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King Abdullah Petroleum Studies and Research Center

Modeling Residential Electricity Demand in the GCC Countries

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Key Points

Our research suggests that consumers’ response to a change in the real electricity price in the GCC region has been very limited during the past three decades.

The low price response coupled with the low administered electricity price regime, together with rapidly increasing income and prosperity, has resulted in residential electricity demand in the GCC region increasing rapidly over the past three decades.

Beyond a certain level of harsh climatic conditions, variations in local temperatures have a minor impact on residential electricity demand in the GCC region since temperatures have traditionally been extreme.

Underlying electricity use due to evolving consumer behavior — holding all other drivers constant — has been increasing in Saudi Arabia, Bahrain and Oman. However, for Kuwait, it reached a level in the early 1990s that has been maintained thereafter. This suggests a sizeable reduction in consumption could be achieved through energy awareness campaigns.

Summary

The Gulf region has seen rapid population and economic growth over the past few decades, changing the landscape of the area, raising living standards and enabling millions to increase their consumption of essential services such as water and electricity. These services have mostly been provided by government-owned utilities at subsidized rates. Despite this, little research has been done on estimating the impact of the drivers of the demand for electricity in the region, with none taking into account factors such as weather and consumer behavior.

It is critical for a policymaker who is facing rising demand for electricity on the back of income and population growth to have comprehensive quantifiable information on which to base decisions. This paper seeks to estimate the way residential electricity demand responds to changes in prices, income, population, weather and other factors in the six Gulf Cooperation Council (GCC) countries – Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates (UAE). The responses are normally measured by the demand elasticity, which is defined as the percentage change in electricity demand, divided by the percentage change in the appropriate driver. Where drivers cannot be adequately measured, such as improvements in the efficiency of appliances and capital stock or exogenous energy-consuming behavior, the impact is captured by a non-linear trend. The estimated model therefore provides information on the price, income, population and weather elasticities as well as identifying the additional underlying trends for residential electricity consumption.

The results suggest that a good econometric relationship can be found for Bahrain, Kuwait, Oman and Saudi Arabia (whereas for Qatar and the UAE the results are a little problematical). The long run price elasticity of electricity demand for Bahrain, Kuwait, Oman and Saudi Arabia is found to range from -0.16 to zero suggesting that the electricity consumers' response to price changes is very limited – i.e., demand is very price inelastic. The income (represented by gross domestic product, GDP) and population elasticities are also found to be inelastic – but generally greater (in absolute terms) than the price elasticities. The long run income and population elasticities of electricity demand for the four countries are found to range from 0.4 to 0.9 and zero to 0.8 respectively.

Even for weather, in the form of cooling degree days, the influence on residential electricity demand is inelastic at 0.2 to 0.7. In addition, the underlying trends are found to vary across the four countries but with all of them generally showing exogenous electricity using behavior.

Our results suggest that given the current pricing regime in the GCC region, residential electricity consumption is likely to continue to increase apace. Based on our findings, successful policies to curtail future residential electricity consumption would likely include improving the efficiency of appliances and increasing energy usage awareness of consumers, possibly through education and marketing campaigns. Furthermore, the estimated price inelasticity of demand suggest that small price increase would have little impact on curbing residential electricity growth. For any significant effect, prices would have to be increased substantially so that expenditure on electricity becomes such a large proportion of income that the price elasticities increase in absolute terms.

Introduction

In a world with increased international focus on energy use, comparing energy consumption behavior across countries can inform decision makers about their country's relative performance and opportunities for future improvement. In particular, understanding the drivers of residential electricity consumption – and by association the intensity and productivity of residential electricity use – has become increasingly important for policy-related international cross-country comparisons. However, the contrasts are arguably more meaningful when comparisons are normalized for uncontrollable exogenous factors, weather being a prime example. Given the rapid development of electricity using appliances such as air conditioners, the interdependency between climate variation and residential electricity consumption has, in all probability, increased – with space heating and cooling representing the largest share of building energy consumption in many countries (Perez-Lombard et al., 2008). Moreover, analyzing the effect of weather on residential electricity demand is of special relevance to GCC countries, which by virtue of being located near the tropics, have one of the hottest and most arid climates in the world.

Furthermore, residential electricity consumption of the GCC countries increased rapidly over recent decades coupled with a steep increase in population and relatively fast economic growth (Squalli, 2007; Reiche, 2010). This is at a time when residential electricity prices in the GCC countries were administered by the state and therefore fixed in nominal terms for a number of years between adjustments. Within this context, this paper models econometrically residential electricity demand for the six GCC countries in order to estimate the GDP, price and population elasticities as well as controlling and quantifying for the effect of weather conditions. The model utilized recognizes that electricity is a derived demand based on the demand for energy services such as heating, cooling and cooking (Hunt and Ryan, 2015). Hence in addition to the key drivers of GDP, prices, population and weather, an explicit allowance is made for energy efficiency and other exogenous effects by estimating a stochastic underlying energy demand trend (UEDT), as suggested by Hunt et al. (2003a, b).

Residential Electricity in the GCC Countries

Despite sharing many common traits, the GCC economies are not as macro-economically unified as might be assumed. Saudi Arabia and the UAE are the economic powerhouses of the region accounting together for around 70 percent of its GDP and 80 percent of its population (World Bank, 2014). Another, more discrete, image emerges when comparing GDP per capita of the GCC countries in 2010; at current values Qatar, Kuwait and the UAE's values stand at around two to four times the values of the remaining countries as illustrated in Figure 1, which for their part are still more than double the world average (World Bank, 2014).

Over the past three decades, the GCC governments invested a large part of their oil and gas rents in infrastructure development, drastically increasing the electrification rate in cities and villages around the region (Squalli, 2007). This has been associated with residential electricity consumption increasing rapidly in each country, as shown in Figure 2.

Related to this is the energy pricing regime in the GCC region, where most power generation is undertaken using locally available hydrocarbon resources, which has resulted in electricity prices traditionally being administrated by governmental bodies – set intermittently as a result of policy changes with little, or no, connection to international commodity markets.

