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Gasoline demand, pricing policy, and social welfare in Saudi Arabia: A quantitative analysis

Tarek N. Atalla[a], Anwar A. Gasim[a,*], Lester C. Hunt[a,b]

[a] King Abdullah Petroleum Studies and Research Center, (KAPSARC), Riyadh, Saudi Arabia
[b] Economics and Finance, University of Portsmouth, UK

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ABSTRACT

Domestic energy prices in Saudi Arabia are set below international market prices. This, coupled with rapid economic and population growth, is believed to have contributed to the rapid growth in domestic energy demand and, recently, affected the government budget in the face of low international oil prices. In December 2015, Saudi Arabia announced increases in domestic energy prices. This paper therefore considers the impacts, focusing on gasoline, by estimating a demand function and using it to estimate the change in social welfare.

Gasoline demand is found to be price inelastic suggesting that it may be difficult for the Saudi government to limit future growth in gasoline consumption using only increases in the administered price of gasoline. Thus, limiting future gasoline consumption in the KSA might require improved energy efficiency of passenger cars, increased energy awareness by drivers through education and marketing campaigns, and the provision of alternative transport modes within cities.

Although the announced gasoline price increase is not expected to reduce demand considerably, it can deliver estimated welfare increases of up to 1.66 billion 2010 US\$ (~6.23 billion 2010 Saudi Arabian Riyals), which is around 0.26% of Saudi gross domestic product.

1. Introduction

The past several decades have seen the Kingdom of Saudi Arabia (KSA) experience a large economic and demographic leap, fuelled by its sizeable oil revenues. Between 1979 and 2015, the KSA's real GDP increased from around 1.26 trillion 2010 Saudi Arabian Riyals (SAR) to 2.52 trillion (SAMA, 2016), population grew from 9.3 million to 31.5 million (World Bank, 2016), and total primary energy consumption increased from about 22.5 million tonnes of oil equivalent (Mtoe) to roughly 200 Mtoe (IEA, 2016). During this period, oil revenues have allowed the Saudi government to provide electricity, fuel, and water to its citizens below international market prices. The IEA (2017) estimates that in 2014, the implicit subsidies for electricity and fossil fuels in the KSA amounted to over \$70 billion. Not surprisingly, rapid economic and population growth, alongside such low administered energy prices, contributed to the KSA's tenfold increase in energy consumption over this period.

According to MEP (2015a), the road transport sector is one of the largest consumers of energy in the KSA. Rising incomes have allowed most households to own private vehicles, while economic development has delivered large cities with extensive road infrastructure and a vast network of highways that connect the numerous cities scattered across the KSA. The need for private vehicles to travel is reinforced by the current lack of public transportation systems within cities. As highlighted above, the low administered price of gasoline seems to have also played a role as the demand for motor gasoline grew from 25 million barrels in 1979 to 204 million barrels in 2015, an average growth of about 6% per annum (MEP, 2015a; MEIM, 2016).

In December 2015, the Saudi government announced an increase in the prices of electricity, fuel, and water, which resulted in the nominal prices for 91- and 95-octane gasoline increasing from 0.45 and 0.60 SAR per liter to 0.75 and 0.90, respectively (although they still remain below international market prices). The price increases have been designed to promote greater efficiency in the KSA's energy economy and reduce the rapid growth in domestic oil consumption, which some believe may possibly have put Saudi Arabia on a trajectory to become a net oil importer sometime in the 2030s (Lahn and Stevens, 2011).

Nevertheless, according to Krane (2015a) low fuel costs are part of

Abbreviations: DOLS, Dynamic Ordinary Least Squares; FMOLS, Fully Modified Ordinary Least Squares; GCC, Gulf Cooperation Council; KSA, Kingdom of Saudi Arabia; LR, Long-Run; Mtoe, Million tonnes of oil equivalent; OLS, Ordinary Least Squares; OPEC, Organization of the Petroleum Exporting Countries; PAM, Partial Adjustment Model; SAR, Saudi Arabian Riyals; SR, Short-Run; STSM, Structural Time Series Model; UEDT, Underlying Energy Demand Trend

* Corresponding author.
E-mail address: Anwar.Gasim@kapsarc.org (A.A. Gasim).

