Energy Policy 102 (2017) 406–413

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Policy implications of considering pre-commitments in U.S. aggregate energy demand system☆

Christopher S. Rowland[a], James W. Mjelde[b], Senarath Dharmasena[b,*]

[a] Chevron, Sugar Land, TX 77479, United States

[b] Department of Agricultural Economics, Texas A & M University, College Station, TX 77843-2124, United States

ARTICLE INFO

JEL classification:
Q41

Keywords:
Pre-commitments
Energy demand
Generalized Almost Ideal Demand System model
Almost Ideal Demand System model

ABSTRACT

Linear approximations of the Generalized Almost Ideal Demand System and Almost Ideal Demand System for U.S. energy are compared to contrast the explicit inclusion and exclusion of pre-committed consumption levels. Results indicate that pre-commitment levels, the quantity of a good that is consumed in the short run with little regard for price, helps to better explain energy demand in the U.S. compared to the system that does not explicitly consider pre-commitments. Policy implications are if pre-commitments are a legitimate assumption, larger price changes are necessary to achieve a given policy objective than if there are no pre-commitments.

1. Introduction

Energy commodities strongly influence the economies of industrialized nations. What makes these commodities unique are the capital and products that depend on them. Oil derivatives, for example, are virtually without substitutes in their roles, including powering and lubricating internal combustion engines. Own-price demand elasticities of energy commodities are expected to be highly inelastic. Such inelastic short run own-price elasticities are consistently found in the literature (Bohi and Zimmerman, 1984; Gately and Huntington, 2002; Krichene, 2002; Cooper, 2003; Labandeira et al., 2012). Inelastic own-price elasticities imply that price increases have little impact on quantity demanded in the short run. Inelastic elasticities arise because energy dependent capital is expensive and purchased in advance by industry and individuals to produce short-run levels of output. These elasticities, however, do not take into account the potential effect of pre-commitment to energy consumption.

Pre-commitments are defined as the quantities of goods that are consumed in the short run with little regard for price; demand is almost perfectly price inelastic. If individuals have committed to consume a given quantity of a commodity then a price change for that commodity will have little effect over that portion of the demand curve. Over the committed portion of demand, the commodity can be treated as non-discretionary with correspondingly inelastic price elasticity. Once pre-commitments have been satisfied price variations have a larger impact on quantity demanded. This portion of the demand curve can be thought of as discretionary.

Households make many decisions that commit them to energy use in the short run. In deciding where to live (location and size) and which automobile to purchase, a consumer is committing to energy consumption. House location and automobile type for a large part determines commuting costs to work. The household is committing to these costs to remain employed. A discretionary component of the demand for gasoline would be purchasing a tank of gas to go on vacation. Size of the house for a large part determines heating and cooling costs. Although a household may adjust temperature settings (discretionary component), most people have a minimum or maximum temperature they are willing to accept; they do not completely turn off the HVAC equipment (pre-commitment). Purchases of other energy using appliances (TVs, computers, stoves, etc.) also have some pre-commitment level associated with them based on their energy efficiency. Businesses make similar decisions that commit them to certain levels of energy use.

The demand for energy may be more accurately modeled by considering these pre-commitments. Relative to elasticity estimates that do not control for pre-commitment levels, estimated own-price elasticity estimates should be larger in absolute value (more elastic) by including pre-commitment levels. To understand this idea, assume demand can be broken into two components: pre-commitment level consumption (having elasticity near zero) and discretionary consump-

☆ This study reflects the work and views of the authors and does not necessarily reflect the views of their organizations.

* Corresponding author.
E-mail addresses: econchris1@gmail.com (C.S. Rowland), j-mjelde@tamu.edu (J.W. Mjelde), sdharmasena@tamu.edu (S. Dharmasena).

http://dx.doi.org/10.1016/j.enpol.2016.12.041
Received 17 July 2016; Received in revised form 21 December 2016; Accepted 22 December 2016
0301-4215/

tion. Ignoring these two components during estimation would result in an elasticity measure that is a weighted average of the two components. A weighted average of both components misrepresents both components with an elasticity measure that is too large in the pre-commitment portion of the demand curve and too small for the discretionary portion. Ignoring pre-commitment levels will lead to an elasticity measure that is too inelastic. But, one must be careful on the interpretation and use of the estimated elasticities.

All elasticities (e.g. own and cross-price) estimated from a model with explicit consideration of pre-commitments only apply to the discretionary component of consumption and not the pre-commitment levels. Pre-commitment levels by assumption have elasticities equal to zero. In models not explicitly considering pre-commitment levels, the estimated elasticity applies to all consumption. With pre-commitment level scenarios, own-price elasticities are more elastic in the discretionary portion, but much less elastic near the pre-commitment level boundary (nearly perfectly inelastic). Raising the price of a nearly perfectly inelastic good does not do much to curtail quantity demanded. This difference in elasticities must be accounted for in policy analysis.

By modeling the energy system with pre-commitments, the effects of pre-commitments on the elasticities for these commodities can be obtained. Estimation of a system also allows energy commodity interdependencies to be examined, while taking into account error relationships across equations in the system. Specifically, the objective of this study is to examine how accounting for pre-commitment levels influences demand responses to price changes. To accomplish this objective, two systems of demands for oil, coal, and natural gas are estimated. The two systems, which are nested, are compared to examine explicit consideration of pre-commitments on elasticities values. The Generalized Almost Ideal Demand System (GAIDS), which endogenously estimates pre-commitment levels, is compared to the Almost Ideal Demand System (AIDS), which is nested in the GAIDS model and does not explicitly consider pre-commitment levels. By estimating both systems, this study addresses the gap in the literature of the lack of explicitly considering pre-commitments in energy demand studies and the potential ramifications of this omission.

2. Literature review

Models have been developed to quantify and predict energy demand. Although the specific approaches vary, the vast majority of models fall into the category of the lagged endogenous models, which model energy demand as a linear or log linear function of wealth and indexes of price and lagged prices (Dahl and Sterner, 1991). Current and lagged price structures allow for both short and long-run price elasticities to be estimated. In most cases, short run is the marginal effect of current price, while long run is the marginal effect of the lagged price. Dagher (2012) provides an excellent review of the literature focusing primarily on natural gas elasticities but intermixing results on electricity. She notes that only four studies on natural gas elasticities are found in the literature during 2000–2007, but almost 70 studies in each of the seventies and eighties decades.