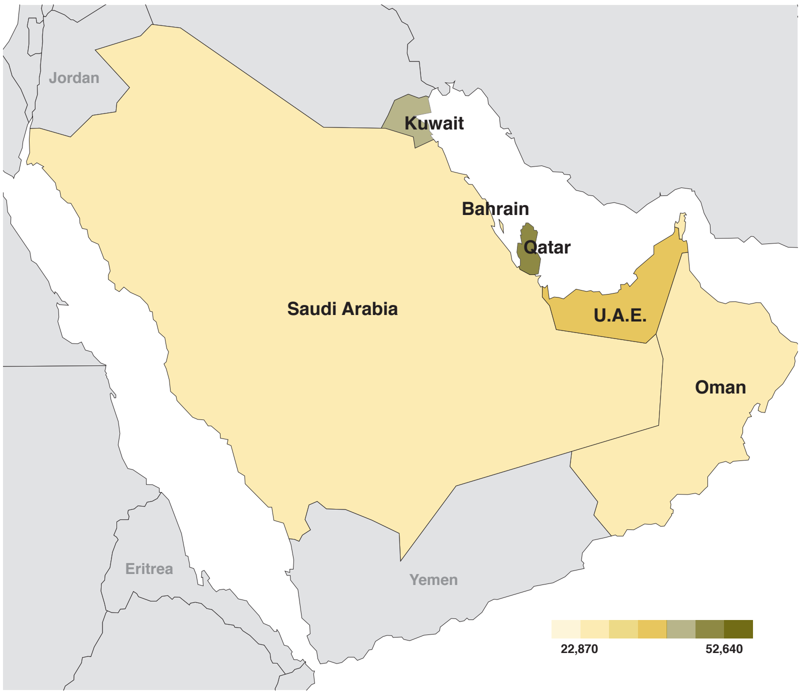

Figure 1. Map of the GCC countries showing per capita GDP in U.S. dollar for 2010.

Source: World Bank, 2014

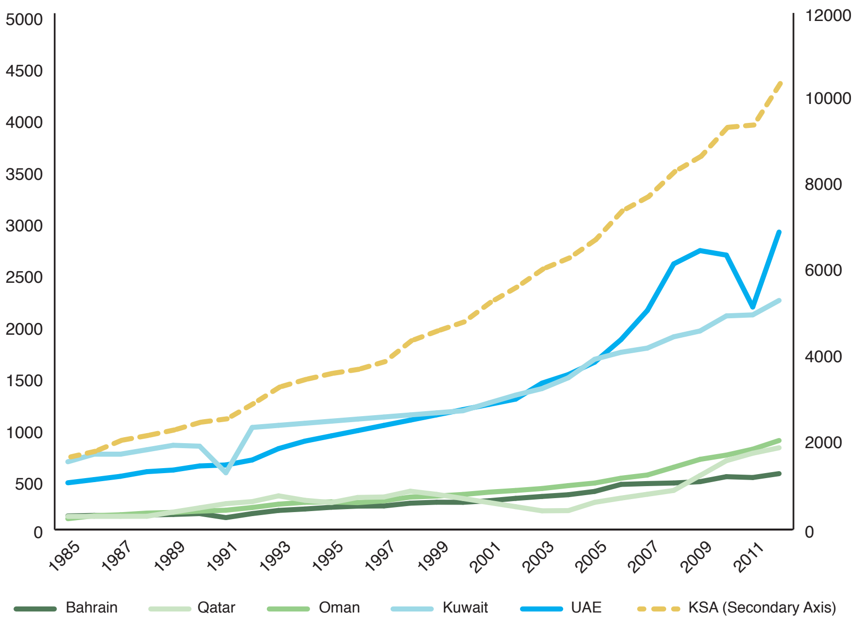

Figure 2. Residential electricity consumption in kilo tonnes of oil equivalent (toe) for the GCC countries from 1985 to 2012 in toe. Saudi Arabia is on the right y axis.

Source: IEA, 2014

The various pricing mechanisms of the countries in the GCC have resulted in different levels of subsidies. Residential electricity retail prices provided in Figure 3 illustrate the large variation between Bahrain's and the UAE values, which were more than five times the price for Kuwait and Saudi Arabia in 2010. Still, when compared internationally, GCC electricity prices are a fraction of those in the European Union and the United States. All of which have probably contributed to the disproportionate residential energy consumption per capita where it is sizably higher than the OECD countries, China and the World average, as shown in Figure 4.

As far as we are aware, there are very few published studies attempting to model residential electricity demand for the GCC countries and most of these are illustrated in Table 1. The studies can be categorized into two groups: one containing research that attempted to model the GCC countries in a panel context, and another studies intended to model the countries individually (either in a one-country or multi-country study). Of those, it can be seen that the early studies by Eltony and associates for Kuwait produced relatively small estimated income and price elasticities. Whereas the more recent multi-country studies published in the 2000s suggest rather large estimated income and price elasticities – the latter being somewhat larger (in absolute terms) than might be expected for countries with the characteristics outlined earlier. Hence, the research undertaken here attempts to re-evaluate these elasticities using a framework (outlined in Appendix A), which we believe is more appropriate for such energy economies. The data used and the full results are given in Appendices B and C, with the results briefly discussed in the next sub-section.

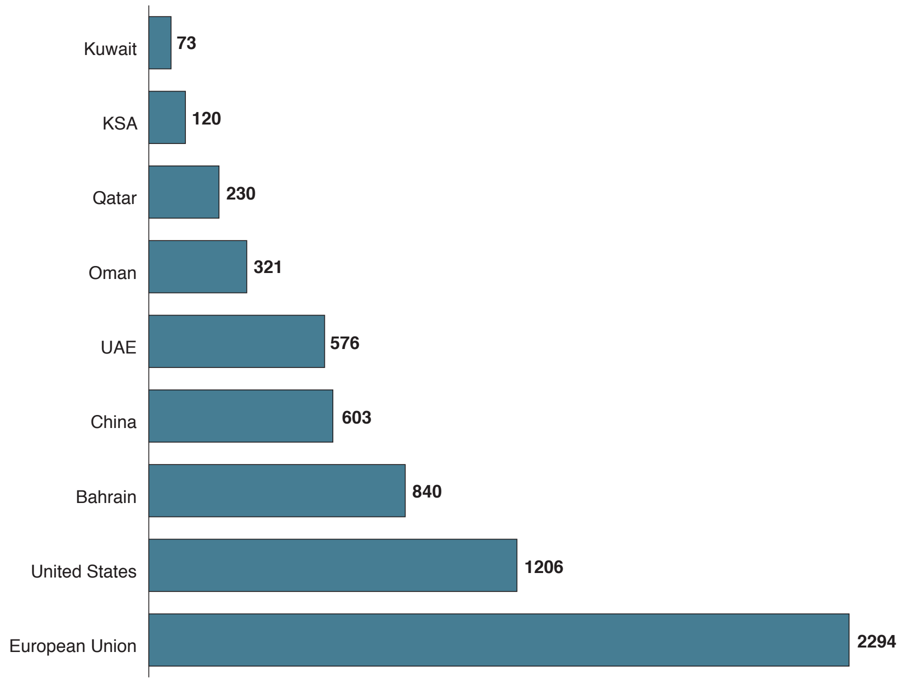

Figure 3. Comparative prices of residential electricity in 2005 (2010$ per toe).

