Review of Key International Demand Elasticities for Major Industrializing Economies

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Abstract

This report conducts a selective review of various estimates for energy demand responses. It emphasizes recent empirical studies that include trends from studies published after 2000. Emphasis is placed on the five major emerging or transitional economies in Brazil, China, India, Mexico and Russia, although other important nations like Chile and South Korea are also discussed when studies are available. The review focuses attention on the long-run responses to changes in prices and income after capital stock turnover has been completed. The terminology often refers to elasticities, or the percentage change in energy use divided by the percentage change in price (or income), holding constant all other factors that could influence energy-use decisions. Most studies have focused upon household and transportation use of liquid fuels; many fewer studies have investigated fuels used by industry or commerce or for electric generation. Based upon the available estimates, price and income elasticities for liquid fuels are generally less than one (unity) for many countries and sectors, except for the long-run income effect for transportation purposes, which can range widely by country between 0.24 and 1.75 while averaging 0.94 for all countries.

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1. Motivation and Scope of the Study

The U.S. Energy Information Administration provides annual projections of domestic energy markets through 2050 in its *Annual Energy Outlook* (AEO) and comparable assessments for international energy markets in its *International Energy Outlook* (IEO). These evaluations include cases that provide projected energy markets given different assumptions of macroeconomic growth, world oil prices, technological progress, and energy policies. Other offices within the U.S. Department of Energy often use the models or these projections in their efforts to evaluate the potential energy implications of introducing various policy and technology options in energy markets. For these reasons, it is important to understand and update key response parameters contained in these models as new information is processed. Insights gained from this information will assist in determining key parameters for specifying internal models of global energy markets as well as for understanding and interpreting simulation results for different scenarios.

Among these parameters, specifying determinants of international energy demand behavior is often one of the most challenging. Determining how different sectors across international regions and countries respond to price and income changes plays a critical role in the energy demand projections for any particular scenario. Reliable and consistent data is usually difficult to obtain, particularly for economies that are still industrializing. Countries with rapidly growing industrializing economies, however, comprise an increasing important role in determining trends in global energy markets. Defined as countries currently outside of the Organization for Economic Co-operation and Development (OECD), these economies account for approximately 58% of world total primary energy consumption in 2015. The Reference case in the IEO 2016 calls for their energy demand to grow by 1.9% per year through 2040 compared to 0.6% within the more industrialized OECD countries.

This report conducts a selective review of various estimates for energy demand responses. It emphasizes recent empirical studies that include trends from studies published after 2000. Emphasis is placed on the five major emerging or transitional economies in Brazil, China, India, Mexico and Russia, although other important nations like Chile and South Korea are also discussed when studies are available.[1] The review focuses attention on the long-run responses to changes in prices and income after capital stock turnover has been completed. The terminology often refers to elasticities, or the percentage change in energy use divided by the percentage change in price (or income), holding constant all other factors that could influence energy-use decisions.

Being selective, this document is not intended to be comprehensive in its treatment of the full literature on this heavily researched area. The purpose has been to integrate various research strands to provide an overview of what empirical economists consider to be the main findings related to energy demand responses within the developing world. It is hoped that this collection of studies will serve as a foundation for organizing other estimates that can be added.

The next section provides a brief conceptual discussion of the economic factors that determine energy use. Section 3 discusses the various empirical approaches used by researchers to determine these

[1] Mexico became an OECD member in 1994 and South Korea in 1996, but they are included because their experiences appear relevant to fast-growing industrializing economies.

responses, often from historical data but also from surveys and existing models used by other groups. Section 4 summarizes responses for liquid fuel consumption (principally gasoline or fuel oil) by sector, while section 5 evaluates responses for the other major energy sources—natural gas and electricity. Shifting focus slightly, section 6 examines available macroeconomic responses indicating how the economy's inflation-adjusted gross domestic product (real GDP) changes with energy price movements. Section 7 covers the few estimates available from large-scale, energy-economy models. Conclusions about how responsive energy demand is to price and income along with recommended next research steps are developed in the final section 8.

2. A Conceptual Discussion of Economic Factors Shaping Energy Use

This section begins with a discussion of the stock-utilization framework that distinguishes between short- and long-run energy use decisions. Data constraints often prevent empirical researchers from relying solely upon this approach. The remaining subsections cover several key issues that arise in many empirical studies.

Stock-Utilization Framework

Energy use is a derived demand for meeting a range of energy-using services like space heating, mobility and production of products like steel or vehicles. For this reason, the purchase and use of energy-using equipment, buildings and other capital stock feature prominently in shaping energy demand trends. The gradual purchase of this equipment over time explains why long-run energy responses may differ starkly from their short-run counterparts.

Economists have recognized two distinct and separate decisions about energy use: (1) the purchase of new equipment to replace old equipment or expand activities and (2) its utilization rate. This capital-stock-utilization framework (Fisher and Kaysen, 1962) explicitly represents the normal energy usage associated with specific energy-using technologies and equipment for a particular vintage or year when the equipment is purchased. Utilization rates may vary in the short run as income, price and other economic and demographic factors change. Energy use evolves over a longer period as new capital stock replaces older vintages. Equipment stocks and utilization are aggregated across individual technologies to reach the desired level of aggregation. Although these frameworks rank highly in terms of how they represent actual decisions, they require massive data on energy-using equipment and are not easy to estimate and maintain. These challenges often become overly burdensome when one wants to understand trends across many sectors for an entire economy like the United States.

In a less data-intensive approach, practitioners frequently opt for a variation of the flow-adjustment model (Houtakker and Taylor, 1970) that incorporates the stocks of capital implicitly but that maintain the distinction between short- and long-run effects. This framework assumes that consumers have a long-run desired flow of energy consumption that they want to reach if all equipment could be turned over immediately. In the short run, they can adjust only partially to the difference between desired and actual flows. A popular version of this approach is the Koyck adjusted-lag specification where current energy consumption (Y_t) is explained by current exogenous variables (X_t) like prices and income as well as the last period's consumption level (Y_{t-1}). Using this notation, the estimated equation becomes

$$Y_t = a_0 + a_1 X_t + a_2 Y_{t-1},$$

where the *a* coefficients are estimated parameters. Short-run effects of each independent variable on energy consumption are revealed by the a_1 coefficient, while long-run effects are determined by the ratio, $a_1/(1-a_2)$. Adding additional lagged terms for the independent variable will change the long-run effects, although the dynamic pattern will be similar as actual consumption flows adjust gradually to the difference between desired and actual consumption flows.

The independent variables (X_t) will differ from one empirical study to another depending upon the availability of data for each country. Most studies of industrializing economies surveyed in this paper include real (inflation-adjusted) prices of the fuel and real income or gross national product. When available or relevant, the equations may also include the real prices of other important substitute fuels, the unemployment rate, the interest rate, and occasionally a time trend.

The equations are often estimated in natural logarithms, which means that changes in the variables can be interpreted as percent deviations. Thus, the short- and long-run effects discussed above will also equal elasticities, which are defined as the percent change in consumption (Δ%Y) divided by the percent change in price or income (Δ%X). Some studies estimate total fuel consumption as functions of total income (or GDP), while other studies estimate the equation where both variables are converted to per-capita terms. Below is further discussion of some key independent variables that conceptually could be included.

Irreversible Price Effects

There exists a voluminous literature (e.g., Dargay, 1992, Walker and Wirl, 1993, Dargay and Gately 1995, 1997, 2010, Gately and Huntington, 2002, Huntington, 2010) on the irreversibility of the price impact on energy consumption. A number of studies have estimated an asymmetric response to price, where consumption increases with lower energy prices by much less than it decreased with higher prices in prior years. An important reason for this asymmetric response is that consumers cannot easily replace the more energy-efficient capital stock once energy prices begin to retreat from previous higher levels. This effect is most pronounced after energy prices reach their peak or maximum levels, which for many studies occurs in the period around 1980.

Substitute Fuels

It is very important to represent competition from other fuels and energy sources. Substitute fuel prices can be incorporated directly into either the stock-utilization or the flow-adjustment methods when the interest is in evaluating a single fuel. For example, purchasing new equipment often involves a decision not only about how much energy to use but also about which fuel to use. In these cases, fuel choice is a long-run decision that is tied to the specific equipment that is purchased. In other cases, the new equipment may be able to use more than one fuel depending upon how the equipment is used and which fuel is more competitive. For these applications, substitute fuel prices may affect both the short- and long-run decisions.

In other cases, analysts (e.g., Atkinson & Halvorsen (1976), Fuss, 1977, Pindyck 1979a, 1979b) have evaluated multiple fuels with a systems approach that evaluates the interfuel substitution opportunities. Systems approaches require specifications that are robust across all fuels and sectors if they are to provide reliable estimates of the opportunities to substitute between fuels. It is difficult to extend this approach to most industrializing economies due to data constraints.

Adjustments to Long-Run Path

Even when one cannot represent the capital stock explicitly, it is important to include the process by which energy consumers adjust to variations in long-run energy market and economic conditions. This issue requires one to consider the long-run relationship between energy use and variables like energy prices and economic activity, or what economists call a co-integrating relationship. This relationship may include a time trend in the long-run equilibrium condition if its inclusion is supported by the data.

In the short run, energy use may depart from this long-run relationship because consumers have not yet adjusted their equipment completely to the new conditions. Current decisions are not yet in balance with long-run goals and consumers gradually react over time by moving towards the new long-run equilibrium.[2] This approach is particularly well suited for separating short-run responses and their longer-run counterparts that evolve as energy use gradually moves closer to its optimal long-run path.

Technical Progress

There has been active discussion about the best way to incorporate technical progress and related time-variant processes that govern energy use. There appears to be general agreement that engineering data is often the best way to incorporate this issue (Kouris, 1983a; Kouris, 1983b), but such data frequently fails to cover all of the important end uses. Although the limitations are widely recognized, many researchers argue that including a simple time trend is superior to ignoring this factor altogether (Beenstock and Willcocks, 1981, Beenstock and Willcocks, 1983). Hunt and Ninomiya (2003, 2005) and Hunt, Judge and Ninomiya (2003a, 2003b) offer an alternative approach that captures the exogenous underlying energy demand trend through a stochastic trend. This latter approach has featured prominently in a debate about whether technical progress is truly exogenous or whether it is induced by (particularly large) price shocks. See, for example, the individual papers by Gately and Huntington (2002), Griffin and Schulman, Huntington (2006), and Adeyami and Hunt (2007, 2014).

Growing Importance of Emerging Economies

Empirical studies on emerging and developing economies confront additional data constraints that can often be overcome to some extent in studies on the United States and other industrialized economies. The lack of relevant data often prevents analysts from exploring some important issues that are directly relevant to the rapidly growing emerging economies that are operating at a different stage of development with less mobility, urbanization and industrialization. Energy demand is often considered

[2] Econometricians refer to this adjustment as an error-correction process, where short-run decisions eventually lead back to the desired long-term goals.

more responsive to economic growth and less responsive to fuel prices than its counterpart within the developed world.

3. Approaches for Estimating the Responses

This survey focuses upon estimates of the response of energy consumption by major fuel type to changes in energy-market conditions (e.g., energy prices) and to economic environments (e.g., per-capita gross national product or disposable income). While the term "consumption" will be reserved for the energy use variable itself, the designation "demand" will cover a wider concept that includes the relationship between consumption and its major determinants like energy prices, technical progress, and real GDP (or real income). These responses are summarized by elasticities that measure the percent change in consumption divided by the percent change in either price or real income (real GDP). Reported price elasticity estimates hold constant other important factors like per-capita income, socioeconomic traits or other conditions that are unrelated to energy prices. Reported income elasticities are similar in that they hold constant other factors unrelated to income (or GDP) including energy prices.

Parameters describing energy demand behavior can be drawn from a range of different sources: econometric studies of past behavior, surveys or meta-analysis studies of multiple studies, or existing large-scale energy or energy-economy models.

Econometric Studies[3]

Empirical estimates representing energy demand behavior are derived primarily from econometric studies of past energy demand trends. These studies explain energy consumption levels (or sometimes their changes over time) and their relationship to such factors as economic growth or service activity, energy prices, demographic trends, and technical progress. Projections based upon these estimates will assume that energy demand behavior—the relationship between energy use and prices (or income)—will be similar to the past. Future energy consumption trends may vary from past trends, however, because future energy market prices, demographic drivers and economic activity may shift. Relationships are expressed as linear or linear in logarithms, although polynomial functions are sometimes used as well.

Econometric studies seek to reduce the estimation error, the variation that is left unexplained after independent variables have been included.[4] Standard econometric practice will adjust the estimation procedure to remove any relationship between the current error and past ones (autocorrelation) or to make the error term have similar variances over all observations (homoscedasticity).

A potential bias in the estimated response may exist if one or more of the independent variables used to explain energy use is not exogenous. The most common culprit is the price of energy, which may be

[3] This section is an informal discussion of the basic econometric approach. Interested readers should consult other sources if they want a more technical and precise explanation.

[4] Technically, the estimates minimize the sum of all squared differences between the observed and explained values. The difference or error associated with any one observation can be either positive or negative. Squaring the errors before their summation means that both positive and negative errors contribute to how well the estimate fits the data.

determined endogenously by the same factors explaining energy consumption. Certain circumstances could lead to a situation where the estimated response to price is too low and below its true value. The demand for oil or gasoline within the United States may be one example, because changes in U.S. consumption represent a large share of world oil market activity. This problem will tend to be less serious when prices can be viewed as unresponsive to the market quantity, as might be the case for a single developing country whose consumption does not dominate global markets. It may also be less of a problem if the demand relationship is relatively stable, while the oil supply relationship fluctuates greatly due to OPEC producers. If the researcher considers this bias to be important, s/he will usually adopt an estimation procedure that uses two-stage least squares or an instrumental variable to represent the exogenous component of the price variable.[5]

Cross-section analysis of multiple regions for a given year provides estimates of the long-run response to changes in prices and income. This approach estimates a price and an income response that applies to all regions. It assumes that a region has had sufficient time to adjust to the new price and income conditions.

Time-series analysis of a single region (including vector autocorrelation regression (VAR) and Bayesian methods) allows one to derive short-term responses to key variable changes. This approach often uses lagged values of the dependent (and sometimes independent) variables to provide a more dynamic response that includes both short and long-run effects. When prices in the region do not vary much over time, the estimated response may not be very robust because it covers only a very small price range.

