a closer substitute to E20/E85 than to Regular 95. Lastly, E20/E85 are a close substitute to Gasohol 95 E10, but not to the E20/E85.

Table 1: Price elasticity, Octane 95 group

Variable	P(Regular 95)	P(Gasohol95 E10)	P(Gasohol95 E20/E85)
Quantity Regular 95	-2.28***	2.88***	-0.60
	(0.44)	(0.80)	(0.57)
Quantity Gasohol95 E10	0.62***	-1.67***	1.05***
	(0.13)	(0.25)	(0.19)
Quantity Gasohol95 E20/E85	-0.30	2.43***	-2.13***
	(0.34)	(0.63)	(0.45)

These estimated substitution patterns are consistent with the combustion engine requirement for gasohol consumption. Since ethanol has a high erosion impact on regular combustion engines, a vehicle must be equipped with a special engine in order to operate on gasoline with high ethanol content (i.e. E20 and E85). Thus, a vehicle that operates on E85 can technically operates on all other Octane 95/91 gasoline with lower ethanol content. A vehicle that operates on Regular 95 gasoline has a capability to operate on Gasohol 95 E10 and vice versa. However, neither of them has a capability to operate on E20 or E85.

Next, table 2 reports the price elasticities of demand for the mid-level gasoline groups: Octane 95, Octane 91, and Diesel.

Table 2: Price elasticity, all gasoline

Variable	P(Octane 95)	P(Octane 91)	P(Diesel)
Quantity Octane 95	-1.08**	0.68	0.40**
	(0.54)	(0.50)	(0.20)
Quantity Octane 91	0.97*	-1.21**	0.25
	(0.53)	(0.51)	(0.22)
Quantity Diesel	0.12	0.05	-0.17**
	(0.17)	(0.16)	(0.08)

Table 2 shows that the own- and cross-price elasticities of demand for the mid-level gasoline group are much smaller than the elasticities within the Octane 95 group. This result is expected. The smaller elasticities stem from the fact that the mid-level gasoline groups are much harder to substitute due to the engine requirement. In particular, a benzene engine can operate on either Octane 91 or Octane 95, but absolutely cannot run on diesel. Similarly, a diesel engine can only run on diesel and not benzene. Thus, we observe larger own- and cross-price elasticities for Octane 95 and 91 group and much smaller own- and cross-price elasticity for diesel.

Overall, these estimated elasticities are relatively large compared to prior studies, as shown in table 3. We also note that these studies use data prior to 2013 and none of them estimates the elasticity of substitution between fuels within a segment (bottom-level). We attribute our large estimated elasticities to the rapid growth of the gasohol market between 2011 and 2015 as indicated by the number of service stations in figure 6. The availability of Gasohol E20/E85 stations throughout Thailand allow consumers to substitute between ULG91R, ULG95R, Gasohol 91 E10, Gasohol 95 E10, and E20/E85 much more easily.