Source: Enerdata, 2015 and World Bank, 2014

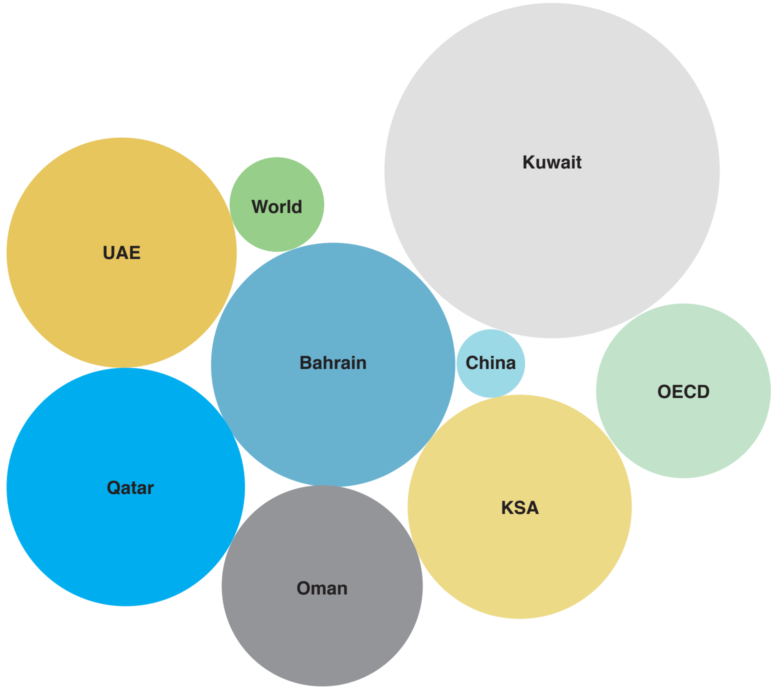

Figure 4. Selected residential electricity consumption in 2010 on a per capita basis.

Source: IEA, 2014

Table 1. Previous GCC electricity demand studies.

Name	Data Type	Countries	LR Income Elasticity	LR Price Elasticity	Notes
Eltony & Mohammad (1993)	Panel	GCC	0.20	-0.14	
Eltony (1995)	Time series	Kuwait	0.09	-0.06	
Eltony & Hoque (1997)	Time series	Kuwait	N/A	N/A	No values for residential sector
Al-Faris (2002)	Time series	Saudi Arabia	1.65	-1.24	
		UAE	2.52	-2.43	
		Kuwait	0.33	-1.10	
		Oman	0.29	-0.82	
		Bahrain	5.39	-3.39	
		Qatar	2.65	-1.09	
Eltony & Al-Awadhi (2007)	Panel	GCC	N/A	N/A	No values for residential sector
Squalli (2006)	Time series	OPEC Countries	Causality only	Causality only	Not only residential
Narayen & Smyth (2009)	Panel	Kuwait	1.32	N/A	With Granger Causality, does not include prices
		Oman	3.86	N/A	
		Saudi Arabia	3.07	N/A	

Estimation Results

The key results from the research are summarized in Table 2. As explained in Appendix C, good econometric relationships could be found for Bahrain, Kuwait, Oman and Saudi Arabia (but not so good for the UAE and Qatar); hence the focus here is on these four countries only.

Table 2 shows that the results suggest that the long run response by electricity consumers to changing real electricity prices is very limited: zero for Bahrain and Kuwait (i.e., perfectly inelastic) and -0.10 and -0.16 for Oman and Saudi Arabia respectively (i.e., relatively inelastic). The low price elasticities are not unexpected given the historically low cost of electricity when compared with household income.

For income (GDP) the responses, although still inelastic, are generally greater (in absolute terms) with the long run income elasticity of electricity demand for the four countries ranging from 0.4 to 0.9. Similarly for population, where the long-run population elasticities are found to be zero for Bahrain and Oman (i.e., perfectly inelastic) but 0.68 and 0.80 for Kuwait and Saudi Arabia, respectively. Table 2 also shows that Bahrain, Kuwait, Oman and Saudi Arabia all respond positively to a change in cooling degree days ranging from just under 0.2 for Kuwait to almost 0.7 for Bahrain.

Figure 5 presents the estimated underlying trends for Bahrain, Kuwait, Oman and Saudi Arabia. This shows that for Bahrain, Oman and Saudi Arabia the trends are generally upward sloping indicating exogenous electricity using behavior. Whereas for Kuwait, it also suggests electricity using behavior over the period considered but is driven primarily by the large increase in the early 1990s. Nonetheless, overall the trends suggest that either there have been no, or very little, electricity efficiency improvements over the period, or if there were, then they have been more than outweighed by electricity using behavioral changes.

Table 2. Estimated elasticities.

	Bahrain	Kuwait	Oman	Saudi Arabia
Long Run Elasticities				
Price	0.00	0.00	-0.10	-0.16
GDP	0.71	0.43	0.86	0.48
Population	0.00	0.68	0.00	0.80
Impact Elasticity				
CDD	0.66	0.18	0.48	0.50

