Elsevier Editorial System(tm) for Energy Economics
Manuscript Draft

Manuscript Number: ENEECO-D-09-00489R1

Title: Sectoral Demand for Petroleum in Thailand

Article Type: Special Issue: Asian Energy

Keywords: petroleum consumption
panel data
general-to-specific

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Manuscript Region of Origin: THAILAND

Sectoral Demand for Petroleum in Thailand

June 2, 2010

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Abstract

This paper examines the short-run and long-run determinants of final oil consumption in seven major economic sectors in Thailand. Two different approaches are compared. The first approach uses dynamic panel data estimation techniques taking into account oil consumption of the whole economy in an aggregate manner. The second approach employs the ADL equilibrium correction framework to model oil demand in each economic sector separately. The dynamic panel data approach estimates appear consistent with economic theory. The coefficients have the correct signs and the magnitudes of long-run responses are larger than the short-run responses. The single sector model approach yields similar but richer results. Relaxing the identical slope assumption reveals interesting sector specific characteristics.

1. Introduction

Thailand is a net energy-importing country. About 60 percent of the energy used is imported from abroad. Energy demand in Thailand has grown substantially between 1981 and 2007. The average growth rate has been about 7.0 percent per year for the past two decades. Economic growth has been slightly slower at an average of about 5.9 percent per year. Oil consumption has risen more than threefold since 1981, yet the share of oil consumption in total energy consumption has dropped from 87 percent in 1981 to 60 percent in 2007. Nevertheless, policy-makers continue to focus on the role of oil in the energy sector and macroeconomic policy.

The purpose of this study is to examine the short-run and long-run demand elasticities for oil in seven major economic sectors of Thai economy including Agriculture, Construction, Electricity, Manufacturing, Mining, Residential & Commercial and Transportation. The impact of oil price movements and shocks has differed across sectors. The main reasons are that the state of development and the specific characteristics like energy intensity and oil mix in consumption affect the degree of flexibility and adjustment of oil consumption in each sector.

These different characteristics are due to the mix of petroleum products consumed by each sector, the degree of substitutability with alternative energy sources, the level of capital accumulation, the output/ income generated, labor inputs, and government policies. These factors are vital for understanding the effects on oil consumption in each sector. Therefore, it is reasonable to take into account the impact of oil consumption in a disaggregate manner rather than using the traditional approach which considers the oil consumption for the aggregate economy.

“Oil consumption” in this paper refers to the “final” use of refined oil products not the “primary” use of all forms of petroleum energy. In other words, it focuses on the “final” users not the “primary” users. In the context of this study, there are seven major users which are represented in the seven economic sectors. These sectors consume oil and produce goods and services. Except for the electricity sector, where oil is transformed to electricity which is considered as another form of energy.

This paper differs from previous research on the subject in two ways. First, the analysis looks at oil defined by products not simply crude for Thailand. This is quite different from previous studies (see e.g. Hoa, 1992; Eltony, 1996; Zou and Chau, 2005; Narayan and Smyth, 2007) which examine aggregate crude demand. Second, the focus of the paper is consumption by seven sectors: agriculture, industrial, residential and commercial, construction, mining, transportation, and electricity. Previous research has looked at a single product or the aggregate petroleum sector or the same product across countries. (see e.g. Bentzen, 1994; Pesaran et al., 1999; Polemis, 2006). This study can provide assistance to policy makers in designing policies which will efficiently affect oil consumption behavior for each sector. They can understand the determinants of petroleum product demand and the limitations for policy

The remainder of this paper is organized into six sections. Section I is a brief review of literature on petroleum demand elasticities. Section II provides background on Thailand's petroleum demand by economic sectors. Section III describes at the data sources and variables. Section IV describes the two methodologies used in this paper i.e. 1) the DPD, dynamic panel data, estimation approach and 2) the ADL-ECM, auto-distributed lag error correction mechanism approach. Section V discusses the empirical findings obtained from these two modeling approaches. Section VI of the paper summarizes the findings of the paper, policy implications and future research direction.

2. Literature Review on Energy Demand Elasticities

This paper focuses on aggregate petroleum product demand in Thailand. Although there have been many previous studies of energy demand in developing countries (Vita et al., 2006; Ahmadian et al., 2007; Akinboade et al., 2008), only a few studies have specifically examined energy demand in Thailand e.g. Hoa (1992) and Sheerin (1992). A number of authors believe that oil demand models from a developing country perspective may require a different framework. Therefore this study oil demand models traditionally used in the literature for industrialized countries for the case of Thailand in two ways.

First, this study takes advantage of a sectoral database spanning 1980-2007 to estimate oil demand elasticities by using two approaches: the disaggregate approach i.e. the single sector demand model and the aggregate approach i.e. the dynamic panel data approach. The single sector approach is a time-series oriented approach and focuses on individual sector demand (see e.g. Bentzen, 1994; Pesaran et al., 1999; Polemis, 2006; Vita et al., 2006) while the dynamic panel data approach is similar to cross section time series approach (see e.g. Frazen and Sterner, 1995; Eltony, 1996; Maddala et al., 1997). we can compare and contrast these two approaches to modeling petroleum consumption for Thai economy.

Second, most studies of oil demand like (Bentzen, 1994; Dahl et al. 2001; Akinboade et al., 2008) have not included the price of substitute energy while some studies pay more attention on the price of substitute energy in the model (see e.g. Vita et al., 2006; Polemis, 2006). The effect of energy substitution has played an increasing role in Thailand during the past decade due to the adverse impacts from excessively high oil prices and the pace of economic development. In this study, the effects of alternative energy prices are considered on a sector specific basis and the available information of substitute energy in the market. The replacement of petroleum (oil) by other types of fuels such as coal, natural gas and electricity can provide a better understanding of how alternative energy has affected the oil consumption behavior in each sector. The diversification of energy supplies and consumption are critical for economic development and energy vulnerability. In addition, the paper also considers the effects of capital stock and labor employment as done in the earlier study by Pindyck and Rotemberg (1983) for the U.S.

Energy elasticity estimates from previous research can provide a benchmark for the analysis of this paper. A comprehensive set of surveys on energy demand elasticities for developing countries has been conducted by Dahl (1993), Dahl (1994a) and Dahl (1994b). From her survey work in Dahl (1993) and Dahl (1994a), she claims that demand for oil in developing countries is income elastic with the magnitude greater than 1.32, implying that with stable prices oil demand will grow at a faster rate than income. Conversely, the price elasticity of oil demand is inelastic at about -0.30, implying that any policies to increase price to curb the rising demand will be effective only if the magnitude of price change is large enough. Dahl (1993) also reports that Thailand's intermediate-run energy price and income elasticities are about -0.26 and 1.01 respectively.

In terms of the demand for petroleum products in Thailand, Hoa (1992) estimates own-price, cross-price and income elasticities of six petroleum products, namely petrol, kerosene, diesel, fuel oil, aviation fuel, and LPG for Thailand, using annual data in the period 1974-1987. The results show that most of the estimated own-price elasticities are positive except for diesel and fuel oil. Although own-price elasticities for diesel and fuel oil are negative, they are not significant. The reason for positive own-price elasticities as claimed by Hoa is that they might be due to the effects of regulated prices of petroleum products for some period of the study. In terms of income elasticities, kerosene is found to be an inferior good with negative income elasticity while income elasticities for diesel and LPG are greater than unity. Comparing the findings in Hoa (1992) provides a broad picture of how the oil demand in Thailand has changed over the past two decades when comparing with the results from this paper.

3. Review on Thailand's Energy Demand and Macroeconomy

3.1 Economic Growth

Thailand enjoyed high economic growth during the 1980s, with a growth rate of about 7.8 percent per year. The real GDP increased substantially from about 914 billion baht[1] (US$ 45 billion) in 1980 to 1,750 billion baht (US$ 68 billion) in 1989, almost doubling within one decade. Unfortunately, the 1997 financial crisis hit the economy severely. Economic growth declined sharply into a deep economic recession, with a negative growth rate of -1.4 and -10.4 percent in 1997 and 1998, respectively. However, the economy recovered quickly and the average growth rate rebounded to 4 percent per year at the end of the 1990s. From 2000 to 2007, the economy has grown continuously with a moderate growth rate of 3.5 percent. Throughout the past decade, the population has increased at a steady rate of 1.1 percent per year while the per capita real income has increased sharply, growing three-fold from 19,721 baht (US$ 963) in 1980 to 67,333 baht (US$ 1,950) in 2007.

[1] The average exchange rate prior to the 1997 financial crisis was around 25 baht/US$, but during the crisis exchange rate increased to about 40 baht/US$. After that, the exchange rate has been stable at around 33 baht/US$.

Even though Thailand does not abound with oil and mineral resources, it is abundant in other natural resources, such as timber and agricultural products, which helped propel its growth in the past decades. Almost fifty years ago, Thailand was a primitive economy whose main output was agricultural products, particularly rice. As a result, the agricultural sector accounted for about 30 percent of the real GDP while industrial sector took only 15 percent share of the real GDP. The structure has been reversed as the country becomes more developed. The share of the agricultural sector has dropped continuously to about 10 percent while the share of industrial sector has increased to 46 between 2000 and 2007. In the same way, the service sector, including transportation and residential and commercial sector, has maintained their important role in the economy and contributing together more than 40 percent of the real GDP.

3.2 Energy Demand

With the rapid economic and steady population growth during the past decades, Thailand's overall energy demand has grown substantially at an average of 7.0 percent per year. Thailand's total energy demand in 1980 was only 9,056 thousand tons of crude oil equivalent (ktoe) but has increased six-fold to 54,405 ktoe in 2007. The per capita energy consumption has increased over the past 27 years by 5.7 percent from 0.2 ktoe in 1980 to 0.9 ktoe in 2007.

Figure 1 shows the trend in GDP and total energy consumption for Thailand since 1980. The trend clearly indicates that there is a strong linkage between energy and the economy. Since 1987 the two curves have diverged somewhat. This can be explained by greater efficiency of energy consumption in the economy and greater productivity resulting from technology advancement especially in the industrial and service sectors.

Table 1 shows that in the past twenty years, the transportation sector has used the largest share, 38 percent, of the total energy consumption. While this sector's share has continued at such a high level since 1986, its contribution to the economy has been comparatively small and remained stable at only about 9 percent of the real GDP. The second and the third major energy users are the industrial and residential and commercial sectors. They account for about 32 and 24 percent of the total energy consumption respectively. However, they contribute significantly to overall real GDP by about 42 and 38 percent of the total real GDP respectively. Agriculture uses the smallest share of energy, consuming only about 11 percent but its real GDP contribution is as large as that of transportation sector.