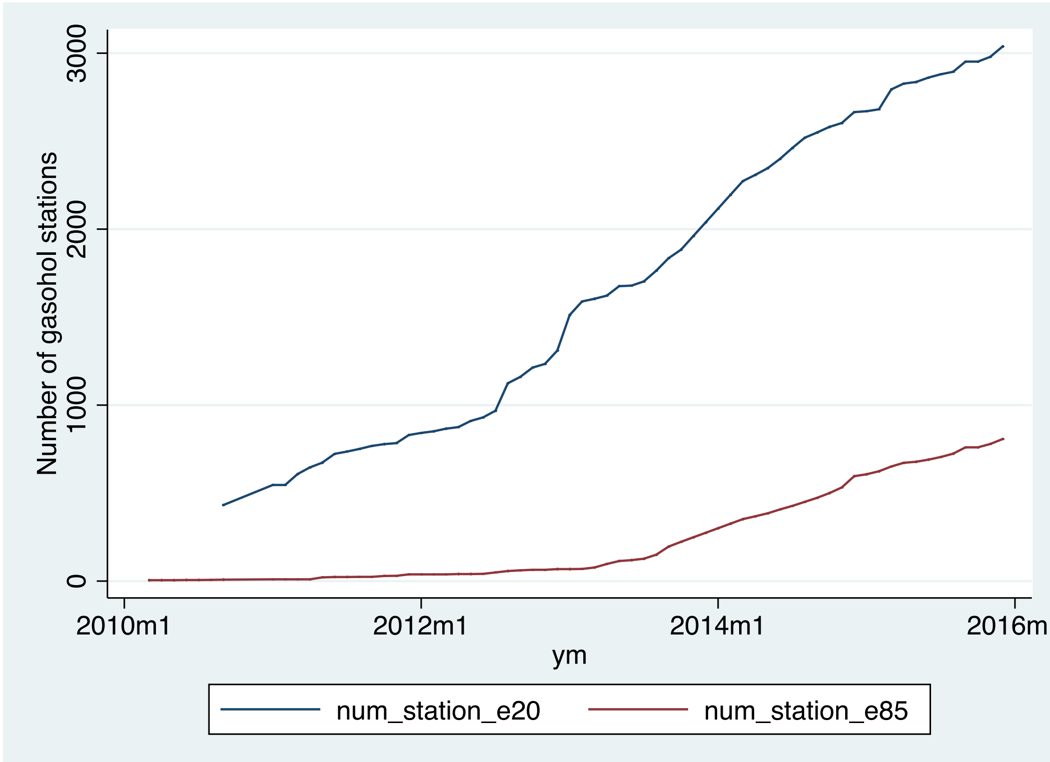
Table 3: Price elasticities of gasoline and diesel, selected studies

Study	Fuel Type	Own-price elasticity	Period
Koomsup et al. (2014)	Octane 91	-0.53	2002 - 2013
	Octane 95	-1.15	2002 - 2013
	Diesel	-0.68	2002 - 2013
Kansuntisukmonkol (2007)*	Benzene	-1.39	1993 - 2006
	Diesel	-1.07	1993 - 2006
Vikitset (2008)	Gasoline	-0.43	2002 - 2004
	Diesel	-0.35	2002 - 2004
Brons et al. (2008)	Gasoline	-0.34 (short-run)	various
	Gasoline	-0.84 (long-run)	various

* refers to Kansuntisukmongkol and Tangkitvanich (2007)

The finding that consumers are recently more responsive to price changes has an important policy implication: any policy that distorts the price structure will result in a larger deadweight loss then before. Thus, policy makers are advised to exercise a more careful judgement on whether price distortion shall be used as a tool to achieve a particular policy objective.

Figure 6: Number of gasohol E20 and E85 stations, 2010–2015



5.2 Welfare loss from suboptimal pricing

Efficient prices

We define the optimal (efficient) pricing as the prices that capture the private costs (importing and refining cost) and the social costs (cost of carbon, local pollutants, congestion, and accidents). Figure 7 and table 4 shows the average components of the efficient pricing structure between 2011 and 2015. Private costs account for 60 to 70 percent of the efficient pricing. Among the social costs, cost of accidents and congestion are the largest components, amounting to 9 THB per liter and 4.5 THB per liter, respectively. Together, the private and social costs lead to the efficient prices of more than 40 THB per liter for all gasoline types.

There are three interesting observations regarding the efficient price structure. First, Diesel has the highest external cost. Not only does Diesel generates the most CO_2 and local pollutants per liter, but it also has the highest congestion and accident costs per liter because of its highest heat content among all the fuels.

