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Energy Subsidies and Energy Consumption—A Cross-Country Analysis

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Abstract

The economic and environmental implications of energy subsidies have received renewed attention from policymakers and economists in recent years. Nevertheless there remains significant uncertainty regarding the magnitude of the impact of energy subsidies on energy consumption. In this paper we analyze a panel of cross-country data to explore the responsiveness of energy consumption to changes in energy prices and the implications of our findings for the debate on energy subsidy reform. Our findings indicate a long-term price elasticity of energy demand between -0.3 and -0.5, which suggests that countries can reap significant long-term benefits from the reform of energy subsidies. Our findings also indicate that short-term gains from subsidy reform are likely to be much smaller, which suggests the need for either a gradual approach to subsidy reform or for more generous safety nets in the short term.

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I. INTRODUCTION

The economic and environmental implications of energy subsidies have received increased attention from policymakers in recent years (e.g., G-20 Pittsburgh communiqué, 2009), due to at least one of three concerns:

- *Efficiency*. In general, subsidies tend to encourage wasteful consumption of the good/service that is subsidized. This not only implies an inefficient use of resources in the economy but also, in the case of energy subsidies, may increase pollution and the emission of greenhouse gases.

- *Equity*. Energy subsidies are typically untargeted, and tend to benefit higher income groups of the population more than lower income groups (Coady, Gillingham, Ossowski, Piotrowski, Tareq, and Tyson, 2010).

- *Sustainability*. The magnitude of energy subsidies creates concerns regarding fiscal sustainability in many countries in light of high energy prices.

In that context, there has been progress on several relevant topics that can help countries and policymakers think through the options for reforming energy subsidies. For instance, Coady et al., (2010) and IEA, OPEC, OECD, and World Bank (2010) quantify energy subsidies for groups of countries and discuss options for subsidy reform, while Gillaume, Zytek, and Farzin (2011) review the 2010 subsidy reform in Iran.

In spite of this progress, significant uncertainty persists regarding the magnitude of the impact of subsidy reform on energy consumption. In the first place, the impact of energy price changes on energy consumption may be difficult to quantify, as it is likely to materialize slowly over time. For instance, it is likely that agents will move gradually towards less energy-intensive technologies, goods, and/or services. Second, energy consumption is affected by a variety of supply and demand factors, and it is not straightforward to disentangle the individual effect of each factor on consumption.

In this paper, we analyze a panel of cross-country data to explore the link between energy prices and energy consumption. We find a responsiveness of the latter to the former—measured by the long-term own-price elasticity of energy demand—on the order of -0.3 to -0.5. While our elasticity estimates are in the middle to lower range of estimates in the literature, they suggest that countries—especially those with large subsidies—can obtain significant gains from subsidy reform.

II. Responsiveness of Energy Consumption to Energy Prices—Findings in the Empirical Literature

As shown in Table 1, the empirical literature contains a wide range of estimates for both short-term and long-term price elasticities. For instance, the work summarized in Hamilton (2009) puts short-term price elasticities for gasoline and oil consumption in a range from nearly zero to -0.25, and long-term price elasticities in a range from -0.21 to -0.86. The IEA (1999), in a study of the implications of subsidy removals for energy consumption and CO_2 emissions used (long-term) price elasticities in the range of -0.25 to -0.5 for different types of fuel and electricity demand. More recently, IMF (2011) produced estimates of a short-term price elasticity of oil demand of nearly zero and a long-term price elasticity of -0.07.

There is broad consensus that income elasticities are close to one, although recent evidence may suggest lower values. The work summarized by Hamilton (2009) indicates a range for the income elasticity of oil and gasoline consumption between 0.88 and 1.32 (Table 1)—i.e., close to unitary income elasticity. IMF (2011), however, suggests lower long-term income elasticities for oil consumption, arguing that this may reflect substitution away from oil and towards other energy sources.