Figure 2 reveals that fossil fuels, especially oil and natural gas, have taken a dominant role, accounting for approximately 76 percent of the country's total energy consumption. Final oil consumption is composed of seven major petroleum products, namely liquefied petroleum gas (LPG), kerosene (jet fuels), premium gasoline, regular gasoline, high-speed diesel (HSD), low-speed diesel (LSD), and fuel oil. In Thailand, high-speed diesel takes the largest share of about 42 percent of the total petroleum consumption and the major consumers of this product are the Transportation and Agricultural sectors with the share of about 74 and 19 percent of the total HSD consumption respectively. The second major petroleum product is fuel oil; it accounts for about 21 percent of total petroleum consumption while the Manufacturing and Electricity sectors take the largest share equally about 43 percent of total fuel oil consumption. The third one is kerosene/ jet fuel with the share of about 11 percent of total oil consumption where the largest consumer is the Transportation sector of about 98 percent of total kerosene consumption (aviation fuel) while the Residential and Commercial sector's share has decreased continuously to only about 2 percent. Premium and regular gasoline take about almost the same proportion at 9 percent of total petroleum use and the largest consumer of both products is the Transportation sector with the share of 99 and 97 percent respectively. The LPG share has increased gradually and averaged at about 8 percent of total oil consumption with Residential and Commercial sector taking the largest share of 70 percent followed by Manufacturing sector with the share of 19 percent of total LPG consumption. Low-speed diesel takes the smallest share at only about 0.5 percent of total petroleum use and the major consumers are the Transportation sector and Manufacturing sector with the share of about 75 and 22 percent of LPG use respectively.

Coal and electricity have comprised 7 percent and 17 percent shares respectively of total energy consumption. In fact, oil has lowered its share in the final energy mix significantly since 1980 as a result of the introduction of new technologies to replace oil with natural gas and coal in heat and electricity generation. Moreover, since 2000, oil prices have risen dramatically and this has raised concerns about heavy oil use in the economy. Therefore, many consumers have switched from oil to other cheaper alternative fuels such as natural gas and biofuels (ethanol and biodiesel), particularly in the transport sector.

4. Data

The data used in this study cover seven major economic sectors and seven primary petroleum products between 1981 and 2007 in Thailand. The data of annual consumption of petroleum products have been published annually in the Thailand Energy Situation Report prepared by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy. Originally, the primary data are collected by Ministry of Commerce, Ministry of Interior and some private sectors, then compiled and classified by DEDE according to petroleum products and consuming sectors.

The annual GDP (Gross Domestic Product), Capital Stock data are obtained from the National Economic and Social Development Board (NESDB), Office of the Prime Minister, while the annual Price Deflator and Labor employment data are from the Bank of Thailand (BOT). The Energy Policy and Planning Office (EPPO), Ministry of Energy, provided the data on petroleum prices, the basic background of overall energy consumption, production, energy policies, regulations and rules for past and present energy situations in Thailand.

Oil consumption in each economic sector in any year is the sum of petroleum products consumed by that sector in that year which is originally measured in million liters (Mlitres) for all products and then converted to be thousand tons of crude oil equivalent (ktoe) by using the conversion factors available in the annual report of DEDE (2007). Similarly, the oil price in each sector is weighted average of real price of petroleum product in terms of Baht per tons of oil equivalent (Baht/toe)[2].

The price of substitute energy for oil is a weighted average of real price of all kinds of energy use apart from oil in that sector which is measured in terms of Baht/toe by using the conversion factors from DEDE (2007). There are three types of substitute energy considered in this paper including electricity, coal and natural gas and the steps of computing the weighted price of substitute energy is the same as those of the weighted real oil price.

The real GDP at 1988 prices in Millions of Baht for each economic sector is used as the real income level of that sector. The real Capital Stock at 1988 prices measured in Millions of Baht for each economic sector is used as a representation of capital input[3] of that sector. The labor employment measured in thousands of people employed by the economic sector is used to represent the labor input of that sector.

It is important to note that the Residential sector does not formally exist in the standard national account but it does exist as one of major energy-consuming sectors in the energy statistics. In the standard national account of Thailand, only the data on Private Households with Employed Persons are reported. In this study, the data of income and energy consumption for the Residential sector follow the same definition. This will ensure the consistency of the analysis in this paper.

5. Methodology

Since the main focus of this study is on the oil consumption behavior of each sector, the study applies the econometric approach of Autoregressive Distributed Lag (ADL) to examine the behavior of each individual sector. However, the big picture of the overall consumption in the economy cannot be ignored as it can be used as a reference of how individual sector behaves compared with the whole economy. Therefore, the second econometric approach, Dynamic Panel Data Estimation Approach (DPD), is employed as well. As a result, the ADL approach yields the estimates of demand elasticities for each individual sector while the DPD combines all sectors and estimates the demand elasticity for the economy as a whole. The details of each approach are provided as follows:

[2] There are three steps of calculating the oil price for any economic sector. First, convert the current price of each petroleum product measured in Baht/liter to the real price by using the GDP deflator (1988 is the base year). Second, convert the real price of all petroleum products in Baht/liter to Baht/toe by using the conversion factor. Third, compute the weighted average of real oil price average in Baht/toe for each sector, which depends on the amount of petroleum products consumed in each sector.

[3] Theoretically, the data of capital input (i.e. flow of capital services) should be used in the estimation, but this data is not available. In practice, the stock of capital is used instead as a proxy of capital input. This is based on an assumption that each machine/ equipment is used at a fixed amount of hours in a year and thus the flow of capital services is just a constant multiple of capital stock. Therefore, in this case the flow of capital services is represented by the capital stock as explained by Barro (2008).

5.1 ADL Single Sector Approach

The ADL modeling approach is based on general-to-specific approach advocated by Hendry (1986) and Hendry and Juselius (2000, 2001). The key objective of this approach is to use econometrics to discover the relationship of variables rather than to use it to validate economic theory. Therefore, it attempts to understand the characteristics of data properties from the sample. There are five basic steps of this approach including:

1) Test for stationarity of the series
2) Estimate and solve for static long-run oil demand equation for all 7 sectors
3) Formulate the ECM (Error Correction Mechanism) terms
4) Incorporate the ECM terms into short-run dynamic model
5) Perform the model reduction process using Autometrics[4].

The models that involve in each step are described as follows:

5.1.1 General ADL(1,1) Model

Oil consumption in each sector is specified to reflect the determinants and the economic development process. All economic variables are transformed to natural logarithms and thus the double log estimation equation for any sector can be written as:

$$\begin{aligned} LOIL_t &= \alpha_0 + \alpha_1 LOIL_{t-1} + \alpha_2 LPOIL_t + \alpha_3 LPOIL_{t-1} + \alpha_4 LPSUB_t + \alpha_5 LPSUB_{t-1} \\ &+ \alpha_6 LGDP_t + \alpha_7 LGDP_{t-1} + \alpha_8 LK_t + \alpha_9 LK_{t-1} + \alpha_{10} LL_t + \alpha_{11} LL_{t-1} + u_t \end{aligned} \qquad (1)$$

where $LOIL_t$ is the natural log of quantity of oil consumption in thousand tons of oil equivalent (ktoe), $LPOIL_t$ is the natural log of weighted real price of all petroleum products used by that sector in baht per toe, $LPSUB_t$ is the natural log of weighted real price of substitute energy available in that sector in baht per toe, $LGDP_t$ is the natural log of real income generated by that sector in millions of baht using 1988 prices, LK_t is the natural log of real capital stock in millions of baht using 1988 prices and LL_t is the natural log of labor employment in thousands.

5.1.2 Long-run Representation – derived from ADL

The long-run solution(s) can be obtained from the distributed lag formulation. Moreover, when the individual series are I(1) there may exist a linear combination which yields an I(0) equilibrium correction framework. Then oil consumption and the explanatory variables are said to be cointegrated as suggested by numerous literature for example by

[4] Autometrics is general-to-specific algorithm developed by Hendry and Krolzig (2001) consisting of five steps i.e. 1) Specification of General Unrestricted Model, 2) Test for misspecification, 3) Elimination of irrelevant variables, 4) Test for congruency and 5) Evaluate the terminal model. The key idea of this algorithm is that it eliminates irrelevant variables from the general model and retains only meaningful variables in the final model.

Engle and Granger (1987) and Hendry (1986). Therefore, the deviation from the long-run equilibrium of oil consumption called Error or Equilibrium Correction Mechanism (EqCM) term can be derived and is given by:

$$ECM_t = LOIL_t - \gamma_1 LGDP_t - \gamma_2 LPOIL_t - \gamma_3 LPSUB_t - \gamma_4 LK_t - \gamma_5 LL_t \quad (2)$$

If the variables are all stationary, I(0), the long-run solution is obtained simply from the rational distributed lag. In the ADL(1,1) case, the EqCM is present if the coefficient on the lagged dependent variable is negative. This coefficient estimate is used to normalize the coefficients for the remaining explanatory variables.

5.1.3 Short-run EqCM (Equilibrium Correction) Model

The error correction model is specified in the first differences, which are stationary, to represent the short-run movements in the variables together with the lag of EqCM term representing the deviation from the long-run equilibrium in the previous period. When the EqCM term is incorporated into the model, both long-run and short-run relations are taken into account simultaneously and thus the dynamics of oil consumption in each sector can be captured.

$$\begin{aligned}\Delta LOIL_t &= \beta_0 + \beta_1 \Delta LOIL_{t-1} + \beta_2 \Delta LPOIL_t + \beta_3 \Delta LPOIL_{t-1} + \beta_4 \Delta LPSUB_t + \beta_5 \Delta LPSUB_{t-1} \\ &+ \beta_6 \Delta LGDP_t + \beta_7 \Delta LGDP_{t-1} + \beta_8 \Delta LK_t + \beta_9 \Delta LK_{t-1} + \beta_{10} \Delta LL_t + \beta_{11} \Delta LL_{t-1} + \beta_{12} ECM_{t-1} + e_t\end{aligned} \quad (3)$$

Since the first difference model is stationary, estimation and statistical inference can be conducted using standard statistical approach. Once the EqCM model was estimated, the following step is to use Autometrics to perform model reduction to obtain the final model which includes only relevant variables in explaining the oil consumption behavior in each economic sector.

5.2 Dynamic Panel Data Approach

In the context of this study and the given structure of panel data, the DPD oil consumption model with one lag of dependent variable and contemporaneous value of explanatory variables can be written as

$$LOIL_{it} = \beta_0 + \lambda LOIL_{it-1} + \beta_1 LPOIL_{it} + \beta_2 LPELE_{it} + \beta_3 LGDP_{it} + \beta_4 LK_{it} + \beta_5 LL_{it} + e_{it} \quad (4)$$

where i and t represent economic sector and time periods of the study respectively. All variables names in this panel setting are the same as those in the ADL approach except that all variables are classified by sector and time index. The only new variable in Equation (4) is $LPELE_{it}$ which is the log of real price of electricity[5]. This is used as a proxy of price of substitute energy.