Many recent studies use panel data techniques combining cross section with time series. The data covers a time series for each nation or state within a country. Estimated responses are often similar across the different nations, but techniques do exist that allow for heterogeneous responses across nations. When they include lagged values of the dependent (and sometimes independent) variables, these systems allow both short- and long-run responses to be estimated. There are several reasons why this approach has become more popular. First, more regions are becoming covered by published data. And second, researchers often believe that their estimates are more robust because more varied conditions can be accommodated by allowing data to vary by both regions and time.

Surveys, Meta Studies or Judgment

Other efforts try to assign values for energy consumer responses by reviewing multiple studies that have been done by individual researchers. They can be comprehensive surveys covering the range and representative values (means or medians) of price and income elasticities. A limitation of the survey approach is that each study is done by applying different assumptions and methodologies that make it difficult to compare them appropriately. Meta-analysis studies try to circumvent this problem by estimating the responses found in different studies, after controlling for key differences in their

[5] A more recent technique for deriving short-term responses involves structural vector autoregressive (SVAR) estimates where the signs of the error terms are restricted to be consistent with economic theory. This approach is not discussed here because it requires short-run data that is often not available for countries outside the OECD members. Moreover, the approach estimates the response to surprise events that are unexpected rather than to long-term evolutionary changes often associated with energy outlooks extending a decade or longer.

methodologies. They can be valuable if the researchers have successfully used all of the correct criteria to explain differences in the responses. Otherwise, they can be quite misleading. In both surveys and meta-analysis studies, judgment is often a key ingredient in any effort to be representative, because the literature often includes a few estimates that appear to be "outliers".

Estimates for Existing Macroeconometric, Process and CGE Models

Although all large-scale, energy-economy models allow energy consumption to vary with energy prices and real GDP, it is difficult to summarize these responses. First, they include many elasticity estimates that cover responses for different fuels, sectors and regions. And second, model documentation tends to emphasize the best way to use the system or the framework's structure rather than individual response parameters. Section 6 includes a brief summary of several responses from some larger energy models.

4. Liquid Fuel Consumption

Estimates by Type, Region and Sector

The articles reviewed to date provided 258 different demand estimates.[6] There are fewer studies in this sample because each study often included both price and income responses, as well as more than one specification or region. Table 1 emphasizes that the estimates focus principally upon explaining the consumption of gasoline (178), electricity (30), crude oil (25), and natural gas (16). About 69% of the estimates refer to gasoline, and 74% cover four countries: Brazil, China, India and Mexico.

Table 1. Number of Estimates by Fuel Use

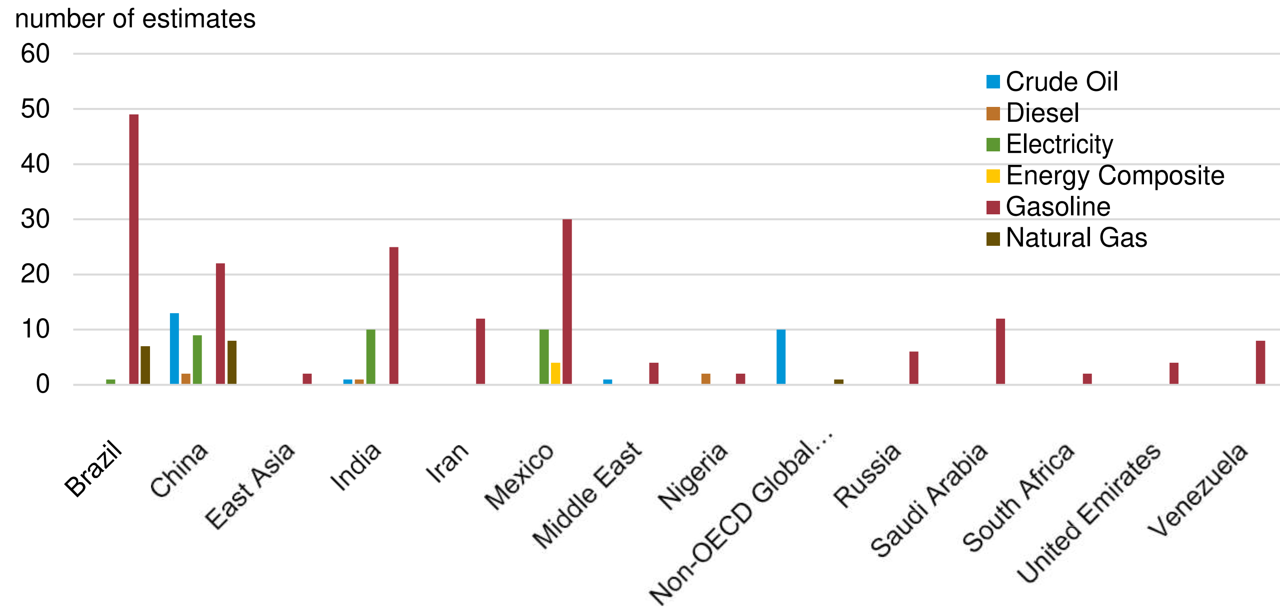
Country/Region	Crude Oil	Diesel	Electricity	Energy Composite	Gasoline	Natural Gas	Total
Brazil			1		49	7	57
China	13	2	9		22	8	54
East Asia					2		2
India	1	1	10		25		37
Iran					12		12
Mexico			10	4	30		44
Middle East	1				4		5
Nigeria		2			2		4
Non-OECD Global Composite	10					1	11
Russia					6		6
Saudi Arabia					12		12
South Africa					2		2
United Emirates					4		4
Venezuela					8		8

[6] Summaries and references for the surveyed studies are presented in Appendix B.

Total	25	5	30	4	178	16	258

This information is also provided graphically in Figure 1.

Figure 1. Number of Estimates by Region and Fuel



These estimates are based upon a very wide range of econometric specifications ranging from ordinary least squares to several estimated with two-stage-least squares. The auto-regressive distributed lag model appears to be a popular approach for deriving both short- and long-run responses. Table 2 displays the adopted procedure by year of publication. In addition, the studies use different data sources from both national accounts and special household surveys. The combined effect of both different methodologies and data sources contributes importantly to the very wide range of results by study. It is unlikely that much of the variation across studies is primarily due to country differences alone.

They are nearly equally divided between income and own-price responses, as revealed by Table 3 and between short- and long-term responses, as shown by Table 4. Again, this information is provided graphically in Figure 2 for elasticity type (price or income) and in Figure 3 for time horizon (short or long run). Most price responses refer to own-price effects (e.g., the effect of gasoline prices on its own consumption) rather than cross-price effects (e.g., the effect of other energy prices for fuels that can be substituted for gasoline consumption). Most estimates are based upon annual data that is more readily available for these countries. Thus, short-run effects can be considered as adjustments that occur within the same year while long-run effects cover a longer period that can reach at least 10 years. The latter may be quite useful for evaluating the longer-run properties of the AEO projections.

Table 2. Number of Estimates by Technique and Publication Year

Row Labels	1984	1994	1996	1997	1998	1999	2003	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
2SLS Regression												6								6
ANCOVA-EC																			4	4
Auto Regressive Distributed Lag											2	50								52
CGE													1						4	5
Cointegration error correction						4	2	4			4							2	4	20
Dynamic OLS														2		6				8
Fixed Effect OLS Non-Spatial															1					1
Fixed Effect OLS Spatial Error															2					2
Fixed Effect OLS Spatial Lag															2					2
Fixed Effect OLS Non-Spatial															1					1
Fully Modified OLS																6				6
GARCH			2																	2
Linear Fixed Effects												2								2
Linear Intersectal						2														2
Log Dynamic OLS																	20			20
Log- multi-var reg	8	2		20			5		4	2	8		6		2		4		5	66
multi-var reg					4			6								4			3	17
Non-Linear Fixed Effects												6								6
PCA Regression																			2	2
Pooled OLS Lag																			1	1
Pooled OLS Non-Spatial															2					2
Pooled OLS Spatial Error															2					2
Pooled OLS Spatial Lag															2					2
Random Effect OLS Non-Spatial															2					2
Random Effect OLS Spatial Error															2					2
Random Effect OLS Spatial Error ML															1					1
Random Effect OLS Spatial Lag															3					3
Random Effect OLS Spatial															2					2
Trans-log												13								13
Time Series																			4	4
Total	8	2	2	20	4	6	7	10	4	2	14	77	7	2	24	16	24	2	27	258

Table 3. Number of Estimates by Country and Elasticity Type

Country/Region	Cross-Price	Income	Own-Price	Total
Brazil	6	26	25	57
China		24	30	54
East Asia		1	1	2
India		17	20	37
Iran		6	6	12
Mexico		19	25	44
Middle East		4	1	5
Nigeria		2	2	4
Non-OECD Global Composite		6	5	11
Russia		2	4	6
Saudi Arabia		8	4	12
South Africa		1	1	2
United Emirates		4		4
Venezuela		4	4	8
Total	6	124	128	258

Table 4. Number of Estimates by Country and Time Horizon

Country/Region	Long-Term	Short-Term	Total
Brazil	22	35	57
China	26	28	54
East Asia	2		2
India	16	21	37
Iran	8	4	12
Mexico	23	21	44
Middle East	5		5
Nigeria	4		4
Non-OECD Global Composite	11		11
Russia	1	5	6
Saudi Arabia	8	4	12
South Africa	2		2
United Emirates	4		4
Venezuela	4	4	8
Total	136	122	258

Figure 2. Number of Estimates by Region and Elasticity Type

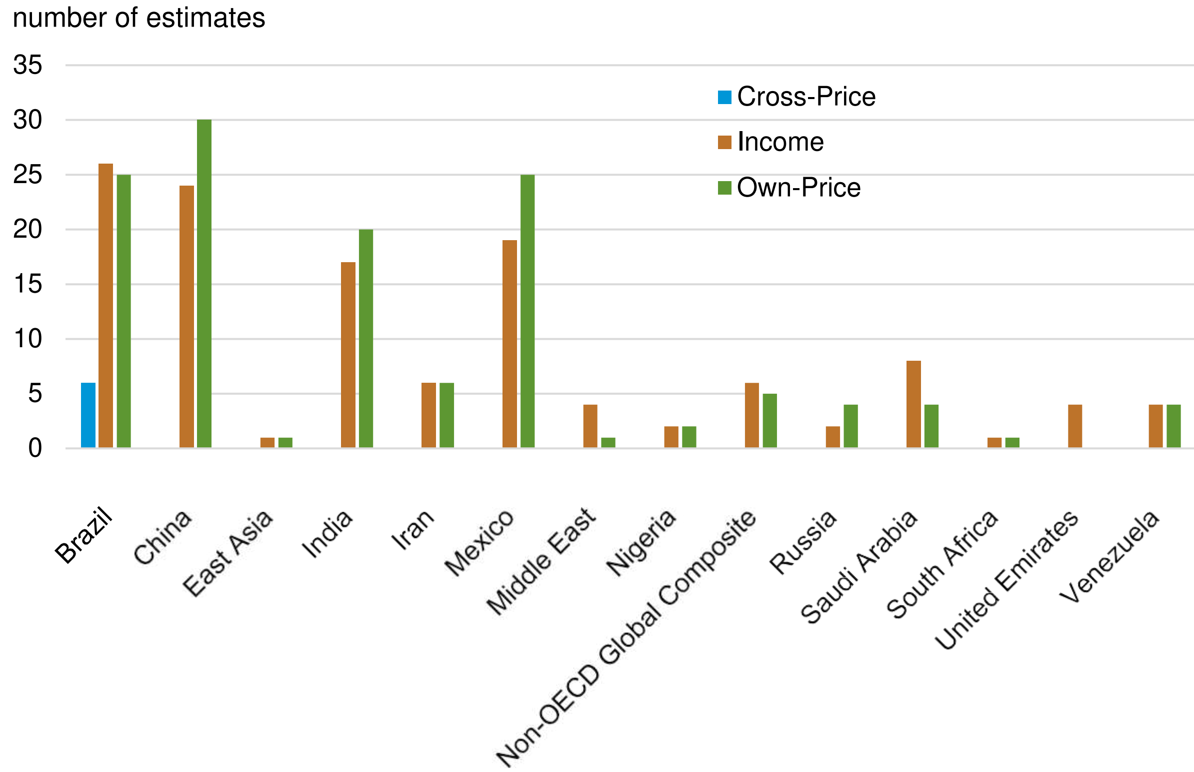
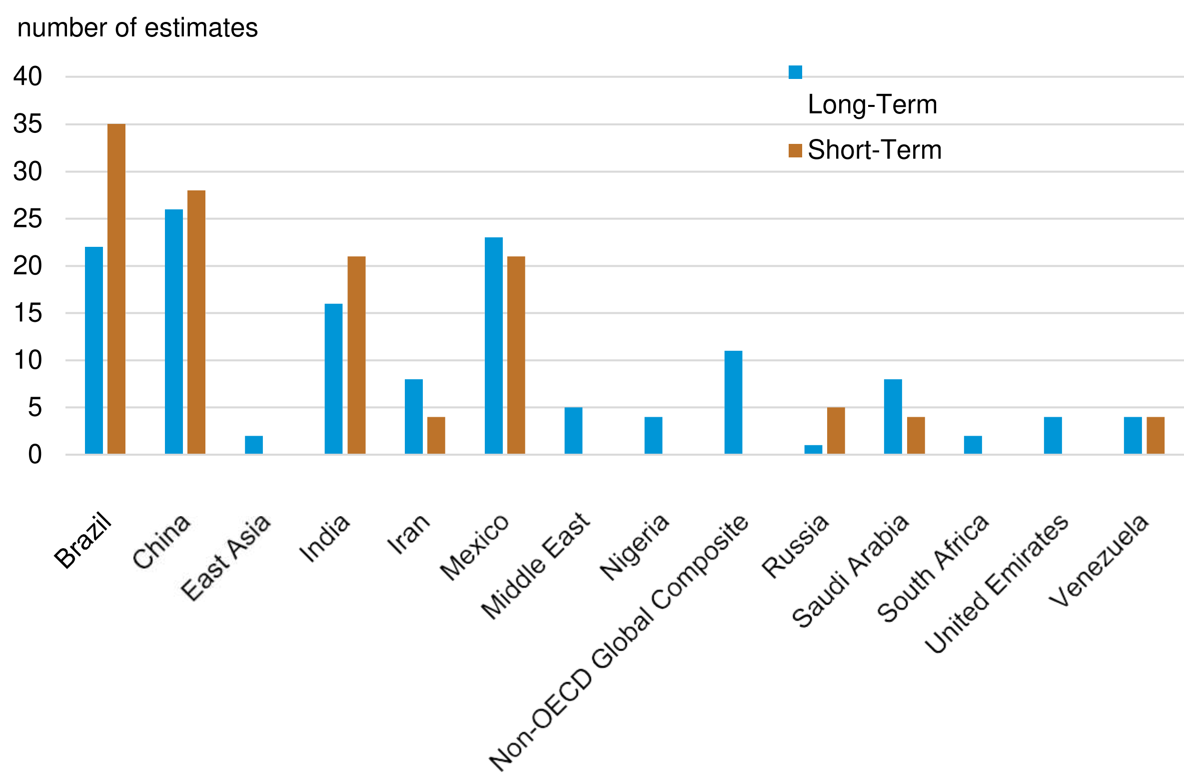


Figure 3. Number of Estimates by Region and Time Horizon



Responses to Crude Oil Prices

Table 5 reports the average income and price elasticities by country and sector for liquid energy products when prices are measured at the crude oil level. For reasons discussed below, these estimates are often smaller than those based upon refined product prices, which will be discussed in the next section. Long-run effects are shown at the top while short-run effects are covered at the bottom.