Table 1. Income and Price Elasticities of Energy Demand: Literature Review

	Study	Sample	Product	Method	Short-term Price Elasticity	Long-term Price Elasticity	Long-term Income Elasticity
Hamilton (2009)	Dahl and Sterner (1991)		Gasoline	Literature survey	-0.26	-0.86	1.21
Hamilton (2009)	Espey (1998)		Gasoline	Literature survey	-0.26	-0.58	0.88
Hamilton (2009)	Graham and Glaister (2004)		Gasoline	Literature survey	-0.25	-0.77	0.93
Hamilton (2009)	Brons et al (2008)		Gasoline	Literature survey	-0.34	-0.84	…
Hamilton (2009)	Dahl (1993)	Developing countries	Oil	Literature survey	-0.07	-0.30	1.32
Hamilton (2009)	Cooper (2003)	22 OECD countries plus China	Oil	Time series regressions	-0.05	-0.21	…
	IEA (1999)		Fuels, Electricity	Selection based on in house expertise		from -0.25 to -0.5	
	Parry and Small (2005)		Gasoline	Parameter selection for callibration		-0.55	
	Narayan and Smyth (2007)	12 Middle East Countries	Oil	Time series regressions and panel co-integration		from 0 to -0.07	0.2 to 1.8
	IMF (April WEO 2011)	45 countries (OECD and non-OECD)	Oil	Panel with fixed-effects	-0.02	-0.07	0.29

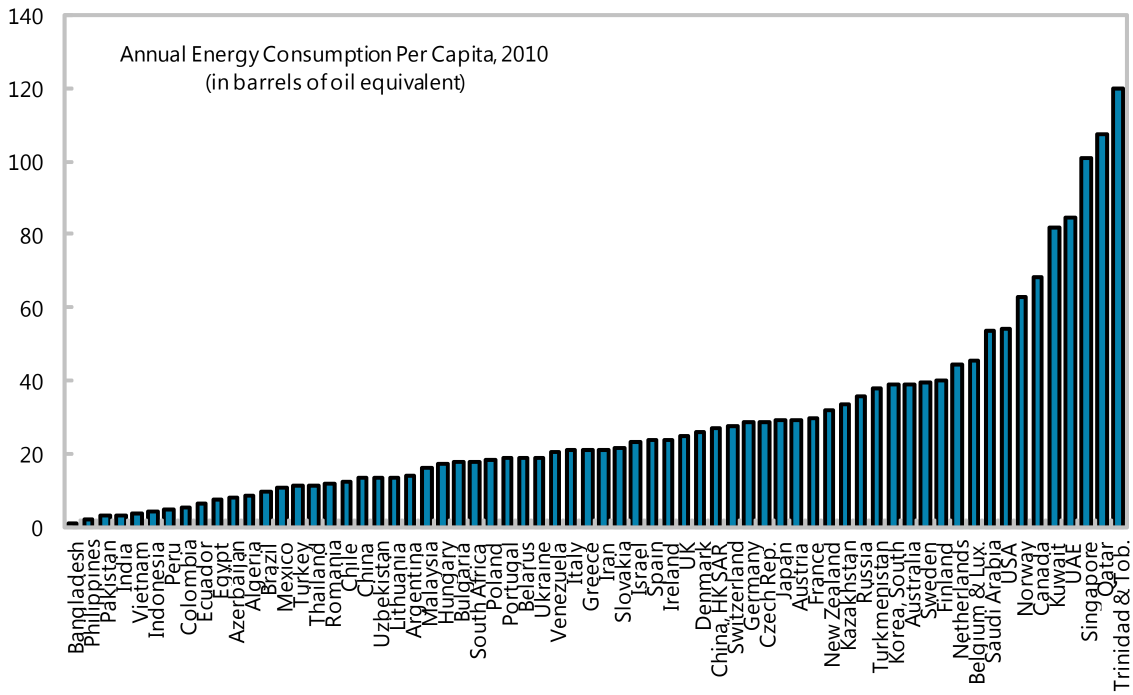
Source: Authors' literature review.