Early reviews of energy demand literature include Taylor (1977), Bohi and Zimmerman (1984), and Dahl and Sterner (1991). One clear inference from these reviews is that estimated demand elasticities vary considerably from study to study. Dagher (2012) notes one must use consensus estimates from these reviews cautiously as often standard errors are not given. Taylor (1977) states own-price elasticities are around −0.15 in the short run, but more elastic in the long run being around −1. Bohi and Zimmerman (1984), for example, provide consensus estimates of short-run (long-run) own-price elasticities for residential natural gas of −0.1 (−0.5), but note elasticities are uncertain for commercial and industrial sectors.

Dahl and Sterner (1991) in their review of over 100 studies, find the average short-run, own-price elasticity of gasoline is −0.26 and the long-run, own-price elasticity is −0.86. Implications of these elasticities are that past prices have a larger impact on quantity demanded than the current price and that purchasing habits are slow to adjust to price changes. Dahl and Sterner (1991) note the studies surveyed take different approaches on seasonality. They find that there is a striking difference between the results obtained when seasonality is taken into account compared to annual measures. Dahl and Sterner (1991) conclude that seasonal data may be inappropriate because the results are unpredictable and lack robustness, especially in the long run.

Cooper (2003) uses a lagged endogenous model to independently model oil demand for 23 countries. U.S. own-price elasticity is found to be −0.06 in the short run and −0.45 in the long run. Krichene (2002) simultaneously estimated world demand models: one for oil and one for natural gas. In doing so, she is able to take advantage of the robustness and simplicity of the lagged endogenous model while accounting for interdependencies. She finds that short-run, own-price demand elasticities are −0.02 for oil and −0.01 for natural gas (both are non-significant) for the most recent period estimated (1973–1999). Krichene (2002, p. 567) states "...crude oil demand is highly price-inelastic in the short run, as energy consumption is essentially determined by fixed capital..." Lin (2011) estimates oil supply and demand simultaneously using monthly data, but decomposes prices and quantities into Organization of the Petroleum Exporting Countries (OPEC) and non-OPEC, yielding one of the most elastic measures for oil own-price elasticity of −0.95.

Substitution between fuel sources has also been examined. Blackorby and Russell (1989) indicate when there are two or more inputs, the Morishima elasticities are the correct measures of substitution. Energy sources in the U.S. being are generally found to be substitutes (Serletis et al., 2010, 2011; Serletis and Shahmoradi, 2008; Stern, 2012). Serletis and Shahmoradi (2008) examine the substitutability of coal, natural gas, and crude oil in the U.S. using the two semi-nonparametric forms, Fourier and asymptotically ideal demand models. Own-price elasticity estimates for the asymptotic and Fourier models are −0.64 and −0.25 for oil, −1.51 and −1.01 for natural gas, and −0.33 and −0.40 for coal. Income elasticities indicate all commodities are normal goods with natural gas being a luxury good. Their estimates of Morishima elasticities of substitution are generally less than one indicating a limited ability of the U.S. economy to substitute between energy commodities. Joutz et al. (2009) estimates for residential natural gas national own-price elasticities are less negative at −0.09 for the short run than for the long run at −0.18. U.S. regional short run own-price elasticities are estimated to range between −0.13 and 0.01 with long run elasticities being between −0.25 and −0.01.

Several studies have compared parametric to nonparametric models for energy demand (Zarnikau, 2003; Xiao et al., 2007; Karimu and Brannlund, 2013). Karimu and Brannlund (2013) argue that energy demand models relying on parametric models are less robust and more likely to be misspecified than nonparametric models. They argue most parametric models in energy demand are chosen for their computational convenience and ease of interpretation, not for their ability to explain underlying behaviors. Karimu and Brannlund (2013) reject the log-linear specification in favor of a nonparametric specification. The nonparametric model generates own-price elasticities of −0.18 to −0.19 for aggregate energy demand. Zarnikau (2003) found a non-parametric kernel estimator was superior to three common parametric specifications (linear, log-linear, and translog) in electricity consumption. Using the same data set and a different criterion, Xiao et al. (2007) found the translog and AIDS models outperformed the log-linear and linear, which is the opposite of the ranking found by Zarnikau (2003). Xiao et al. (2007, p. 166) conclude "These findings highlight what is already obvious to many energy economists, namely that model selection remains a very difficult task and different model selection criteria may steer one towards different model choices." Stern (2012, p. 326) in his meta-analysis concludes on the topic of interfuel substitution there is less substitutability at the national level than at lower levels of aggregation but additional studies are necessary.

Studies have discussed pre-commitment levels, in general, and have examined pre-commitments in empirical demand estimation for various commodities (e.g. Bollino et al., 2000; Alston et al., 2001; Bigerna and Bollino, 2014, 2105, 2016). Bollino et al. (2000) find a model with pre-commitments satisfies concavity and Slutzky's negativity conditions, concluding that satisfying these regularity conditions provides additional evidence on the adequacy of including pre-commitments. Alston et al. (2001) note pre-commitment quantities are independent of prices. Bigerna and Bollino (2016) estimate a GAIDs demand model for electricity with pre-commitments, however, no discussion of the estimated values is presented. Bigerna and Bollino (2015) suggest hourly elasticity demands show substitutability and complementarity characteristics depending on the hour of the day. In both Bigerna and Bollino articles, little discussion is provided on the pre-commitment levels or on how to use the elasticities. In studies presenting and using the elasticities (Hovhannisyan and Gould, 2014; Bigerna and Bollino, 2105), it is not clear from the discussions that the elasticities apply only to the discretionary part of the demand curve and how the authors adjusted quantities to account for this fact before providing implications of the elasticities with pre-commitments. Further, Marsh and Piggott (2013) note price flexibilities between models with and without pre-commitments are not robust across model specifications. Nonrobustness is expected given the previous discussion on how pre-commitments should influence elasticities. This brief literature review barely scratches the surface of the multitude of energy demand studies, but illustrates the range of studies' objectives and results.