Each of the first four columns displays results for an end-use sector. This information may be useful when one is primarily interested in the response for a particular end use. The last column displays the average response without regard to which end-use is covered. It summarizes the simple average responses within any country computed from all studies. This is a useful metric when one is primarily interested in the average response across all studies. This result is not weighted by the consumption shares for each sector shown in the first four leftward columns.

The average long-run income response is 0.50 for all estimates, while the short-run response is only slightly lower at 0.39. The average long-run price response is -0.15, while its short-run counterpart is about half at -0.07. Variations by country are very large. Long-run income responses range from 0.42 for all Non-OECD countries combined to 0.66 in China. Long-run price responses appear very small for China (-0.01) but can be about -0.25 in the Middle East and -0.26 for all Non-OECD countries combined.

Gasoline

The survey has a much richer set of estimates for gasoline than for other liquid fuels. Table 6 summarizes the long- and short-run responses by sector and country in the same format as Table 5. Results are few and unreliable for gasoline use outside households and commercial entities that are classified in the industrial sector. Those for the transportation sector are similar to those for all estimates (the last column) because most gasoline studies focus upon household and commercial use in the transportation sector. When averaged across all nations, the long-run income elasticity for the transportation sector (second column) averages 0.94 and the long-run price elasticity averages -0.61. Short-run averages for these two responses are smaller than their longer-run counterparts: 0.64 for the income effect and -0.33 for the price response.

The price elasticities are substantially larger (more negative) in Table 6 than in the previous Table 5. Percent price changes appear in the denominator of the elasticity measure. If refinery costs and taxes do not change, a ten percent increase in crude oil prices will result in a smaller percent increase in end-use prices for gasoline. With a smaller denominator, the measured price elasticity should be higher when prices are measured at the refined product level than at the crude oil level.

Although averages are a useful metric for summarizing the aggregate results, there exists a very wide range in the country-by-country estimates for gasoline use within the transportation sector. Figures 4 and 5 amply demonstrate the broad range in short-run and long-run price elasticities across different countries and regions.[7] Short-run responses range from -0.05 (Venezuela) to -0.77 (Russia) and long-run price responses range from -0.06 (Nigeria) to -1.03 (Brazil). Countries relatively rich with oil resources (e.g., Iran, Nigeria, Saudi Arabia and Venezuela) often have relatively small own-price elasticities that are

[7] Appendix A provides more results on price and income responses by country, relating them to such factors as the GDP level and gasoline price level.

-0.10 or smaller (closer to zero). Households in these countries purchase fuels under administered rather than market prices, a situation where governments apply very large subsidies to prevent prices from increasing when supplies are tight. All consumers may not have readily available access to energy. As a result, these estimates may not adequately represent the true consumer demand response for changes in energy prices. Meanwhile, the higher Brazilian response is expected, because gasoline faces considerable competitive pressure from a vigorous substitute fuel program instituted by the government over the last several decades.

Table 5. Average Crude Oil Elasticity by Region and Sector

Type/Region	Industrial	Power Sector	Residential	Transportation	All Estimates[a]
Long-Term					
Income	0.49		0.54	0.49	0.50
China				0.66	0.66
Non-OECD Global Composite	0.49		0.54	0.23	0.42
Own-Price	-0.33	-0.25	-0.30	-0.03	-0.15
China		-0.25		0.07	-0.01
Middle East				-0.25	-0.25
Non-OECD Global Composite	-0.33		-0.30	-0.12	-0.26
Short-Term					
Income				0.39	0.39
China				0.39	0.39
Own-Price				-0.07	-0.07
China				0.05	0.05
India				-0.41	-0.41

[a] This column reports the average response for a country or region from all studies regardless of end-use sector. It is not an average of the sectoral estimates in the leftward columns, nor is it a consumption-weighted average of these sectoral estimates. The metric reported in this column serves as a useful aggregate indicator of the responses derived from all of the studies.

Table 6. Average Gasoline Elasticity by Region and Sector

Type/Region	Industrial	Transportation	All Estimates[a]
Long-Term			
Cross-Price		0.03	0.03
Brazil		0.03	0.03
Income	2.10	0.94	0.99
Brazil	2.10	0.83	1.15
China		0.84	0.84
East Asia		0.55	0.55

Type/Region	Industrial	Transportation	All Estimates[a]
India		1.53	1.53
Iran		1.75	1.75
Mexico		1.14	1.14
Middle East		0.79	0.79
Nigeria		0.75	0.75
Russia		0.24	0.24
Saudi Arabia		0.50	0.50
South Africa		0.36	0.36
United Emirates		0.43	0.43
Venezuela		1.20	1.20
Own-Price	-0.12	-0.61	-0.58
Brazil	-0.12	-1.03	-0.80
China		-0.91	-0.91
East Asia		-0.41	-0.41
India		-0.40	-0.40
Iran		-0.73	-0.73
Mexico		-0.46	-0.46
Nigeria		-0.06	-0.06
Saudi Arabia		-0.20	-0.20
South Africa		-0.47	-0.47
Venezuela		-0.26	-0.26
Short-Term			
Cross-Price		0.61	0.50
Brazil		0.61	0.50
Income	1.13	0.64	0.66
Brazil		0.44	0.44
China		1.80	1.80
India	1.13	0.82	0.91
Iran		0.08	0.08
Mexico		0.41	0.41
Russia		0.22	0.22
Saudi Arabia		0.52	0.52
Venezuela		0.21	0.21
Own-Price	-0.50	-0.33	-0.34
Brazil		-0.48	-0.48
China		-0.37	-0.37
India		-0.20	-0.20
Iran		-0.10	-0.10
Mexico		-0.22	-0.22
Russia	-0.50	-0.77	-0.70

Type/Region	Industrial	Transportation	All Estimates[a]
Saudi Arabia		-0.08	-0.08
Venezuela		-0.05	-0.05

[a] This column reports the average response for a country or region from all studies regardless of end-use sector. It is not an average of the sectoral estimates in the leftward columns, nor is it a consumption-weighted average of these sectoral estimates. The metric reported in this column serves as a useful aggregate indicator of the responses derived from all of the studies.

Figure 4. Average Short-Run Price Elasticities by Region for Gasoline

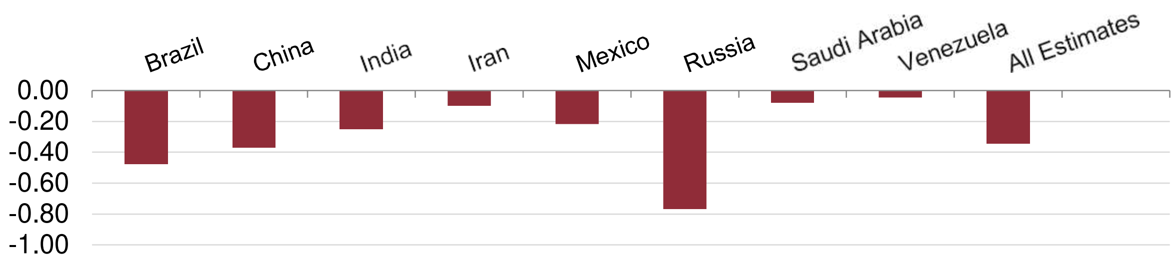


Figure 5. Average Long-Run Price Elasticities by Region for Gasoline

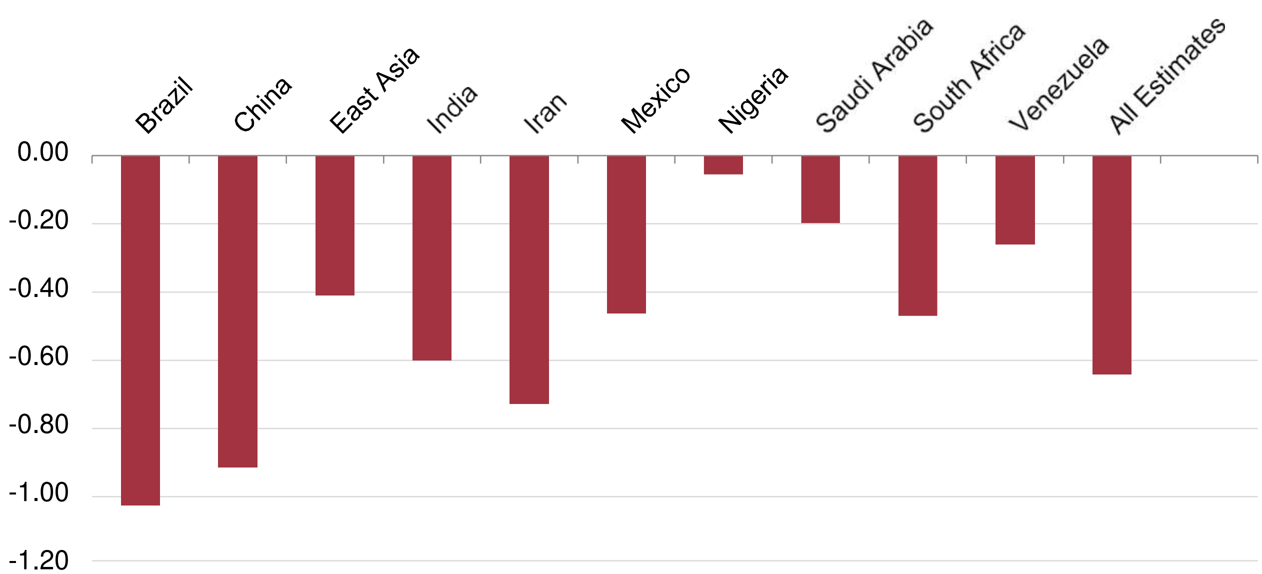


Figure 6 and 7 underscore the variability in the income responses by country for gasoline use in the transportation sector. Short-run income responses range from 0.08 (Iran) to 1.80 (China), while long-run income responses vary between 0.24 (Russia) and 1.92 (India). The results for India and China emphasize the rapid, energy-intensive growth in many Asian economies. Some oil-rich nations have relatively small income elasticities at the moment, but these conditions could shift if these economies become much more diversified in future decades. In addition, subsidies and government allocation, rather than income levels alone, may determine liquid fuel consumption in these countries.

Figure 6. Average Short-Run Income Elasticities by Region and Sector (Liquid Energy Products)

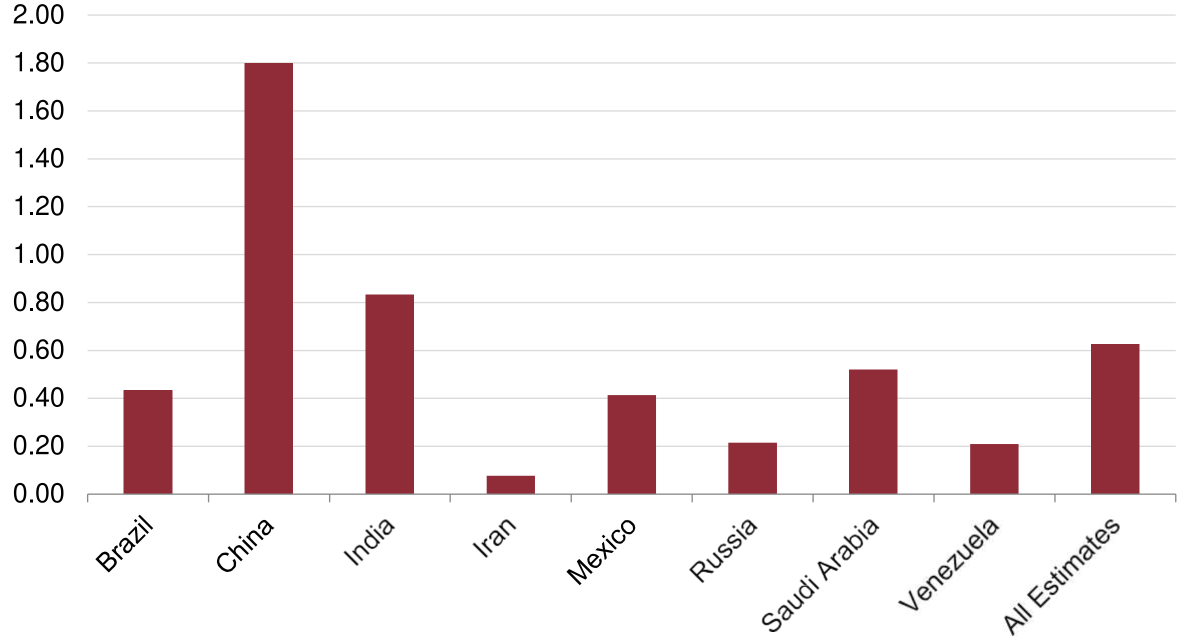
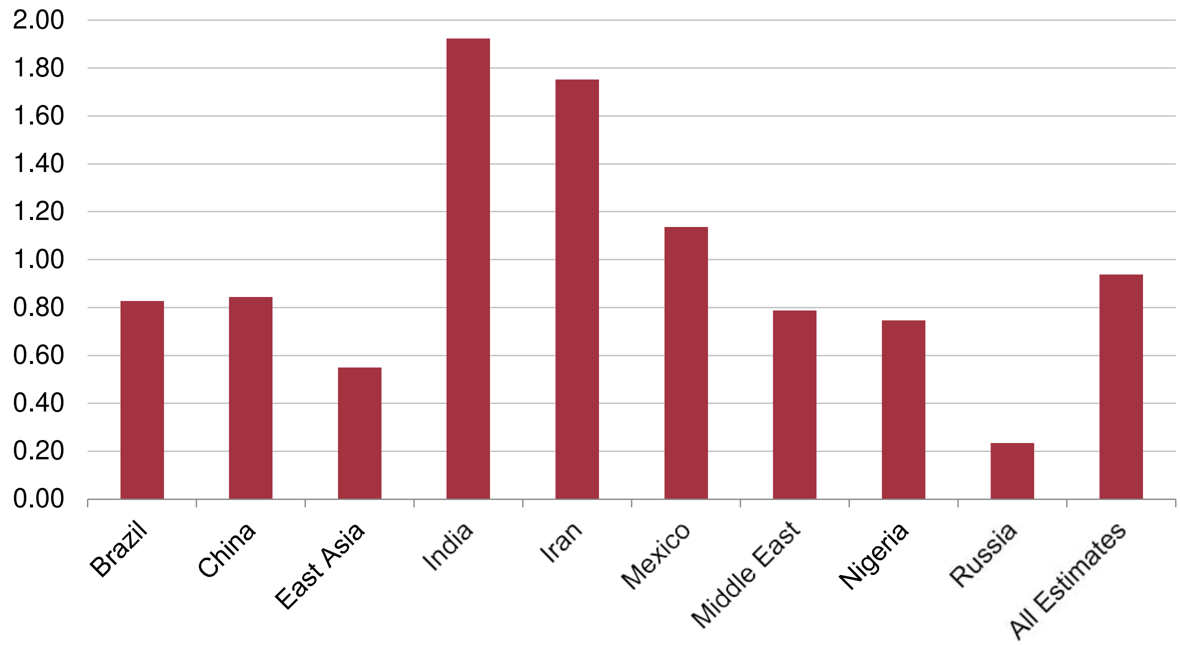


Figure 7. Average Long-Run Income Elasticities by Region and Sector (Liquid Energy Products)



The estimates provide little information about substitution between fuels. This conclusion applies not only to the gasoline results but also to the other estimates in this survey. This gap is unfortunate because many of the interesting policy analysis issues will be focusing on the degree to which natural gas and electricity can replace liquid fuels in the transportation sector. The substitute fuel for the cross-price effects shown for Brazil in Table 6 is alcohol.