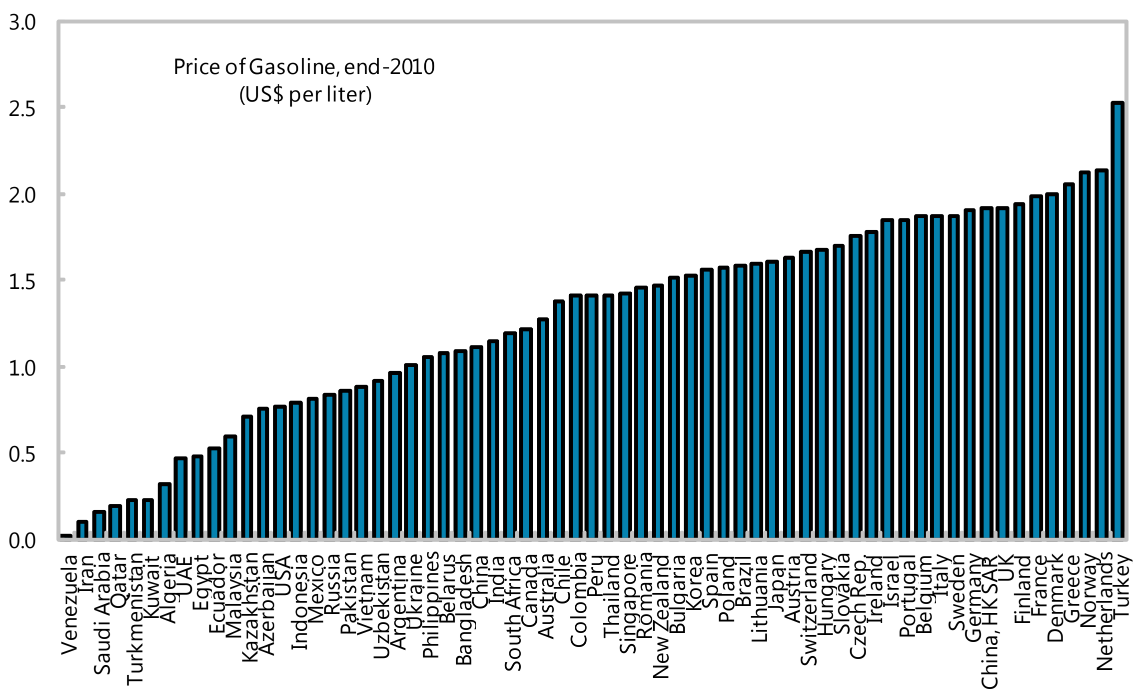
III. Reexamining the (Long-term) Price Elasticity of Energy Consumption

Given the wide range of empirical estimations set out in the literature, we reexamine the issue by comparing cross-country energy consumption and its determinants. The use of cross-country data provides key sources of heterogeneity to estimate income and price elasticities of energy demand, as countries differ widely in their energy consumption, income per capita, and energy prices. The price differences are mainly due to different taxation regimes, ranging from high tax rates on energy to subsidized energy consumption. Cross-country data also provide other sources of heterogeneity that can affect energy consumption, such as weather conditions and the level of development (e.g., more developed countries typically have stricter environmental regulations that can affect energy consumption).

Figure 1 illustrates some of this cross-country variation. The upper panel shows a wide disparity in countries' per capita energy consumption, with the top of the distribution composed of either high-income countries or energy exporters (or both, as in the case of the Gulf Cooperation Council countries). As illustrated in the lower panel, there is also a wide disparity in countries' energy prices (proxied here by gasoline prices), with the top of the distribution being composed mainly of OECD countries, and the bottom of the distribution mainly of energy exporters.

Figure 1. Energy Consumption and Gasoline Prices, 2010





Sources: Energy consumption is from British Petroleum Statistical Review of World Energy (2011) and authors' calculations. Gasoline prices are from GTZ online data.

Analytical framework

Our starting point for estimating the determinants of cross-country energy demand is the following standard demand equation:

$$q_{i,t} = \alpha\gamma_t A_i y_{i,t}^{\delta} p_{i,t}^{\beta} \qquad (1)$$

Where $q_{i,t}$ denotes energy demand of country *i* at time *t*, α denotes a constant, γ_t denotes a time-varying parameter (e.g., technology), A_i denotes country-specific factors (e.g., weather or environmental regulations), $y_{i,t}$ denotes the (real) income of country *i* at time *t*, $p_{i,t}$ denotes the real price of energy, δ is the income elasticity of energy demand—which is expected to be positive, and β is the price elasticity of energy demand—which is expected to be negative.

Taking natural logs on both sides of equation (1) we obtain:

$$\ln(q_{i,t}) = \ln(\alpha) + \ln(\gamma_t) + \ln(A_i) + \delta\ln(y_{i,t}) + \beta\ln(p_{i,t}) \qquad (2)$$

Data

The data are collected from a variety of sources and are available for periods of different length:

- Data on energy consumption (measured in million tons of oil equivalent) come from British Petroleum's 2011 Review of Energy Statistics, while data on population come from the United Nations. These data are available for 1965–2010 for a group of 66 countries, which defines the country dimension of the dataset.

- Data on GDP per capita in U.S. dollars (used as a proxy for countries' income) is and U.S. CPI data (used to deflate variables denominated in U.S. dollars) come from the IMF's World Economic Outlook database. These data are available for 1965–2010.