3. Methodology and data

Estimating a linear, reduced form demand equation, the predominant method in the literature, only partially controls for pre-commitment levels through estimation of a constant term. For a more precise treatment and interpretation of pre-commitment levels, the AIDS developed by Deaton and Muellbauer (1980) was extended by Bollino (1987) to explicitly include pre-commitments. This extension gave rise to the GAIDS model. The GAIDS model provides the basis for the demand system estimation

$$w_i = \frac{c_i p_i}{m} + (1 - \sum_i \frac{c_i p_i}{m})\left[\alpha_i + \sum_j \gamma_{ij} lnp_j + \beta_i ln\left(\frac{m - \sum_i c_i p_i}{P}\right)\right] + \varepsilon_i \quad (1)$$

where

w_i is the expenditure (budget) share where $i = 1,2,3$ (oil, natural gas and coal);.

p_i is the inflation adjusted price of oil, natural gas and coal;.

m is the total expenditures on oil, natural gas and coal;.

c_i is the pre-commitment parameter for oil, natural gas and coal;.

α_i and β_i are parameters to be estimated;.

P is the Stone's price index, expressed as $P = \sum_j w_j lnp_j$; and.

ε_i is the random error terms, $\varepsilon_i \sim iid(0,1)$.

For computational convenience, Stone's price index is used. Using Stone's index instead of the translog price index leads to what is known as the Linear Approximate Generalized Almost Ideal Demand System (LA/GAIDS). Pre-commitment levels for each commodity are endogenous. When the pre-commitment levels, c_i, are restricted to zero, the LA/GAIDS reduces to the Linear Approximate Almost Ideal Demand System (LA/AIDS).

A common problem in applied demand analysis is the total expenditure variable, m, suffers from endogeneity, because this variable is calculated using prices and quantities consumed of each energy source (Attfield, 1985). Endogeneity is addressed by using predicted values of total expenditures as an instrument following Capps et al. (1994) and Dharmasena and Capps (2012).[1] Predicted values of total expenditures obtained through regressing observed total expenditures on real gross domestic product (GDP) and on prices of each fuel source are used in lieu of observed total expenditures. Parameter estimates from this auxiliary regression are available from the authors upon request. Serial correlation of residuals is corrected using a procedure suggested by Berndt and Savin (1975). Both demand systems (LA/GAIDS and LA/AIDS models) are estimated using iterated seemingly unrelated regression within the Proc Model procedure (SAS Institute, 2015).

Restrictions to satisfy demand theory of adding up, homogeneity, and symmetry

$$\sum_i \alpha_i = 1, \quad \sum_i \beta_i = 0, \quad \sum_i \gamma_{ij} = 0,$$
$$\sum_j \gamma_{ij} = 0, \text{ and}$$
$$\gamma_{ij} = \gamma_{ji}, \quad (2)$$

are imposed during estimation. Deaton and Muellbauer (1980) find that homogeneity is often rejected, which leads to the rejection of symmetry, given that symmetry is more restrictive than homogeneity. Nevertheless, it is common practice to impose all three sets of restrictions in accordance with economic theory. Further, the addition of the symmetry restriction may not significantly alter results after the imposition of homogeneity (Deaton, 1974). These restrictions are imposed because they are consistent with economic theory and to minimize the number of estimated parameters. Only oil and natural gas equations are estimated with the parameter estimates for the coal equation being derived using the theoretical restrictions.

Following Barnett and Serletis (2008), the regularity conditions of positivity, monotonicity, and curvature are examined after estimation. These conditions arise from the assumption of neoclassical economic theory in the derivation of demand curves from indirect utility functions. Positivity is satisfied when for all observations the indirect utility function is positive. Monotonicity is satisfied if the first gradient vector of the indirect utility function is negative (for expenditure normalized prices). Curvature requires that the monotonicity condition holds and the Allen elasticity of substitution matrix to be negative semidefinite.

Uncompensated, compensated, and Allen elasticity estimates (own-price, cross-price, and expenditure) for both models are presented. Estimated elasticities are short-run given the fixed nature of pre-commitments. Calculated uncompensated own-price and cross-price elasticities are then used to calculate Morishima Elasticities of Substitution (MES) (Blackorby and Russell, 1989). If $MES_{ij}>0$, then the two fuels are Morishima net substitutes, whereas, if $MES_{ij}<0$, two fuels are Morishima net complements. Allen elasticities of substitution (AES) matrix (upper diagonal) are calculated using compensated elasticities and respective expenditure shares for each good (Allen, 1938). If AES >0 then the two goods are net Allen substitutes and if AES < 0, then two goods are net Allen complements.

Annual primary energy consumption by source and prices from 1980 to 2014 for oil, natural gas, and coal (U.S. Department of Energy, 2015) are used in this analysis (35 yearly observations with degrees of freedom for the systems of 53 and 57 for the LA/GAIDS and LA/AIDS models, 35 observations x 2 equations minus the number of parameters). Data units are quadrillion British Thermal Units (BTUs) for each fuel. GDP and the GDP deflator are from the Federal Reserve Bank (2015). Prices are deflated using the GDP deflator to real 2009 dollars in the estimation.

In reporting consumption of primary energy, the Department of Energy controls for double counting of energy used. Coke from coal mined in the U.S., for example, is not included as the energy would be

[1] The adding-up condition of the total expenditure variable (see Eq. (2)) where sum of the product of observed prices and quantities of each good sums to observed total expenditure, m, is still satisfied during estimation, because the expected value of error in the auxiliary regression conducted to generate the m_{hat} is zero.

counted in coal consumption because is an input in generating coke; however, net imports of coal coke are included as this is coal form outside the U.S. Coal consumption includes residential, commercial and electric power sectors, along with industrial coke plants and other industrial consumption. Petroleum consumption is the sum of products supplied for each petroleum product: crude oil, unfinished oils, and gasoline blending components. Natural gas data includes consumption in the following sectors: residential, commercial, industrial, transportation, and electric power. Consumption figures include net imports for all energy sources. Coal prices are free on board prices at the point of first sale excluding freight and insurance costs. Natural gas prices are wellhead prices. Likewise, crude oil prices are first purchase prices.

4. Results

The LA/GAIDS model satisfies the regularity conditions of positivity, monotonicity, and curvature for all observations. Positivity is satisfied for all observations in the LA/AIDS model, whereas, monotonicity and curvature are satisfied for only nine of the 35 observations. As noted by Bollino et al. (2000) satisfying these conditions provides evidence on the adequacy of including pre-commitments in demand models.