Estimates for diesel fuel are rarer. Table 7 reports a long-run own-price elasticity equal to -0.80 in China and a short-run own-price elasticity of -0.41 for India. The Chinese results are classified as residential because the data source was a household survey.

Table 7. Average Diesel Elasticity by Region and Sector

Type/Region	Residential	Transportation	All Estimates[a]
Long-Term			
Income		-0.10	-0.10
Nigeria		-0.10	-0.10
Own-Price	-0.80	0.10	-0.50
China	-0.80		-0.80
Nigeria		0.10	0.10
Short-Term			
Own-Price		-0.41	-0.41
India		-0.41	-0.41

[a] This column reports the average response for a country or region from all studies regardless of end-use sector. It is not an average of the sectoral estimates in the leftward columns, nor is it a consumption-weighted average of these sectoral estimates. The metric reported in this column serves as a useful aggregate indicator of the responses derived from all of the studies.

Findings and Gaps

The major conclusion from the gasoline results suggests that gasoline consumption is both price and income inelastic (absolute value <1) in the short as well as long run. When averaged across all nations, the long-run income elasticity for the transportation sector averages near unity at 0.94 and the long-run price elasticity averages -0.61. Short-run averages for these two responses are smaller than their longer-run counterparts: 0.64 for the income effect and -0.33 for the price response.[8] The longer-run response to price incorporating equipment adjustments appears to be about twice as large as the near term effect. There is also a tendency for price responses to be considerably lower in the major oil-exporting countries than elsewhere. As the developing world matures and vehicle ownership begins to saturate, one should expect lower income responses over time.

Most empirical estimates cover liquid fuels with a heavy emphasis on gasoline consumption. Coverage for petroleum product consumption by industry and for electric generation is much sparser and hence more uncertain. The other major omission is the very limited results for vehicles powered by natural gas, ethanol and electric power, as well as those that are dual fueled.

A promising area for future research will be to expand the analysis to incorporate inter-fuel substitution opportunities for electricity, natural gas, and biofuels as replacements for gasoline or diesel. There is also a need for more evaluation of countries at different stages of development in order to understand the complex role of vehicle penetration in shaping future transportation fuel demands. As available data

[8] At the crude oil level, this short-run response could be about -0.15 if half of the gasoline price covers refinery costs and taxes and these non-crude costs do not change.

covers more industrializing countries over longer durations, pooled samples will provide the basis for evaluating these types of issues.

5. Non-Liquid Fuel Consumption

Outside of liquid fuels, most studies have focused upon natural gas and electricity. There has been very limited investigation of coal use.

Natural Gas

Table 8 summarizes the long-run and short-run responses for natural gas demand by sector and country. The last column summarizes the simple average responses within any country computed from all studies. This response is not weighted by the consumption shares for each sector shown to the left. Averaged across all nations, the long-run income elasticity was 0.89 while its long-run own-price counterpart was -1.36. Both responses appear quite strong, although they are based upon fewer estimates than those for liquid fuels evaluated above. A surprising finding was the very strong price and income responses within the residential sector, relative to those within the power sector. Short-run responses to both price and income appear to be much more modest.

Table 8. Avg. Natural Gas Elasticity by Region and Sector

Type/Region	Power Sector	Residential	All Estimates[a]
Long-Term			
Cross-Price		2.16	2.16
Brazil		2.16	2.16
Income	1.00	0.85	0.89
Brazil		0.66	0.66
China	1.00	1.23	1.12
Own-Price	-0.25	-1.59	-1.36
Brazil		-1.03	-1.03
China	-0.25	-1.88	-1.48
Non-OECD Global Composite		-1.25	-1.25
Short-Term			
Cross-Price		-0.01	-0.01
Brazil		-0.01	-0.01
Income		0.11	0.11
Brazil		0.11	0.11
Own-Price		-0.23	-0.23
Brazil		-0.02	-0.02
China		-0.33	-0.33

[a] This column reports the average response for a country or region from all studies regardless of end-use sector. It is not an average of the sectoral estimates in the leftward columns, nor is it a consumption-weighted average of these sectoral estimates. The metric reported in this column serves as a useful aggregate indicator of the responses derived from all of the studies.

The natural gas responses need to be interpreted carefully. Natural gas use in many industrializing countries is probably more constrained by infrastructure and pipeline availability rather than by price and interfuel competition issues. Strong income elasticities in some countries may reflect decisions by the national government to expand pipelines rather than by end-use natural gas consumers. Additional studies on the fuel would be quite valuable.

Electricity

Table 9 summarizes the long- and short-run responses for electricity demand by sector and country. The last column summarizes the simple average responses within any country computed from all studies without regard to which sector was analyzed. This response is not weighted by the consumption shares for each sector shown to the left.

Table 9. Avg. Electricity Elasticity by Region and Sector

Type/Region	Industrial	Residential	Total[a]
Long-Term			
Income	0.76	0.53	0.59
Brazil		0.48	0.48
India		0.62	0.62
Mexico	0.76	0.28	0.60
Own-Price	-0.81	-0.32	-0.46
China		-0.32	-0.32
India		-0.41	-0.41
Mexico	-0.81	-0.08	-0.57
Short-Term			
Income	0.38	0.36	0.36
China		0.27	0.27
India	0.49	0.88	0.69
Mexico	0.33		0.33
Own-Price	-0.38	-0.49	-0.44
China		-0.42	-0.42
India	-0.45	-0.65	-0.55
Mexico	-0.35		-0.35

[a] This column reports the average response for a country or region from all studies regardless of end-use sector. It is not an average of the sectoral estimates in the leftward columns, nor is it a consumption-weighted average of these sectoral estimates. The metric reported in this column serves as a useful aggregate indicator of the responses derived from all of the studies.

Averaged across all nations, the long-run income elasticity was 0.59, while its long-run own-price counterpart was -0.46. Both responses are considerably less elastic than those for natural gas. Residential sector long-run elasticities are lower than industrial responses—a result that is not unexpected. Again, there are fewer estimates than with liquid fuels. Short-run responses are lower than they are for the long run but still register 0.36 for income and -0.44 for price when averaged across all sectors and countries.

As was the case with natural gas, electricity responses need to be interpreted carefully. Electricity use in many industrializing countries is probably more constrained by infrastructure and electric grid access rather than by price and interfuel competition issues. Strong income elasticities in some countries may reflect decisions by the national government to expand the electrical grid network rather than by consumer decisions.

Aggregate Energy

Table 10 reports the results from one study on aggregate energy use within Mexico. The authors found a short-run elasticity equal to -0.20 and a long-run response equal to -0.35.

Table 10. Avg. Energy Composite Elasticity by Region and Sector

Type/Country	Residential	Total
Long-Term		
Own-Price	-0.35	-0.35
Mexico	-0.35	-0.35
Short-Term		
Own-Price	-0.20	-0.20
Mexico	-0.20	-0.20

Findings and Gaps

It is much more challenging to derive general conclusions about natural gas and electricity demand responses, because access to key infrastructure will often dictate responses within each country. The general impression is that natural gas use may respond strongly to price (with a long-run elasticity in the range of -1.2 to -1.3) and to income (with a long-run elasticity of 0.9). Similarly, electricity use may respond to price with a long-run elasticity in the range of -0.4 or -0.5 and to income with a long-run elasticity of 0.6.

Important caveats include the need for additional studies on a range of countries focused upon electricity and non-liquid fuel use. Until these estimates are done, one needs to qualify what one knows about the underlying demand responses. A promising area for future research will be to expand the analysis to incorporate interfuel substitution opportunities between electricity, natural gas, petroleum products and new energy sources like biofuels.

6. Estimates from Large Energy-Economy Models

The Global Change Assessment Model (GCAM) is a climate framework for exploring climate change mitigation policies. It adopts a dynamic-recursive approach with considerable technology detail in representing the economy, energy sector, land use and water. This framework uses income elasticities that decline over time in order to incorporate eventual saturation of energy-using equipment in the long run. Table 11 reports income elasticities for 2015 and 2040 for six major industrializing economies. Income elasticities for both industry and transportation sectors range widely across key countries. Industry elasticities in 2015 vary between 0.16 for Russia and South Korea to 1.10 for India. By 2040, they decline to 0.12 in Russia to 0.70 in Mexico. Transportation elasticities in 2015 vary between 0.54 in South Korea to 1.20 in India, falling to 0.45 in South Korea and to 1.09 in India by 2040.

Table 11. Income Elasticities in GCAM3

Industry	2015	2040
Brazil	0.599	0.447
China	0.456	0.257
India	1.102	0.647
Mexico	0.82	0.696
Russia	0.158	0.124
South Korea	0.16	0.141
Transportation	2015	2040
Brazil	0.946	0.804
China	1.094	0.698
India	1.202	1.093
Mexico	0.858	0.751
Russia	1.07	0.828
South Korea	0.537	0.452

The current study excludes computable general equilibrium (CGE) models because their structures prevent useful estimates that would be comparable to those derived in this survey. This approach is briefly reviewed in the remainder of this section.[9]

CGE models estimate how an economy might react to changes in policy, technology or other external factors. They employ numerous elasticities showing how easily inputs to production or consumption for different goods and services may be substituted for each other or how final consumption changes with income. Inputs are bundled together in a series of composites, often nested within each other, such as electricity and direct fuels to form an energy composite that can be combined with capital and labor to produce output. Prices and quantities in all sectors are determined endogenously within the framework. Through an input-output framework for the economy, these models can provide important insights when evaluating how changes in one part of the economy (the energy sector) influence the remaining sectors.

It is not meaningful to express the CGE model's outcome in terms of simple price and income elasticities. The challenge is that the response of any energy demand like oil and natural gas to changes in price is governed by several factors: the ability to substitute between fuels in each sector, the market shares of different fuels, the willingness to change the composition of goods and services, the costs of alternative fuels like biofuels, and the costs of important technologies like electric vehicles. These responses depend very much upon the initial conditions such as energy price levels and market shares for different fuels and can vary widely.

Informal discussions with modeling teams like those at the Massachusetts Institute of Technology (MIT) suggest that simulations support that the general equilibrium elasticity of demand for oil and natural gas

[9] Readers who want more information about CGE models and how they compare with other macroeconomic models for representing energy-economy linkages are referred to Arora (2013).

varies across scenarios and by year but are often between -0.35 and -0.6. Another reference point is the values with which CGE modelers use to calibrate their systems. CGE modelers carefully review their parameters to make them as consistent as possible with the empirical literature, such as emphasized in this report. Dimaranan, McDougall, and Hertel (n.d.) report targeted income elasticities of about unity and uncompensated own-price elasticity ranging between -0.2 and -0.6 in the long run for household purchases within the utilities sector that includes electricity and fuels.

It may be possible to derive these responses directly from CGE models by choosing appropriate scenarios, but this effort would not be simple. If one allows changes in the fuel supply conditions (perhaps including fuel tax changes) while holding demand conditions unchanged,[10] there may be some useful insights about energy demand responses.

7. Economy-Wide Impacts of Energy Price Movements

Empirical Studies

Whether they are sudden surprises or gradual long-term shifts, energy price changes have short- and long-run effects on energy use. By contrast, the available empirical literature on oil price changes in developed economies like the United States emphasizes the short-run impacts of sudden surprise upward price shocks. They tend to show little effects from gradual price changes or price decreases. Moreover, they tend to show no long-run effects from energy price changes.