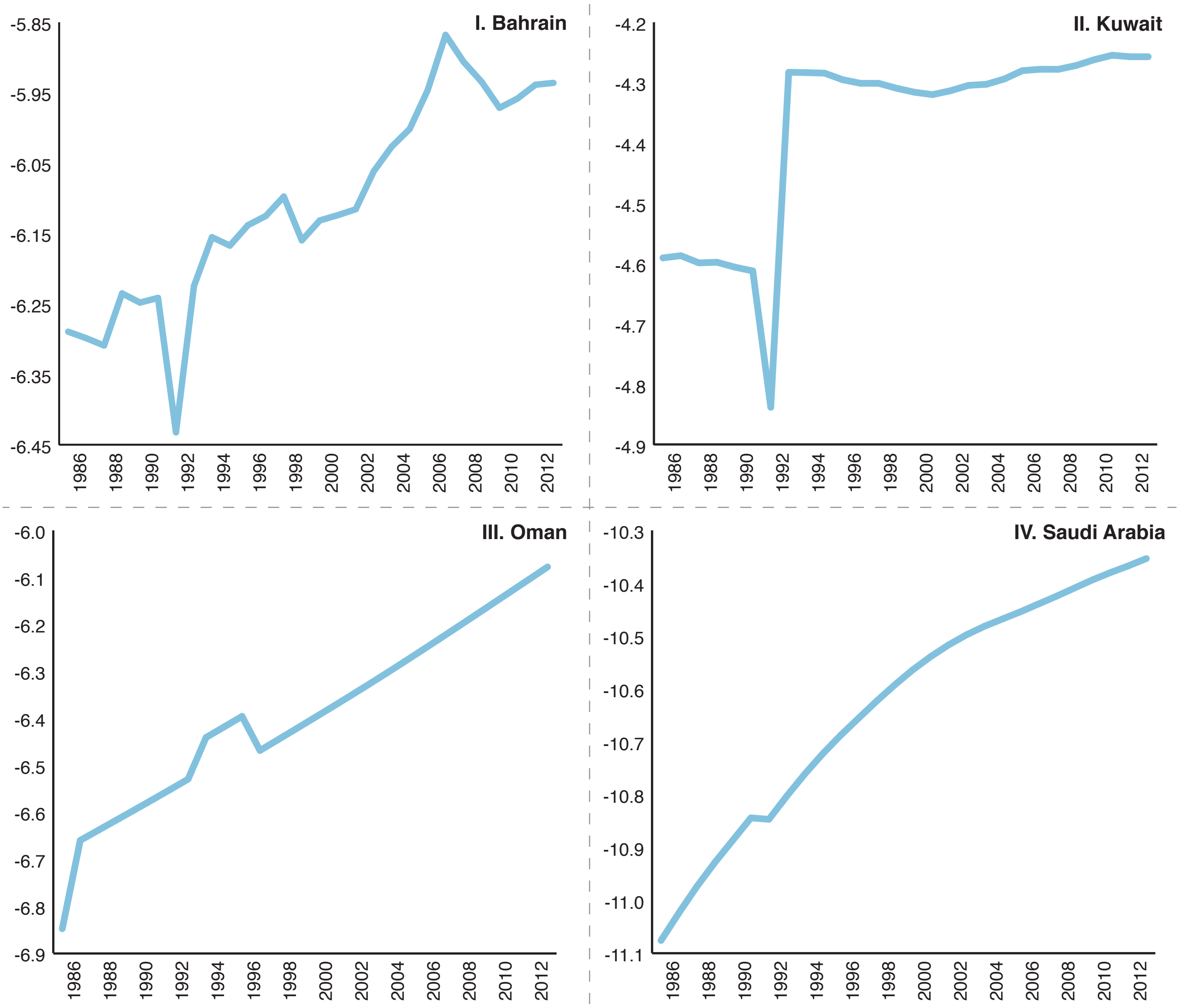

Figure 5. Estimated underlying energy demand trends.

Conclusion and Policy Implications

This paper presents the results from estimating residential electricity demand functions for the six GCC countries – a region with particular characteristics, such as the macroeconomic and political environment, as well as the electricity-pricing regime. The findings suggest that good statistical results can be found for Bahrain, Kuwait, Oman and Saudi Arabia whereas for Qatar and the UAE some statistical problems were encountered.

Focusing on Bahrain, Kuwait, Oman and Saudi Arabia, the estimated long-run GDP elasticities from the analysis range from 0.43 to 0.71, being generally somewhat lower than the estimates from papers published since the start of the 21st century where more traditional econometric methodologies were applied; thus, not allowing for the impact of an exogenous stochastic UEDT nor weather changes. Long-run population elasticities are also estimated, but are found to be zero for Bahrain and Oman but 0.68 and 0.80 for Kuwait and Saudi Arabia respectively, suggesting that the impact of population change is somewhat greater for the latter two countries.

Furthermore, for all countries residential electricity demand is found to be very price inelastic with the estimated long-run price elasticities ranging from -0.16 to zero, which again are not too out of line with the early estimates for Kuwait but somewhat lower (in absolute terms) than those found in papers published over the past 15 years.

Unlike a number of previous attempts to model GCC residential electricity demand, the results obtained here using a novel application for the region provides policymakers with valuable and quantifiable information. Not only do they provide vital elasticity estimates, other things being equal, they also provide information on the separate behavioral aspects, which interestingly for Bahrain, Kuwait, Oman and Saudi Arabia generally suggest electricity using behavior.

Thus, given the current pricing regime, residential electricity consumption in these countries is likely to continue to increase apace as GDP grows and the exogenous electricity using behavior continues. This suggests that if policy makers in the region wish to curtail future residential electricity consumption they would need to improve the efficiency of appliances and increase consumers' energy usage awareness, possibly by education and marketing campaigns. Moreover, even if prices were raised, the estimated price inelasticity of demand suggest that this would have little impact on curbing residential electricity growth in the region. To have a noteworthy effect, prices would need to be raised somewhat higher than in the past, so that expenditure on electricity becomes a large enough proportion of income that the price elasticities increase in absolute terms.

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Appendix A: Econometric Methodology

There are many examples of modeling the demand for aggregate energy and individual energy sources in the energy economics literature that involves a range of different specifications and methodologies. This is particularly true for countries from the developed world but this is not the case for residential electricity demand in the GCC countries. Possible reasons for this could be the difficulty in modeling sectors in countries with administered prices that change periodically as well as being rather volatile with a number of economic and geopolitical shocks occurring during the estimation period.