Following Ryan and Wales (1998) local curvature is imposed on the LA/AIDS model at the observation that provided the least number of violations of the regularity conditions. Imposition of local curvature provided nonsensical results. Barnett and Usui (2006, p. 124) conclude, “Imposition of curvature alone does not assure regularity, and imposing local curvature alone can have very adverse consequences.” Regularity conditions arise from deriving demand curves from maximizing a consumer's indirect utility function (Barnett and Serletis, 2009). When aggregating to national level, the conditions may be violated. As noted by Muellbauer (1975, p. 525) “... there is, in general, no reason why aggregated market data should obey the same rules as the micro data of any individual even when, as econometricians usually assume, everyone has the same tastes.” For the remainder of the discussion here, the model with local curvature imposed is not discussed because of questionable results. The LA/AIDS model with regularity conditions not imposed leads to some concerns that it is an appropriate form. This model remains in the discussion for several reasons. First, many demand studies ignore regularity conditions (Tenkorang et al., 2015; Hunt and Ryan, 2015) because of various issues including aggregation concerns. Further, the LA/AIDS model is the model most similar to the LA/GAIDS formulation.

Parameter estimates, including the endogenously estimated pre-commitment levels for each commodity demand equation are in Table 1. By far the majority of coefficients are significant at a ten percent level or less in both LA/GAIDS and LA/AIDS specifications. With the exception of the pre-commitment levels, the parameters themselves do not directly yield to economic interpretation. All three pre-commitment levels are significant at the one percent level. In BTU terms, oil has the largest pre-commitment level. Pre-commitment levels account for 87% of average oil consumption, whereas pre-commitment levels are 60% and 69% for natural gas and coal (Table 2).

Adjusted R^2's are nearly identical between the two models (Table 1). A Wald test with the null hypothesis that the three pre-commitment levels are jointly equal to zero is rejected at the 0.0001 level. This test suggests the LA/GAIDS model is more appropriate than the LA/AIDS model. Demand forecasts for each commodity are also used as a measure to compare the models. Given the small number of observations, in-sample forecasts are generated rather than the preferred out-of-sample forecasts. The actual annual quantity of each commodity consumed, as well as, quantity demanded estimates using LA/GAIDS and LA/AIDS are graphed in Fig. 1. As expected, the estimated quantities are similar. Both systems forecast oil and natural gas “better” than coal. In-sample mean squared errors and mean absolute deviations by commodity and for the system as a whole for each model are presented in Table 3. The LA/GAIDS specification by these two measures performs better than the LA/AIDS for each fuel source and the system as a whole.

Elasticities calculated at the variable means are presented in Tables 4, 5. One premise for this study is relative to elasticity estimates that do not control for pre-commitment levels, elasticity estimates should be larger in absolute value (more elastic) by explicitly considering pre-commitment levels. This premise should especially hold for own-price elasticities. Of the 33 elasticities presented in Tables 4, 5, the elasticities associated with the LA/GAIDS specification are larger in absolute value for 26 of the estimates. All own-price elasticities are more elastic in the LA/GAIDS specification. The seven that did not have a larger absolute value are: uncompensated cross-price for oil and natural gas, oil and coal, and coal and natural gas; compensated cross-price elasticities for oil and natural gas; Morishima elasticity for natural gas and oil; Allen elasticity for oil and natural gas; and the expenditure elasticity for oil. The Morishima elasticity and the uncompensated cross-price elasticity for coal and natural gas are not significant in either specification. These results are similar to Radwan et al. (2009) results, in which the Marshallian own-price elasticities are larger for most but not all commodities when estimating a GAIDS versus an AIDS demand model.

Table 1
Energy commodity system parameter estimates for the LA/GAIDS and LA/AIDS models.

	LA/GAIDS		LA/AIDS	
Parameter	Estimated coefficient	Standard error	Estimated coefficient	Standard error
c_1	30.5639***	1.0492		
c_2	13.1208***	4.3792		
c_3	13.5273***	1.6666		
γ_{11}	0.2297***	0.0421	0.2164***	0.0055
γ_{12}	−0.1612***	0.0529	−0.1501***	0.0061
γ_{13}	−0.0684***	0.0205	−0.0663***	0.0039
γ_{22}	0.1847***	0.0664	0.1693***	0.0092
γ_{23}	−0.0235	0.0196	−0.0192***	0.0063
γ_{33}	0.0919***	0.0187	0.0855***	0.0063
α_1	−0.3764	0.3719	0.1222	0.1266
α_2	1.2173***	0.3417	0.5630***	0.1547
α_3	0.1591	0.1223	0.3148***	0.1019
β_1	0.2148**	0.0863	0.0966***	0.0310
β_2	−0.2238**	0.0835	−0.0644*	0.0379
β_3	0.0090	0.0313	−0.0322	0.0248
rho[a] oil	0.9167***	0.0737	1.0136***	0.0216
rho natural gas	0.9737***	0.0445	1.0326***	0.0507
$\bar{R}^2$		0.99		0.99
R^2		0.99		0.98
Objective Function Value		1.6571		1.7429

2) Total expenditures.
* Indicates that the estimated coefficient is statistically significant at the 10% level.
** Indicates that the estimated coefficient is statistically significant at the 5% level.
*** Indicates that the estimated coefficient is statistically significant at the 1% level.
[a] Rho is the first order autocorrelation coefficient correcting for first order autocorrelation/serial correlation in each equation.

Table 2
Pre-commitment levels as a percentage of average quantity demanded[a].

Commodity	Average	Pre-commitment	Pre-commitment Percentage
Oil	35.14	30.56	87.0
Natural Gas	21.81	13.12	60.2
Coal	19.67	13.53	68.8

[a] All units are quadrillion BTU / year. The “Average” column displays the average quantity demanded for the respective commodities over the data period. The “Pre-commitment” column is the endogenously estimated pre-commitment level. The “Pre-commitment Percentage” is the pre-commitment level as a percentage of average quantity demanded.