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the social contract in the Gulf Cooperation Council (GCC) countries. It is therefore important to understand and quantify the impact of the increased gasoline price on both demand and social welfare in the KSA. Our analysis follows the approach in Ahmadian et al. (2007) by estimating a gasoline demand function using the structural time series model (STSM), thus providing estimates of price and income elasticities and an underlying energy demand trend (UEDT) for gasoline in the KSA. The preferred econometric estimates for the gasoline demand function are then used to estimate the change in social welfare that might arise from increasing the gasoline price (in other words, reducing the implicit subsidy) in the KSA.

The remainder of this paper is organised as follows. Section 2 reviews the literature related to econometric estimates of gasoline demand and welfare. Section 3 introduces the estimation strategy for the gasoline demand function, describes the data, and presents the results of the estimation. Section 4 uses the preferred econometric estimates of gasoline demand to conduct the welfare analysis. Finally, Section 5 offers a brief summary and concludes.

2. Literature review

2.1. Econometric studies of gasoline demand

A plethora of articles has attempted to model econometrically gasoline demand for a wide range of countries and groups of countries. Therefore, following a brief discussion of some previous surveys and meta-studies on modelling gasoline demand, econometric studies of gasoline demand that focused on the KSA are reviewed, followed by a discussion on the development of the STSM/UEDT approach to modelling energy demand, given this is the approach used in this paper.

A number of surveys of gasoline demand modelling and elasticity estimates have been conducted by Dahl and her associates. The average short- and long-run price elasticities were found to be −0.29 and −1.02, respectively, by Dahl (1986), and −0.24 and −0.80, respectively, by Dahl and Sterner (1991). On the other hand, the average short- and long-run income elasticities were found to be 0.47 and 1.38, respectively, by Dahl (1986), and 0.45 and 1.16, respectively, by Dahl and Sterner (1991). Furthermore, Dahl (2012) found that for static models only, gasoline price elasticities ranged between −0.11 (for middle-income economies with low gasoline prices) to −0.33 (for high-income economies with high gasoline prices). She also found that the income elasticity had a median size of 0.57 across the surveyed studies. These surveys therefore suggest that gasoline demand is generally price inelastic in both the short and long run but more inelastic in the short run. Within the ranges there exists considerable variation across different countries but Dahl (1986) suggests that the results also vary because of the different models, data series, time horizons, functional forms, and/or econometric techniques used by researchers, even when studying the same country.

Meta-analysis (an approach that uses statistical techniques to compare different studies in order to understand how the methods used by the authors of each study affect its estimates) has been used to consider gasoline demand elasticity estimates by a number of researchers. This includes Espey (1998), who examined both gasoline price and income elasticity estimates and found that they were sensitive to the inclusion or exclusion of some measure of vehicle ownership and that gasoline demand was getting more price elastic and less income elastic over time. Furthermore, Brons et al. (2008) found that the geographic area, study year, time horizon, and functional form significantly affected the gasoline demand price elasticity estimates, concluding overall that the average short- and long-run price elasticities were −0.34 and −0.84, respectively.

Havranek et al. (2012) built on these two earlier meta-analyses by considering the same studies used in Brons et al. (2008) and using the same definitions of the short and long run used by Espey (1998). In doing so, Havranek et al. (2012) demonstrated that when controlling for publication bias (the tendency to suppress negative and insignificant elasticity estimates) the estimated short- and long-run gasoline price elasticities of demand were "approximately *half* compared to the results of the previously published meta-analyses" (p. 206). Consequently, after correcting for publication bias, Havranek et al. (2012) found that the short- and long-run gasoline price elasticities averaged −0.09 and −0.31, respectively. Finally, Havranek and Kokes (2015) undertook a meta-analysis of estimated income elasticities using the studies surveyed by Dahl (2012) and, like Havranek et al. (2012), found that there was publication bias. After correcting for the bias, they found that the short- and long-run gasoline income elasticities averaged 0.1 and 0.23, respectively.