Figure 7: Efficient price structure, average 2011–2015

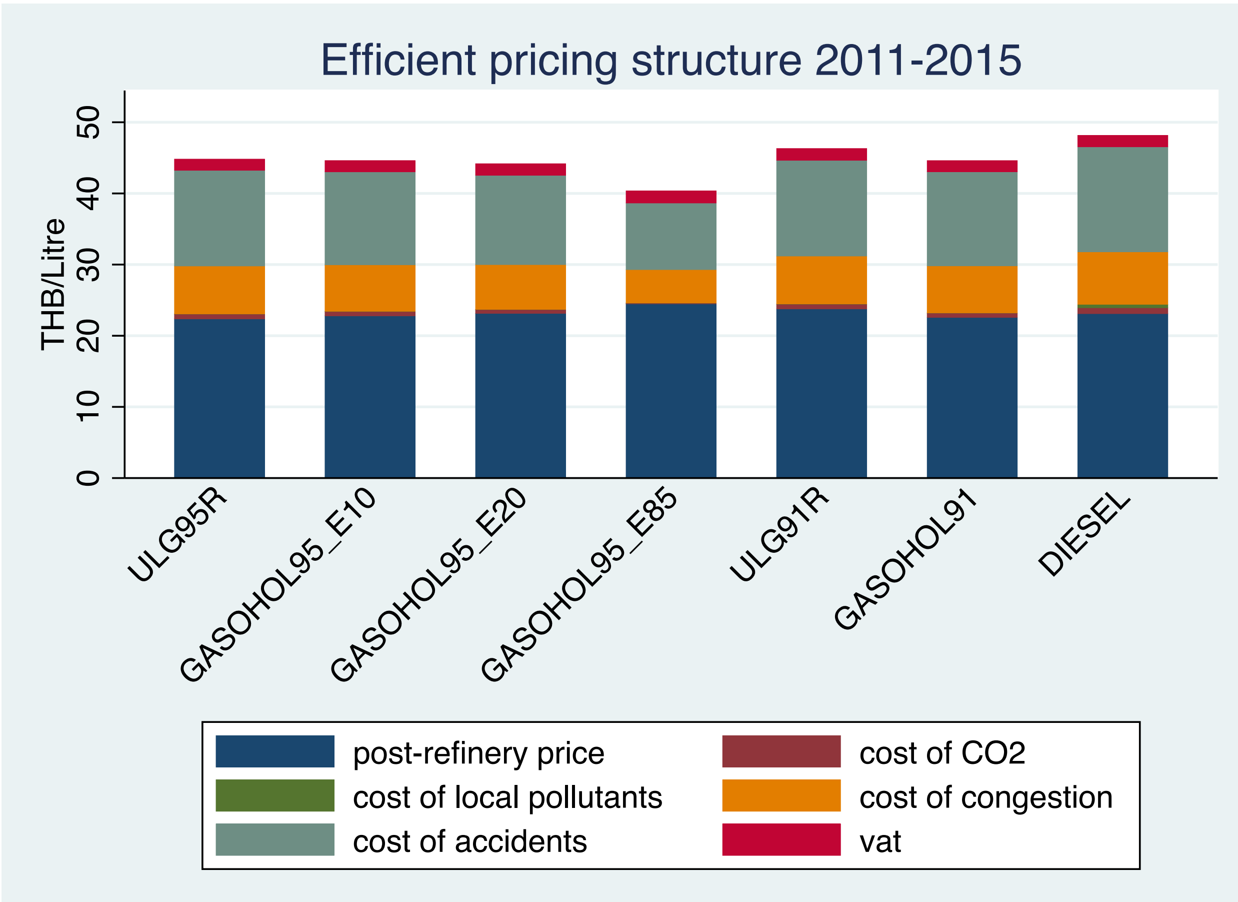


Table 4: Efficient price structure, average 2011 – 2015

Variable	Post-Refinery	CO_2	Local Pollutants	Congestion	Accidents
ULG95R	22.37	0.67	0.03	6.73	13.46
GASOHOL95 E10	22.80	0.60	0.03	6.53	13.06
GASOHOL95 E20	23.14	0.54	0.03	6.28	12.57
GASOHOL95 E85	24.48	0.10	0.03	4.68	9.36
ULG91R	23.77	0.67	0.03	6.73	13.46
GASOHOL91	22.57	0.60	0.03	6.61	13.22
DIESEL	23.10	0.83	0.48	7.38	14.76