[5] The reason for using the electricity price as a proxy is that apart from oil, electricity is the only energy commonly used by all seven sectors while coal and natural gas are used by only some sectors. If prices of coal and natural gas are included in some sectors but not the others, it will create the problem of

There is a problem of inconsistent estimators in Equation (4) as the lagged dependent variable is correlated with the error term even though the assumption of no autocorrelation of the e_{it} still holds, Greene (2003). According to Arellano and Bond (1991) and Arellano and Bover (1995), the GMM (Generalized Method of Moments) estimator can be used to deal with this problem and the first step of the solution involves taking first differences of the original model. When taking first differences of Equation (4), the constant term and the individual effect have been removed. The first differencing equation is then given by

$$\Delta LOIL_{it} = \lambda_1 \Delta LOIL_{it-1} + \lambda_2 \Delta LPOIL_{it} + \lambda_3 \Delta LPELE_{it} + \lambda_4 \Delta LGDP_{it} + \lambda_5 \Delta LK_{it} + \lambda_6 \Delta LL_{it} + \Delta u_{it} \quad (5)$$

After first differencing, the correlation between the difference lagged dependent variable and the error term still exists. The instruments for the lagged dependent variable must be constructed subsequently to deal with this problem. Arellano and Bover (1995) and Blundell and Bond (1998) recommend improving the instruments in the modified version to include lagged levels and lagged differences of the dependent variable, the strictly exogenous variables as well as others that may be specified. Following the approach of Arellano and Bond (1991), the group dummy variables[6] representing each individual sector will be created and these dummies are part of the GMM instruments. This procedure implicitly assumes that the regression parameters do not differ between sectors i.e. it is DPD model with homogenous slopes. Only the intercepts are different between sectors. In the context of this study, there are seven cross-section groups implying that six group dummy variables are created and the constant term is used as a reference case for the Agricultural sector.

6. Empirical Results

In this section, the results of the ADL single sector approach and the Dynamic Panel Data approach will be discussed. The analysis starts from a general model of oil consumption incorporating both demand and supply determinants. Our general model includes the standard demand variables like own-price and income and production function determinants like capital, labor, and the price of substitutes. If capital and labor do not provide explanatory power, then we would interpret the model as one for consumer demand. Otherwise, we consider the model as explaining the demand for oil in a production function, with income/output representing scale effects.

6.1 The Results of ADL Single Sector Approach

6.1.1 Unit Root Tests

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inconsistent definition of substitute energy in the panel settings which can in turn affect the accuracy of the estimation.

[6] In Arellano and Bond (1991), they include time dummies in their estimation. But the group dummies can also be included using the same logic applied to the LSDV (Least Squares Dummy Variables) estimator. For more details please consult Doornik and Hendry (2006).

The unit root tests used in this section is the Augmented Dickey-Fuller tests (ADF). The ADF tests with a constant and trend are applied to the level series to check for the presence of unit roots. Table 2 reports that the null hypothesis of a unit root cannot be rejected at 5 percent in most cases. Even though POIL (in Electricity), GDP (in Agriculture), L (in Construction) are rejected, when the trend is not included the results[7] support the presence of unit root in those variables. To examine the order of integration in the series, the ADF tests are applied to the first difference series. Table 3 contains the ADF tests for the variables in first differences. It was found that the null hypothesis of unit root in most cases across all sectors except in the case of K are rejected. Although the t-statistics for K might not be statistically significant, the coefficients of the lag one period of K in the ADF tests are numerically far from unity. Also, the idea that a slowly evolving real variable follows an I(2) process is counterintuitive. Thus, it can be concluded that the variables in this analysis are I(1) series.

6.1.2 Modeling the Long-run Static Relations

Table 4 presents the long-run relationship between oil consumption and the determinant factors including oil price, price of substitute energy, income, capital and labor. In all cases these explanatory variables are jointly significant except in Mining sector in which the $\chi^2(5)$ statistic is fairly low at 0.53. Moreover, it appears that none of the variables in Mining sector is individually significant. Given the relatively small contribution of the Mining sector to oil consumption in the economy and the unfavorable outcomes from these statistical tests, Mining sector will be dropped out and the analysis will be proceed to the next step with only six sectors.

6.1.3 General-to-Specific Modeling Approach

To model the demand for oil for all sectors in a more comprehensive way, a short-run error correction model is used. The equilibrium error correction framework models the variables of interest in differences and the coefficients on the differenced variables are interpreted as short-run elasticities. Under the EqCM framework, the model includes an EqCM term obtained from the long-run relationship (as reported in Table 4) representing the deviations in oil consumption from its long run equilibrium level. The estimated coefficient of the EqCM measures the speed of adjustment to return to the long-run equilibrium. In this step, the General Unrestricted Model[8] (GUM) as specified in Equation (3) for each sector is estimated.

Then, the final parsimonious model was obtained from conducting the model reduction process by applying general-to-specific modeling algorithm known as Autometrics to the GUM. The basic ideas of model reduction is that it eliminates irrelevant variables from the GUM and retains only meaningful variables by employing statistical tests of

[7] Due to limited space, the results of ADF tests with only constant term in ADF regression specification are not reported in this paper but they can be provided upon request.
[8] Due to limited space, the results of general model are not presented in this paper. But, they can be provided upon request.

significance and misspecification through residual diagnostics and evaluating the final models through encompassing tests as suggested by Hendry and Krolzig (2001). In this study, the significance level of five percent was chosen as a cut off point of irrelevant variables and the outlier detection is set at one percent. The results of specific model for each sector are reported in Table 5.

In general, the coefficients in the final parsimonious model in each sector have the expected signs and reasonable magnitude. The residual diagnostics indicate that the distribution of errors is normal. There is no evidence to support the presence of autocorrelation and conditional heteroscedasticity. The one-step residuals[9] lie within two standard error confidence bounds suggesting that there are no heavy outliers detected. The stability of the model is examined by testing parameter constancy through recursive estimation. The one-step ahead and n-step ahead Chow tests for individual equation of each sector have been examined. Overall, it appears there is evidence of structural breaks only in the Electricity sector. Models in the other sectors do not show the sign of structural breaks and it can be concluded that all equations satisfy parameter constancy condition at one percent significant level. In other words, the estimates are stable. Hence, the parsimonious model of oil consumption in six sectors can successfully capture the dynamics of oil consumption and is also robust based on statistical grounds.

6.1.4 Discussion of the Short- and Long-run Elasticities

Several interesting details appear from the interpretation of the explanatory variables and sectors for both short run and long run are discussed in this section. The long-run elasticities are drawn from Table 4 while their short-run counterparts are reported in Table 5.

6.1.4.1 Price of Oil

From Table 4, the long-run oil price elasticity is inelastic in five of six sectors. As can be expected, the oil price is most inelastic in the Transportation sector with the value of -0.17. This can be explained by the limited choices of fuels and the constraints in transportation technology. Even though the Thai government has promoted the use of more natural gas for vehicles (NGV) and biofuels such as gasohol and biodiesel in the past 10 years, the impacts are still not significant. Conversely the Thai government has pursued low transportation fuel price policies even though the oil market has been fully deregulated since 1991, Amranand (2002). For example, during the U.S.-Iraq War 2003, the Oil Fund[10] was used to stabilize the retail prices for premium gasoline, regular gasoline and high-speed diesel which are the major fuels in the Transportation sector.

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[9] The graphical results from general and specific models by sector for Residual Diagnostics and Recursive Stability Tests can be provided upon request.

[10] The Oil Fund was established in 1979 and has been used to stabilize oil prices in Thailand in the unusual events. During periods of unusually high oil prices, the Oil Fund is used to subsidize retailers in order to maintain the level of domestic prices, but during times of normal prices, a portion of revenue from retail oil sales is allocated to the Oil Fund, EPPO (2003).

The short-run oil price elasticity estimates from Table 5 are very close to the long-run results for Agricultural and Transportation sector. Moreover, among all sectors, the Transportation sector's oil demand is least sensitive to price with the magnitude of only -0.16. The values of the long-run and short-run are approximately the same, suggesting that there is little change in the behavior of transportation fuel consumption in the short run and long run.

The long-run oil consumption in the Manufacturing and Residential and Commercial sectors are more price elastic with the value of -0.87 and -1.03 respectively as shown in Table 44, which implies that these two sectors are more flexible in adjusting consumption when oil price change. The main reason is that during the past 27 years, Manufacturing and Residential and Commercial sectors have been able to switch to other cheaper alternative energy choices. The Manufacturing sector has switched to use more coal and natural gas while the Residential and Commercial sector switched to greater electricity consumption and less kerosene. The short-run price elasticity of Manufacturing and Residential and Commercial sector as shown in Table 5 are -0.24 and -0.79 respectively, suggesting there is significant adjustment in consumption behavior from the short run to the long run in these two sectors.

6.1.4.2 Price of Substitute Energy

The role of alternative energy in each sector is different depending on the sector's end use characteristics and technology. This may explain the different signs of the estimates in various sectors. Theoretically, the positive sign of the estimate suggests that other forms of energy used by that sector seems to be a substitute for oil while the negative sign indicates that alternative energy appears to be a complement. As presented in Table 5, the price of alternative energy in Agriculture, Manufacturing and Residential and Commercial sector appears to be substitutes with the value of 0.21, 0.74 and 1.28. The situation in the Agricultural sector may be explained by the expansion of the electricity grid in the rural areas. Auto-generators using diesel oil are less utilized and only kept for blackout purposes. Nevertheless, this replacement is still not significant since oil is still a dominant energy required for other machines and equipment used in the field and areas where the electricity grid is not available. Therefore, the elasticity value in the Agricultural sector is positive but relatively small when compared with other sectors.

In contrast with the Agricultural sector, the situation in the Residential and Commercial sector is different because electricity demand has risen rapidly over time in this sector and has already dominated the total commercial energy consumption. The level of oil consumption has remained quite stable over time in this sector. Therefore, this is part of the reason explaining the greater magnitude of the long-run elasticity estimates for substitute energy in the Residential and Commercial sector comparing with other sectors.

However, in the Electricity sector, alternative energy appears to be a complement rather than a substitute with the elasticity value of -0.61 as reported in Table 4. This is consistent with the current situation in Thailand's electricity generation sector where oil has been used as a complementary fuel with natural gas for the old power plants and for the peak power generation. The study by Phumpradab et al. (2009) reports that the thermal power plants in Thailand use a fuel mix of 56 percent of natural gas and 44 percent of fuel oil by energy content. That may explain why the alternative choices of fuel appear complementary in the Electricity sector.

The short-run effects for the price of substitute energy results are really interesting. It turns out that from the statistical point of view price of substitute energy does not play a major role in influencing oil consumption in the short run. As can be seen in Table 5, price of substitute energy could not pass the criteria of the model reduction process and it has been dropped out in all sectors. One possible explanation is that in the short run variations in price of energy substitutes might not create a sufficient impact and lead to a significant change in the behavior of oil consumption in all sectors. Only when the price of energy substitutes has manifested a clear pattern in the long run will oil consumers be more confident to invest in new machines and equipment in order to switch from oil to other fuels. In other words, the trade off between the cost from investment in new technology and benefits from oil saving will be clearly realized only in the long run.

6.1.4.3 Income

As can be seen from Table 4, GDP has a positive long-run impact on oil consumption in all sectors. The impact of GDP on oil consumption is largest in the Electricity sector at 3.22. One possible explanation is that as economy grows, electricity consumption has grown accordingly. Rapidly growing electricity demand has induced the power generators to expand their capacity especially coal-fired power plants which are considered the most cost effective. However, after 1991[11], power generators have been faced with many social and environmental protests from villagers and pro-environment groups. They have made it difficult to build new coal-fired power plants. Therefore, their second-best option is to revamp the old power generators using a fuel mix of natural gas and fuel oil. As a result, oil consumption in the Electricity sector has increased in line with a strong effect from the GDP.

