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A look at the response of households to time-of-use electricity pricing in Saudi Arabia and its impact on the wider economy

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ABSTRACT

Households in Saudi Arabia account for about half of domestic electricity demand. This high level of consumption is partly due to historically low prices. These prices have also been flat throughout the day. Policymakers are exploring different pricing policies to help reduce this share. Time-of-use (TOU) pricing is one such option. This paper assesses the potential effects TOU pricing will have on households and the wider economy.

We quantify how households may react to a price change by focusing on two of the biggest electricity-consuming household items: appliances and air-conditioners. Price response features that deal with the usage of these items are incorporated in a modeling framework that we have developed. Based on an assumed TOU price that the power utility may charge during peak summer hours, the main findings of our analysis for the year 2011 are:

- Households would pay 42% to 57% more in the summer months as a result of a TOU price that is three times the average summer price under the current flat tariff.
- Total electricity load is reduced in all TOU scenarios during the afternoon peak hours, and households that are not inconvenienced by shifting appliance use move some of their consumption to the hours before the peak rates.
- The power utilities would realize additional profit mostly from higher revenue from households. Reduced operating costs to the utilities play a minor role, if any.
- Oil consumption for electricity generation is generally reduced, while the average operating efficiency marginally increases due to lower dependence on inefficient gas turbines.

1. Introduction

Households demand amounts to around half of the total electricity used in Saudi Arabia. One reason for the high consumption has been low electricity prices. Residential electricity prices in Saudi Arabia have been fixed in nominal terms between the years 2000 and 2015. In that period, the electricity tariff for households started at 0.05 Saudi Arabian Riyals (SAR) (1.33 US cents) per kWh for the first 2 MWh per month and progressively increased to 0.26 SAR (6.93 US cents) per kWh for every unit used beyond 10 MWh per month [1]. These prices do not vary throughout the day and therefore provide no incentive for load shifting during peak hours.

Policymakers have been looking at alternative pricing schemes to reduce the high level of residential electricity demand. The chairman of the Saudi Electricity Company suggested using time-of-use (TOU) pricing for households as a way of managing consumption [2]. TOU prices have been previously applied in various US states and European countries. Yang et al. [3] cite a 41% reduction in electricity use during the peak period in Florida, and an 8% decline in Norway. Faruqui and Sergici [4] provide some examples of past residential TOU programs in the United States, including in Missouri and Washington. This paper explores the implications of establishing TOU pricing for residential customers in Saudi Arabia on both the households and the wider economy.

One could ask, how can we estimate the potential deviations in the hourly load profile if an alternative pricing scheme is introduced? We could use hourly own- and cross-price elasticities to measure the response of households to a price change, if they are available; but they would not be for Saudi Arabia as prices in the Kingdom have been fixed for 15 years. The lack of variation in intraday prices also means that it is not possible to estimate cross-price elasticities between hourly electricity uses.

Consequently, we apply bottom-up models that we have developed for the residential sector and the energy sectors in the

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local economy [5–7]. The study considers that households can respond to price changes in two ways; they can either alter their thermostat set-point or shift the discretionary use of appliances. Given reference appliance use schedules and thermostat set-points, the residential model is augmented with features that can reschedule appliance use and allow for deviation in thermostat setting. Overall, the regional housing stock within Saudi Arabia is categorized in archetypes, taking into consideration structural attributes, households' tolerance for discomfort, appliance time-use schedules, income levels, and their willingness to shift discretionary loads.

The literature concerning demand response has been summarized nicely by Gyamfi et al. [8]. It has been either focused on econometric estimates of price elasticity, optimization approaches (e.g. [9,10]), or qualitative discussions of human behavior (e.g. [11]). It is often difficult to estimate a statistically-significant price elasticity of electricity load demand. This may be due to lack of historical data or the nature of the price series; for instance, in the case of low historical prices that do not change significantly over time. Others, like [12], have argued against traditional economic theory based on rational agents. Major reasons given for sub-optimal choices include lack of information available to the household and bounded rationality, where people are incapable of simultaneously assessing all possible options to decide optimality. We retain some of the major behavioral factors in optimization approaches as discussed in later sections.

The paper is structured as follows: The next section provides a background on the Saudi power industry and residential electricity issues. The following section details the approach we employed for the price response features. Section 4 describes the modeling tools used and the archetype designs. The section after that gives the assumptions surrounding the electricity pricing scheme we use. The paper is concluded with the results and discussion.