The approach followed here therefore is based on Hunt and Ryan (2015) who explicitly show that when a model of energy demand is based upon the demand for the energy services that are produced with appliances, then there should be an allowance for the efficiency of the appliances, separate from the price driver. Therefore, following Hunt et al. (2003a; b), the general model outlined in the following section includes the key drivers of GDP, prices, population and weather (discussed further below) as well as a stochastic underlying energy demand trend (UEDT) to allow for exogenous changes in the use of residential electricity that comes about from energy efficiency improvements and other exogenous effects such as changes in tastes, behavior and legislation. This is achieved using an unobserved components model via the Structural Time Series Model (STSM) introduced by Harvey et al. (1986), Harvey (1989), Harvey and Shephard (1993), Harvey and Scott (1994) and Harvey (1997). Moreover, such a model allows for interventions that take account of the impact on the UEDT from one-off impacts and/or from structural breaks brought about by key events such as wars – which is particularly relevant to the countries being studied. Thus, given the nature of the data being modelled, the instability of the region and the pricing regimes, arguably the unobserved components model is particularly relevant for modeling GCC countries' residential electricity demand – as well as being consistent with the Hunt and Ryan (2015) energy services derivation. Furthermore, given the extreme climatic situation in the Gulf countries the impact of weather is explicitly considered; briefly discussed in the next sub-section.

It is therefore assumed that generally each GCC country's residential electricity demand is identified by:

$$E_t = f(Y_t, P_t, POP_t, HDD_t, CDD_t, UEDT_t) \quad (1)$$

where;

E_t= Residential electricity demand;

Y_t= Real GDP;

P_t= Real residential electricity price;

POP_t= Population;

HDD_t= Heating degree days;

CDD_t= Cooling degree days; and

$UEDT_t$= Underlying Energy Demand Trend.

Eq.1 is estimated using a dynamic autoregressive distributed lag specification with a two year lag as follows (the lag length is chosen to capture any possible dynamic effects and is seen as a reasonable length given the data set being used):

$$e_t = \alpha_1 e_{t-1} + \alpha_2 e_{t-2} + \gamma_0 y_t + \gamma_1 y_{t-1} + \gamma_2 y_{t-2} + \delta_0 p_t + \delta_1 p_{t-1} + \delta_2 p_{t-2} + \theta_0 pop_t + \theta_1 pop_{t-1} + \theta_2 pop_{t-2} + \lambda_0 hdd_t + \varphi_0 cdd_t + UEDT_t + \varepsilon_t \quad (2)$$

Where e_t, y_t, p_t, pop_t, hdd_t, and cdd_t are the natural logarithms of E_t, Y_t, P_t, POP_t, HDD_t, and CDD_t in year t respectively and ε_t is a random white noise error term. The coefficients γ_0, δ_0, θ_0, λ_0. and φ_0 therefore represent the short-run impact elasticities for GDP, real electricity prices, heating degree days and cooling degree days respectively and the long-run GDP, real electricity price, and population elasticities are given by

$$\Gamma = \frac{\gamma_o+\gamma_1+\gamma_2}{1-\alpha_1-\alpha_2}, \Delta = \frac{\delta_o+\delta_1+\delta_2}{1-\alpha_1-\alpha_2}, \text{ and } \Theta = \frac{\theta_o+\theta_1+\theta_2}{1-\alpha_1-\alpha_2}$$

retrospectively.

Furthermore, the UEDT is a stochastic trend estimated using the STSM as follows:

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \,; \quad \eta_t \sim NID\ (0, \sigma_\eta^2) \qquad (3)$$

$$\beta_t = \beta_{t-1} + \xi_t \,; \quad \xi_t \sim NID\ (0, \sigma_\xi^2) \qquad (4)$$

Where μ_t and β_t are the level and slope of the UEDT respectively. η_t and ξ_t are the mutually uncorrelated white noise disturbances with zero means and variances σ_η^2 and σ_ξ^2 respectively (known as hyper-parameters). The disturbance terms η_t and ξ_t determine the shape of the stochastic trend component (Harvey and Shephard, 1993). Where necessary irregular or outlier interventions (Irr), level interventions (Lvl) and slope interventions (Slp) are added to the model to aid the fit and help ensure the model passes the diagnostic tests for the standard residuals and the auxiliary (irregular, level and slope) residuals. Moreover, the interventions provide information about important breaks and structural changes during the estimation period (Harvey and Koopman, 1992). In the presence of such interventions, the UEDT can be identified as:

$$UEDT_t = \mu_t + \textit{irregular interventions} + \textit{level interventions} + \textit{slope interventions} \qquad (5)$$

The estimation strategy involves estimating Eqs. (2), (3) and (4) by a combination of maximum likelihood and the Kalman filter and then eliminating insignificant variables and adding interventions but ensuring the model passes an array of diagnostic tests. This continues until the preferred parsimonious model is obtained (normally with a maximum significance level of 10% when accepting or rejecting the null hypothesis for individual parameter coefficients, interventions, and diagnostic tests). The software package STAMP 8.10 (Koopman et al, 2007) is used for the estimation of the model discussed in the results section.

Appendix B: Data

Data for this research was gathered from different sources. Residential electricity demand for the six countries was obtained through the IEA (2014) and World Bank (2014). Time series for real and nominal GDP and population were obtained through the World Bank's database (World Bank, 2014). Furthermore, cooling degree days and heating degree days were taken from the CMCC-KAPSARC database (Atallah et al., 2015) for Kuwait, Oman, Saudi Arabia and United Arab Emirates. The specific degree days time-series were generated from the temperature-based index with a reference temperature of 21.1°C for cooling and 18.3°C for heating and, as such, it does not account for the effects of humidity or solar radiation. As the above-mentioned database does not include cooling degree days and heating degree days data for Qatar and Bahrain, these were instead computed using Wolfram Alpha's (2015) engine. Unlike the data from the CMCC-KAPSARC database, no population weighting was necessary for the Wolfram Alpha degree days as Qatar and Bahrain have relatively small area sizes, which makes the weather conditions relatively homogenous across all their cities. The real residential electricity prices were generated from different sources. Kuwait's nominal prices were obtained from Fattouh and Mahadeva (2014), later transformed into real 2005$ per toe. Data for Bahrain's prices was constructed from Akbari et al. (1996) and Al-Faris (2002) and completed by recent years' prices from the national Kingdom of Bahraini Energy and Water Authority (2015) and the successive statistical bulletins of the Arab Union of Electricity (n.d.). Saudi Arabia's residential electricity prices were obtained from the Electricity and Co-generation Regulation Authority (ECRA, 2015) while Omani prices were gathered from Al-Faris (2002), El-Kathiri (2011), the Omani Chamber of Commerce and Industry (2015) and IRENA's Oman Renewable Readiness Assessment (2014). Prices for the United Arab Emirates and Qatar were generated based on data from Al-Faris (2002), various ministerial decrees and the successive statistical bulletins of the Arab Union of Electricity (2012). Although very limited in occurrence, missing yearly data was interpolated or assumed constant. When applicable, various data was corroborated with the information provided by Enerdata (2015).