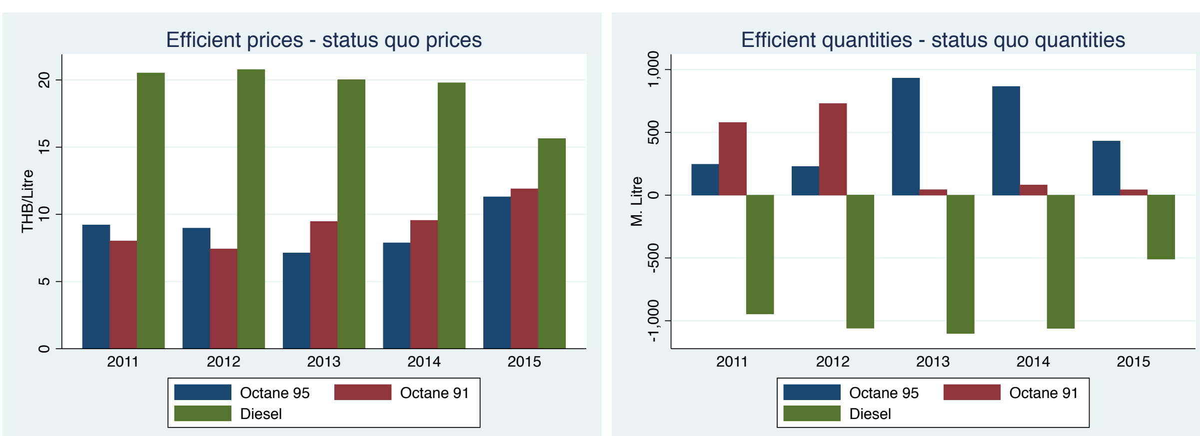
Second, benzene gasoline has higher carbon pollution cost than the ethanol-blended gasoline because ethanol is considered carbon neutral. "Carbon neutral" in this case comes from the logic that ethanol is produced from plant products (mostly molasses and sugar cane). These plants already absorbed carbon from the atmosphere. Thus, the release of carbon from ethanol combustion does not considered the net addition of atmospheric carbon.

Lastly, to the extent that ethanol-blended gasoline has an external benefit of relieving fuel scarcity, the efficient prices for ethanol-blended gasoline might be overstated.

Efficient consumption

We use the efficient prices shown in Figure 7, along with the estimated price elasticities, to calculate the efficient level of consumption for each gasoline. Figure 8 shows the difference between the efficient price and quantity relative to the status quo price and quantity for each of the mid-level gasoline group. This suggests that all three types of gasoline were priced below the efficient level with Diesel being the most underpriced. Switching to the efficient pricing scheme leads to an increased consumption of Octane 95 and Octane 91 and a significant reduction in Diesel consumption.

FIGURE 8: Difference between the efficient and the status quo, all gasoline group

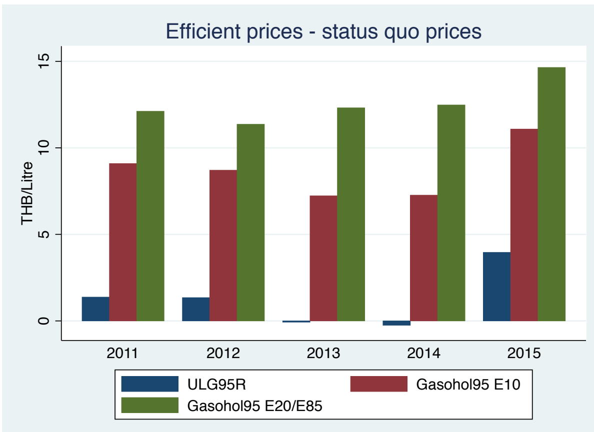


(A) Difference from the efficient prices

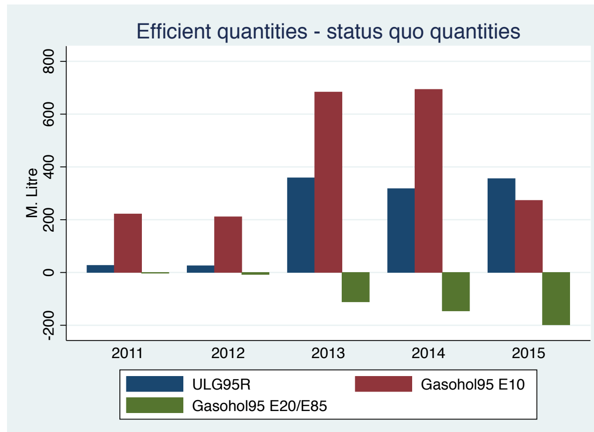
(B) Difference from the efficient quantities

We next discuss the efficient price and quantity for the Octane 95 level. Figure 9 shows that ULG95R is overpriced under the status quo, while Gasohol 95 E10 and Gasohol 95 E20/E85 are underpriced under the status quo. Switching to the efficient pricing leads to an increased consumption of ULG95R and Gasohol95 E10, and a decreased consumption of Gasohol 95 E20/E85.