Moreover, the situation in the Manufacturing sector is the same as that of Electricity sector as suggested by a fairly high elasticity value of 2.75 from Table 4. The Manufacturing sector tends to consume more oil, electricity and coal during peak production periods. The greater use of electricity in manufacturing sector reinforces the peak power demand which is met by fuel oil using power plants. However, the greater use of coal by the Manufacturing sector tends to drive up the coal price in the domestic market and can induce the Electricity sector to consume slightly less coal but more oil, which will indirectly promote higher oil consumption in the Electricity sector.

In the Residential and Commercial sector, the higher income is associated with the expansion of urbanization, LPG (known as cooking gas) has therefore risen sharply

[11] This is the year that residents around Mae Moh district, Lampang province, started to complain about the air pollutions generated from the lignite mine, which had caused respiratory diseases to the residents in that area. Even though EGAT (Electricity Generating Authority of Thailand) had solved the problems later, the tarnished image of coal-fired power plants is still not much improved.

throughout the period of study. As a result of the economic development and urbanization throughout the country, the Transportation sector has grown accordingly and thus increasing oil use in the sector substantially.

The results in Table 5 show that the short run effect of GDP on oil consumption is highly significant in Manufacturing, Residential and Commercial and Transportation sector with the magnitude of 1.58, 1.21 and 0.94 respectively. The short run elasticities are smaller than the income long run elasticities. However, GDP is not significant in the short run for the Electricity sector since the generating capacity of power plants using oil is quite limited in the short run and it takes some time for power generators to install or revamp the power generation units into the system.

6.1.4.4 Capital

As seen from Table 4, it appears that the elasticity of oil consumption with respect to capital turns out to be negative in all sectors except Agriculture where the value is close to unity. The positive value for the capital elasticity is associated with the agricultural development process which requires more oil consumption for irrigation and mechanization. However, the negative values in other sectors can be interpreted as the saving of oil consumption due to the technology advancement and the efficiency improvements in equipment and techniques of production.

The Thai government has attempted to promote energy efficiency policies for almost a decade. The results may reflect some of the benefits from these policies. The Electricity sector and the Manufacturing sector manifest this energy efficiency with the elasticity values of -2.52 and -0.66 respectively as reported in Table 4. This can be explained by the fact that new efficient machines were installed in the power plants and industry. These are designed to diversify energy uses in those sectors to natural gas and renewable energy. Therefore, the greater investment in new machines, the less oil will be consumed.

However, oil saving effect is smallest in the Transportation sector with the magnitude of only -0.16. There are two possible explanations. The first may be explained by oil prices and efficiency reasons. This can be understood clearly if we take a look back on the technology of automobiles during the past decade. The automobile industry does not pay much attention on producing energy-saving cars especially in the period of 1986-1998 when oil price was relatively cheap. The trend of technology in that time is geared towards the luxurious and speedy cars. Recently higher oil prices have made automakers become more alert to producing more fuel efficient cars, hybrid cars and alternative-energy cars. Although these technology options are not fully integrated into the markets, it can help reduce future fuel oil consumption in the Transportation sector. The second may be due to the rebound effect. Even if there have been (marginal) efficiency improvements they have been overwhelmed by the increases in the motor vehicle stock.

The short-run elasticity of oil consumption with respect to capital also shows the same sign as what had been found in the long run as can be seen from Table 5. The increase in capital in the short run appears to help lower oil consumption especially in Agriculture, Construction, and Manufacturing sector. However, greater capital investment in the Electricity sector turns out to accelerate oil consumption in the short run.

6.1.4.5 Labor

The results from Table 4 are consistent and indicate that a the long run an increase in employment in a sector will lead to the higher oil consumption. The results for the Manufacturing and Agricultural sectors show that the elasticity values with respect to labor are 1.56 and 1.19 respectively. These results are not surprising because as greater labor is employed in these sectors the requirements of equipment to perform the tasks would increase and that would lead to higher oil use.

The labor induced oil use effects are less in the Electricity sector and Transportation sector; the elasticities are less than unity, only 0.36 and 0.68 respectively. The explanation is that labor is not as critical in producing power in electricity sector. The employment of labor is driven by the capital stock and technical aspects to ensure that the system will run smoothly and safely.

In the Transportation sector, the movement of goods and passengers is done primarily the public sector and some private licensed operators. There are exact schedules and routine routes running all year round with controls on the amount of oil regularly used. Therefore, higher employment in Transportation sector tends to generate higher oil consumption by a smaller proportion.

The short-run elasticity of oil consumption with respect to labor has the same sign as the long run. As can be seen from Table 5, the impact of labor on oil consumption is largest, 1.45, in the Construction sector. This is due to the fact that labor is a primary input in the Construction sector. But in the Agriculture, Manufacturing and Transportation sector, the short-run elasticity values are reported to be smaller than their long-run counterparts at 0.32, 0.66 and 0.39 respectively. This implies that as labor employment increases, the required machines and equipment for workers to perform the task are better provided in the long run rather than in the short run.

6.1.4.6 EqCM

From Table 5, the equilibrium error correction (EqCM) term is significant in all sectors and has a negative sign. It is less than unity except in the Construction sector where the value of coefficient is almost equal to unity. The size of the EqCM term indicates the speed of adjustment when the demand is above or below equilibrium. As seen from Table 5, the Construction sector has the fastest speed of adjustment among all sectors. It means that if there is a deviation from the long-run equilibrium of oil consumption, the Construction sector tends to completely adjust within one year from a deviation from the long run equilibrium. The Transportation sector has the slowest speed of adjustment at 55 percent. Although it is the lowest number, it still indicates that oil consumption in the Transportation sector can adjust fairly fast by more than half back to its long-run equilibrium. This finding can somewhat emphasize the fact that oil is essential fuel and hard to be replaced in the long run in the Transportation sector.

6.2 The Results of the Dynamic Panel Data Approach

The main distinction between the ADL single sector approach and the Dynamic Panel Data (DPD) approach is that the estimated slope coefficients obtained from the DPD approach represents the elasticity value of oil consumption with respect to the corresponding variable across the whole economy not for any particular individual sector as discussed in the earlier part. Table 6A reports the estimated results and t-statistics of the DPD estimation approach for several model specifications. These model choices differ by the explanatory variables included and the treatment of group effects which capture the sector specific non-modeled characteristics.

There are six group effect variables including Group 2 (Construction), Group 3 (Electricity), Group 4 (Manufacturing), Group 5 (Mining), Group 6 (Residential and Commercial) and Group 7 (Transportation). The Agriculture sector is the reference grou. In addition, under the GMM framework, all variables shown in Table 6A are in the first differences of natural logarithm.

Column 1 contains the results of Model I of Table 6A in which there are only three explanatory variables: the lag of oil consumption, oil price and GDP. The different characteristics of oil consumption among sectors are not considered in Model I. It is the simplest case in the sense that it is the oil demand function depending on own price and income, it is used as a reference model for comparing the other model specifications.

Model II as shown in column 2 adds one additional variable, price of electricity to represent price of substitute energy. Likewise, Model III adds three new variables for comparison with Model I i.e. the price of electricity, capital and labor. Based on the results in Models II and III, it appears that price of substitute energy are not significant and does not help increase explanatory power of the model. Therefore, price of electricity has been dropped out from consideration. Model IV does not include price of electricity but include capital and labor. Model V is the same as Model IV but it takes into account the group effects which allow the intercept to adjust accordingly. Model VI is the same as Model V but it does not include capital and labor. As can be seen in Table 6A, labor and capital are significant in Models III and IV, but when the group effects are included, only labor is significant but not capital. Considering the group effects in Model V and VI, the group effects turn out to be significant in all cases except Group 3 (Electricity) in Model V. The (de-meaned) consumption growth is not significant between Electricity and Agriculture. Model V is the best model based on likelihood ratio tests.

The estimates for lagged oil consumption are significant in all of six model specifications and the values are quite close ranging between 0.62 and 0.76. The oil price estimates in all specifications are negative and less than one around -0.26 and -0.40, which indicate that the oil demand is rather inelastic in the short-run. The income estimates are positive and significant in all cases ranging from 0.13 to 0.31. The capital elasticity is negative and significant in two of three cases with the value around -0.30. The negative sign for the capital appears to be the same as those obtained from the ADL single sector approach. This suggests that additional capital stock tends to help save oil use in the economy which might be due to the technology improvement in machines and equipment. The response to labor is the reverse; it tends to accelerate oil use with the short-run elasticity values around 0.23 to 0.47.

The results obtained in each specification were used to compute the short-run and long-run elasticity values as shown in Table 7. The short-run elasticity values with respect to all variables are less than the elasticity values in the long-run. These findings are consistent with the economic theory stating that consumption is more responsive to changes in economic variables in the long run than in the short run. In the context of this study, oil consumption behavior in the Thai economy seems to be consistent with standard economic predictions.

An increase in the price of petroleum products or oil by one percent in the short run can cause a reduction in oil consumption by about 0.26 to 0.40 percent. However, in the long run, an increase in oil price by one percent might lead to a decrease in oil consumption by 0.76 to 1.70 percent. When income increases by one percent in the short run oil consumption tends to increase by 0.13 to 0.31 percent while in the long run the effects are stronger at 0.34 to 0.92 percent. If the capital stock increases by one percent, it might help lower oil consumption by 0.3 percent in the short run and 1.19 percent in the long run. An increase in employment by one percent will cause higher oil consumption in the short run by about 0.20 to 0.47 percent and by about 0.74 to 1.24 percent in the long run.

The residual diagnostic test results are provided in Table 6B. The results from the tests do not indicate any serious problems for these six models. The Wald (joint) tests showing the overall significance of all regressors are highly significant in all models. The Wald (dummy) tests including constant term are significant in four out of six cases. The Sargan test indicates that the null hypothesis of validity of the instruments cannot be rejected in all models. The residual diagnostic tests show that the error terms behave nicely and do not show any signs of autocorrelation either AR(1) or AR(2). Therefore, it can be concluded that the results from the dynamic panel data approach are fairly reliable and can provide us some clues of how much oil consumption of the whole economy would be affected by the change of each variable.

7. Conclusion

This study examine oil consumption behavior by sector in Thailand from 1980 to 2007. Oil consumption is the aggregate of seven petroleum products. The sectors are Agriculture, Construction, Electricity, Manufacturing, Mining, Residential & Commercial, and Transportation.

The analysis begins with a general model of oil consumption incorporating both demand and supply determinants. The general model includes the standard demand variables like own-price and income and production function input determinants like capital, labor, and the price of substitutes. If capital and labor do not provide explanatory power, then the model as one for consumer demand would be interpreted. Otherwise, the model is interpreted as explaining the demand for oil in a production function, with income/output representing scale effects.