Appendix C: Detailed Estimation Results

Following the estimation strategy outlined in the methodology, section the preferred models for each country are shown in Table A1 along with an array of diagnostic tests. Table A1 shows that the preferred models for all countries pass almost all the diagnostic tests including the additional normality tests for the auxiliary residuals generated by the STSM approach. However, the results for the individual countries differ considerably; consequently, each country is discussed in detail below. Nonetheless, it should be noted that both Qatar and the UAE were difficult countries to model and for both countries the original general Eq. (2) above was replaced by a per capita model (and, for the UEA, some difficulties still arose) as is explained further below. Hence, Bahrain, Kuwait, Oman and Saudi Arabia are discussed first followed by the discussion of Qatar and the UAE.

Table A1. Preferred GCC residential energy demand models.

	Bahrain	Kuwait	Oman	Saudi Arabia	Qatar	UAE
Estimated Coefficients						
α_1	-	-	0.1655*	-	0.5660***	-
γ_0	-	0.2988***	0.7198***	-	-	-
γ_1	-	0.1271**	-	0.4801***	-	-
γ_2	0.7130***	-	-	-	-	-
δ_0	-	-	-	-0.1597**	-	-
δ_1	-	-	-0.0853**	-	-	-
θ_0^{99-12}	n/a	n/a	n/a	n/a	-0.0276*	n/a
θ_0^{03-12}	n/a	n/a	n/a	n/a	n/a	0.0072***
θ_0	-	-	-	4.2004***	1.0000##	-0.1165***
θ_1	-	0.3869***	-	-3.4003***	-0.5660***	0.1165***
θ_2	-	0.2887***	-	-	-	-
λ_0	0.6649***	0.1806	0.4829**	0.5034***	0.5752	-
φ_0	-	-	-	0.1624***		-
LR elasticity estimates						
Γ (GDP)	0.71	0.43	0.86	0.48	0.00	0.00
Δ (Price)	0.00	0.00	-0.10	-0.16	0.00	0.00
Θ (Pop)	0.00	0.68	0.00	0.80	1.00	0.00
Θ^{99-12} (Pop 1999-2012)	n/a	n/a	n/a	n/a	0.94	n/a
Θ^{03-12} (Pop 2003-2012)	n/a	n/a	n/a	n/a	n/a	0.01
Hyperparameters						
Irregular	0.000000	0.000419	0.000001	0.000227	0.000000	0.000287
Level	0.001144	0.000197	0.000000	0.000000	0.008425	0.000000
Slope	0.000000	-	0.000000	0.000004	0.000000	0.000000

Appendix C: Detailed Estimation Results

	Bahrain	Kuwait	Oman	Saudi Arabia	Qatar	UAE
Interventions	Irr1991***	Lvl1991***	Lvl1986***	Lvl1991*	Lvl1989***	Lvl1993***
	Lvl1998	Lvl1992***	Lvl1993**		Irr1993**	
			Lvl1996***		Irr2005***	
Goodness of fit						
p.e.v.	0.000899	0.000602	0.000451	0.000392	0.006019	0.000230
AIC	-6.514	-6.815	-6.990	-7.129	-4.470	-7.898
R^2	0.997	0.997	0.999	0.999	0.951	0.965
R_d^2	0.916	0.976	0.881	0.766	0.768	0.832
Residual Diagnostics						
Std Error	0.030	0.025	0.021	0.020	0.076	0.015
Normality	0.10	0.72	1.64	0.58	2.04	0.41
$H_{(h)}$	$H_{(7)} = 2.55$	$H_{(6)} = 0.82$	$H_{(6)} = 0.25$	$H_{(6)} = 0.85$	$H_{(6)} = 0.86$	$H_{(6)} = 1.57$
$r_{(1)}$	0.14	0.12	-0.02	-0.33*	-0.06	-0.04
DW	1.71	1.75	1.71	2.27	2.07	1.81
$Q_{(p, d)}$	$\chi_3^2 = 1.76$	$\chi_4^2 = 5.84$	$\chi_3^2 = 2.86$	$\chi_3^2 = 5.13$	$\chi_3^2 = 1.17$	$\chi_3^2 = 0.81$
Auxiliary residuals:						
Normality – Irregular	2.55	1.36	0.87	1.11	0.24	0.28
Normality – Level	0.85	0.32	0.10	0.31	3.25	2.72
Normality – Slope	3.67	-	2.37	0.69	1.36	0.93
Pred. Failure χ_f^2	$\chi_3^2 = 0.23$	$\chi_3^2 = 2.43$	$\chi_3^2 = 0.83$	$\chi_3^2 = 2.64$	$\chi_3^2 = 0.71$	$\chi_3^2 = 6.46$*

Notes for Table A1:

i. All estimated preferred models and tests obtained from the software package STAMP 8.10 (Koopman et al., 2007);

ii. The estimation period is 1985 to 2012, other than for Kuwait which is for 1985 to 2009;

iii. The estimated preferred models for Bahrain, Kuwait, Oman, and Saudi Arabia were obtained after testing down from Eq.(2) as explained in the methodology section, whereas the preferred models for Qatar and the UAE were obtained from a restricted per-capita version of Eq.(2) as explained in the results section;

iv. ***, **, & * denotes statistical significance at 1 percent, 5 percent and 10 percent respectively;

v. ## represents a constrained estimate;

vi. Given the second lag of residential electricity demand and the second lag of the real electricity price were omitted for every country during the estimation process, the rows for α_2 and δ_2 are omitted from the table.

vii. p.e.v. is the prediction error variance and AIC the Akaike information criterion;

viii. R^2 is the coefficient of determination and R_d^2 is the coefficient of determination based on differences;

ix. Normality is the Bowman-Shenton test; approximately distributed as χ_2^2;

x. H(h) is the test for heteroscedasticity, distributed approximately as $F_{(h,h)}$;

xi. $r_{(1)}$ are the residual autocorrelations at lag τ distributed approximately as $N(0, 1/T)$;

xii. DW is the Durbin-Watson statistic;

xiii. $Q(p,d)$ is the Box-Ljung statistic based on the first p residuals autocorrelations and distributed approximately as χ_d^2; and

xiv. Pred. Failure χ_f^2 is the predictive failure test for the last three years of the estimation period distributed approximately as χ_3^2.