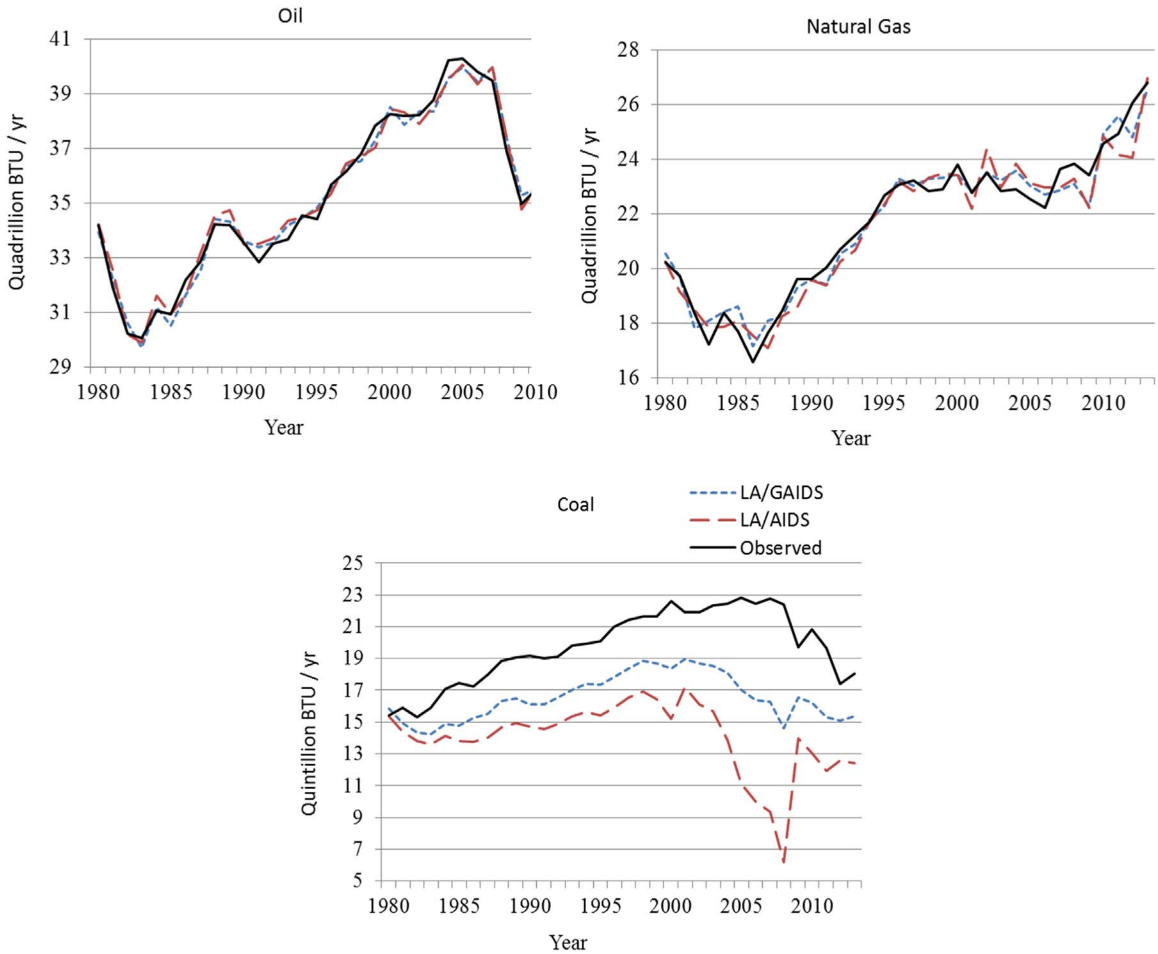

Fig. 1. In-sample estimates for oil, natural gas, and coal, using LA/GAIDS and LA/AIDS models and actual consumption for 1980–2013. For clarity, the y-axis varies by graph.

Table 3
Calculated in-sample mean squared error and mean absolute deviation between the predicted quantity consumed and actual quantity consumed in quadrillion BTU / year.

	Mean Squared Error		Mean Absolute Deviation	
Commodity	LA/GAIDS	LA/AIDS	LA/GAIDS	LA/AIDS
Oil	0.117[b]	0.144	0.301[b]	0.304
Natural Gas	0.320[b]	0.432	0.453[b]	0.5322
Coal[2]	12.42[b]	30.883	3.181[b]	5.677
System[a]	4.524[b]	14.626	1.312[b]	2.171

[a] System mean square error is the average of predicted minus actual for all three commodities.
[b] Smallest value for a given energy fuel (row) and metric.

All Allen, compensated, and uncompensated own-price elasticities are negative and significant for both specifications, except for compensated and Allen coal own-price elasticities in the LA/GAIDS specification, which are not significant. As previously noted, own-price elasticity measures for each commodity estimated using the LA/AIDS specification are more inelastic than own-price elasticity measures estimated using LA/GAIDS (at the average price and consumption levels). These results reinforce the intuition that if pre-commitment levels are a legitimate restriction on demand then own-price elasticity estimates that do not account for pre-commitment levels will be more inelastic. Differences between the uncompensated (gross elasticities or expenditure effects remain in the elasticities) and compensated (expenditure effects removed) are seen in the cross-price elasticities. All uncompensated cross-price elasticities in both specifications are negative and significant except coal and natural gas cross-price elasticity which is not significant. More of compensated cross-price elasticities become positive in the LA/AIDS model than in the LA/GAIDS model. Further, approximately one-half of the compensated elasticities are insignificant. The main difference in the Allen cross-price elasticities is the oil-natural gas cross-price elasticity is negative and insignificant in the LA/GAIDS specification, but positive and significant in the LA/AIDS specification.

All expenditure elasticities for both the LA/GAIDS and LA/AIDS specifications are positive and significant. Taking expenditure elasticity as a proxy for income (or wealth) elasticity, as is widely used in applied analyses, all energy sources are normal goods. Expenditure elasticities are larger in the LA/GAIDS specification except for oil.

All Morishima elasticities between the three energy sources are positive for both specifications indicting the fuel sources are substitutes. Five of the six Morishima elasticities are significant at the one percent level in the LA/GAIDS specification, but only one Morishima elasticity is significant at the one percent level in the LA/AIDS specification. Two additional Morishima elasticities are significant at the 10% level in LA/AIDS specification. Statistical significant Morishima elasticities in the LA/GAIDS specification are: natural gas and coal substituting for oil; coal substituting for both oil and natural gas; and oil substituting for coal. In the LA/AIDS specification, significant Morishima elasticities are between oil substituting for both natural and coal and natural gas substituting for coal.