- Gasoline prices—used as a proxy for overall energy prices—for 2002–09 come from the IMF's Fiscal Affairs Department data prepared for the paper by Coady and others (2010), while 2010 gasoline prices come from GTZ. These data are available for the period 2002–10, which sets the time dimension of the dataset.

- Raw daily weather data come from the U.S. National Oceanic and Atmospheric Administration.[1] These data were processed to compute a *cold weather index* (average temperature of the three coldest months) and a *hot weather index* (average

[1] For a number of countries, more than one weather collection point was available. In such cases, we chose the collection point in the capital of the country, or closest to the capital of the country.

temperature of the three hottest months). The time coverage of these data varies from country to country. For our empirical exercise we collapsed these variables into two time-invariant variables (with variation across countries) by taking the average of the specific variable during the observation period available for each country.[2]

- An advanced countries dummy follows the IMF World Economic Outlook country classification. This classification indicates that our sample is composed of 29 advanced economies and 37 non-advanced economies.

In total, we have a highly balanced panel (for some countries gasoline prices were missing in some years) of 66 countries covering the period 2002–10.

Estimation strategy

We use OLS (with robust standard errors and adjusting for within-cluster correlation) to estimate equation (2). An alternative to our estimation method would be to use fixed-effects (Within) estimation, but this procedure may be problematic given the short time series of our dataset (see below) and given that this method will likely capture short-term elasticities. On this issue, Baltagi and Griffin (1984) have shown with Monte Carlo simulations that OLS estimation is likely to be superior to fixed-effects (and random-effects) estimation if the objective is to estimate long-term elasticities, particularly for panels with a short time dimension.

Before proceeding with the estimation, it is illustrative to analyze the data under the case of unit income elasticity.[3] In this case equation (2) can be rearranged to obtain:

$$\ln\left(\frac{q_{i,t}}{y_{i,t}}\right) = \ln(\alpha) + \ln(\gamma_t) + \ln(A_i) + \beta\ln\left(p_{i,t}\right) \qquad (3)$$

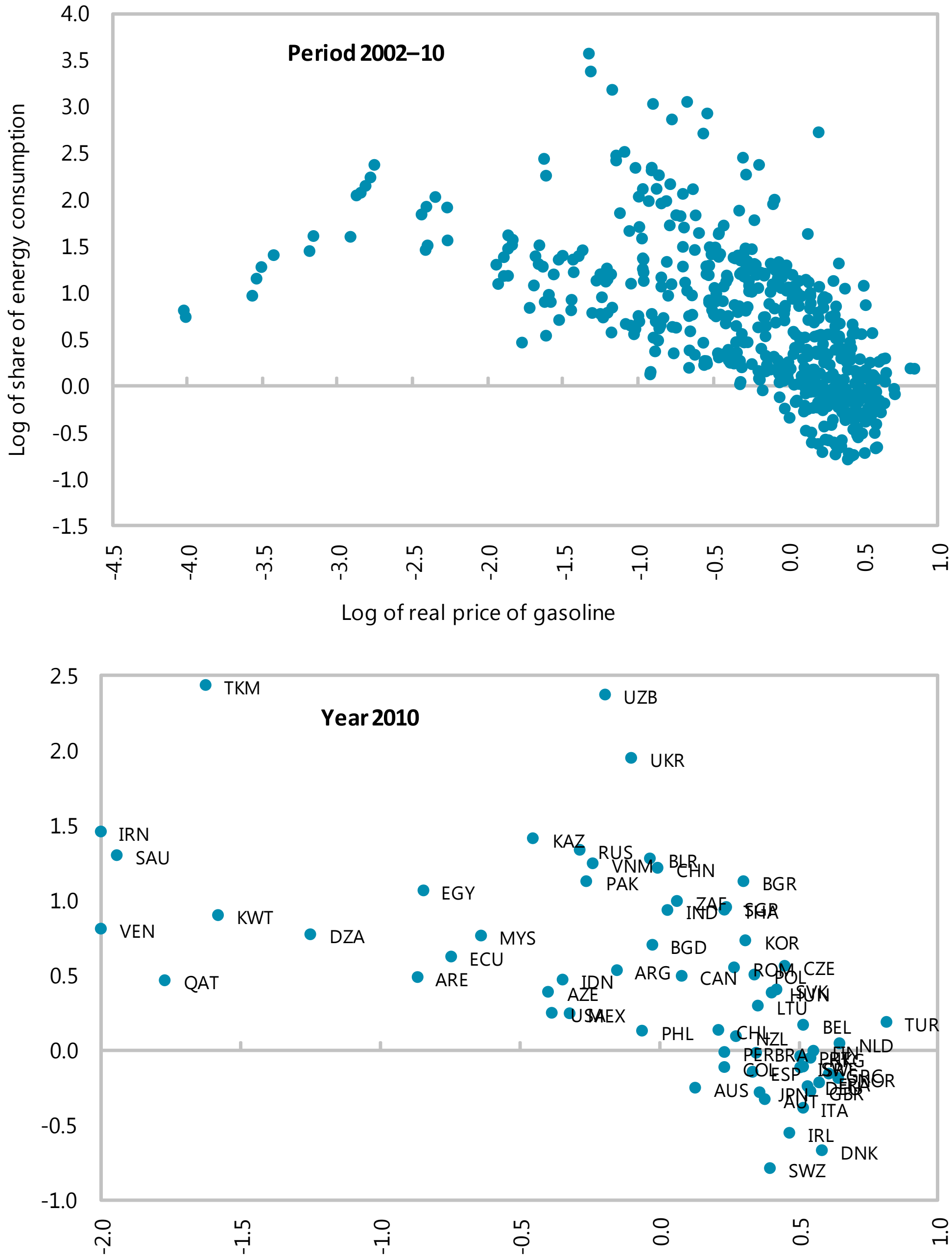
Where the left-hand side is the share of energy consumption in total (real) GDP.[4] Figure 2 shows the share of energy consumption in GDP against the domestic gasoline price (which, as noted above, is taken as a proxy for the overall domestic cost of energy). The chart suggests an inverse relation between energy consumption share and energy prices despite outliers that show low prices and medium levels of energy consumption.