The survey includes 29 estimates for emerging economies outside the OECD membership. Some studies include more than one estimate. Table 12 classifies these 29 estimates by country, with nine of them done for China. For the reasons stated above, these estimates should be considered as short-run estimates that might cover the first two years after a sudden oil price change. Figure 8 shows relatively small GDP impacts (with elasticities -0.03 or less) for most countries, except China (-0.09) and two oil-producing nations (Nigeria and Russia). The very large positive impacts of higher oil prices on the two oil-producing countries reflect the dominant role of the oil and natural gas producing sector in the total economy. This industry's export revenue comprised 58% of Nigeria's total government revenue in 2014.[11] Their revenues accounted for 43% of Russia's federal budget revenues in 2015.[12]

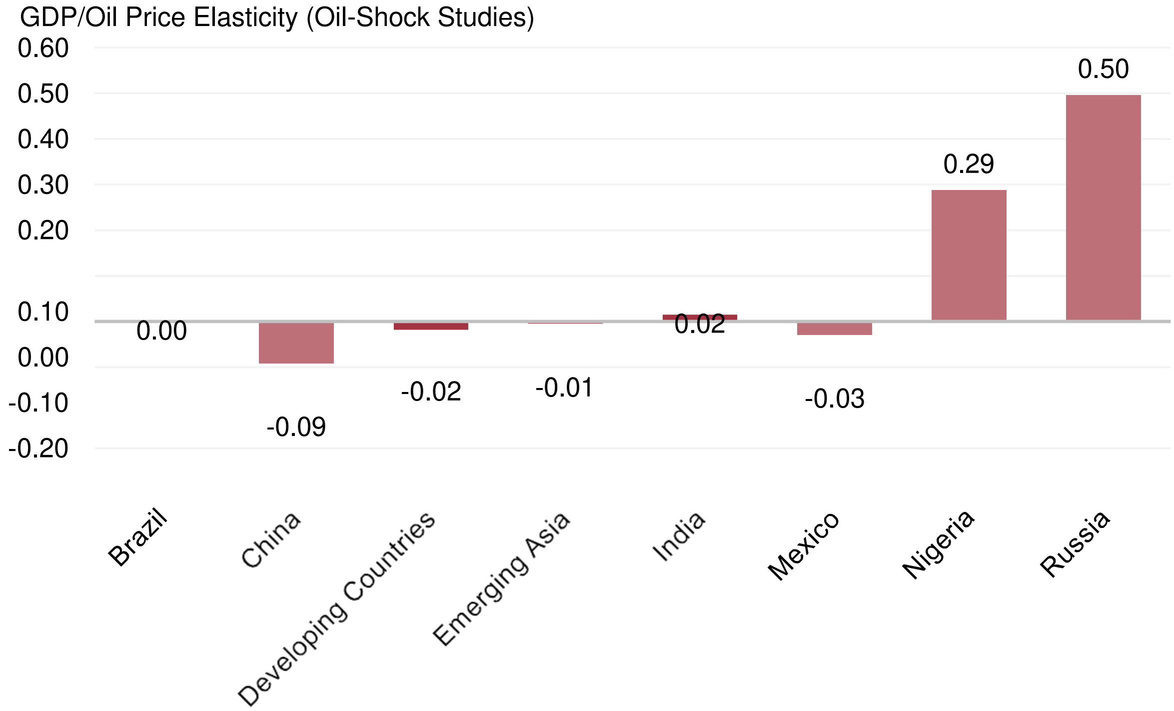
Table 12. Number of Oil-GDP Estimates by Country

Country/Region	Total
Brazil	2
China	9
Developing Countries	4
Emerging Asia	1
India	3
Mexico	4

[10] Holding demand conditions unchanged would mean not allowing exogenous non-price factors to shift energy demand. The remaining changes in energy consumption would be attributable to changing delivered energy prices.
[11] U.S. Energy Information Administration, https://www.eia.gov/beta/international/analysis.cfm?iso=NGA (accessed August 2, 2017).
[12] U.S. Energy Information Administration, https://www.eia.gov/beta/international/analysis.cfm?iso=RUS (accessed August 2, 2017).

Nigeria	2
Russia	3
Grand Total	**28**

Figure 8. Oil Price Elasticity of Real GDP



Oxford Economics' Global Economic Model

The U.S. Energy Information Administration conducted a series of simulations with the Oxford Economics' Global Economic Model. The exercise focused upon understanding how that system represented the impacts of oil and natural gas price shocks on inflation-adjusted gross national product (real GDP). It compared the GDP impacts on the United States, the European Union (EU) and the major Asian economies of India and China. Crude oil and natural gas prices were escalated by 10, 20, 30, 40, and 50% over 2 and 4 quarters as well as for 1 and 2 years. The oil price shocks represented sudden price increases due to three separate events: an oil supply shock, U.S. productivity increases, and an upward shift in world petroleum stocks and inventories. The natural gas price shocks represented sudden price increases due only to a natural gas supply shock.

Results were summarized as oil (gas) price elasticities that measured the percent difference in the real GDP path divided by the energy price difference between the shock and no-shock cases. A key finding was that the oil price elasticities in this large-scale macroeconomic model do not depend much on why the oil price change occurs. A 1% oil price rise leads GDP to fall by about 0.02% in China, EU, and India and by about 0.015% in the U.S. With the exception of the EU, the natural gas price elasticities are small. A 1% price rise for this fuel causes GDP to fall by about 0.002% in China, 0.004% in India, 0.009% in the EU, and 0.005% in the U.S.

Research on GDP Elasticities for the United States

Much of the previous research on this topic was conducted on the U.S. economy. Over time, these estimates have been declining due to a range of factors including macroeconomic policy that has moderated the high inflation conditions of the 1970s, the declining aggregate energy intensity of economic activity, the compositional shifts within the economy, and world oil market conditions in the last several decades that are almost completely void of major geopolitical disruptions like those in 1973, 1979-80, and 1990.

Krupnick et al (2017) provide a useful comparison of several recent modeling exercises on the U.S. economy. They provide a point estimate of -0.018 for what they call the newer literature, based upon a dynamic stochastic general equilibrium (DSGE) model, structural vector autoregressive (SVAR) specifications, and various scenarios from EIA's National Energy Modeling System (NEMS) model used for the AEO. These estimates are sensitive to key input assumptions about important parameters and the historical experience from which the estimates are derived. For example, the DSGE estimates tend to vary around midpoints of -0.007 and -0.010, while the SVAR estimates tend to vary around midpoints of -0.027. The NEMS results range between -0.013 and -0.025. These results are broadly consistent with the estimates of -0.03 or less in the above survey of developing countries as well as the range of -0.015 to -0.020 provided by the Oxford model above.

Research Findings and Gaps

For the most part, the general findings for developing countries appear consistent with the evidence for developed economies, with important exceptions for important oil and gas producing regions like Russia and Nigeria. The oil-price elasticity of real GDP is relatively modest compared to the response of energy demand. This result appears confirmed by at least one major macroeconomic model.

Additional studies on a range of different emerging nations would help to clarify the impact of oil price shocks on these economies. It would also be useful to expand these studies to include the GDP impacts of sudden changes in either the natural gas or electricity price.

8. Conclusions and Next Research Steps

The developing world's consumption of most major energy sources, with perhaps the exception of natural gas, appear to be both price and income inelastic (absolute value <1) in the short as well as long run. Within this very diverse group of countries, however, there are some striking differences. Given that there are sometimes only a few estimates for each country, one should not necessarily attribute these differences to the varying consumption patterns in these countries alone. For this reason, we caution readers to use the country estimates judiciously and perhaps emphasize the average responses across all countries as being representative. These average estimates serve as useful benchmarks, which can then be adjusted upward or downward to incorporate new factors shaping future energy demand patterns.

Although price responses are generally in line with those for developed countries, the income responses are often larger. The latter result is expected because these energy-intensive lifestyles and economic activities often grow rapidly when the economy expands.

Liquid Fuels

When averaged across all nations, the long-run income elasticity for gasoline use in the transportation sector averages near unity at 0.94 and the long-run price elasticity averages -0.61. Short-run averages for these two responses are smaller than their longer-run counterparts: 0.64 for the income effect and -0.33 for the price response.[13] The longer-run response to price incorporating equipment adjustments appears to be about twice as large as the near-term effect. There is also a tendency for price responses to be considerably lower in the major oil-exporting countries than elsewhere, because administered prices change relatively infrequently. As the developing world matures and vehicle ownership begins to saturate, one should expect income responses to decline over time.

This long-run response to price appears similar to those estimated for more advanced economies, but the income response is somewhat higher (36%). Table 13 compares the price and income elasticities in this survey at the top with those for higher-income countries towards the middle and bottom. The latter have been reported by Dahl and Roman (2004) in a set of studies that cover many more estimates than have been included in this study. The last set of entries refer to a survey (Dahl, 2014) of recent estimates for gasoline elasticities covering both developed and developing countries.

Table 13. Comparison of Elasticities for Developing and Industrialized Economies

	Price		**Income**	
	Short	Long	Short	Long
LDC Estimates				
Oil (wrt Crude Price)	-0.07	-0.15	0.39	0.50
Gasoline	-0.33	-0.61	0.64	0.94
Diesel	-0.41	-0.50	#N/A	-0.10
Natural Gas	-0.23	-1.36	0.11	0.89
Electricity	-0.44	-0.46	0.36	0.59
Electricity-residential	-0.32	-0.49	0.36	0.53
Dahl (2004)				
Oil	-0.11	-0.43	0.47	0.84
Gasoline	-0.13	-0.61	0.25	0.69
Diesel	-0.13	-0.67	0.55	1.13
Natural Gas Industry	-0.03	-1.35	0.12	1.39
Natural Gas Residential	-0.13	-0.56	0.18	0.11
Electricity	-0.14	-0.32	0.37	1.04
Electricity - residential	-0.23	-0.43	0.28	0.60
Dahl (2014)				
Gasoline				
Low Response	-0.20	-0.60	0.30	0.50
High Response	-0.30	-0.90	0.50	1.50

[13] At the crude oil level, this short-run response could be about -0.15 if half of the gasoline price covers refinery costs and taxes and these non-crude costs do not change.

Most empirical estimates cover liquid fuels with a heavy emphasis on gasoline consumption. The results for diesel use are too sparse for revealing broad conclusions about this fuel. Moreover, coverage for petroleum product consumption by industry and for electric generation is much sparser and hence more uncertain. The other major omission is the very limited results for vehicles powered by natural gas, ethanol and electric power as well as those that are dual fueled.

Non-Liquid Fuels and Power

It is much more challenging to derive general conclusions about natural gas and electricity demand responses, because access to key infrastructure will often dictate responses within each country. The general impression is that natural gas use may respond strongly to price (with a long-run elasticity in the range of -1.2 to -1.3) and to income (with a long-run elasticity of 0.9). Similarly, electricity use may respond to price with a long-run elasticity in the range of -0.4 or -0.5 and to income with a long-run elasticity of 0.6.

The long-run natural gas price elasticity is similar to those for the developed world, although the income response appears to be smaller. Meanwhile, the long-run electricity price elasticity is bigger, while the income response is again smaller. The smaller income effects may reflect constraints imposed by underdeveloped infrastructure (pipelines and electric grids) that limit the expansion of this fuel when incomes rise. Interestingly, the long-run electricity price elasticity and income response for residential consumption are both similar to the estimates for the more developed economies.

Macroeconomic Impacts

Higher oil prices seldom curtail macroeconomic performance by much in many developing economies—a result very similar to those for developed countries. Doubling the oil price generally reduces real gross national product by no more than 3%. Important exceptions, however, are some significant oil and gas producing regions like Russia and Nigeria. Additional studies on a range of different emerging nations would help to clarify the impact of oil price shocks on these economies. It would also be useful to expand these studies to include the GDP impacts of sudden changes in either the natural gas or electricity price.

Gaps and Future Research

Although energy economists and other researchers have conducted many more studies on energy demand than on other major market factors, there are some important gaps in the current literature.

First, a systematic study of all fuels for many countries would provide significant value added to the energy policy community. There have been surprisingly very few efforts to be as comprehensive in scope as the early studies by Pindyck (1979a, 1979b). A systematic study would apply the same methodology to all countries and fuels, thereby eliminating one of the main contributors—functional form of the regression equation—to the wide range of estimates in the literature. It would also allow researchers to evaluate the critical interfuel substitution opportunities that play such a critical role in many emerging topics. These issues include the policy discussions about climate-change strategies, as well as the sharp shift in relative fuel prices caused by such developments as the hydraulic fracturing revolution in the discovery and development of oil and natural gas shale resources. There is also a need for more evaluation of countries at different stages of development in order to understand the complex role of vehicle penetration in shaping future transportation fuel demands. As available data covers more industrializing countries over longer durations, pooled samples will provide the basis for evaluating these types of issues.

Second, technical progress has made some major shifts in the consumption pattern of different fuels and power. Most economists recognize the limitations of assuming a constant rate of energy-efficiency improvements. However, there are limited opportunities to use an alternative to a constant time trend in a regression equation. Stochastic trends (Adeyemi and Hunt, 2007, 2014) provide an interesting alternative, but more studies need to be done to understand the benefits and limitations of this approach.

Third, more single-fuel studies should expand outside gasoline use. Other oil products such as diesel, jet fuel, and fuel oil are important contributors to the demand for crude oil. Another promising area for future research will be to expand the analysis to incorporate interfuel substitution opportunities for electricity, natural gas, and biofuels as replacements for gasoline or diesel.

Fourth, researchers should carefully consider the evolving nature of future energy consumption. In addition to the rapidly expanding scope for interfuel substitution discussed above, major transitions are underway in the demand for mobility, the lifestyles and changing age structure of future drivers, advancements in car connectivity and technology, and business plans influencing how people own and use vehicles. These factors are often difficult to incorporate in empirical studies using aggregate demand, but there may be opportunities to supplement national studies with more specialized efforts to track these developments with more focused data sets.

And fifth, studies on each country's national economy and its response to oil price shocks are becoming more plentiful. Many efforts try to distinguish by the source of the price shock: (i) aggregate demand stimulated by higher GDP levels and increasing productivity, (ii) sudden petroleum supply interruptions, and (iii) petroleum-specific adjustments (such as precautionary inventory behavior). One useful extension would be to expand consideration to natural gas and electricity shocks causing both price increases and decreases. Another contribution would be to an explicit treatment of how an energy shock affects a country through not only the direct effect but also through its trading linkages with other countries that are also experiencing the shock.

9. References

Adeyemi, O.I., Hunt, L.C., 2007. Modelling OECD industrial energy demand: asymmetric price responses and energy-saving technical change. Energy Econ. 29, 693–709.

Adeyemi, O.I., L.C. Hunt, 2014. Accounting for asymmetric price responses and underlying energy demand trends in OECD industrial energy demand, Energy Economics 45 (2014) 435–444.

Arora, Vipin, 2013. Models for Use at EIA. Working Paper Series, U.S. Energy Information Administration, Washington, DC 20585, December, available at https://www.eia.gov/workingpapers/pdf/macro_models-vipin-wappendix.pdf.

Atkinson, S., & Halvorsen, R. (1976). Interfuel Substitution in Steam Electric Power Generation. Journal of Political Economy, 84(5), 959-978.

Beenstock, M., Willcocks, P., 1981. Energy consumption and economic activity in industrialized countries. Energy Econ. 3, 225–232.

Beenstock, M., Willcocks, P., 1983. Energy and economic activity: a reply to Kouris. Energy Econ. 5, 212.

Dahl, C., 2014. What Do We Know about Gasoline Demand Elasticities?, Colorado School of Mines, Division of Economics and Business Working Paper No. 2014-11, November.