FIGURE 9: Difference between the efficient and the status quo, Octane 95 group



(A) Difference from the efficient prices



(B) Difference from the efficient quantities

Deadweight loss

Having quantify the efficient prices and quantities, we calculate the deadweight loss from suboptimal pricing using the framework present in section 3. Table 5 reports the annual deadweight loss in each market. The total deadweight loss in the transportation fuel market amounts to 42.5 billion THB between 2011 and 2015. To put this number in perspective, the 5-year deadweight loss is about 1.2 percent of Thailand's GDP in the first quarter of 2016 and about 2 percent of total expenditure on final energy consumption in 2014.[3]

Among all the fuels being considered, the Diesel market incurred the highest efficiency loss between 2011 and 2015, followed by the markets for Octane 95 and Octane 91, respectively. The total deadweight loss for Diesel amounts to 19 billion THB, which is almost twice as

[3] GDP in the fist quarter of 2016 is estimated to be around 3,526.2 billion THB. Source `http://www.nesdb.go.th/ewt_dl_link.php?nid=5176` The estimated expenditure on final energy consumption in 2014 was around 2,280 billion THB. Source `http://www2.eppo.go.th/info/cd-2015/index.html`

large as the deadweight loss in the Octane 95 and Octane 91 markets combined. Within the Octane 95 market, the total deadweight loss is the largest in the Gasohol 95 E20/E85 market, follows by the ULG95R and Gasohol 95 E10 markets, respectively.

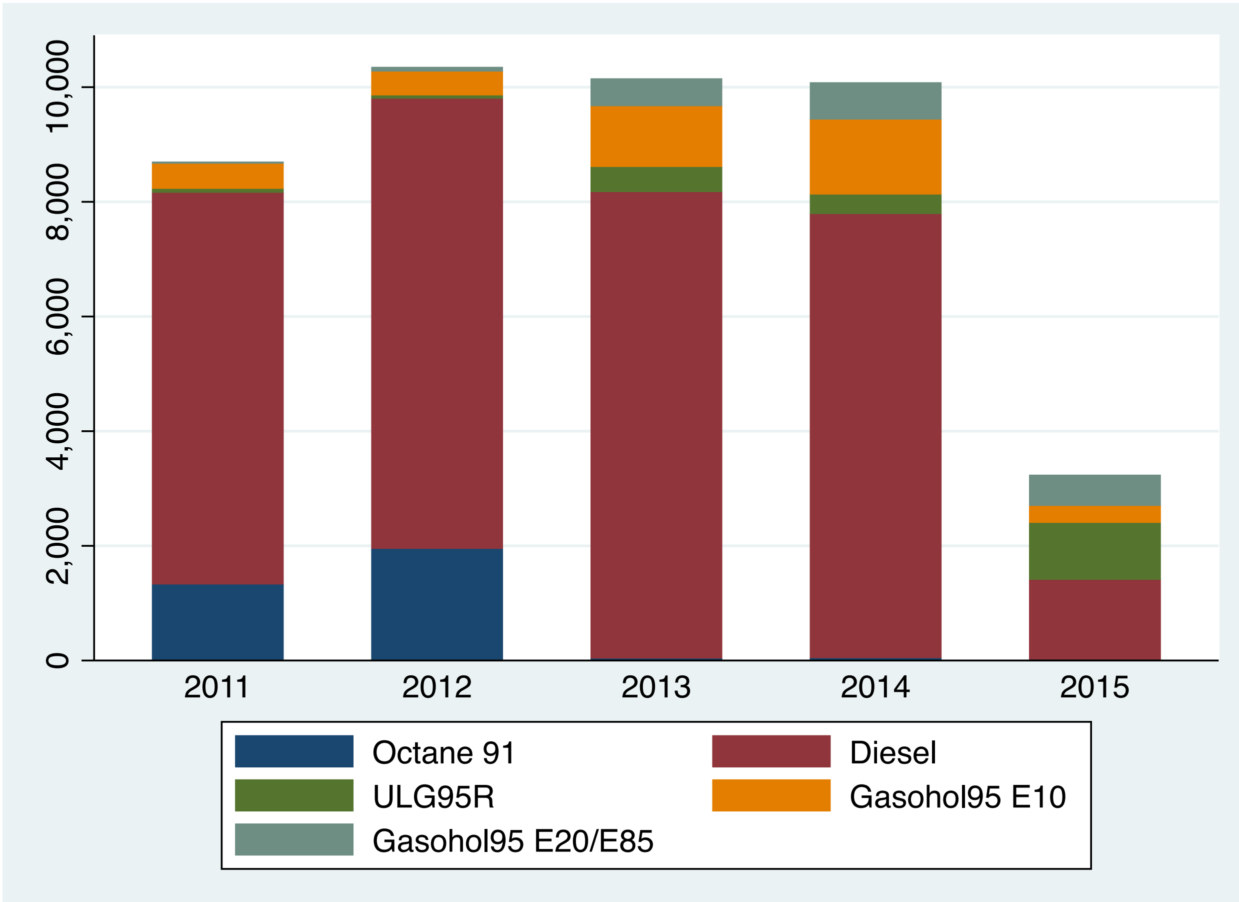
Table 5: Total annual deadweight loss in each market (million THB)