[2] This was done to avoid losing observations due to missing weather data and under the assumption that weather patterns are similar over time.

[3] The case of unit income elasticity is appealing as an illustrative tool on several grounds. First, empirical data suggests that income elasticity should be close to one. Second, an income elasticity equal to one can be easily obtained from standard assumption on demand functions, such as when consumer preferences are assumed to be homothetic.

[4] As noted above, nominal variables in U.S. dollars have been deflated by the U.S. CPI to obtain the equivalent variable in real terms.

Figure 2. Log of Share of Energy Consumption to (real) GDP and Log of Real Gasoline Prices in a Sample of 66 Countries, 2002–10



Sources: Authors' calculations using data from British Petroelum 2011 Statistical Review of World Energy; IMF; and GTZ databases on gasoline prices, and World Economic Outlook database.

Note: Values for the Islamic Republic of Iran and the Bolivarian Republic of Venezuela were adjusted for presentational purposes in the lower panel. The actual values of the log of the real price of gasoline (horizontal axis) are -2.4 and -4.0, respectively.

IV. Estimation Results[5]

The estimation of equation (2) suggests a relatively good fit and a statistically significant link between energy consumption and the explanatory variables. The explanatory power of the estimated equation is quite high with *R*-squareds on the order of 0.75–0.81. In terms of the significance of the regressors, column (3) of Table 2 shows that:

- Real per capita GDP has the expected (positive) sign, is statistically significant, and implies an income elasticity of around 0.77. This elasticity is somewhat lower than the range reported by the empirical literature.
- The gasoline price also has the expected (negative) sign, is statistically significant, and implies a (long-term) price elasticity of around -0.3. This elasticity is in the lower end of the range reported by the empirical literature.
- The weather variables are both statistically significant and have the expected sign. They imply that having a winter (summer) period that is on average 10 degrees Celsius colder (hotter) will increase energy consumption by 2.9 (2.6) percent.
- The advanced-countries dummy was not significant.

Testing for different elasticities across country groups (i.e., advanced versus non-advanced) and for the impact of outliers suggests a lower income elasticity in advanced countries and a higher price elasticity (but equal) across countries.

- Column (1) of Table 3 shows the results of a regression with interaction variables that allow the income and price elasticities to differ between advanced and non-advanced countries. This column shows that the interaction terms are only statistically significant for the income elasticity, whose interaction term is negative. This implies an income elasticity for advanced countries on the order of 0.46.
- Column (2) of Table 3 shows the results of dropping the observations of the two countries with gasoline prices at the bottom of the distribution, which are outliers with respect to energy consumption. The results of this regression show that the price elasticity increases to around -0.5 (in the middle range of the empirical literature), but remains equal for advanced and non-advanced countries (i.e., the interaction term is not significant).

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[5] Given that the main information in our dataset comes from the cross section dimension (we have 66 countries but only nine time periods), our price elasticity should be mainly interpreted as a long-term elasticity—as per the findings of Baltagi and Griffin (1984).