2. The Saudi electricity sector and residential electricity use

The Saudi Electricity Company (SEC) holds most of the power generation capacity in Saudi Arabia, followed by independent power producers and cogeneration plants. SEC also has total control over the transmission and distribution network, and thus the sale of electricity. Power plants purchase fuels at regulated prices. In 2011, crude oil and natural gas were sold to the power utilities at $4.24 per barrel and 75 US cents per MMBTU, respectively. Heavy fuel oil (HFO) was sold at $14.05 per metric ton and diesel at $26.66 per metric ton [5]. Fuel prices have since increased, but are still administered by the government and are well below international market prices.

The World Energy Council states the average household in Saudi Arabia consumed 23.81 MWh of electricity during 2014 [13]. That is the third highest consumption per household globally, after the 37.7 MWh and 31.8 MWh for Kuwait and Qatar, respectively. In fact, the top four consumers in the world are from the Gulf Cooperation Council (GCC). The high levels of consumption in these countries are due to a combination of the weather and historically low prices. In one extreme, electricity is free for Qatari citizens and very inexpensive in Kuwait. Households in Saudi Arabia have historically consumed around half of the domestic electricity produced, making this demand segment a prime target for price reform.

Low domestic electricity prices for residential consumers have been maintained for decades in Saudi Arabia. As shown in Table 1, local prices rise with increased monthly consumption. The electricity prices, before the reforms that took place at the end of 2015, started at 1.33 US cents per kWh and progressively increased to 6.93 US cents per kWh for every unit consumed above 10 MWh in a billing period [1]. These prices were last changed in October 2000, which means they have been declining once inflation is taken into account. The government on December 28th, 2015, announced a new set of energy prices, including electricity prices for residential customers. Effectively in 2016, the prices for first 4 MWh per month are the same, but are higher for incremental consumption. These prices still do not vary throughout the day and therefore do not incentivize load shifting. According to an interview with the Saudi Deputy Crown Prince in The Economist [14], there are plans to deregulate energy prices over time.

3. Approach to analyzing household demand response

Customers have no incentive to reduce their demand during peak hours under a traditional flat tariff scheme. As such, utilities often use pricing as an incentive to alter household behavior with the aim of reducing system peak demand and improving overall grid reliability. Two examples of pricing schemes are time-of-use (TOU) tariffs and real-time pricing (RTP). A TOU scheme exhibits a higher electricity price during the peak period while maintaining a lower flat tariff for the rest of the day. With RTP, the price of delivered electricity varies hourly to reflect the variations in the cost of generation. Hence, to lower their electricity bills, many households may choose to use their appliances during off-peak hours. Electricity prices may either be specified exogenously in the residential model, or in the case of RTP, the marginal cost of electricity may be incorporated.

Using reference behavior under a flat tariff system as an input to the residential model we developed [5], we estimate the possible deviations in indoor thermostat temperature setting and discretionary appliance use in response to price changes. Scenarios are designed below to illustrate how these variations affect the load.

3.1. Appliance load shifting in response to a price change

The direct use of electricity by appliances and the associated heat gains may shift during demand response (DR) events. Setlhaolo et al. [10] have shown that households react by considering both the cost of electricity and a non-monetary cost of inconvenience when shifting appliances. Following them, we here take a deterministic approach to simulate possible outcomes of introducing TOU tariffs or RTP. This sub-routine is triggered only if the ratio between the highest and lowest prices throughout the day exceeds a predefined threshold, and provides the physical model with alternative appliance use schedules. Only appliances used for discretionary purposes, such as consumer electronics, washing machines, and clothes dryers are considered eligible for load shifting.

We assume that households are provided with electricity prices sufficiently in advance, and thus have the time to react accordingly and minimize their total perceived cost, shown by Equation (1). The perceived cost accounts for the monetary cost of electricity and the perceived cost of inconvenience due to potentially rescheduling the use of an appliance.

$\pi_{h,s,d,r}$ is the hourly price of electricity throughout the day (h), and may vary by season (s), type of day by weekdays and weekends (d) and regions (r). $P_{h,s,d,r}$ is the total direct power load resulting from the use of discretionary appliances. $NU_{a,h,h2,s,d}$ is a binary variable that equals unity if the device, a, is turned on and zero when it is off. It keeps track of when the device was originally used ($h2$) and to what point in time its use is shifted (h). Δt_h is the discrete time step and is equal to 1 h in our analysis. γ_{inconv} denotes an increasing rate of cost to the household by shifting their use of an appliance further away from its original time of use. $(t_h^{new} - t_{a,h2,s,d}^{original})^2$ represents the extent of deviation in appliance use, and yields a value that increases quadratically the farther in time