Dahl, C. and C. Roman, 2004. Energy Demand Elasticities - Fact or Fiction: A Survey Update, Colorado School of Mines, Division of Economics and Business, Golden, CO 80401, April.

Dargay, J.M., 1992. The irreversible effects of high oil prices: empirical evidence for the demand for motor fuels in France, Germany and the UK. Chapter 6 In: Hawdon, D. (Ed.), Energy Demand: Evidence and Expectations. Surrey University Press, Guildford, UK, pp. 165–182.

Dargay, J.M., Gately, D., 1995. The Imperfect Price-reversibility of Non-transport Oil Demand in the OECD. Energy Econ 17 (1), 59–71.

Dargay, J.M. Gately, D., 1997. The demand for transportation fuels: imperfect price reversibility? Transp. Res. B 31, 71–82.

Dargay, J.M., Gately, D., 2010. World oil demand's shift toward faster growing and less price-responsive products and regions. Energy Policy 38, 6261–6277.

Dimaranan, B.V., R.A. McDougall, and T.W. Hertel (n.d.), GTAP Resource 783, Chapter 20: Behavioral Parameters, https://**www**.gtap.agecon.purdue.edu/resources/download/861.pdf

Fisher, F.M. and C. Kaysen, 1962. *A Study in Econometrics: The Demand for Electricity in the United States*, Amsterdam: North–Holland Publishing Co.

Fuss, Melvyn A., 1977. The demand for energy in Canadian manufacturing: An example of the estimation of production structures with many inputs, Journal of Econometrics, 5(1): 89-116.

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.

Griffin, J.M., Schulman, C.T., 2005. Price asymmetry in energy demand models: a proxy for energy-saving technical change? Energy J. 26, 1–21.

Houthakker, H.S. and L.D. Taylor, 1970. Consumer Demand in the United States, 1929-1970 Cambridge: Harvard University Press.

Hunt, L.C., Ninomiya, Y., 2003. Unravelling trends and seasonality: a structural time series analysis of transport oil demand in the UK and Japan. Energy J. 24, 63–96.

Hunt, L.C., Ninomiya, Y., 2005. Primary energy demand in Japan: an empirical analysis of long-term trends and future C02 emissions. Energy Policy 33, 1409–1424.

Hunt, L.C., Judge, G., Ninomiya, Y., 2003a. Underlying trends and seasonality in UK energy demand: a sectoral analysis. Energy Econ. 25, 93–118.

Hunt, L.C., Judge, G., Ninomiya, Y., 2003b. Modelling underlying demand trends. Chapter 9 In: Hunt, L.C. (Ed.), Energy in a Competitive Market: Essays in Honour of Colin Robinson. Edward Elgar, Cheltenham, UK, pp. 140–174.

Huntington, H., 2006. A note on price asymmetry as induced technical change. Energy J. 27, 1–7.

Huntington, H.G., 2010. Short- and long-run adjustments in U.S. petroleum consumption. Energy Econ. 33, 63–72.
Kouris, G., 1983a. Fuel consumption for road transport in the USA. Energy Econ. 5, 89–99.
Kouris, G., 1983b. Energy consumption and economic activity in industrialised economies: a note. Energy Econ. 5, 207–212.
Krupnick, A., R. Morganstern, N.S. Balke, S.P.A. Brown, A.M. Herrera, and S. Mohan, 2017. *Oil Supply Shocks, US Gross Domestic Product and the Oil Security Premium,* Report, Resources for the Future, Washington, D.C.
Pindyck, R.S., 1979a. *The Structure of World Energy Demand*. Cambridge, MA: MIT Press.
Pindyck, R.S., 1979b. Interfuel Substitution and the Industrial Demand for Energy: An International Comparison. *The Review of Economics and Statistics, 61*(2), 169-179.
Prosser, R.D., 1985. Demand elasticities in OECD: dynamic aspects. Energy Econ. 7, 9–12.
Walker, I.O., Wirl, F., 1993. Irreversible price-induced efficiency improvements: theory and empirical application to road transportation. Energy J. 14, 183–205.

10. Appendix A. Income and Price Elasticities by Country

There are only a few estimates for some countries. As a result, the methodology used to estimate a country's response may explain as much or more of the variation in elasticities as does the energy demand pattern within that country. This appendix shows that it is difficult to generalize about country-level elasticities by showing that the gasoline response estimates do not conform to the following hypothesis: (a) estimated income elasticities are higher when GDP levels are lower, and (b) estimated price elasticities decline when gasoline price levels are lower.

Table A-1 reports the average income elasticity and real per-capita GDP level (2005 $) for 2016. These two variables are plotted in Figure A-1. The United States is one of the most industrialized, high-income countries. The remaining economies are industrializing with lower income levels and display a mixed pattern. Although China, Mexico, Venezuela and Iran have higher income elasticities than the United States, South Africa and Russia do not. The oil-rich and wealthier countries, Saudi Arabia and United Arab Emirates, have per-capita GDP levels closer to the United States but have slightly lower income elasticities than the U.S. response. Despite much smaller GDP levels, Nigeria and Brazil have similar income elasticities.

Table A-2 reports the average price elasticity and gasoline price level ($ per liter) for May 15, 2017. These two variables are plotted in Figure A-2. Venezuela, Saudi Arabia have lower (administered) prices and lower price elasticities. Iran has lower prices but a relatively high price response. The other countries have higher price elasticities and higher price levels. Thus, there exists some modest support for the relationship that the price response shifts higher as the price level increases. Once again, these results are suggestive but by no means conclusive.

Table A- 1. Income Elasticity and GDP Level

GDP per capita, 2016

Country	$	Income Elasticity
United Arab Emirates	67,871	0.43
United States	57,436	0.69
Saudi Arabia	55,158	0.50
Russia	26,490	0.24
Mexico	18,938	1.14
Iran	18,077	1.75
China	15,399	0.84
Brazil	15,242	0.73
Venezuela	13,761	1.20
South Africa	13,225	0.36
India	6,616	1.92
Nigeria	5,942	0.75

Source: International Monetary Fund, World Economic Outlook Database, April 2017 (Database updated on April 12, 2017, accessed on May 19, 2017). http://www.imf.org/external/pubs/ft/weo/2017/01/weodata/index.aspx

Figure A- 1. Income Elasticity and GDP Level

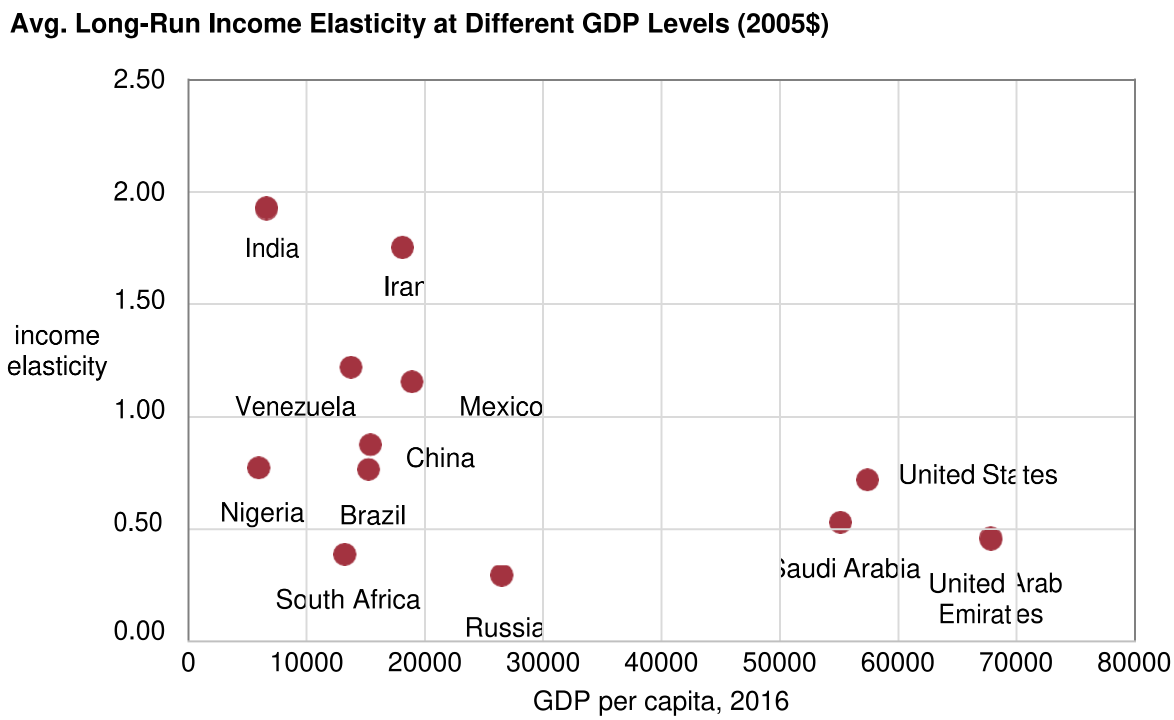


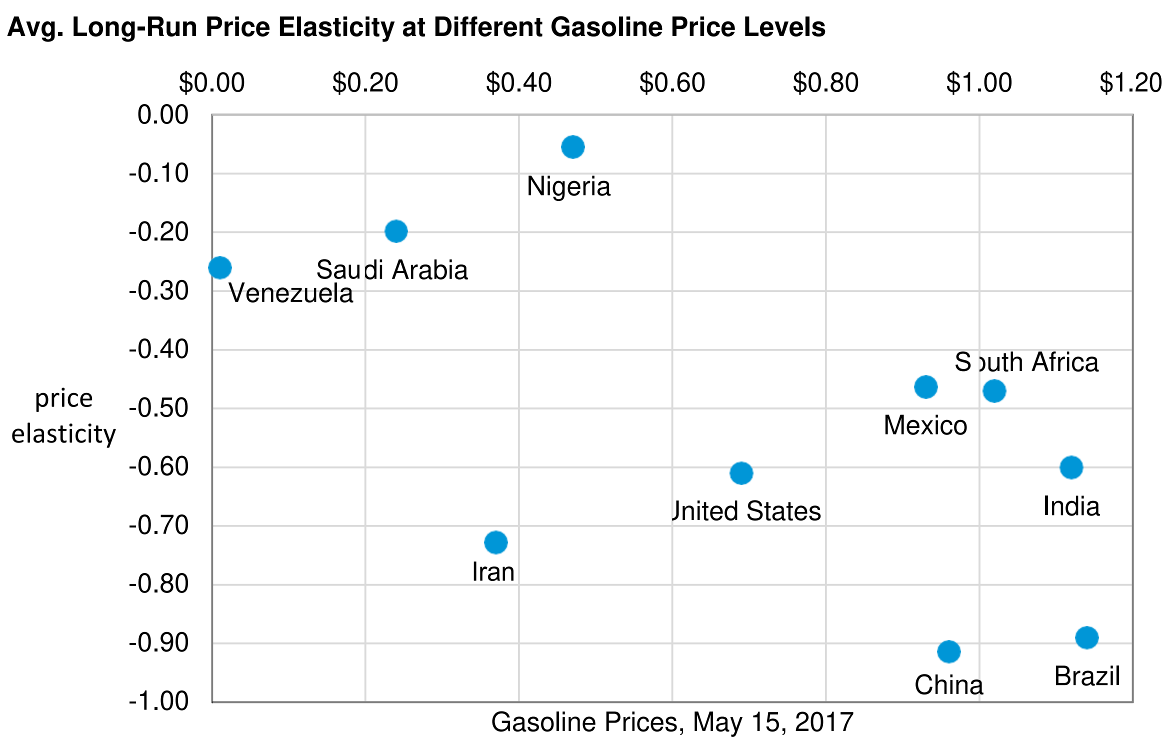
Table A- 2. Gasoline Price and Price Elasticity

Gasoline Prices, May 15, 2017

Country	$/liter	Price Elasticity
Venezuela	0.01	-0.26
Saudi Arabia	0.24	-0.20
Iran	0.37	-0.73
Nigeria	0.47	-0.06
UA Emirates	0.52	
Russia	0.69	
USA	0.69	-0.61
Mexico	0.93	-0.46
China	0.96	-0.91
South Africa	1.02	-0.47
India	1.12	-0.60
Brazil	1.14	-0.89

Source: GlobalPetrolPrices.com, http://www.globalpetrolprices.com/gasoline_prices/ , accessed May 19, 2017 (Includes taxes and subsidies)

Figure A- 2. Price Elasticity and Gasoline Price Level



Appendix Table B-1: Energy Demand Elasticity Studies

Authors	Date	Region	Horizon	Sector	Key Findings
Agrawal	2012	India	Short-Term	Transportation	This paper empirically estimates demand relations for crude oil, diesel, and petrol for India for the period between 1970–71 and 2010–11 using the ARDL co-integration procedure and uses these estimations to project demand for these products up to 2025 under various scenarios of gross domestic product (GDP) growth (with a mean of 7%) and oil prices.
Akinboade, Ziramba	2008	South Africa	Long-Term	Transportation	Using Cointegration Techniques to estimate the price and income elasticity in South Africa. Results show that demand for gasoline is income and price inelastic.
Alves, Bueno	2003	Brazil	Long-Term	Transportation	Paper examines income/price elasticity, as well as cross price elasticity between gas and alcohol inside of Brazil. Findings show that demand is inelastic in short and long run.
Bentham & Romani	2009	Non-OECD Global Composite	Long-Term	Transportation, Residential, Industrial	Paper examines 24 Non-OECD countries price/income elasticities, finding demand increases non-linearly with respect to price and that demand is more responsive to end user price than international prices.
Berndt & Samaniego	1984	Mexico	Short-Term, Long-Term	Industrial	Study aimed at determining electricity income and price elasticity for electricity inside of Mexico. Study suggest that demand is both price and income inelastic in the short and long-run
Bose	1998	India	Short-Term	Residential, Industrial	Study looking at India's elasticity pertaining to electricity consumption. The results show that electricity consumption in commercial and large industrial sectors are income elastic, while residential, agricultural and small and medium industries are income inelastic. The short-run price elasticities vary from sector to sector.
Burke and Yang	2016	Non-OECD Global Composite	Long-Term	Residential	Aggregate long run price elasticity is around -1.25 for natural gas according to a cross-section study focused on many international countries.
Cheung and Thompson	2004	China	Short-Term, Long-Term	Transportation	Using Cointegration techniques, study finds demand to be inelastic to price between 1980-2002. The study suggest that gasoline demand is long-run inelastic to price.