4.1. Examples of the impact of pre-commitments

Several examples using the short-run own-price elasticities (calcu-

Table 4
Uncompensated and compensated estimated elasticities for LA/GAIDS and LA/AIDS models.

	Oil	Natural Gas	Coal	Expenditure Elasticities
LA / GAIDS				
Uncompensated own and cross-price				–
Oil	−1.354***	−0.183***	−0.076***	0.623***
	0.069	0.018	0.007	0.126
Natural Gas	−1.163***	−1.091***	−0.117***	1.85***
	0.206	0.198	0.018	0.235
Coal	−0.668***	−0.067	−0.868***	0.988***
	0.206	0.064	0.066	0.267
Compensated own and cross-price				
Oil	−0.970***	−0.011	−0.010	
	0.034	0.026	0.009	
Natural Gas	−0.024	−0.580**	0.079***	
	0.058	0.232	0.021	
Coal	−0.058	0.206***	−0.668***	
	0.055	0.056	0.206	
LA / AIDS				
Uncompensated own and cross-price				–
Oil	−0.746***	−0.287***	−0.124***	1.157***
	0.032	0.017	0.008	0.050
Natural Gas	−0.399***	−0.324***	−0.044	0.767***
	0.087	0.045	0.028	0.137
Coal	−0.437***	−0.096	−0.163**	0.697***
	0.147	0.083	0.067	0.234
Compensated own and cross-price				
Oil	−0.032***	0.033***	0.001	
	0.009	0.010	0.006	
Natural Gas	0.075***	−0.112***	0.037	
	0.022	0.033	0.022	
Coal	0.007	0.097	−0.089	
	0.037	0.062	0.059	

All elasticities are calculated at the mean prices and quantities. Standard errors are given below each elasticity.
*Indicates statistical significance at the 10% level.
** Indicates statistical significance at the 5% level.
*** Indicates statistical significance at the 1% level.

Table 5
Allen and Morishima estimated elasticities for LA/GAIDS and LA/AIDS models.

	Oil	Natural Gas	Coal
LA/GAIDS			
Allen own- and cross-price			
Oil	−1.572***	−0.039	−0.095
	0.055	0.094	0.089
Natural Gas		−2.095**	0.745***
		0.839	0.201
Coal			−7.181***
			0.801
Morishima			
Oil	–	0.908***	0.792***
		0.199	0.067
Natural Gas	0.191	–	0.751***
	0.255		0.069
Coal	0.685**	1.023***	–
	0.259	0.222	
LA/AIDS			
Allen own- and cross-price			
Oil	−0.052***	0.121***	−0.011
	0.014	0.035	0.060
Natural Gas		−0.403***	0.349***
		0.119	0.119
Coal			−0.843
			0.553
Morishima			
Oil	–	0.037	0.039
		0.062	0.069
Natural Gas	0.347***	–	0.119
	0.114		0.090
Coal	0.308*	0.228*	–
	0.153	0.120	

All elasticities are calculated at the mean prices and quantities. Standard errors are given below each elasticity.
* Indicates statistical significance at the 10% level.
** Indicates statistical significance at the 5% level.
*** Indicates statistical significance at the 1% level.

lated at the mean) are presented for clarification (Table 6). If a demand system without pre-commitments is appropriate, a policy aimed at reducing oil consumption could accomplish a decrease in quantity demanded from 7.6 billion barrels (bbls) / year to 7 billion bbls / year by increasing the price of a barrel of oil by 10.5%. The policy goal of decreasing consumption by 0.6 bbls is a 7.9% decrease in oil consumption. Assuming all oil consumed reacts to the price change, the percentage change in quantity demanded divided by estimated own-price elasticity of −0.746 gives the 10.5% price increase. If the demand system with pre-commitments is appropriate, the same reduction in quantity demanded would necessitate a price increase of 44.9%, because of the large pre-commitment level associated with oil. Now only 13% of oil consumed reacts to price, 87% is pre-committed and does not react to price changes. The 0.6 bbls decrease is a 60.7% decrease in discretionary oil consumption of 0.988 bbls (7.6*0.13). Dividing this percentage change by the estimated own-price elasticity of −1.354 gives a 44.9% price increase. Even with an elasticity that is almost double in absolute value, a much larger price increase is necessary because of the reduced amount of quantity demanded that reacts to price. Consider a second example, using the above values. A one percent change in price leads to a 0.057 bbls (0.746%) change in quantity demanded for the LA/AIDS model. In the LA/GAIDS model, the change in quantity demanded is 1.354% of the discretionary consumption or 0.013bbls. This is a 0.176% change of the original 7.6 bbls. Policies aimed at the other commodities in the system results in similar outcomes.

As another example consider the strategic oil reserve. By having ready estimates for pre-commitment levels, the government can establish a cushion of economic viability in terms of how much oil is necessary at minimum to keep the economy running. Such an estimate has implications in calculating its longevity of economic support available if the reserve is tapped. The U.S. petroleum reserve contains approximately 0.641 billion bbls of oil (example uses annual averages for 1993–2015). U.S. imported 1.704 billion bbls of oil from OPEC. The average consumption for the U.S. was 7.024 billion bbls, with a pre-commitment level of 6.111 billion bbls. If OPEC were to embargo the U.S., the U.S. would still be supplied with 5.320 billion bbls (7.024 − 1.704=5.320). To just meet the pre-commitment level without oil from OPEC, there would have to be another 0.791 billion bbls

Table 6
Summary of the examples of considering and not considering pre-commitment levels on oil consumption based on estimated own-price elasticity and pre-commitment percentage.

	LA/AIDS	LA/GAIDS
Example 1		
Current oil consumption (billion bbls / year)	7.6	7.6
Policy goal (billion bbls / year)	7.0	7.0
Goal's percentage decrease in consumption	7.9	7.9
Own-price elasticity	0.746	1.354
Pre-commitment percentage	0	87
Discretionary consumption (billion bbls / year)	7.6	0.988
Necessary price change - percent	10.5	44.98
Example 2		
Current oil consumption (billion bbls / year)	7.6	7.6
Percentage increase in price	1	1
Oil consumption change (billion bbls / year)	0.057	0.013
Own-price elasticity	0.746	1.354
Percent decrease in consumption	0.746	0.176
Example 3		
U.S. Petroleum reserve (billion bbls)	NA	0.641
Oil imported from OPEC		1.704
Average U.S. Oil Consumption		7.024
Average pre-commitment level		6.111
Additional barrels necessary if OPEC embargo to meet pre-commitments		0.791
Petroleum reserve last to meet pre-commitment level (days)		295

(6.111−5.320=0.791) generated from domestic and foreign sources. In this circumstance, the strategic petroleum reserve would provide support for only 295 days (0.641/0.791×365) or about 10 months (Table 6).