Table 2. Estimating Energy Demand—Baseline Estimations

	Dependent Variable is Log of Total Energy Consumption per Capita		
	(1)	(2)	(3)
Log real per capita GDP	0.704 ***	0.76 ***	0.766 ***
	(0.056)	(0.07)	(0.068)
Log real price of gasoline	-0.357 ***	-0.310 ***	-0.306 ***
	(0.083)	(0.086)	(0.068)
Advanced		-0.237	-0.236
		(0.189)	(0.185)
Cold weather			0.029 ***
			(0.009)
Hot weather			0.026 ***
			(0.008)
R-square	0.75	0.76	0.81
Observations	548	548	548
Countries	66	66	66

Note: Standard errors in parentheses. Standard errors are robust and adjust for within-cluster correlation. Time dummies included but not reported. ***/**/* denote significance levels of 1, 5, and 10 percent, respectively. Estimation is done using OLS for the period 2002–10.

Source: Authors' calculations.

Table 3. Estimating Energy Demand—Allowing for Different Income and Price Elasticities Across Country Groups

	Dependent Variable is Log of Total Energy Consumption per Capita	
	(1)	(2)
Log real per capita GDP	0.798 ***	0.784 ***
	(0.071)	(0.070)
Advanced*(log real per capita GDP)	-0.335 **	-0.348 ***
	(0.129)	(0.126)
Log real price of gasoline	-0.309 ***	-0.507 ***
	(0.073)	(0.103)
Advanced*(log real price of gasoline)	-0.058	0.086
	(0.218)	(0.242)
Advanced	0.848 **	0.987 *
	(0.401)	(0.383)
Cold weather	0.027 ***	0.028 ***
	(0.009)	(0.010)
Hot weather	0.022 **	0.018
	(0.008)	(0.009)
R-square	0.82	0.83
Observations	548	527
Countries	66	64

Note: Standard errors in parentheses. Standard errors are robust and adjust for within-cluster correlation. Time dummies included but not reported. ***/**/* denote significance levels of 1, 5, and 10 percent, respectively. Estimation is done using OLS for the period 2002–10. The second column excludes observations for which the real price is below $0.14 cents per liter.

Source: Authors' calculations.

V. Robustness Checks

Before exploring the implications of the results in the previous section, it is important to explore whether they are subject to biases arising from our empirical strategy. In particular, we explore whether: (i) the use of a proxy for energy prices may be producing a bias in the estimation of the price elasticity; (ii) the implication of other estimation strategies, such as the Between and the Within estimators; and (iii) the implication or removing time-dummies from the estimation. As we argue below, the results obtained in the previous section seem to be robust enough to provide guidance on the the price elasticity of energy consumption.

Measurement error

Gasoline prices are an imperfect proxy of energy prices, which could cause the estimated price elasticity to be biased towards zero (due to measurement error). In order to address this problem one would need either to have a better measure of energy prices, or to do the regressions with a measure of gasoline consumption as dependent variable. While our data availability precludes us from conducting any of those fixes, the BP data provide data on oil consumption, which is likely more related to gasoline consumption.

The first column of Table 4 repeats the regression in the last column of Table 2, but with the dependent variable being (log) oil consumption rather than (log) energy consumption. The modification of the dependent variable produced a small increase in the estimated income elasticity and in the *R*-square, but essentially produced no change in the estimation of the price elasticity. This suggests that the bias due to measurement error is likely to be small.

Other estimation strategies

As discussed in Section III, the work of Baltagi and Griffin (1984) suggests that OLS estimation may be superior to other estimation methods—such as fixed effects, random effects, or between estimations—when the objective is to estimate long-term elasticities. Nonetheless, it is useful to assess the implications of other methods, in particular to understand the main source of variation present in the data.

Columns 2 and 3 of Table 4 repeat the regression in the last column of Table 2 but using Between and Within estimators, respectively. The results of the Between estimator (column 2) are very close to those of the OLS estimation, which is in line with the results of Baltagi and Griffin (1984) and suggest that the cross-country variation is a key source of variation in the data. On the other hand, the Within estimator (column 3) implies income and price elasticities that are not significantly different from zero. The previous result suggests that the short-term elasticities may be much smaller than long-term elasticities, as argued by most of the empirical literature on this topic (e.g., Table 1).