The econometric modeling is approached from two perspectives: an autoregressive distributed lag perspective by sectors individually and a dynamic panel data approach. In both cases the model appears to explain oil consumption as an input demand in the production function. The dynamic panel data approach yielded estimates consistent with economic theory. The signs of the coefficients are correct and the long-run responses are larger than the short-run responses. The panel data approach combines information from all seven sectors and should be more efficient. However, this approach is restrictive in that the elasticity estimates are the same across sectors. This may mask interesting issues when oil use is heterogeneous.

Several examples of the sector heterogeneity phenomenon are described below. The long-run labor elasticities are approximately unity in all sectors except in the Electricity sector where it is less than unity. Also, the short-run own price elasticity in the Electricity sector turned out to be positive. A possible explanation is that during peak demand periods and when energy prices increase, the sector has no other alternative generating capability and must use residual fuel in legacy oil plants. The is no short-run effects for the price of oil substitutes. Finally, it was found that an increase in capital has a long-run negative impact on oil consumption in all sectors except Agriculture. This result might be interpreted as greater capital accumulation in Agriculture sector leads to more demand for irrigation and mechanization in the economic development process.

There are several distinctions between this paper and the results in Hoa (1992). Note, however that nearly 20 years have elapsed since that study. First, the own-price elasticities are positive and significant for several petroleum products in the first study. It was found that the own price elasticities are negative in both the short run and long run in this study. Further the short-run elasticity is inelastic and rather elastic in the long-run. Second, the income elasticity is positive and highly significant in this paper in all sectors while in Hoa (1992), the income elasticity is negative for kerosene and positive in other petroleum products but only marginally significant. Third, in this paper, the magnitude of the income elasticity is less than unity in both short run and long run, but in the previous paper the magnitude is quite large between 0.4 and 3.1. Fourth, the previous paper does not distinguish between the short run and long run elasticities and did not consider the price of energy substitutes. The results in this paper are consistent with those found in the surveys by Dahl (1994) and in the study of Indonesia by Dahl and Kurtubi (2001).

The Thai government has pursued the policies to lower oil consumption in the economy in order to lower the reliance on foreign oil and also to reduce the environmental effects from oil consumption. The estimated elasticities from this study can be used as guidelines for the policy makers. The policy recommendations for several major oil consuming sectors i.e. Transportation, Manufacturing and Residential and Commercial sector are addressed as follows:

Oil consumption growth in the transportation sector can be attributed to rising income and falling fuel prices and greater employment in the sector. The results also suggest that the demand for oil in Transportation sector is inelastic with respect to income, price and labor employment. The relatively small price elasticity implies that the government can raise the oil taxes in order to generate the revenue with small impacts on oil consumption even in the long term. This source of revenue should be used in two ways. First, it may be used to improve the quality of vehicles in this sector to be more fuel efficient as capital plays an important role in lowering oil consumption from the study. Second, it could be used to educate labor to be more aware of energy conservation and know how to use energy efficiently.

The effective policy recommendations for the Manufacturing sector should be focused on four variables the oil price, capital, labor and substitute energy. The oil price variable was found to be inelastic for both short run and long run, suggesting that the higher oil tax rates would not have much impact on consumption in the manufacturing sector in both short run and long run. This portion of tax revenue should be allocated to the energy efficiency and conservation projects in the industry because the improvement in machines and equipment as well as better-educated labor will have a considerable impact in saving oil consumption in this sector. These kinds of policies have already been implemented under the requirements by Energy Conservation Promotion Act (1992) specifically on designated factories and buildings. Apart from that, the funds should be set aside for ongoing projects to support a substantial fuel switching in the industry. These efforts are expected reduce or moderate oil consumption as GDP in the sector grows.

In the Residential and Commercial sector, the variables most important determinants for reducing oil consumption are the own price and capital. The short-run oil price elasticity is fairly high but inelastic, suggesting that prices should not be raised too high otherwise it will affect the standard of living and business activities in this sector. Therefore, it is recommended that the focus should be placed only on promoting the higher use of energy-efficient equipment particularly the cooking appliances and stoves since LPG is the main fuel used by this sector. Although this policy will greatly lower oil consumption in this sector, it might not be enough to offset the strong increase in oil or petroleum product demand resulting from the growth in the GDP of this sector.

There are several ways for future research. First, since oil demand in this paper combined all refined products together the future research may use the ADL framework in this study to investigate more on particular oil products in each sector separately. The focus might be place on the major oil consumers like Transportation, Manufacturing, Agriculture and Residential and Commercial sector and then select only some relevant oil products for each sector. Second, the role of substitute energy has been increasingly important. The future research should be more focused on the role of natural gas, coal and renewable energy in the Manufacturing and Electricity sector. Third, future research can be more narrowly to specific industries such as Food and Beverages, Chemical, Textiles, Paper, Basic metals and Non metallic industry. These industries consume more than a 70 percent share of total oil consumption in the Manufacturing sector. The data for these individual industries is available for further analysis. Fourth, another way of considering individual oil products is to study the panel data of each oil product across all sectors by applying DPD estimation technique as used in this paper to examine the consumption behavior of each specific product for the whole economy. Lastly, it is also interesting to see this framework applied to other developing countries so that the results can be compared and conclusions can be drawn from the comparative study.

Acknowledgements

The authors wish to express our sincere thanks to two anonymous referees of this journal for their constructive comments and suggestions in the previous version of this paper. The authors are also grateful for the scholarship support from IAEE to participate in the 32nd IAEE International Conference in San Francisco. David Ryan, Lester Hunt, Steven Brown, and Hill Huntington provided useful comments along with other participants at the 2nd International Workshop on Empirical Methods in Energy Economics, Jasper, Alberta where an earlier version of this paper was presented. All errors and omissions belong to the authors.

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Tables Sectoral Demand for Petroleum in Thailand

Table 1: Final Energy Consumption and GDP contribution by sector (Unit: percent)

	1986-1990	1991-1995	1996-2000	2001-2005	Average 1986-2005
Share of Final Energy Consumption by Sector[1]:					
Transportation	37	38	39	37	38
Industry	28	32	34	36	32
Residential & Commercial	30	24	21	21	24
Agriculture	5	6	6	6	6
GDP Contribution by Sector[2]:					
Transportation	7	8	9	10	9
Industry	37	42	43	46	42
Residential & Commercial	42	40	38	34	38
Agriculture	14	11	10	10	11

Source: 1. Department of Alternative Energy Development and Efficiency and 2. National Economic and Social Development Board

Modeling Oil Demand using the ADL Single Sector Approach (1981-2007)

Table 2: ADF Statistic Testing for a unit root in level with constant and trend in ADF regression specifications

Sector	Variable											
	OIL		**POIL**		**PSUB**		**GDP**		**K**		**L**	
	t-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag
Agriculture	-1.96	0	-0.28	2	-1.67	0	-3.68*	0	-3.23	3	-2.22	0
Construction	-1.10	0	-1.42	0	-	-	-2.49	1	-1.72	1	-4.78**	0
Electricity	-0.96	3	-3.84*	0	-1.52	0	-1.03	0	-0.09	2	-1.78	0
Manufacturing	-0.67	1	-3.15	0	-1.11	0	-2.21	1	-3.60	1	-1.52	0
Mining	-4.21	3	-0.55	2	-1.63	0	-1.85	2	-0.98	2	-2.96	3
Res. & Com.	-2.35	3	-2.03	1	-1.26	0	-2.16	2	-1.57	0	-1.99	0
Transport	-1.85	1	-0.91	2	-	-	-1.26	0	-1.92	2	-0.92	3

Table 3: ADF Statistic Testing for a unit root in first difference with constant and trend in ADF regression specifications

Sector	Variable											
	OIL		**POIL**		**PSUB**		**GDP**		**K**		**L**	
	t-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag	*t*-statistics	Lag
Agriculture	-4.28*	0	-4.69**	3	-5.74**	0	-6.37**	1	-1.97	0	-5.89**	0
Construction	-4.75**	0	-4.58**	3	-	-	-2.29	0	-2.32	0	-3.28	1
Electricity	-4.10*	2	-4.27*	1	-3.38	0	-3.38*	0	-2.62	3	-4.13*	0
Manufacturing	-3.39	0	-5.39**	0	-4.39*	0	-4.03*	0	-3.56	1	-4.74**	0
Mining	-4.15*	3	-4.32**	3	-5.44**	0	-5.07**	3	-2.29	1	-6.09**	2
Res. & Com.	-5.49**	3	-3.53	1	-4.62**	0	-2.11	0	-4.30	0	-4.29*	0
Transport	-3.39	0	-4.49	3	-	-	-3.68*	0	-1.82	1	-4.18*	2

Note: The ADF test covers the sample period from 1981 to 2007. All variables are in natural logarithms. A maximum of three lags is used to examine the autocorrelation of the residuals. The critical values for *t*-tests at 5% and 1% are -3.63 and -4.44, respectively. The rejection of the hypothesis of the presence of unit roots is denoted by * and ** for 5% and 1% respectively.

Modeling Oil Demand using the ADL Single Sector Approach (1981-2007)

Table 4: The static long-run equation for oil demand by sector

Variable	Agriculture	Construction	Electricity	Manufacturing †	Mining	Residential & Commercial	Transportation
Constant	-22.89*** (-3.27)	10.36 (1.09)	9.09 (0.60)	-29.25*** (-3.99)	7.99 (0.26)	-17.16** (-2.28)	-0.39 (-0.42)
LGDP	0.45 (0.67)	0.18 (0.23)	3.22* (1.87)	2.75** (2.51)	0.49 (0.31)	1.08 (1.11)	0.76*** (5.23)
LK	1.05** (2.16)	-0.79 (-1.33)	-2.52 (-1.50)	-0.66 (-0.92)	-0.61 (-0.41)	-0.55 (-1.04)	-0.16 (1.58)
LL	1.19* (1.89)	1.47 (1.35)	0.36 (0.48)	1.56*** (2.98)	-0.99 (-0.52)	1.60 (1.55)	0.68** (2.09)
LPOIL	-0.27 (-1.17)	-0.91** (-2.00)	-0.23 (-0.19)	-0.87** (-2.71)	0.25 (0.20)	-1.03 (-1.24)	-0.17*** (-3.17)
LPSUB	0.21 (0.42)	-	-0.61 (-0.32)	0.74** (2.20)	-0.11 (-0.03)	1.28 (1.61)	-
Long-run sigma	0.09	0.24	0.37	0.07	0.67	0.13	0.03
Wald test:	$\chi^2(5) =$ 252.317 [0.0000]**	$\chi^2(4) =$ 23.4112 [0.0001] **	$\chi^2(5) =$ 31.157 [0.0000] **	$\chi^2(6) =$ 503.534 [0.0000] **	$\chi^2(5) =$ 0.527401 [0.9911]	$\chi^2(5) =$ 205.827 [0.0000] **	$\chi^2(4) =$ 3210.22 [0.0000] **

*Notes: 1. t-statistics are in ( ). 2. p-values are in [ ]. 3. ***, ** and * denote 1%, 5% and 10% significance level respectively. 4. † indicates that the trend term was included in the model specification of the Manufacturing sector as it helps improve the results comparing with the specification without the trend term. 5. The period of this study starts from 1981 to 2007.*