5. Conclusion and policy implications

From a practical standpoint, the idea of pre-commitment levels for energy use is appealing. Households and business are going to use some level of energy in their day-to-day activities. A large portion of this energy use is based on factors such as house / business size, automobile / trucks owned, and appliances / equipment installed. Households and businesses cannot easily change these factors; they are committed to a certain energy level. From an economic theory and statistical standpoints, the model containing pre-commitment levels performs better than the specification without explicit pre-commitment levels. The inference being pre-commitment levels are important. A major take away from this study is even if the estimated elasticities are higher in absolute value, the fact that there is a pre-committed (so no reacting) quantity implies that the policy action to achieve a given target must be stronger. In other words, a higher price change is needed to induce a target quantity change. Pre-commitments models provide short-run elasticities.

The demand system which includes pre-commitment levels is more consistent with neoclassical economic theory of indirect utility – from which demand curves are derived. Further, the coefficients representing pre-commitment levels are highly significant. Pre-commitment levels represent 60% or more of average quantity demanded. Because energy prices heavily influence macroeconomic variables, responses to price fluctuations are important in forecasting economic welfare impacts and efficacy of various policies. Concerns of self-sufficiency and climate change, as well as, shifting political climates have brought with them ideologies which affect the energy sector. If policy makers wish to reduce carbon emission, they need an accurate measure of the responsiveness of quantity demanded to price changes, which is captured through price elasticities. They must also be aware of substitution effects. Policies in one commodity market will affect other commodity markets, ceteris paribus. Implications to policy and government involvement in energy markets are readily apparent.

Although not perfectly comparable because of different time periods, type of data, and modeling techniques, the LA/AIDS model estimates of short-run own-price elasticities vary in absolute value to those estimates provided in the literature review. The magnitudes of differences depend on whether uncompensated or compensated elasticities are considered. Previous coal own-price elasticity, for example, are between −0.3 and −0.4; whereas, the uncompensated LA/AIDS estimate is −0.16. Own-price elasticity for oil ranges between −0.02 to −0.25 for previous studies and is −0.7 for the LA/AIDS model. For the LA/GAIDS own-price elasticities are in absolute value either larger or are in the upper range of previous estimates. Coal own-price elasticity is −0.8 for the LA/GAIDS model, which although is still inelastic, is more elastic than previous estimates. For oil, LA/GAIDS own-price elasticity is −1.4. These differences in elasticities are the anticipated result; a model explicitly incorporating pre-commitment levels will find demand is more own-price elastic when quantity demanded is above pre-commitment levels. Another consideration is that when the consumption of any energy commodity in the system is near its pre-commitment level, policy makers need to be aware that price responsiveness of demand is much smaller and price-centric abatement policies will have less of an impact on consumption and more of an impact on consumer wealth.

The Morishima elasticities indicate that in the short run all energy commodities in the system are substitutes (although not all are significant). This finding is consistent with previous studies (Serletis et al., 2010, 2011; Serletis and Shahmoradi, 2008; Stern, 2012). The Morishima elasticities estimates are less than one indicating limited ability to substitute between energy sources. Limited ability is not unexpected given fixed capital discussed early within households and business. Imposing policies on one energy source if that market is independent of the other(s) could unanticipated impacts on the industry in question or the energy sector as a whole. The relationships between commodities could cause a policy to be ineffective. For example, a policy that results in an increase in the price of oil would reduce the quantity demanded of oil, but increase the demand for coal. If the goal of the policy is to reduce carbon emissions by increasing oil prices, coal consumption would increase as a result, yielding potentially greater overall carbon emissions, ceteris paribus.

Additional studies that disaggregate energy by sector would improve our understanding of how pre-commitments affect the demand for energy. Seasonal considerations may also provide some useful insights for policy analyses. Further, other demand specifications that provide for endogenously estimated pre-commitment levels should be developed and estimated to determine the robustness of the idea of pre-commitments and the effect on inferences from demand models. Further work on potential interactions between theoretical conditions and pre-commitments is necessary. The question arises, why does including pre-commitments lead to satisfying theoretical regularity and produces results consistent with the theory? Is this result consistent across other functional forms that explicitly consider pre-commitments and energy demand? Pre-commitments at the micro-level should also be examined.

Although additional research is necessary on pre-commitments, including pre-commitments provides "better" inside into how effective a policy will be in influencing the various energy markets. This is true not only for econometric estimation and satisfying economic theory, but pre-commitments are intuitively pleasing.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Senarath Dharmasena would like to thank Dr. David A. Bessler, Regents Professor, Department of Agricultural Economics, Texas A&M

University for providing insightful comments on several sections of this paper.