Bahrain

The preferred model for Bahrain passes all the diagnostic tests with dynamic terms limited to the second lag of GDP with no role for the real electricity price nor population. Thus the estimated short-run (impact) GDP, price and population elasticities are all zero (i.e., they are all perfectly inelastic in the short run) but in the long run the estimated GDP elasticity is 0.71 (i.e., it is inelastic) whereas the estimated long-run price and population elasticities are zero (i.e., they are also perfectly inelastic in the long run). Arguably, the zero price elasticity is not that unexpected given the historical low cost of electricity when compared with the household disposable income although it was expected that population would have more of an impact. For weather, only the cooling degree days variable is found to be significant with an estimated impact elasticity of -0.66. This is in line with prevailing weather conditions, as the country is one of the hottest in the world with consistently high CDD values. By contrast, Bahrain's HDD values are very low and are not likely to play any role in shaping the electricity demand due to space conditioning.

During the estimation process, an irregular intervention for 1991 and a level intervention for 1998 were added to ensure that the full array of diagnostic tests were passed; thus even though the 1998 intervention is only significant at the 12 percent level it was maintained. These interventions probably reflect two international events. 1991 saw the zenith of the first Gulf War with Bahrain's economy being specially hit due to its proximity to the war zone in the Arab gulf. The second intervention pertaining to year 1998 is probably a repercussion of the Asian financial crisis of 1997 and the drastic reduction in oil price that ensued given the Bahraini economy was still sizably dependent on oil rents, which were noticeably reduced (and the estimated GDP elasticity is unlikely to adequately pick up this effect). As shown in the main text (Figure 5) the estimated UEDT is generally upward sloping (after allowing for the sharp reduction in 1991 caused by the 1991 intervention) suggesting generally exogenous electricity using behavior.

Kuwait

Given the estimation period covers the buildup to, and the period of, the Gulf War in 1990 – 1991, not surprisingly the preferred model for Kuwait required the inclusion of interventions around that period – a level intervention in 1991 and another in 1992 – in all probability reflecting the invasion of Kuwait by Iraq, leading to a mass exodus of its population and a long-lasting damage in its infrastructure. The level intervention in 1991 at the height of the war suggests a notable exogenous reduction in electricity demand followed by an over compensating recovery in in 1992 – shown in the main text (Figure 5). Thus in the period leading up to 1991, and after 1992 until about 2000, the estimated UEDT falls slightly suggesting exogenous electricity saving behavior during these periods, whereas after 2000 the estimated UEDT rises suggesting exogenous electricity using behavior during this period.

The resultant preferred model includes the CDD variable despite being only statistically significant at 20 percent, although it was retained to ensure that all the diagnostic tests were passed. Kuwait traditionally has quite harsh weather conditions in the summer with little year-to-year variation so, unsurprisingly, it was not possible to find the CDD variable significant at the required level. However, no price terms are included in the preferred model with dynamic terms limited to the first lag of GDP and population. This gives estimated short-run (impact) GDP and population elasticities of 0.30 and 0.29 respectively and estimated long-run GDP and population elasticities of 0.43 and 0.68 respectively (i.e., although larger in the long run both GDP and population are inelastic in the long run). For the real electricity price, however, both the short-run and the long-run elasticities are estimated to be zero (suggesting that Kuwait's residential electricity demand is perfectly price inelastic in both the short- and the long-run).

Oman

The Omani preferred model again passes all the diagnostic tests and includes a lagged dependent variable and contemporaneous terms for GDP, price and the cooling degree days variable – but no role is found for population. This gives estimated short-run (impact) GDP and price elasticities of 0.72 and -0.09 respectively and estimated long-run GDP and price elasticities of 0.86 and -0.10 respectively (i.e., the long-run estimated elasticities are slightly larger in absolute terms in the long run, but suggest that Omani residential electricity demand is inelastic in both the short- and long-run).

For Oman, three level interventions were found to be required and significant during the estimation process; 1986, 1993, and 1996. These probably reflect the reduced income from oil rents that was characteristic of the mid-1980s oil glut and changes in pricing mechanisms for 1993 and 1996. The estimated UEDT from the process is deterministic but is 'non-linear' given the three level interventions, as shown in the main text (Figure 5). Nonetheless, the estimated Omani UEDT is generally increasing throughout the estimation period, suggesting exogenous electricity using behavior.

Saudi Arabia

The preferred model for Saudi Arabia passes almost all the diagnostic tests, the one slight issue being the first order autocorrelation coefficient; however, the Durbin-Watson statistic for first order serial correlation suggests that this is not necessarily a problem and the Box-Ljung test suggests that general serial correlation is not a problem. The preferred model therefore includes contemporaneous terms for the real electricity price and population but not for GDP; however, it does include one year lagged terms for GDP and population. This results in estimated short-run and long-run GDP elasticities of zero and 0.48 respectively – suggesting that Saudi Arabia's residential electricity demand is perfectly income inelastic in the short run but relatively inelastic after a year and in the long run. For the real electricity price, however, the estimated short-run and long-run elasticities are both -0.16 – suggesting that Saudi Arabia's residential electricity demand is relatively price inelastic in both the short- and the long-run. For population, the preferred equation suggests that the short-run (impact) effect is very large with the estimated elasticity being 4.20, however this is dampened down in the long run given the estimated long run population elasticity is 0.80. A probable reason is that Saudi Arabia has a large expatriate population (around 30 percent of total population) that has a fluctuating size and purchasing power over the years. Many in the expatriate labor force are low-wage workers with short-term and project specific contracts. For weather, Saudi Arabia is the only GCC country where both the cooling and heating degree day variables were found to be significant and therefore retained in the preferred model. This is in line with expectations as Saudi Arabia has a large, more diverse geography than its

GCC neighbors. The northern and southern parts of the country have a mountainous topography that yields lower temperatures and thus resulting in higher heating degree days values. Still, the CDD is considerably higher than HDD.

For Saudi Arabia, a level intervention for 1991 is included in the preferred model, which probably reflects, as for Kuwait, the spillover effects of the first Gulf War (1990-1991). Despite this, the estimated UEDT shown in the main text (Figure 5) is generally rising over the estimation period, suggestion exogenous electricity using behavior.