Table 5: The Specific Model of Oil Demand by sector taking into account the effects of oil price, price of substitute energy, income, labor employment and capital stock

Variable	Agriculture	Construction	Electricity	Manufacturing †	Mining	Residential & Commercial	Transportation
Constant				-0.09*** (-5.85)			
Δ LGDP				1.58*** (6.82)	2.14** (2.73)	1.21*** (4.66)	0.94*** (13.5)
Δ LGDP_1		-0.79** (-2.78)					
Δ LK	-3.26*** (-5.28)	-2.4*** (-5.93)	10.74*** (6.76)	-3.99*** (-5.67)		-0.40*** (-3.09)	
Δ LL	0.32* (1.76)	1.45*** (4.85)		0.66*** (3.80)			0.39*** (4.18)
Δ LPOIL	-0.24** (-2.44)		1.47*** (3.00)	-0.24*** (-3.10)	-1.73*** (-3.47)	-0.79*** (-3.21)	-0.16*** (-3.11)
Δ LPSUB					-1.11 (-1.02)		
ECM_1	-0.74*** (-6.83)	-1.01*** (-7.69)	-0.81*** (-7.08)	-0.59*** (-6.83)	-0.51*** (-4.27)	-0.64*** (-5.50)	-0.55*** (-4.17)
Dummy 1983						0.25*** (-4.16)	
Test Summary							
AR 1-2 test:	F(2,19) = 0.037530 [0.9632]	F(2,19) = 0.023982 [0.9763]	F(2,20) = 0.12864 [0.8800]	F(1,17) = 0.66489 [0.5272]	F(2,19) = 0.28163 [0.7576]	F(2,18) = 0.52501 [0.6003]	F(2,19) = 0.41956 [0.6633]
ARCH 1-1 test:	F(1,19) = 0.36505 [0.5529]	F(1,19) =0.0034011 [0.9541]	F(1,20) = 0.29203 [0.5949]	F(1,17) = 0.020972 [0.8866]	F(1,19) = 5.3151 [0.0326]*	F(1,18) = 0.54240 [0.4709]	F(1,19) = 1.8714 [0.1873]
Normality test	$\chi^2(2) =$ 2.9267 [0.2315]	$\chi^2(2) =$ 2.7966 [0.2470]	$\chi^2(2) =$ 0.96329 [0.6178]	$\chi^2(2) =$ 0.30051 [0.8605]	$\chi^2(2) =$ 3.1036 [0.2119]	$\chi^2(2) =$ 7.7895 [0.0203]*	$\chi^2(2) =$ 4.0372 [0.1328]
Hetero test:	F(8,12) = 4.4005 [0.0109]*	F(8,12) = 1.1384 [0.4051]	F(6,15) = 3.7616 [0.0174]*	F(10,8) = 0.38630 [0.9197]	F(8,12) = 0.68827 [0.6958]	F(9,10) = 3.1529 [0.0440]*	F(8,12) = 0.75955 [0.6434]
Reset test:	F(1,20) = 7.7173 [0.0116]*	F(1,20) = 0.30649 [0.5860]	F(1,21) = 0.18740 [0.6695]	F(1,18) = 3.6847 [0.0709]	F(1,20) = 13.572 [0.0015]**	F(1,19) = 3.8900 [0.0633]	F(1,20) = 0.021020 [0.8862]

Notes: 1. The automatic model selection (Autometrics) is a useful feature in PcGive often used to perform general-to-specific modeling approach by searching through many available reduction paths and selecting the best model that can pass a set of statistical criteria. In this study, the criteria assigning for Autometrics are target size: 0.05 and Outlier detection: Large residuals. For more details please consult Doornik and Hendry (2007).

2. In each sector, the general model before applying Autometrics is of the form:

$$\Delta LOIL_t = \beta_0 + \beta_1\Delta LOIL_{t-1} + \beta_2\Delta LPOIL_t + \beta_3\Delta LPOIL_{t-1} + \beta_4\Delta LPSUB_t + \beta_5\Delta LPSUB_{t-1} + \beta_6\Delta LGDP_t + \beta_7\Delta LGDP_{t-1} + \beta_8\Delta LK_t + \beta_9\Delta LK_{t-1} + \beta_{10}\Delta LL_t + \beta_{11}\Delta LL_{t-1} + \beta_{12}ECM_{t-1} + e_t$$

*3. ***, ** and * denote 1%, 5% and 10% significance level respectively.*

4. t-statistics are in ( ). 5. p-values are in [ ].

6. † indicates that in the Manufacturing sector the ECM term with trend has been used in the General Model.

Table 6A: The estimated coefficients from Dynamic Panel Data Approach

Variable	Model I	Model II	Model III	Model IV	Model V	Model VI
Δ LOIL_1	0.75*** (22.0)	0.76*** (20.8)	0.74*** (13.2)	0.73*** (15.3)	0.62*** (5.59)	0.66*** (6.71)
Δ LPOIL	-0.31*** (-3.75)	-0.40*** (-6.09)	-0.37*** (-5.51)	-0.33*** (-5.63)	-0.33*** (-2.77)	-0.26** (-2.53)
Δ LPELE	-	0.19 (0.26)	0.06 (0.23)	-	-	-
Δ LGDP	0.14* (1.81)	0.15** (2.61)	0.19*** (3.07)	0.20** (2.49)	0.13*** (2.90)	0.31*** (3.89)
Δ LK	-	-	-0.31** (-2.33)	-0.32*** (-3.58)	-0.25 (-1.28)	-
Δ LL	-	-	0.23** (2.57)	0.20** (1.98)	0.47*** (11.2)	-
Constant	0.001 (0.31)	0.003 (0.68)	0.02** (2.21)	0.02** (2.59)	0.03*** (4.99)	0.009*** (3.04)
Group 2 (Construction)	-	-	-	-	-0.04*** (-3.18)	-0.01*** (-3.15)
Group 3 (Electricity)	-	-	-	-	-0.01 (-1.44)	-0.02*** (-2.90)
Group 4 (Manufacturing)	-	-	-	-	-0.02*** (-2.75)	-0.02* (-1.82)
Group 5 (Mining)	-	-	-	-	-0.04*** (-2.77)	-0.04*** (-2.82)
Group 6 (Res. & Comm.)	-	-	-	-	-0.03*** (-10.8)	-0.007* (-1.95)
Group 7 (Transportation)	-	-	-	-	-0.02*** (-3.78)	-0.01* (-1.84)

*Notes: 1. ***, ** and * denote 1%, 5% and 10% significance level respectively. 2. t-statistics are in* ( ). *3. p-values are in* [ ].

Table 6B: Test Summary of the Dynamic Panel Data Approach

	Model I	Model II	Model III	Model IV	Model V	Model VI
Wald (joint):	$\chi^2(3)=$ 715.3 [0.000] **	$\chi^2(4)=$ 873.7 [0.000] **	$\chi^2(6)=$ 2221. [0.000] **	$\chi^2(5)=$ 1995. [0.000] **	$\chi^2(5)=$ 2967. [0.000] **	$\chi^2(3)=$ 236.8 [0.000] **
Wald (dummy):	$\chi^2(1)=$ 0.09424 [0.759]	$\chi^2(1)=$ 0.4627 [0.496]	$\chi^2(1)=$ 4.903 [0.027] *	$\chi^2(1)=$ 6.685 [0.010] **	$\chi^2(7)=$ 1.636e+010 [0.000] **	$\chi^2(7)=$ 41.53 [0.000] **
Sargan test:	$\chi^2(322)=$ 168.9 [1.000]	$\chi^2(321)=$ 150.6 [1.000]	$\chi^2(324)=$ 149.7 [1.000]	$\chi^2(324)=$ 164.8 [1.000]	$\chi^2(325)=$ 172.1 [1.000]	$\chi^2(322)=$ 170.3 [1.000]
AR(1) test:	N(0,1) = -1.345 [0.179]	N(0,1) = -1.349 [0.177]	N(0,1) = -1.364 [0.173]	N(0,1) = -1.354 [0.176]	N(0,1) = -1.400 [0.162]	N(0,1) = -1.402 [0.161]
AR(2) test:	N(0,1) = 1.237 [0.216]	N(0,1) = 1.233 [0.218]	N(0,1) = 1.228 [0.220]	N(0,1) = 1.222 [0.222]	N(0,1) = 1.175 [0.240]	N(0,1) = 1.244 [0.213]

Table 7: Elasticity values of Oil Demand with respect to interested variables from Dynamic Panel Data Approach

	Model I	Model II	Model III	Model IV	Model V	Model VI
SR Price Elasticity	-0.31	-0.40	-0.37	-0.33	-0.33	-0.26
LR Price Elasticity	-1.28	-1.70	-1.42	-1.27	-0.88	-0.76
SR Income Elasticity	0.14	0.15	0.20	0.20	0.13	0.31
LR Income Elasticity	0.57	0.64	0.75	0.77	0.34	0.92
SR Capital Elasticity	n.a.	n.a.	-0.31	-0.32	-0.25	n.a.
LR Capital Elasticity	n.a.	n.a.	-1.19	-1.19	-0.66	n.a.
SR Labor Elasticity	n.a.	n.a.	0.23	0.20	0.47	n.a.
LR Labor Elasticity	n.a.	n.a.	0.88	0.74	1.24	n.a.

Figure(s)

Figures Sectoral Demand for Petroleum in Thailand

Figure 1: Comparative Trend in Thailand's GDP and Total Final Energy Consumption

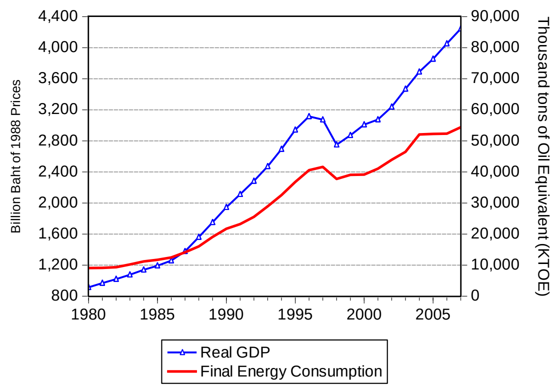
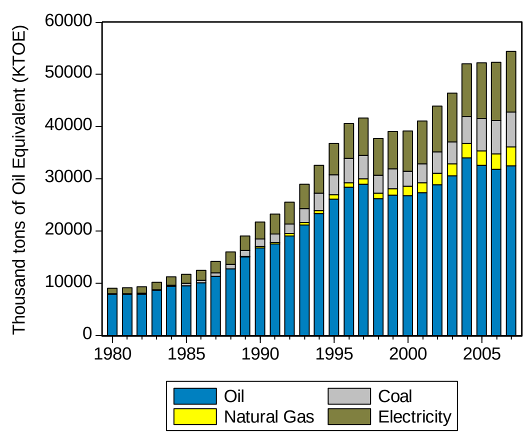


Figure 2: Composition of Thailand's Final Energy Demand



Abstract

This paper examines the short-run and long-run determinants of final oil consumption in seven major economic sectors in Thailand. Two different approaches are compared. The first approach uses dynamic panel data estimation techniques taking into account oil consumption of the whole economy in an aggregate manner. The second approach employs the ADL equilibrium correction framework to model oil demand in each economic sector separately. The dynamic panel data approach estimates appear consistent with economic theory. The coefficients have the correct signs and the magnitudes of long-run responses are larger than the short-run responses. The single sector model approach yields similar but richer results. Relaxing the identical slope assumption reveals interesting sector specific characteristics.