References

Allen, R.G.D., 1938. Mathematical Analysis for Economists. Macmillan, London.
Alston, J.M., Chalfant, J.A., Piggott, N.E., 2001. Incorporating demand shifters in the Almost Ideal demand system. Econ. Lett. 70.1, 73–78.
Attfield, C.I.F., 1985. Homogeniety and endogeneity in systems of demand equations. J. Econ. 27, 197–209.
Barnett, W.A., Usui, I., 2006. The theoretical regularity properties of the normalized quadratic consumer demand model. In: Barnett, W.A., Serletis, A. (Eds.), Functional Structure Inference (International Symposia in Economic Theory and Econometrics 18. Emerald Group Publishing Limited, Bingley, U.K, 107–127.
Barnett, W.W., Serletis, A., 2008. Consumer preferences and demand systems. J. Econ. 147, 210–224.
Barnett, W.W., Serletis, A., 2009. Measuring consumer preferences and estimating demand systems. In: Slottje, D.J. (Ed.), Quantifying Consumer Preferences. Emerald Group Publishing Limited, Bingley U.K, 1–36.
Berndt, E.R., Savin, N.E., 1975. Estimation and hypothesis testing in singular equation systems with autoregressive disturbances. Econometrica 43, 937–957.
Bigerna, S., Bollino, C.A., 2014. Electricity demand in wholesale Italian market. Energy J. 35, 25–46.
Bigerna, S., Bollino, C.A., 2015. A system of hourly demand in the Italian electricity market. Energy J. 36, 129–147.
Bigerna, S., Bollino, C.A., 2016. Ramsey prices in the Italian electricity market. Energy Policy 88, 603–612.
Blackorby, C., Russell, R.R., 1989. Will the real elasticity of substitution please stand up? (A comparison of the Allen/Uzawa and Morishima elasticities). Am. Econ. Rev. 79, 882–888.
Bohi, D.R., Zimmerman, M.B., 1984. An update on econometric studies of energy demand behavior. Annu. Rev. Energy 9, 105–154.
Bollino, C.A., 1987. GAIDS: a generalised version of the almost ideal demand system. Econ. Lett. 23, 199–202.
Bollino, C.A., Perali, F., Rossi, N., 2000. Linear household technologies. J. Appl. Econ., 275–287.
Capps, O., Jr., Tsai, R., Kirby, R., Williams, G., 1994. A comparison of demand for meat products in the Pacific rim region. J. Agric. Resour. Econ. 19, 210–224.
Cooper, J.C.B., 2003. Price elasticity of demand for crude oil: estimates for 23 countries. OPEC Rev. 27, 1–8.
Dagher, L., 2012. Natural gas demand at the utility level: an application of dynamic elasticities. Energy Econ. 34, 961–969.
Dahl, C., Sterner, T., 1991. Analysing gasoline demand elasticities: a survey. Energy Econ. 13, 203–210.
Deaton, A.S., 1974. The analysis of consumer demand in the United Kingdom, 1900–1970. Econometrica 42, 341–367.
Deaton, A.S., Muellbauer, J., 1980. An Almost Ideal demand system. Am. Econ. Rev. 70, 312–326.
Dharmasena, S., Capps, O., Jr., 2012. Intended and unintended consequences of a proposed national tax on sugar-sweetened beverages to combat the U.S. obesity problem. Health Econ. 21, 669–694.
Federal Reserve Bank of St. Louis, 2015. FRED economic data. ⟨http://research.stlouisfed.org/fred2/⟩ (accessed 15.06.06).
Gately, D., Huntington, H.G., 2002. The asymmetric effects of changes in price and income on energy and oil demand. Energy J. 23, 19–55.
Hovhannisyan, V., Gould, B.W., 2014. Structural change in urban Chinese food preferences. Agric. Econ. 45, 159–166.
Hunt, L.C., Ryan, D.L., 2015. Economic modelling of energy services: rectifying misspecified energy demand functions. Energy Econ. 50, 273–285.
Joutz, F., Trost, R., Shin, D., McDowell, R., 2009. Estimating regional short-run and long-run price elasticities of residential natural gas demand in the U.S. United States Association of Energy Economics Working Paper 09-021. ⟨http://ssrn.com/abstracts=1444927⟩ (accessed 13.06.08).
Karimu, A., Brannlund, R., 2013. Functional form and aggregate energy demand elasticities: a nonparametric panel approach for 17 OECD countries. Energy Econ. 36, 19–27.
Krichene, N., 2002. World crude oil and natural gas: a demand and supply model. Energy Econ. 24, 557–576.
Labandeira, X., Labeaga, J.M., Lopez-Otero, X., 2012. Estimation of elasticity price of electricity with incomplete information. Energy Econ. 34, 627–633.
Lin, C.Y., 2011. Estimating supply and demand in the world oil market. The J. energy. Development 34, 1–32.
Marsh, T.L., Piggott, N.E., 2013. Measuring pre-committed quantities through consumer price formation. 2013 Conference (57th), February 5-8, 2013, Sydney, Australia. No. 152165. Australian Agricultural and Resource Economics Society. ⟨http://ageconsearch.umn.edu/bitstream/152165/2/CP%20Marsh.pdf⟩ (accessed 16.23.06).
Muellbauer, J., 1975. Aggregation, income distribution and consumer demand. Rev. Econ. Stud. 42, 525–543.
Radwan, A., Gil, J.M., Ben Kaabia, M., Serra, T., 2009. Food safety information and meat demand in Spain. *Contributed paper* prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China. ⟨http://ageconsearch.umn.edu/bitstream/51540/2/IAAE2009-Radwan-Gil-Kaabia-Serra.pdf⟩ (accessed 16.23.06).
Ryan, D.L., Wales, T.J., 1998. A simple method for imposing local curvature in some flexible consumer-demand systems. J. Bus. Econ. Stat. 16, 331–338.
SAS Institute, 2015. SAS 9.4 Statistical software. Cary, North Carolina, USA. SAS OnlineDoc. ⟨http://support.sas.com/documentation/cdl/en/etsug/60372/PDF/default/etsug.pdf⟩ (accessed 16.12.02)
Serletis, A., Shahmoradi, A., 2008. Semi-nonparametric estimates of interfuel substitution in U.S. energy demand. Energy Econ. 30, 2123–2133.
Serletis, A., Timilsina, G., Vasetsky, O., 2010. Interfuel substitution in the United States. Energy Econ. 32, 737–745.
Serletis, A., Timilsina, G., Vasetsky, O., 2011. International evidence on aggregate short-run and long-run interfuel substitution. Energy Econ. 33, 209–216.
Stern, D.I., 2012. Interfuel substitution: a meta-analysis. J. Econ. Surv. 26, 307–331.
Taylor, L.D., 1977. The demand for energy: a survey of price and income elasticities. In: Nordhaus, W.D. (Ed.), International Studies of the Demand for Energy. North-Holland, Amsterdam, 3–43.
Tenkorang, F., Dority, B.L., Bridges, D., Lam, E., 2015. Relationship between ethanol and gasoline: aids approach. Energy Econ. 50, 63–69.
U.S. Department of Energy, 2015. Energy Information Administration. Total energy. ⟨http://www.eia.gov/beta/MER/index.cfm?Tbl=T01.03#/?F=A&start=1973&end=2013&charted=13⟩ (accessed 15.21.05).
Xiao, N., Zarnikau, J., Damien, R., 2007. Testing functional forms in energy modeling: an application of the Bayesian approach to U.S. electricity demand. Energy Econ. 29, 158–166.
Zarnikau, J., 2003. Functional forms in energy demand modeling. Energy Econ. 25, 603–613.