Authors	Date	Region	Horizon	Sector	Key Findings
Crotte and Nolan	2010	Mexico	Short-Term, Long-Term	Transportation	Time series panel study focusing on income and price elasticity of Mexico's transportation sector. Study suggest that the rapid increase in light vehicle sales have contributed to an inelastic gasoline demand and that the vehicle stock greatly influences gasoline consumption.
Dos Santos and Faria	2012	Brazil, China, India, Iran, Mexico, Saudi Arabia, Venezuela	Short-Term, Long-Term	Transportation	Using spatial models to estimate price, income, and cross-price elasticity inside of Brazil fuel market for light vehicles. Study shows gasoline demand to be inelastic, especially in population dense regions.
Filippini and Pachauri	2004	India	Long-Term	Residential	Estimating residential electricity demand inside of India. Results suggest India is income and price inelastic and that household, demographic and geographical variables are significant in determining electricity demand.
Fullerton & Salazar	2015	Mexico	Long-Term	Transportation	Using cointegration to estimate the price and income elasticity for residential gasoline consumption. Study found income to be inelastic and that the income effects outweigh the substitution effects.
Galiando	2005	Mexico	Short-Term, Long-Term	Residential	Paper analyzing the relationship between Mexican income and price elasticity across various sectors. Study found demand to be inelastic and the substitution effect to be low.
He, Yang, and Wang	2010	China	Long-Term	Residential	The elasticity absolute value of Industry & Commerce is around 0.018, that of Residents is around 0.300 and that of Agriculture is around 0.066.
Iwayen, Adenikinju	2008	Nigeria	Long-Term	Transportation	Using cointegration techniques to estimate the price and income elasticity of various fuel types (mainly gas and diesel) inside of Nigeria.
Jobling & Jamasab	2011	Non-OECD Global Composite	Long-Term	Residential	Using a dynamic model to compare the elasticities of developing and developed countries from 1980 to 2012. Found large income effect inside of developing countries.

Authors	Date	Region	Horizon	Sector	Key Findings
Lin and Zeng	2009	China	Short-Term	Transportation	Study focused on using various log based models to estimate the elasticity of price and income in China for gasoline fuels, aggregated across all industries.
Lopez and Perez	2008	Mexico	Short-Term	Residential	Study find demand to be both price and income inelastic in northern region of Mexico (Note: Paper is published in Spanish)
Ma and Sturn	2016	China	Long-Term	Residential	The results show that demand for coal and electricity in China is very inelastic, while demand for diesel and gasoline is elastic.
McRae	1994	India	Short-Term, Long-Term	Transportation	This paper presents econometric estimates of motor gasoline demand in eleven developing countries of Asia. The price and GDP per capita elasticities are estimated for each country separately, and for several pooled combinations.
Nolan & Crotte	2008	Mexico	Short-Term	Transportation	Estimating the elasticity for the transportation sector inside of Mexico City.
Orlov	2016	Russia	Short-Term	Transportation, Residential, Industrial	Estimating the elasticity of natural gas across various sectors of the Russian Economy.
Parry & Shang	2016	China	Long-Term	Power Sector, Transportation	Paper estimates the effects of different elasticities on the power sector and evaluating the effect taxes on carbon emissions in China. Empirical studies mentioned inside the paper found for different countries suggests a range for this elasticity of around 0.5–1.5.
Perroni	2016	Brazil	Long-term	Transportation, Residential, Industrial	This study aims to estimate and analyze the income elasticities of Brazil’s energy matrix, represented by the supply and consumption of energy. Compares the income elasticities of both energy products and consumption through secondary sources and consumer sectors.
Phoumin and Kimura	2014	China	Short-Term, Long-Term	Transportation, Residential	This study uses time series data of selected ASEAN and East Asia countries to investigate the patterns of price and income elasticity of energy demand.

Authors	Date	Region	Horizon	Sector	Key Findings
Ramathan	1999	India	Short-Term, Long-Term	Transportation	In this paper, the relationship between gasoline demand, national Indian income and price of gasoline is empirically examined using cointegration and error correction techniques.
Santos	2009	Brazil	Short-Term, Long-Term	Transportation, Residential	This paper is to evaluate the sensitivity of fuel consumers regarding price and income, taking recent changes in the Brazilian fuel market into account. While demands for gasoline and natural gas are inelastic to price, demand for ethanol is elastic in Brazil.
Sheinbaum & Martinez	1996	Mexico	Long-Term	Residential	Paper looks a Mexican household electricity use. The top-down approach shows that household energy demand has been non-elastic to energy price and that changes in household size were more important than income in determining per capita energy demand between 1970 and 1990.
Silva and Tiryaki	2003	Brazil	Short-Term, Long-Term	Transportation	Using a dynamic model with panel data including all Brazilian federal states, this paper estimates an econometric model to measure the effect of the introduction of this flex fuel technology on the demand for gasoline in Brazil. The results indicate the expansion of ethanol's participation in the fuels market has led to a substantial increase in the price and cross-price elasticity of the demand for gasoline.
Sun/ Ouyang	2016	China	Long-Term	Transportation, Residential	Paper analyzes residential sector elasticities in regard to natural gas and transport fuels inside China. Empirical results from the Almost Ideal Demand System model are in accordance with the basic expectations: the demands for electricity, natural gas and transport fuels are inelastic in the residential sector due to the unreasonable pricing mechanism.
Takeuchi and Cropper	2006	India	Short-Term	Transportation	Paper explores impact of measures to reduce air pollution inside of Mumbai, India. Study found that a higher percent of the total reduction in emissions will come from a tax on gasoline, the more elastic is the demand for gasoline.

Authors	Date	Region	Horizon	Sector	Key Findings
Tiwari	1999	India	Short-Term	Industrial	The paper uses an input-output framework to calculate energy intensities for different sectors in Indian economy. As the GDP growth rate tends to fluctuate under the influence of monsoons (rainy season on which agricultural output is dependent), such elasticity estimates are affected by the fluctuations.
Trotter & Bolkesja	2016	Brazil	Long-Term	Residential	This paper examines the relationship between electricity use and the effects of weather patterns on Brazilian electricity use.
Wohlgemuth	1997	Mexico, Brazil, Middle East, China, India, East Asia	Long-Term	Transportation	The paper also shows the underlying long-term income and price elasticities for OECD and non-OECD regions inside of the transportation sector.
Xie, Ouyang, and Gao	2016	China	Short-Term	Residential	This study proposes an innovative hybrid model for estimation of residential electricity demand based on the three categories of variables as building & appliances, family features and householders' evaluation about indoor thermal comfort. The empirical results indicate that the thermal environment rated as neutral or slightly warm by householder has a positive coefficient with residential electricity demand.
Yousef	2013	Saudi Arabia, United Emirates, Iran	Long-Term	Transportation	The goal of this paper is to examine the determinants of oil refined products' consumption for a panel consisting of 7 OPEC countries, namely, Algeria, Kuwait, Libya, Qatar, Saudi Arabia, United Emirates and Iran for the period of 1980–2010. The study estimates the demand for Gasoline, Kerosene and Diesel.
Yu and Zheng	2014	China	Short-Term, Long-Term	Residential	Using a set of unbalanced panel data for Chinese's cities during the period of 2006–2009, this study aims to estimate the price and income elasticities of residential demand for natural gas. Paper finds that natural gas consumption is price elastic and income inelastic.

Authors	Date	Region	Horizon	Sector	Key Findings
Zhou and Teng	2013	China	Short-Term	Residential	This paper uses annual urban household survey data of Sichuan Province from 2007 to 2009 to estimate the income and price elasticities of residential electricity demand, along with the effects of lifestyle-related variables. The empirical results show that in the urban area of Sichuan province, the residential electricity demand is price- and income-inelastic, with price and income elasticities ranging from 0.35 to 0.50 and from 0.14 to 0.33, respectively.

Appendix Table B-2: Macroeconomic Response Studies

Authors	Date	Region	Horizon	Sector	Shock Type	Key Findings
Adegboye	2013	Russia	Long-Term	Macroeconomy	Increase	This paper seeks to assess the impact of oil price shock and real exchange rate instability on real economic growth in Nigeria on the basis of quarterly data from 1986 to 2012. Nigeria appears to increase GDP output in the face of an oil-price shock.
Akay	2016	Mexico	Long-Term	Macroeconomy	Increase	The aim of this study is to investigate that how economic conditions change when crude oil shocks occurred in 1980-2013 for Mexico, Indonesia, South Korea, Turkey (MIST) countries. Another objective of the study is to determine accurately the functional forms of the relationships between oil prices and macroeconomic variables. Papers suggest that Oil Shocks have very little effect on GDP.
Cashin	2014	Mexico, China, Nigeria	Short-Term	Macroeconomy	Increase	The results indicate that the economic consequences of a supply-driven oil-price shock are very different from those of an oil-demand shock driven by global economic activity, and vary for oil-importing countries compared to energy exporters.
Cavalcanti & Jalles	2012	Brazil	Short-Term, Long-Term	Macroeconomy	Increase	This paper studies the effects of oil price shocks in the last 30 years on the Brazilian and American inflation rate and rhythm of economic activity. Paper shows oil shocks have very little effect on GDP output.
Cuando	2015	China, India	Short-Term	Macroeconomy	Increase	Paper identifies 3 different structural oil shocks via sign restrictions: an oil supply shock, an oil demand shock driven by global economic activity and an oil-specific demand shock. The main results suggest that economic activity and prices respond very differently to oil-price shocks depending on their types.

Authors	Date	Region	Horizon	Sector	Shock Type	Key Findings
Ito	2008	Russia	Short-Term	Macroeconomy	Increase	The analysis leads to the finding that a 1% increase in oil prices contributes to real GDP growth by 0.25% over the next 12 quarters, whereas that to inflation by 0.36% over the corresponding periods. We also find that the monetary shock through interest rate channel immediately affects real GDP and inflation as predicted by theory.
Kumar	2009	India	Short-Term	Macroeconomy	Increase	Evidence of asymmetric impact of oil price shocks on industrial growth is found. Oil price shocks negatively affect the growth of industrial production and we find that an hundred percent increase in oil prices lowers the growth of industrial production by one percent.
Malakhovskaya	2013	Russia	Long-Term	Macroeconomy	Increase	The model yields plausible estimates, and the impulse response functions are in line with empirical evidence. We found that despite a strong impact on GDP from commodity export shocks, business cycles in Russia are mostly domestically based.
Raghavan	2015	Emerging Asia	Short-Term	Macroeconomy	Increase	The empirical results highlight that for monetary policy responses to be more supportive of growth, policy makers in these economies should examine the underlying causes of the future oil shocks.
Rasmussen	2011	Developing Countries	Short-Term	Macroeconomy	Increase	Paper finds that the impact of higher oil prices on oil-importing economies is generally small: a 25% increase in oil prices typically causes GDP to fall by about 0.5% or less.
Shi & Sun	2014	China	Short-Term	Macroeconomy	Increase	In contrast to the usual argument for price control, paper finds that the price distortion negatively affects the output growth in China in both the short run and long run, 16 which is robust to different measures of output and price distortion.

Authors	Date	Region	Horizon	Sector	Shock Type	Key Findings
Tang and Wu	2009	China	Short-Term	Macroeconomy	Increase	Results show that an oil-price increase negatively affects output and investment, but positively affects inflation rate and interest rate.
Yoshino & Hesary	2014	China	Short-Term	Macroeconomy	Increase	The results obtained suggest that the impact of oil price fluctuations on developed oil importers' GDP growth is much milder than on the GDP growth of an emerging economy.

References

Adeyemi, O.I., Hunt, L.C., 2007. Modelling OECD industrial energy demand: asymmetric price responses and energy-saving technical change. Energy Econ. 29, 693–709.

Adeyemi, O.I., Hunt, L.C., 2014. Accounting for asymmetric price responses and underlying energy demand trends in OECD industrial energy demand. Energy Econ. 45 (2014), 435–444.

Agrawal, P., 2015. India's petroleum demand: estimations and projections. Applied Economics 47 (12), 1199–1212.

Akay, E.C., Guler, S.K.U., 2016. Determining the functional form of relationships between oil prices and macroeconomic Variables : the case of Mexico. Int. J. Econ. Financ. Issues 6 (3), 880–891.

Akinboade, O.A., Ziramba, E., Kumo, W.L., 2008. The demand for gasoline in South Africa : an empirical analysis using Co-integration techniques. Energy Econ. 30, 3222–3229.

Aliyu, S.U.R., 2009. Impact of oil price shock and exchange rate volatility on economic growth in Nigeria: an empirical investigation. Res. J. Int. Stud. 11, 4–15 8 July.

Alom, F., Ward, B., Hu, B., 2011. Spillover effects of world oil prices on food prices: evidence for Asia and pacific countries. In: Proceedings of the 52nd Annual Conference New Zealand Association of Economists 29.

Alves, D.C.O., De Losso da Silveira Bueno, R., 2003. Short-run, long-run and cross elasticities of gasoline demand in Brazil. Energy Econ. 25 (2), 191–199.

Arora, Vipin, 2013. Models for Use at EIA. Working Paper Series, vol 20585 U.S. Energy Information Administration, Washington, DC December, available at: https://www.eia.gov/workingpapers/pdf/macro_models-vipin-wappendix.pdf.

Atkinson, S., Halvorsen, R., 1976. Interfuel substitution in steam electric power generation. J. Political Econ. 84 (5), 959–978.

Beenstock, M., Willcocks, P., 1981. Energy consumption and economic activity in industrialized countries. Energy Econ. 3, 225–232.

Beenstock, M., Willcocks, P., 1983. Energy and economic activity: a reply to Kouris. Energy Econ. 5, 212.

Benthem, A. van, Romani, M., 2009. Fuelling growth: what drives energy demand in developing countries? Energy J. 30, 91–114.

Berndt, E.R., Samaniego, R., 1984. Residential electricity demand in Mexico - a model distinguishing access from consumption. Land Econ. 60 (3), 268–277 August.

Bhattacharyya, S.C., Blake, A., 2009. Domestic demand for petroleum products in MENA countries. Energy Policy 37 (4), 1552–1560 April 1.

Bildirici, E.M., Bakirtas, T., 2016. The relationship among oil and coal consumption, carbon dioxide emissions, and economic growth in BRICTS countries. J. Renew. Sustain. Energy 8, 4.

Bose, R.K., Shukla, M., 1999. Elasticities of electricity demand in India. Energy Policy 27 (3), 137–146.

Boshoff, W.H., 2012. Gasoline, diesel fuel and jet fuel demand in South Africa. J. Stud. Econ. Econom. 36 (1), 43–78.