Although the results of the Within estimation are to a large extent consistent with the low short-term elasticities found in the empirical literature, and with the Monte Carlo simulations done by Baltagi and Griffin (1984), they nonetheless raise questions about other possible variables being behind the cross-country inverse correlation between energy consumption and energy prices. For instance, if countries that have high energy prices also have tighter regulations for energy consumption, then the price elasticity estimated in the OLS regressions may be picking up the effect of an unobservable variable.

The results shown in Table 3, however, suggest that the concerns raised in the previous paragraph may not be problematic. In particular, while advanced countries tend to have more environmental regulations that could affect energy consumption (and also higher energy prices), the price elasticity of energy consumption seems to be the same across advanced and non-advanced countries. Accordingly, an omitted variable bias does not seem to be the driver behind the inverse correlation between energy consumption and energy prices observed in the data.

Time dummies

The regression results presented so far in this and the previous sections have included time dummies. While the inclusion of time dummies may be a useful strategy to account for unobserved time effects, those dummies may affect the results by preventing the regression from capturing the link between the trend in energy consumption and the trend in the regressors.

The last column of Table 4 repeats the regression in the last column of Table 2, but removing time dummies from the list of regressors. As the results indicate, both the income and price elasticities are similar to those observed in the last column of Table 2, with the income elasticity becoming slightly lower and the price elasticity slightly higher. (in absolute value).

Table 4. Estimating Energy Demand—Robustness Checks

	Dependent Variable is Log of Total Energy Consumption per Capita 1/			
	(1)	(2)	(3)	(4)
Log real per capita GDP	0.828 ***	0.740 ***	0.099	0.739 ***
	(0.056)	(0.060)	(0.063)	(0.064)
Log real price of gasoline	-0.306 ***	-0.305 ***	0.046	-0.341 ***
	(0.072)	(0.095)	(0.034)	(0.070)
Advanced	0.000	-0.130		-0.160
	(0.145)	(0.188)		(0.169)
Cold weather	0.004	0.034 ***		0.028 ***
	(0.007)	(0.007)		(0.009)
Hot weather	0.025 ***	0.027 **		0.024 ***
	(0.007)	(0.011)		(0.009)
R-square 2/	0.87	0.86	0.18	0.80
Observations	548	548	548	548
Countries	66	66	66	66
Estimation method	OLS	Between	Within	OLS

Note: Standard errors in parentheses. Standard errors are robust and adjust for within-cluster correlation in the OLS and Within regressions. Time dummies included (except in column 4) but not reported. ***/**/* denote significance levels of 1, 5, and 10 percent, respectively. Estimation period is 2002–10.

1/ Dependent variable on column (1) is log of oil consumption per capita.
2/ Between and Within R-squares reported for the Between and Within regressions, respectively.

Source: Authors' calculations.

VI. Implications for Subsidy Reform

The estimations of the price elasticity of energy demand set out above suggest that countries with high energy subsidies could benefit from undertaking a subsidy reform accompanied by safety nets to protect lower-income segments of the population.

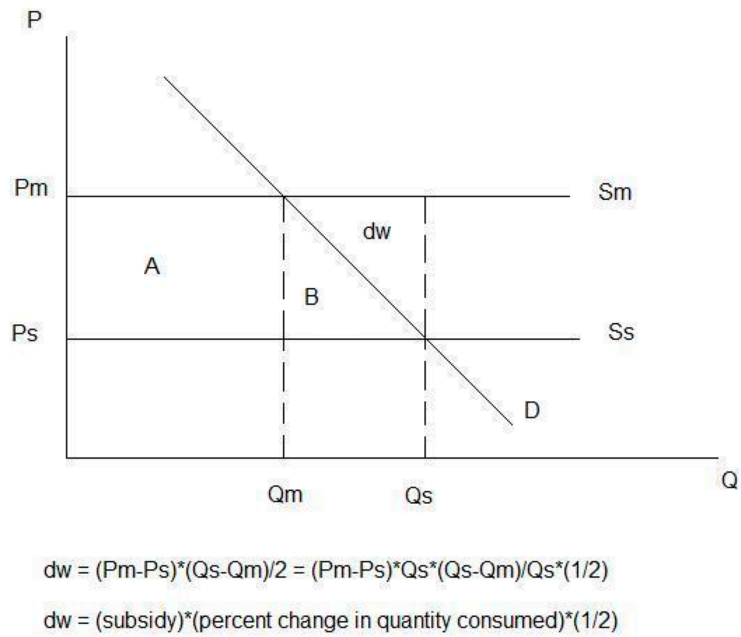
Figure 3 serves to illustrate this point with the help of a linear demand function: S_s is the energy supply in a country that is selling energy at the subsidized price P_s, which is lower than the international market price P_m (which is also the opportunity cost).[6] Given the country's demand curve, the country ends up consuming the amount of energy Q_s, which is higher than the energy it would consume if the price of energy were equal to its opportunity cost (Q_m). The rectangle formed by the areas *A*, *B*, and *dw* constitutes the total subsidy that the government is giving to consumers. Notice that *dw* is a deadweight loss from the subsidy—that is, the area in which willingness to pay by consumers (given by the height of the demand curve) is below the opportunity cost. Notice also that the higher the price elasticity of demand, the higher the deadweight loss is going to be.