Year	2011	2012	2013	2014	2015	Total
Octane 95	536.0	547.9	1,976.1	2,290.2	1,825.2	7,175.4
ULG95R	68.4	57.6	437.8	340.1	992.5	1,896.3
GASOHOL95 E10	439.5	418.8	1,060.5	1,307.5	296.7	3,523.1
GASOHOL95 E20/E85	28.1	71.5	477.8	642.6	535.9	1,755.9
Octane 91	1,329.8	1,951.1	38.4	45.6	19.0	3,383.9
Diesel	6,832.6	7,851.7	8,135.8	7,745.9	1,393.0	31,959.0
Total	8,698.4	10,350.7	10,150.3	10,081.7	3,237.2	42,518.3

A couple caveats are worth mentioning. First, to the extent that ethanol-blended gasoline has substantial external benefit of relieving fuel scarcity, the deadweight loss for ethanol-blended gasoline might be overstated. Second, and more importantly, this calculated deadweight loss has not taken into account additional distortions in the natural gas (LPG/NGV) market. This deadweight loss in the natural gas market are presumably large given that LPG/NGV have been heavily and consistently subsidized during the sample period.

Figure 10 explores the time trend of the deadweight loss more closely. The deadweight loss was at its peak during 2012 and 2014, when the crude oil price was high. Overconsumption of Diesel contributes to a majority of the deadweight loss during this period. The situation changes in 2015, when the deadweight loss was reduced by more than half compared to 2014. This big drop in the deadweight loss is due to two reasons. First, the price of crude oil dramatically plummeted in late 2014 and remained low in 2015. Second, taking advantage of the low oil price, the government implemented a major fuel price restructuring in 2015. The price restructuring removed most of the distortions in the price structure, except the biofuel subsidies. Thus, subsidies to Gasohol E20 and E85 accounts for the majority of the deadweight loss in 2015. The fact that deadweight loss from gasohol subsidies increased in the past two years may signal that the market has expanded enough to start scaling down these subsidies.

Figure 10: Annual deadweight loss



6 Policy Recommendations

As discussed in section 4, the status quo price structure between 2011 and 2015 reflects two major government objectives: (i) to encourage consumers to substitute towards biofuels, and (ii) to alleviate consumer's burden on rising transportation costs by making Diesel cheap. Table 5 suggests that these objectives were achieved at a cost of almost 30 billion THB in efficiency loss over the 5-year sample period. In this section, we consider an alternative price structures and revenue recycling strategies that could have achieved these two objectives with smaller efficiency loss.

The starting point to eliminate efficiency loss is to set the retail prices of all gasoline equal to the efficient prices calculated in section 5. This can be achieved by collecting an excise tax or a "corrective tax" equals the marginal social cost of each liter of gasoline.