Burke, P.J., Liao, H., 2015. Is the price elasticity of demand for coal in China increasing? China Econ. Rev. 36, 309–322.

Burke, P.J., Yang, H., 2016. The price and income elasticities of natural gas demand: international evidence. Energy Econ. 59, 466–474.

Cashin, P., Mohaddes, K., Raissi, M., Raissi, M., 2014. The differential effects of oil demand and supply shocks on the global economy. Energy Econ. 44, 113–134.

Cavalcanti, T., Jalles, J.T., 2013. Macroeconomic effects of oil price shocks in Brazil and in the United States. Appl. Energy 104, 475–486.

Chary, S.R., Bohara, A.K., 2010. Energy consumption in Bangladesh, India, and Pakistan— a cointegration analysis. J. Dev. Areas 44 (1), 41–50.

Cheung, K.Y., Thomson, E., 2004. The demand for gasoline in China: a cointegration analysis. J. Appl. Stat. 31 (5), 533–544.

Crôtte, A., Noland, R., Graham, D., 2009. Estimation of road traffic demand elasticities for Mexico city, Mexico. Transp. Res. Rec.: J. Transp. Res. Board 2134, 99–105.

Crotte, A., Noland, R.B., Graham, D.J., 2010. An analysis of gasoline demand elasticities at the national and local levels in Mexico. Energy Policy 38 (8), 4445–4456.

Cunado, J., Jo, S., Perez de Gracia, F., 2015. Macroeconomic impacts of oil price shocks in Asian economies. Energy Policy 86, 867–879.

Dahl, C., 2014. What Do We Know about Gasoline Demand Elasticities? Colorado School of Mines Division of Economics and Business Working Paper No. 2014-11, November.

Dahl, C., Roman, C., 2004. Energy Demand Elasticities - Fact or Fiction: A Survey Update, vol 80401 Colorado School of Mines, Division of Economics and Business, Golden, CO

Dahl, C., Sterner, T., 1991. Analysing gasoline demand elasticities: a survey. Energy Econ. 13 (3), 203–210.

Dargay, J.M., 1992. The irreversible effects of high oil prices: empirical evidence for the demand for motor fuels in France, Germany and the UK. In: Hawdon, D. (Ed.), Energy Demand: Evidence and Expectations. Surrey University Press, Guildford, UK, pp. 165–182 (Chapter 6).

Dargay, J.M., Gately, D., 1995. The imperfect price-reversibility of non-transport oil demand in the OECD. Energy Econ. 17 (1), 59–71.

Dargay, J.M., Gately, D., 1997. The demand for transportation fuels: imperfect price reversibility? Transp. Res. B 31, 71–82.

Dargay, J.M., Gately, D., 2010. World oil demand's shift toward faster growing and less price-responsive products and regions. Energy Policy 38, 6261–6277.

Dimaranan, B.V., McDougall, R.A., Hertel, T.W., 2006. Behavioral parameters. In: Dimaranan, B.V. (Ed.), Global Trade, Assistance, and Production: the GTAP 6 Data Base, Center for Global Trade Analysis. Purdue University. https://www.gtap.agecon.purdue.edu/resources/download/861.pdf.

Dossary, N. Al, Dahl, C.A., 2009. Is Global Gasoline Demand Still as Responsive to Price? Colorado School of Mines, Division of Economics and Business Working Papers. Colorado School of Mines, Division of Economics and Business.

Elekdag, S., Lalonde, R., Laxton, D., Muir, D., Pesenti, P., 2008. Oil price movements and the global economy: a model-based assessment. IMF Staff Pap. 55 (2), 297–311.

Filippini, M., Pachauri, S., 2004. Elasticities of electricity demand in urban Indian households. Energy Policy 32 (3), 429–436.

Fisher, F.M., Kaysen, C., 1962. A Study in Econometrics: the Demand for Electricity in the United States. North–Holland Publishing Co, Amsterdam.

Fullerton, T.M., Salazar, I.J., Elizalde, M., 2015. Microeconomic gasoline consumption anomalies in Mexico 1997 - 2007. Asian Econ. Financ. Rev. 5 (4), 709–722.

Fuss, M.A., 1977. The demand for energy in Canadian manufacturing: an example of the estimation of production structures with many inputs. J. Econom. 5 (1), 89–116.

Galindo, L.M., 2005. Short- and long-run demand for energy in Mexico: a cointegration approach. Energy Policy 33 (9), 1179–1185.

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.

Griffin, J.M., Schulman, C.T., 2005. Price asymmetry in energy demand models: a proxy for energy-saving technical change? Energy J. 26, 1–21.

Haro, A., Ibarrola, L., 1999. Gasolina en La Zona fronteriza Norte de México. Gaceta de Economía

Año 6 (11), 237–264 Núm. 11 6.
He, Y.X., Yang, L.F., He, H.Y., Luo, T., Wang, Y.J., 2011. Electricity demand price elasticity in China based on computable general equilibrium model analysis. Energy 36 (2), 1115–1123.
Houthakker, H.S., Taylor, L.D., 1970. Consumer Demand in the United States, 1929-1970. Harvard University Press, Cambridge.
Hunt, L.C., Ninomiya, Y., 2003. Unravelling trends and seasonality: a structural time series analysis of transport oil demand in the UK and Japan. Energy J. 24, 63–96.
Hunt, L.C., Ninomiya, Y., 2005. Primary energy demand in Japan: an empirical analysis of long-term trends and future C02 emissions. Energy Policy 33, 1409–1424.
Hunt, L.C., Judge, G., Ninomiya, Y., 2003a. Underlying trends and seasonality in UK energy demand: a sectoral analysis. Energy Econ. 25, 93–118.
Hunt, L.C., Judge, G., Ninomiya, Y., 2003b. Modelling underlying demand trends. Chapter 9. In: Hunt, L.C. (Ed.), Energy in a Competitive Market: Essays in Honour of Colin Robinson. Edward Elgar, Cheltenham, UK, pp. 140–174.
Huntington, H., 1994. Oil price forecasting in the 1980s: what went wrong? Energy J. 15 (2), 1–22.
Huntington, H., 2006. A note on price asymmetry as induced technical change. Energy J. 27, 1–7.
Huntington, H.G., 2010. Short- and long-run adjustments in U.S. petroleum consumption. Energy Econ. 33, 63–72.
Huntington, H., Barrios, J., Arora, V., 2017. Review of Key International Demand Elasticities for Major Industrializing Economies. MPRA Paper 87532. University Library of Munich, Germany.
Inglesi-Lotz, R., Blignaut, J.N., 2011. Estimating the price elasticity of demand for electricity by sector in South Africa. S. Afr. J. Econ. Manag. Sci. 14 (4), 449–465.
Ito, K., 2008. Oil price and macroeconomy in Russia. Econ. Bull. 17 (17), 1–9.
Iwayemi, A., Adenikinju, A., Babatunde, M.A., 2010. Estimating petroleum products demand elasticities in Nigeria: a multivariate cointegration approach. Energy Econ. 32 (1), 73–85.
Jobling, A., Jamasb, T., 2017. Price volatility and demand for oil: a comparative analysis of developed and developing countries. Econ. Anal. Policy 53 (March), 96–113.
Ju, K., Zhou, D., Zhou, P., Wu, J., 2014. Macroeconomic effects of oil price shocks in China: an empirical study based on Hilbert–Huang transform and event study. Appl. Energy 136 (December 31), 1053–1066.
Kennedy, P., 2008. A Guide to Econometrics, sixth ed. Blackwell Pub., Malden, MA.
Kouris, G., 1983a. Fuel consumption for road transport in the USA. Energy Econ. 5, 89–99.
Kouris, G., 1983b. Energy consumption and economic activity in industrialised economies: a note. Energy Econ. 5, 207–212.
Krupnick, A., Morganstern, R., Balke, N.S., Brown, S.P.A., Herrera, A.M., Mohan, S., 2017. Oil Supply Shocks, US Gross Domestic Product and the Oil Security Premium, Report. Resources for the Future, Washington, D.C.
Kumar, S., 2009. The macroeconomic effects of oil price shocks: empirical evidence for India. Econ. Bull. 29 (1), 15–37.
Labandeira, X., Labeaga, J.M., Lopez-Otero, X., 2017. A meta-analysis on the price elasticity of energy demand. Energy Policy 102, 549–568.
Lenzen, M., Wier, M., Cohen, C., Hayami, H., Pachauri, S., Schaeffer, R., 2006. A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan. Energy 31 (2–3), 181–207.
Liddle, B., Huntington, H., 2018. Revisiting the income elasticity of energy consumption: a heterogeneous, common factor, dynamic OECD & Non-OECD country panel analysis. SSRN Electronic J. https://doi.org/10.2139/ssrn.3307173.
Lin, C.-Y.C., Zeng, J. (Jean), 2013. The elasticity of demand for gasoline in China. Energy Policy 59 (August 1), 189–197.

Ma, C., Stern, D.I., 2016. Long-run estimates of interfuel and interfactor elasticities. Resour. Energy Econ. 46, 114–130.

Malakhovskaya, O.A., Minabutdinov, A.R., 2013. Are Commodity Price Shocks Important? A Bayesian Estimation of a DSGE Model for Russia. National Research University Higher School of Economic Working Paper.

Matthew, A.O., Adegboye, F.B., 2014. An analysis of the effect of oil price shock and exchange rate instability on economic growth in Nigeria. Scott. J. Arts, Soc. Sci. Sci. Stud. 94–107.

McRae, R., 1994. Gasoline Demand in Developing Asian Countries. The Energy Journal 15 (1), 143–155.

Orlov, A., 2015. An assessment of optimal gas pricing in Russia: a CGE approach. Energy Econ. 49, 492–506 October.

Parry, I., Shang, B., Wingender, P., Vernon, N., Narasimhan, T., 2016. Climate Mitigation in China: Which Policies Are Most Effective? IMF Working Paper.

Perroni, M.G., da Costa, S.E.G., da Silva, W.V., de Lima, E.P., da Veiga, C.P., 2016. Analysis of income elasticities of Brazil's energy matrix. Int. J. Energy Econ. Policy 6 (3), 431–441.

Phoumin, H., Kimura, S., 2014. Analysis on price elasticity of energy demand in East Asia: empirical evidence and policy implications for ASEAN and East Asia. ERIA Discuss. Pap. Ser. 05, 1–26.

Pindyck, R.S., 1979a. The Structure of World Energy Demand. MIT Press, Cambridge, MA.

Pindyck, R.S., 1979b. Interfuel substitution and the industrial demand for energy: an international comparison. Rev. Econ. Stat. 61 (2), 169–179.

Raghavan, M., 2015. The Macroeconomic Effects of Oil Price Shocks on ASEAN-5 Economies. Tasmanian School of Business and Economics Discussion Paper Series No.2015-10.

Ramanathan, R., 1999. Short- and long-run elasticities of gasoline demand in India: an empirical analysis using cointegration techniques. Energy Econ. 21 (4), 321–330.

Rasmussen, T.N., Roitman, A., 2011. Oil Shocks in a Global Perspective : Are They Really that Bad ? IMF Working Paper.

Salazar, J.I., Cervantes, L.S., 2008. La demanda de Gasolina en méxico el efecto en La frontera Norte. Front. Norte 20, 131–156 no. Enero-Junio.

Santos, G.F., 2013. Fuel demand in Brazil in a dynamic panel data approach. Energy Econ. 36, 229–240.

Santos, A.I., Colomer, M., 2014. The elasticity of demand for gasoline in Brazil with the introduction of the flex-fuel fleet. In: IAEE International Conference 1–19.

Santos, G.F., Faria, W.R., 2014. Spatial panel data models and fuel demand in Brazil. Texto Para Discussão Nereus 10–2012.

Sheinbaum, C., Martínez, M., Rodríguez, L., 1996. Trends and prospects in Mexican residential energy use. Energy 21 (6), 493–504.

Shi, X., Asia, E., Sun, S., 2007. Oil Price Shocks, Market Distortion and Output Growth : Theory and Evidence from China. Chinese Economics Society Australia Working Paper.

Silva, G.F. da, Tiryaki, G.F., Pontes, L.A.M., 2009. The impact of a growing ethanol market on the demand elasticity for gasoline in Brazil. In: 32nd Annual International Association for Energy Economics Conference, San Francisco.

Sun, C., Ouyang, X., 2016. Price and expenditure elasticities of residential energy demand during urbanization: an empirical analysis based on the household-level survey data in China. Energy Policy 88, 56–63.

Takeuchi, A., Cropper, M., Bento, A., 2007. The impact of policies to control motor vehicle emissions in Mumbai, India. J. Reg. Sci. 47 (1), 27–46 February.

Tang, W., Wu, L., Zhang, Z.X., 2010. Oil price shocks and their short- and long-term effects on the Chinese economy. Energy Econ. 32, S3–S14 SUPP-1.

Teng, M., Burke, P.J., Liao, H., 2019. The demand for coal among China's rural households:

estimates of price and income elasticities. Energy Econ. 80, 928–936.
Tiwari, P., 2000. An analysis of sectoral energy intensity in India. Energy Policy 28 (11), 771–778.
Trotter, I.M., Bolkesjø, T.F., Féres, J.G., Hollanda, L., 2016. Climate change and electricity demand in Brazil: a stochastic approach. Energy 102, 596–604.
Walker, I.O., Wirl, F., 1993. Irreversible price-induced efficiency improvements: theory and empirical application to road transportation. Energy J. 14, 183–205.
Wohlgemuth, N., 1998. World transport energy demand modelling. Energy 25 (97), 1109–1119.
Xie, Q., Ouyang, H., Gao, X., 2016. Estimation of electricity demand in the residential buildings of China based on household survey data. Int. J. Hydrogen Energy 41 (35), 15879–15886.
Yoshino, N., Taghizadeh-hesary, F., 2014. Economic impacts of oil price fluctuations in developed and emerging economies. IEEJ Energy J. 9 (3), 1–17.
Yousef, N. Al, 2013. Demand for oil products in OPEC countries: a panel cointegration analysis. Int. J. Energy Econ. Policy 3 (2), 168–177.
Yu, Y., Zheng, X., Han, Y., 2014. On the demand for natural gas in urban China. Energy Policy 70, 57–63 October 2016.
ZhiDong, L., 2003. An econometric study on China's economy, energy and environment to the year 2030. Energy Policy 31 (11), 1137–1150.
Zhou, S., Teng, F., 2013. Estimation of urban residential electricity demand in China using household survey data. Energy Policy 61, 394–402 2013.