If the government removes the subsidy (i.e., price increases to P_m) it saves the areas *A*, *B*, and *dw*, but the welfare of consumers declines because they are now consuming less of the good and paying more for each unit. The government can then decide on how to rebate part of the resources it has saved to compensate consumers. If the government wants to keep consumers completely indifferent, then it can rebate back areas *A* and *B*, which would still provide the government a net saving equal to *dw*—i.e., savings equal to the deadweight loss. These savings can be significant for some countries: for instance, Charap, Ribeiro da Silva, and Rodriguez (2012) estimate that for Kuwait this would imply in the long term a net permanent saving of approximately between 0.9–1.4 percent of GDP per year.

The government also has other alternatives for rebating the proceeds of subsidy reform: For instance, it could rebate only area *A*—i.e., only rebate the subsidy for the amount of energy that would have been consumed without the subsidy—in which case the net permanent savings would amount to areas *B* and *dw*. Finally, the government could choose a more targeted approach, focusing only on low-income consumers, in which case the savings would depend on the scope of the government's rebate program.

[6] We assume that the country can buy/sell energy freely in the international market and that the country's consumption decisions do not affect the international price of energy. These assumptions imply a horizontal supply curve.

Figure 3. Cost and Deadweight Loss from Subsidies



Source: Author's illustration.

The analysis presented above, and the elasticities estimated in the previous section, suggest that some countries could achieve significant gains from subsidy reform in the long term. Nevertheless, it is also essential to consider the implications of subsidy reform in the short term. As the empirical literature cited in Section 2 suggests, the short-term price elasticity of energy demand is likely to be much lower than the long-term elasticity, which would imply that the loss of consumer welfare in the short term is higher than the long-term loss.[7] The higher impact that changes in energy prices would have on consumer welfare in the short-term versus the long-term calls for either a gradual approach to subsidy reform or more generous safety nets in the short-term.

VII. Conclusions

In this paper we have analyzed a panel of cross-country data to explore the responsiveness of energy consumption to changes in energy prices and other variables. Overall, our findings indicate a long-term price elasticity of energy demand between -0.3 and -0.5 and an income elasticity in the order of 0.7–0.8. Both results are in the middle to lower range of estimates produced by a large body of empirical literature. In addition, we found that the price elasticity of energy demand did not vary significantly across country groupings (i.e., advanced versus non-

[7] Because consumers would be less able to substitute away from energy in the short term. For the case of Figure 3, a lower price elasticity would imply a steeper demand curve, which would imply higher losses for consumers: If the demand curve passes through the point P_sQ_s, but is steeper, then the deadweight loss (dw) is smaller and the loss of consumer welfare due to an elimination of the subsidy (i.e., areas A and B) is larger.

advanced countries), but that the income elasticity of energy demand appeared lower for the advanced countries group.

These findings seem robust to potential biases arising from: measurement error of the cross-country price of energy, omitted variables, and the inclusion of time dummies. The use of other estimation strategies—Within and Between estimations—highlights that the cross-country variation is the key source of variation in our dataset. Furthermore, these other estimation strategies suggest that short-term elasticities may be much smaller than long-term elasticities. Nonetheless, datasets with a longer time dimension than the one used in this paper (nine years) may be needed to explore more deeply the link between long-term and short-term price elasticities.

The estimations of the price elasticity of energy demand set out above suggests that subsidy reform could have large implications for energy consumption in the long term and that countries could reap significant long-term benefits from the reform of their energy subsidies. In this connection, our analysis highlights the importance of designing appropriate safety nets to mitigate the impact of subsidy reform on vulnerable parts of the population. In addition, our analysis indicates that the loss of consumer welfare as a result of subsidy reform is likely to be larger in the short term than in the long term, which calls for either a gradual approach to subsidy reform or more generous safety nets in the short term.

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