Response to Reviewers’ Comments

Response to Comments of Reviewer 1

Comment #1:
page 2, Residential & Commercial sector: I understood that the Residential sector is basically a big sector in energy statistics. However, the Residential sector does not exist in a standard National Account, apart from residential services. That is, there is no GDP for the Residential sector. It is important to handle this inconsistency problem because GDP is one of the key explanatory variables in the model.

Response to Comment #1:
We agree that the “Residential” sector does not formally exist in the standard National Account. Therefore, we have attempted to use the GDP of the category that best match the “Residential” sector of Thailand.

“Residential” GDP comes from the GDP under the category of “Private Households with Employed Persons”. The data is collected by the National Economic Social Development Board (NESDB), Office of the Prime Minister of Thailand (all data is downloaded from website: http://www.nesdb.go.th/Default.aspx?tabid=94). The energy consumption of the “Residential” sector also follows the same definition of the NESDB, but the energy consumption data is collected by Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy of Thailand (some parts of the data are downloaded from: http://www.dede.go.th/dede/index.php?id=152).

Since the two sources of the data NESDB and DEDE use the same definition and both sources interpret the “Residential” sector in the same way, it can ensure the consistency of data between these two sources.

==

Comment #2:
page 2, the fourth to the sixth paragraphs and the Section on the Literature Review: From the fourth paragraph: 'There have been numerous empirical studies …', to the end of the sixth paragraph: 'Second, not many studies …', should be moved to the Literature Review section. The Literature Review section should be carefully reorganized and revised. Please also refer to the comments below.

Response to Comment #2:
Those paragraphs had been removed from page 2 as suggested and were incorporated into the Literature Review section.

==

Comment #3:
page 3 and the rest of the paper, 'We find that the dynamic …': Please do not use the first-person nouns: 'We', 'I', 'Our' in the present paper. Please use the third person such as: 'the

present paper' or 'this paper' instead.

Response to Comment #3:
We have made changes as advised.

===

Comment #4:
page 4, Literature Review: The basic purpose behind the Literature Review is to provide a solid background of related studies and to support the logic underlying the selection of the methodology/model used in a paper. The authors did not provide a good Literature Review for both reasons; therefore, this section needs to be seriously revised/reorganized. As in the paper, the authors repeatedly state that there are numerous studies in measuring energy demand elasticity. However, the literature review is obviously not sufficient. At least, based on my own recollections, there are many other studies that can be cited or reviewed, such as:

Adams, F. G. & Shachmurove, Y. (2008). "Modeling and forecasting energy consumption in China: Implications for Chinese energy demand and imports in 2020". Energy Economics, 30, 1263-1278.
Akinboade, O. A., Ziramba, E. & Kumo, W. L. (2008). "The demand for gasoline in South Africa: An empirical analysis using co-integration techniques". Energy Economics, 30, 3222-3229.
Eltony, M. N. (1996). "Demand for gasoline in the GCC: An application of pooling and testing procedures". Energy Economics, 18, 203-209.
Houri Jafari, H. and Baratimalayeri, A. (2008). "The crisis of gasoline consumption in Iran's transportation sector". Energy Policy, 36, 2536-2543.
Hu, J. L. & Lin, C. H. (2008) "Disaggregated energy consumption and GDP in Taiwan: A threshold co-integration analysis". Energy Economics, 30, 2342-2358.
Narayan, P. K. & Smyth, R. (2007). "A panel cointegration analysis of the demand for oil in the Middle East". Energy Policy, 35, 6258-6265.
Polemis, M. L. (2006). "Empirical assessment of the determinants of road energy demand in Greece". Energy Economics, 28, 385-403.
Vita, G. D., Endresen, K. & Hunt L. C. (2006). "An empirical analysis of energy demand in Namibia". Energy Policy, 34, 3447-3463.
Zou, G. & Chau, K. W. (2006). "Short- and long-run effects between oil consumption and economic growth in China". Energy Policy, 34, 3644-3655. more …

The way the Literature Review is introduced is awkward. Please arrange the literature chronologically, or based on theoretical classifications, or by importance, or by last name. So far, it is a mess and has no focus at all. Please remember that the basic information regarding the literature should guide the paper to find a reasonable methodology (i.e., your model).

Response to Comment #4:

Thank you for your comments and suggested list of literature. We have rewritten the literature review and your recommended articles which are good sources of references have been included in the revised version of our literature review.

===

Comment #5:
pages 5, Hoa (1992): 'The estimated results are presented in Table 1.': There is no need for Table 1. Please delete it and rewrite the paragraph.

Response to Comment #5:
We have removed Table 1 from the paper and made some changes on that paragraph on page 5.

===

Comment #6:
page 5, section 4.1, Figure 1, and the rest of the paper: Please add the exchange rate of the Thai baht to the US dollar so that international readers can understand the value of the Thai economy and energy prices.

Is the GDP 'real GDP' in this paper? If it is, please change the name of the term to 'real GDP' and keep it consistent with the data. If not, please change it to real GDP.

Response to Comment #6:
We have added the exchange rate in the footnote of page 5.

Yes, it is real GDP. We have made changes for the entire paper from GDP to "real GDP".

===

Comment #7:
page 6, paragraph 'Figure 2 …': Please delete this paragraph and Figure 2 because it is not meaningful at all.

Response to Comment #7:
We have deleted Figure 2 and the paragraph describing Figure 2 from the paper.

===

Comment #8:
page 7 and the rest of the paper: Please change 'figure' to 'Figure'; 'table' to 'Table'; 'equation' to 'Equation'.

Response to Comment #8:
All changes have been made for the entire paper.

===

Comment #9:
page 7, second paragraph: Please change '… in heat and power generation.' to '… in heat and electricity.'.

Response to Comment #9:
The change has been made.

===

Comment #10:
page 7, paragraph 'Figure 4 …': Delete this paragraph and Figure 4 because of the repeated information in Table 4.

Response to Comment #10:
This paragraph has been deleted.

===

Comment #11:
page 7, last paragraph: Please provide major outlets of demand for these energies. Together with the shares in terms of numbers, this information provides readers with a fair idea of who by and large consumes these energies in Thailand.

Response to Comment #11:
As "Section 4.3 Demand for Petroleum Products" has been deleted to save the space, this paragraph has been rewritten as your comments and moved to Section **3.2 Energy Demand**.

===

Comment #12:
page 8, Table 5: Table 5 contains misleading information in its statistics. Structures cannot go together over a period of time. Please delete it and the related description.

Response to Comment #12:
Table 5 and the associated paragraph have been deleted.

===

Comment #13:
page 8, last two paragraphs: From 'This study …' to '… 7) Fuel Oil' are repeated/ redundant wordings. Please delete these paragraphs.

Response to Comment #13:
These paragraphs have been deleted.

==

Comment #14:
page 9, regarding the energy heat conversion information: Those heat conversion data following the first paragraph should be the same as in international energy reference books or energy statistics books; therefore, just cite the reference and delete this redundant

Response to Comment #14:
All conversion factors are removed and the reference has been provided i.e. DEDE (2007).

==

Comment #15:
page 9, above the unit price conversion information: Those conversion data from physical unit prices to heat unit prices following the third paragraph should be in a footnote. Please keep the paper concise and clear.

Response to Comment #15:
All conversion factors are removed and the reference has been provided. Details of calculation are provided in the footnote.

==

Comment #16:
page 9: Please rewrite page 9 consistently in line with the above comments.

Response to Comment #15:
These paragraphs have been rewritten as your comment.

==

Comment #17:
pages 9, the real Capital Stock at 1988 prices: Does the capital stock (stock variable) equal the capital input (flow variable) in economics? If the authors do not have capital input data, then it is better to specify in a footnote why the authors use the capital stock as a proxy for the capital input.

Response to Comment #17:
The explanation is provided in the footnote:
"Theoretically, the data of capital input (i.e. flow of capital services) should be used in the estimation, but this data is not available. In practice, the stock of capital is used instead as a proxy of capital input. This is based on an assumption that each machine/ equipment is used at a fixed amount of hours in a year and thus the flow of capital services is just a constant multiple of capital stock. Therefore, in this case the capital stock really represents the flow of capital services as explained by Barro (2008)."

==

Comment #18:
page 9-10, Methodology: Why use two different methods? Please also follow the above comments in the reference review; the authors should provide a reasonable explanation here.

Response to Comment #18:
This paragraph has been rewritten to explain more details of the rationale behind these two approaches:
"Since the main focus of this study is on the oil consumption behavior of each sector, the study applies the econometric approach of Autoregressive Distributed Lag (ADL) to examine the behavior of each individual sector. However, the big picture of the overall consumption in the economy cannot be ignored as it can be used as a reference of how individual sector behaves comparing with the whole economy. Therefore, the second econometric approach, Dynamic Panel Data Estimation Approach (DPD), taking into account all sectors has been applied. As a result, the ADL approach yields the estimates of demand elasticities for each individual sector while the DPD combines all sectors and estimates the demand elasticity for the economy as a whole. The details of each approach are provided as follows:"

==

Comment #19:
page 11, Dynamic Panel Data Approach: The methodology should have a brief theoretical review and provide references.

Response to Comment #19:
The brief theoretical explanation and references have been added as seen in section **5.2 Dynamic Panel Data Approach**.

==

Comment #20:
page 12, The Static Model and The Dynamic Model and the rest of the paper: All equations should be numbered at the end of the equations.

Response to Comment #20:
All equations have been numbered as your comment.

==

Comment #21:
page 12, 6.2.1: '… of the equation is given by': Which equation is given by this equation? It should be changed to '…of the equation is given by Equation ??'. Obviously, this

equation is exactly the same as The Dynamic Model above. It is really not a good way to repeat the equations again and again. This is also the reason why all the equations need specific numbers.

Response to Comment #21:
"The Dynamic Panel Data Approach" section has been rewritten. All equations are numbered.

==

Comment #22:
page 13: the first paragraph: Change 'In our study' to 'In this paper' or 'In the present paper'. What is the 'the 1-step GMM estimation method'? Please provide a definition or delete it. What are the "group dummies"? Please provide an explanation. If the electricity price is not a good proxy, why do the authors use it as a key variable? Overall, the first paragraph is not clear at all. The authors need to rewrite the first paragraph.

Response to Comment #22:
The change has been made from 'In our study' to 'In this paper'. "The Dynamic Panel Data Approach" section has been rewritten. This section is now shortened and some minor details have been deleted. The explanations for "group dummies" are provided together with references.