Next, we turn to the objective of supporting biofuels. Since the objective is to change individual's consumption behavior, using the price instrument to make gasohol cheaper than other fuels is the most effective strategy. Two important parameters for policy consideration is the level of the price discount (or subsidy) and how the price discount should be phased out over time. The price discount for gasohol should be large enough to jump start the gasohol market, but should not be too high to induce excessive consumption and distortions in other markets. Additionally, the price discount should be removed once the market is established.

The second objective to relieve consumers' burden on the rising cost of transportation fuel, especially for the low-income families, has been at the forefront of every governments' agenda. Thus, it deserves a more lengthy discussion. Despite the importance of the issue, past efforts to assist the low-income families were not very successful because the program design was either too narrow and missed the target population or too broad to prevent leakage to the non-targeted population.

An example of the narrow program design is the subsidized LPG for the low-income families. The program allows eligible families to purchase LPG for cooking at a subsidized rate. There are two problems with this program. First, the subsidized LPG is only slightly cheaper than normal LPG. Second, low-income families need to register to become eligible for the subsidized LPG. The registration requirement imposes a high opportunity cost to the low-income families that it is not worth the small price discount. Indeed, the Asian Development Bank reports that only 2 percent of the 7.7 million eligible recipients registered for access to the subsidized LPG (Asian Development Bank, 2015).

The case of Diesel's price distortions considered in this study is an example of a program design that is too broad. The status quo price structure gives a broad-based price discount to all Diesel consumers, many of which are high incomes. A broad-based policy like this one not only results in inefficient consumption, but also in the leakage of tax revenue towards the non-targeted consumers.

In short, poorly design subsidy programs can create both consumption inefficiency and revenue leakage. Thus in what follows, we propose a combination of the short- and long-run strategies that allows the government to relieve consumers' burden on the rising cost of transportation fuel with minimal leakage and inefficiency.

The *short-run strategy* involves collecting an efficient level of Diesel tax, then redistribute the revenue to a targeted consumers especially the logistic sector and the low-income population. As mentioned above, an important factors for such wealth transfer program to be successful is the eligibility criteria that must be broad enough to cover the target population and narrow enough to prevent leakage.

The *long-run strategy* involves a gradual phase out of the subsidies and redistribution associated with Diesel and a mode shift towards public transportation and rail transportation. The corrective tax revenue can be used to finance infrastructure for mass transit and improve the operational efficiency of the existing public transportation. Not only will this ensure an accessible and affordable mode of transport to the population, it will also reduce Thailand's dependence on imported oil.

In the future work, we will quantify the welfare and fiscal impact of implementing this proposed gasoline pricing and revenue recycling policy.

7 Conclusion

Thailand relies on crude oil import for more than 99 percent of its total transportation fuel consumption. As such, the country is vulnerable to the fluctuation in the world's oil price and the situation of oil scarcity. Therefore, Thailand's transportation fuel pricing policy has been plagues with two recurring themes: (i) capping the price of Diesel to support the low-income and curb inflation, and (ii) subsidizing consumption of the domestically-produced biofuels to enhance energy security.

The two objective are not necessarily consistent with each other. Capping the price of Diesel encourages inefficient and excessive use, which increases our dependence on the imported oil even more. Subsidizing the use of biofuel, which has higher actual production cost than imported oil, imposes a higher overall cost to the economy.

This study estimates the deadweight loss associated with the distortions in the status quo price structure of Thailand's major transportation fuels between 2011 and 2015. On average, we find that consumers are more responsive to the change in fuel prices than ever before. This means that any policy that creates price distortions will tend to result in a large deadweight loss. Specifically, we calculate the deadweight loss during this period to be around 42.5 billion THB. To put this number in perspective, the deadweight loss amounts to almost 2 percent of total expenditure on energy in 2014. A majority of the deadweight loss comes from Diesel, which has been consistently underpriced by 15 to 20 THB per liter.

Going forward, our policy recommendations include restructuring the transportation fuel price to better reflect its total cost. This can be done by setting the excise tax to reflect the social cost of global warming, local pollution, accident and congestion costs. Revenue collected from the higher excise tax should be used for a targeted income transfer to the poor and the logistic sector to alleviate the short-run impact of tax increase. In the medium to the long run, revenue from the higher excise tax should be use to expand the rail transport system, improve existing public transportations, and encourage transportation mode shifting.

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