Qatar and UAE

Modeling for Qatar and the UAE proved to be somewhat problematical since it was impossible to find preferred models that pass all the diagnostic tests with GDP, the real price of electricity and population being individually statistically significant. Consequently, electricity per capita models were modeled instead, which involved omitting y_t and pop_t from the right hand side of Eq.2, replacing them by the natural logarithm of Y_t/POP_t, and replacing e_t by the natural logarithm of E_t/POP_t on the left hand side of Eq.2. Furthermore, for the UAE sample period it was still necessary to curtail the estimation period to 1985 to 2009 since it proved impossible to find a statistically acceptable model for the whole period up to 2012 and, even then, the preferred model failed the predictive failure test at the 10 percent level.

When testing down using the per capita models, it was not possible to find a role for GDP. In addition, the real electricity price variable was excluded for Qatar and only the first difference of the real electricity price was found to be significant for the UAE. Furthermore, differential slope dummies were needed for population during certain periods (explained further below). Given this, the preferred model for Qatar given in Table A1 includes a lagged dependent variable (electricity per capita in this case), cooling degree days (despite only being significant at the 16 percent level) and a slope dummy for population covering the period 1999-2012 but with a stochastic UEDT (see Figure A1 and further discussion below). Whereas for the UAE, the preferred model in Table A1 includes only the change in the real electricity price and a slope dummy for population covering the period 2003-2012, but with a deterministic trend with a large structural break in 1993 (see Figure A1 and further discussion below).

The estimated Qatar short- and long-run GDP and price elasticities are therefore zero (suggesting that electricity demand is perfectly income and price inelastic in both the short- and long-run). Whereas for population, the short-run and the long run estimated population elasticities are unitary for the period 1985 to 1998 but for the period 1999 to 2012 falls to 0.94 in the long run. Furthermore, the preferred equation for Qatar includes a level intervention for 1989 and two irregular interventions, one for 1993 and one for 2005. These probably reflect the repercussions of the Tankers' war (a closing stage of the Iran-Iraq War where tankers were targeted and Qatar's offshore fields, mostly shared with Iran, had limited outcome), electricity price reform in 1993, and a sharp increase in expatriate population starting mid-2000 that coincided with Qatar's fast-paced economic boom. The resulting estimated UEDT shown in Figure A1 is flat or rising from 1985 until the late 1990s but generally falling thereafter (allowing for the sharp increase in 2005 caused by the irregular intervention) – suggesting generally exogenous electricity saving behavior in the 2000s onwards.

Appendix C: Detailed Estimation Results

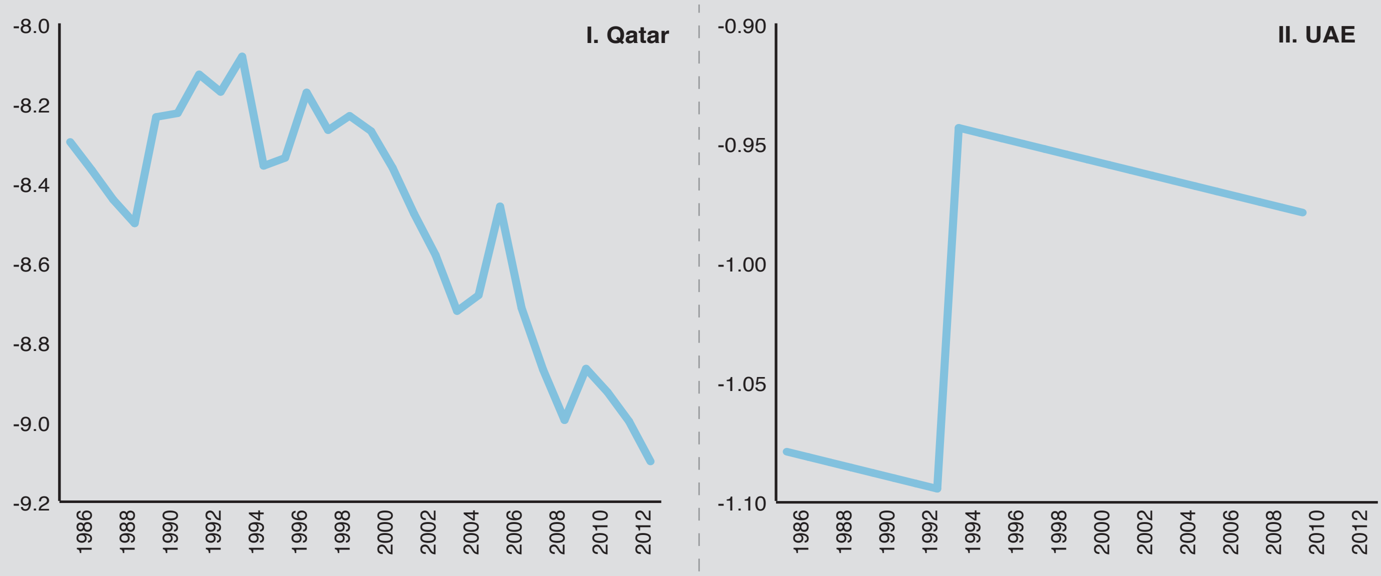

Figure A1. Estimated underlying energy demand trends

The estimated UAE short- and long-run GDP elasticities are also zero (again suggesting that electricity demand is perfectly income inelastic in both the short- and long-run). Whereas for the real electricity price the estimated (impact) short run elasticity is -0.12 but falls to zero in the long run (i.e., suggesting that Qatar's residential electricity demand is relatively inelastic in the short run and perfectly inelastic in the long run). For population, the estimated short- and the long run population elasticities are zero for the period 1985 to 2002, but for the period 2003 to 2012 the inclusion of the slope dummy suggests a slight increase to 0.01 – so effectively almost perfectly inelastic with respect to population in both the short and the long-run. Furthermore, the preferred equation for the UAE includes a level intervention for 1993, which could reflect the sudden change in the electricity pricing mechanism that occurred in that year – especially given the actual real electricity price variable was never significant and therefore omitted from the analysis. The resulting estimated UEDT shown in Figure A1 is deterministic and is clearly generally falling (after allowing for the sharp increase in 1993 caused by the level intervention) – suggesting generally exogenous electricity saving behavior.

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About the Project

This project attempts to model econometrically residential electricity demand for the six Gulf Cooperation Council countries – Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. Using the Structural Time Series Model, the impact of the drivers of residential electricity demand – prices, income, population, weather and other exogenous factors – are considered in order to provide information on their relative importance. This project is part of a larger body of KAPSARC research analyzing energy demand, energy efficiency, and rebound.

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