The reason of using the electricity price as a proxy is provided in the footnote:
"The reason of using electricity price as a proxy is that apart from oil, electricity is the only energy commonly used by all seven sectors while coal and natural gas are used by only some sectors. If prices of coal and natural gas are included in some sectors but not the others, it will create the problem of inconsistent definition of energy substitute in the panel settings which can in turn affect the accuracy of the estimation"

==

Comment #23:
page 13-14, regarding the definition of differencing in the model: Usually, I(d) represents the numbering for the differencing in time series models. I(0) indicates that no differencing has taken place in the model and I(1) indicates that one difference has been taken in the model. The authors made a mistake to treat I(1) as a no difference model and I(2) as a first difference model. This is not consistent at all in the model's estimation and wording. It is very confusing. In fact, there is only one difference in the whole model throughout the paper. Please revise the error.

Response to Comment #23:
We have made some changes on this paragraph by making it shorter and dropping two tables (Table 6 and 7) out from the paper. The fact that we mentioned about I(2) series because we just want to reiterate that it is unlikely that the K series are I(2). But at the end after testing the series in level and in first differences, we conclude that all series are I(1).

==

Comment #24:
page 13: regarding Tables 6-7: Table 6 and Table 7 are not needed in the paper because they are of no use and due to the redundant wording. Please delete them when rewriting the paper.

Response to Comment #24:
Both Table 6 and 7 have been deleted. As said in the footnote, Table 6 and 7 will be provided to readers upon request.

==

Comment #25:
pages 14, price of oil: '… the limited choices of fuels available in the Transportation sector'. How about the possibilities of price control and the limitations of technology in transportation in Thailand?

Response to Comment #25:
Thank you for pointing out these important reasons. We have included these two reasons in the paragraph:

"From Table 4, the long-run oil price elasticity is inelastic in five of six sectors. As can be expected, the oil price is most inelastic in the Transportation sector with the value of -0.17. This can be explained by the limited choices of fuels and the constraints in transportation technology. Even though the Thai government has promoted the use of more natural gas for vehicles (NGV) and biofuels such as gasohol and biodiesel in the past 10 years, the impacts are still not significant. Conversely the Thai government has pursued low transportation fuel price policies even though the oil market has been fully deregulated since 1991, Amranand (2002). For example, during the U.S.-Iraq War 2003, the Oil Fund[1] was used to stabilize the retail prices for premium gasoline, regular gasoline and high-speed diesel which are the major fuels in the Transportation sector."

==

Comment #26:
page 14-15, regarding the Agricultural sector: On page 14, the paper says that the agricultural sector has limited choices of fuels; however, on page 15, the paper says that they find alternative energy in the Agricultural sector. It is confusing. Please clarify it.

Response to Comment #26:

[1] The Oil Fund was established in 1979 and has been used to stabilize oil prices in Thailand in the unusual events. During periods of unusually high oil prices, the Oil Fund is used to subsidize retailers in order to maintain the level of domestic prices, but during times of normal prices, a portion of revenue from retail oil sales is allocated to the Oil Fund, EPPO (2003).

We have removed the ambiguous part from the page 14. But we have rewriten the new paragraph to explain the situation in the Agricultural sector:

"The situation in the Agricultural sector may be explained by the expansion of the electricity grid in the rural areas. Auto-generators using diesel oil are less utilized and only kept for blackout purposes. Nevertheless, this replacement is still not significant since oil is still a dominant energy required for other machines and equipment used in the field and areas where the electricity grid is not available. Therefore, the elasticity value in the Agricultural sector is positive but relatively small when compared with other sectors."

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Comment #27:
page 17, Table 11: Table 11 is not needed in the paper because of the redundant wording. Please delete it and rewrite the paper.

Response to Comment #27:
This table has been deleted. The result discussion was also rewritten.

===

Comment #28:
page 18, the first, second, and third paragraphs: These paragraphs are not needed in the paper because they are of no use and because of the redundant wording. Please delete them and rewrite the paper.

Response to Comment #28:
These paragraphs have been deleted.

===

Comment #29:
page 18, Table 12: Table 12 is not needed in the paper because they are of no use and the wording is redundant. Please delete it and rewrite the paper.

Response to Comment #29:
This table has been deleted. The result discussion was also rewritten.

===

Comment #30:
page 19 and 21, regarding the short-run elasticity and long-run elasticity: It is better to compare the findings of the long-run elasticity together so as to provide rich implications. Please also state clearly where you get the numbers (e.g., which parts of your model).

Response to Comment #30:
We have rewritten the empirical discussion part and bring the short-run and long-run empirical results to discuss under the same section **6.1.4 Discussion of the Short- and Long-run Elasticities.**

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Comment #31:
page 19, regarding Table 14 in the last paragraph: 'table 14' should be 'Table 13'. Please note that all Tables, Figures, and Equations should be re-numbered when revising the paper.

Response to Comment #31:
We have changed it to Table 5 and all Figures and Equations were re-numbered.

==

Comment #32:
page 20, regarding the appendix or appendices (?): None of the appendices is needed in the paper because they are of no use and the homework-style material is redundant. Please delete all of them.

Response to Comment #32:
All appendices have been removed.

==

Comment #33:
page 22, 'How do our results …': Please move the comparison into the Conclusion section. Do not use first-person pronoun and do not use question sentences. Just state what you find directly.

Response to Comment #33:
This part has been moved to the conclusion section and rewritten as suggested. All first-person pronouns have been changed to the third-person pronouns.

==

Comment #34:
pages 22-23, regarding the Conclusion section: The Conclusion should be rewritten or revised. Please summarize the important findings, the solid policy implications, and the limitations of this paper in this section. Please also add serious directions for future work in relation to this paper (i.e., how the study could be improved in the future).

Response to Comment #34:

The Conclusion section has been rewritten. The policy implications and directions of future research have been added in the Conclusion section as well.

==

Comment #35:
page 24, References: All references must be cited inside the paper. References not cited should be removed from the list of References. Please add any other necessary references (see the above comments).

Response to Comment #35:
List of References has been revised.

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Comment #36:
All Tables, Figures, and Equations must be re-numbered when revising the paper. Delete all unnecessary Tables, Figures, and Equations according to the above comments.

Response to Comment #36:
All Tables, Figures and Equations have been re-numbered.

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Response to Comments of Reviewer 2

Comment #1:
Section 1. Introduction: It should be brief, providing background and rational for and contribution of your undertaking this study. Delete those results and move discussion on other studies to literature review section.

Response to Comment #1:
The Introduction section has been rewritten to make it more concise. It provides some brief background of Thailand petroleum demand, purpose of the study and contributions to the existing literature in this section. The results have been deleted and the discussion on other studies has been moved to the Literature Review section.

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Comment #2:
Section II. As Reviewer 1 points out, this section needs to be heavily revised by providing a solid background of related studies. No need to provide Table 1 for only one other study. With more literature to be added in your revised version, you could use one table to provide different elasticity estimates from other studies instead of lengthy discussion on results from others as you do now in order to save the space. Once one study from others is discussed in this section, don't repeat to introduce it again in other sections, which you do frequently in current version throughout the whole paper.

Response to Comment #2:
The Literature Review section has been significantly revised. The papers recommended by Reviewer 1 have been added to the Literature Review section, which greatly help inform the readers and provide a solid background for the work in this paper comparing with the related past studies. Table 1 has been deleted.

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Comment #3:
There is no Section III in your current version.

Response to Comment #3:
All sections are re-numbered and they are now consistent with the content in the text.

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Comment #4:
Section IV. Review of Thailand's Petroleum Demand by Economic Sectors:
Delete this whole Section, and put brief introduction of energy-related issues that are currently in this Section into Introduction Section.

Response to Comment #4:

This section has been deleted. A brief summary of the demand for petroleum products for each sector has been added to the Introduction section to inform readers, which will allow them to better understand the situation of oil demand in Thailand and make more sense for them when discussing the estimated results.

This paragraph is newly added to section **3.2 Energy Demand**.

"…Final oil consumption is composed of seven major petroleum products, namely liquefied petroleum gas (LPG), kerosene (jet fuels), premium gasoline, regular gasoline, high-speed diesel (HSD), low-speed diesel (LSD), and fuel oil. In Thailand, high-speed diesel takes the largest share of about 42 percent of the total petroleum consumption and the major consumers of this product are the Transportation and Agricultural sectors with the share of about 74 and 19 percent of the total HSD consumption respectively. The second major petroleum product is fuel oil; it accounts for about 21 percent of total petroleum consumption while the Manufacturing and Electricity sectors take the largest share equally about 43 percent of total fuel oil consumption. The third one is kerosene/ jet fuel with the share of about 11 percent of total oil consumption where the largest consumer is the Transportation sector of about 98 percent of total kerosene consumption (aviation fuel) while the Residential and Commercial sector's share has decreased continuously to only about 2 percent. Premium and regular gasoline take about almost the same proportion at 9 percent of total petroleum use and the largest consumer of both products is the Transportation sector with the share of 99 and 97 percent respectively. The LPG share has increased gradually and averaged at about 8 percent of total oil consumption with Residential and Commercial sector taking the largest share of 70 percent followed by Manufacturing sector with the share of 19 percent of total LPG consumption. Low-speed diesel takes the smallest share at only about 0.5 percent of total petroleum use and the major consumers are the Transportation sector and Manufacturing sector with the share of about 75 and 22 percent of LPG use respectively."

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Comment #5:
Section V. Data: Don't use bullets for list of sectors and products considered to save the space. No need to discuss how to calculate/convert prices. No need to list conversion factors - providing references is sufficient.

Response to Comment #5:
All bullets have been removed from the Data Section. The discussion of how to calculate the weighted prices has been dropped out. The conversion factors are not reported anymore. Only the source of the conversion factors, DEDE (2007), is cited.

==

Comment #6:
Section VI. Methodology: You implement several econometric techniques/models. More connection of these econometric techniques/models is needed to help readers to

understand/realize the logic behind every econometric analysis.

Response to Comment #6:
The beginning paragraph of this section has been rewritten to inform the readers that there are two approaches, namely ADL (Auto Distributed Lag) and DPD (Dynamic Panel Data) which are discussed in the Methodology Section. It is also emphasized that the ADL approach is used for examining individual sectors while the DPD approach is for the whole economy. The DPD approach methodology has been rewritten as well. Moreover, the original papers discussing this methodology are also provided for readers who want more details.

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Comment #7:
Section VII. Empirical Results: A lot of discussions on elasticity estimates are redundant. Their values in the tables speak themselves, and no need for lengthy discussion in the main text to repeat what is already in the tables. Focus on your discussions on those unusual results.

Response to Comment #7:
The discussion on the elasticity estimates has been shortened. Only the interesting estimates have been discussed in more details by drawing the real situation to support the estimated results.

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Comment #8:
Page 15, Second paragraph below sub-section heading: you wrote "In the Manufacturing sector, the situation is slightly more flexible than the Agricultural sector…" With price elasticity of 0.74 for the former and of 0.21 for the latter, is this relative magnitude of difference just "slightly"?

Response to Comment #8:
This part has been dropped out to save the space.

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