The studies above covered a wide range of countries, techniques, and data periods but the core message is that gasoline demand is price (and income, to an extent) inelastic in both the short and the long run. Given the scope of the research being undertaken here, Table 1 focusses explicitly on previous studies that have econometrically modelled gasoline demand in the KSA either specifically or within a group or panel. Table 1 shows that in general the estimated elasticities are in line with the above, suggesting that the short- and long-run price and income elasticities of gasoline demand in the KSA are inelastic – the estimated long-run income elasticity by Al-Sahlawi (1997) being the only exception. In summary, most models of gasoline demand suggest that it is price and income inelastic, which is equally true for the KSA, whether individually or as part of a panel. Given this, it is interesting to consider whether similar results are obtained using the STSM/UEDT approach used in this paper. The previous literature on this approach is therefore considered next.

2.2. Discussion of methodological issues

The studies considered above generally used time series or panel data models in order to estimate the price and income elasticities of gasoline demand. Furthermore, some of the models incorporated a measure or proxy to try to capture the impact of improvements in the energy efficiency of the stock of passenger cars over time. An alternative approach, particularly useful where there are data constraints, is to incorporate a UEDT, as suggested by Hunt et al. (2003a, 2003b). The UEDT captures the influence of exogenous factors that influence demand over time such as energy efficiency and behaviour changes, and can be modelled stochastically using Harvey's (1990) STSM (aka the unobserved components model), which Hunt et al. (2003a, 2003b) argue provides more realistic estimates of energy demand models.

Subsequently, the STSM/UEDT approach to modelling energy demand relationships has been applied to a number of areas of energy demand modelling,[1] including transportation oil and gasoline demand.[2] The only study that we are aware of that has used the STSM/UEDT approach for Saudi Arabia that is connected to gasoline consumption is Alkhathlan and Javid (2015), who attempted to analyse the effect of transport and total oil consumption on the environmental quality of the KSA.[3] Although connected to the research undertaken here, Alkhathlan

[1] Such as for: UK aggregate energy demand in different sectors with different data frequencies (Hunt et al., 2003a, 2003b; Dimitropoulos et al., 2005); natural gas demand in Ghana (Ackah, 2014); aggregate energy demand for the whole economy and the residential sector in South Korea (Sa'ad, 2011); electricity consumption in Pakistan (Javid and Qayyum, 2014; European natural gas demand Dilaver et al., 2014); and industrial aggregate energy demand in the OECD countries (Adeyemi and Hunt, 2014).

[2] These include studies of: British and Japanese transport oil demand (Hunt and Ninomiya, 2003c); Iranian gasoline demand (Ahmadian et al., 2007); Indonesian petroleum products demand (Sa'ad, 2009); British transport oil demand (Broadstock and Hunt, 2010); South Korean transport energy demand (Sa'ad, 2010); UK gasoline and diesel demand (Broadstock et al., 2011); Ghanaian gasoline demand (Ackah and Adu, 2014); Swedish and British gasoline demand (Karimu, 2014); Nigerian petroleum products demand (Abdullahi, 2014; Adagunodo, 2014); and Greek gasoline demand (Broadstock and Papathanasopoulou, 2015).

[3] Using data for the period 1971–2013, Alkhathlan and Javid (2015) use the STSM to estimate what they refer to as the UEDT for total carbon emissions and carbon emissions from the domestic transport sector, which is found to be non-linear for both the total and the transport sector.

Table 1
Previous articles with econometric estimates of gasoline demand for the KSA (or include the KSA as part of a panel).

Study	Country or Region of Estimates	Period	Data	Methodology	Price Elasticities		Income Elasticities		Notes
					SR	LR	SR	LR	
Al-Sahlawi (1988)	KSA	1970–1985	Annual/Time Series	OLS / PAM	−0.08	−0.67	0.11	0.92	Per capita model that also included the real price of automobiles.
Al-Faris (1992)	KSA	1970–1990	Annual/Time Series	OLS / PAM	−0.08	−0.30	0.02	0.07	Model also includes stock of cars variable. Paper presents estimates for the monetary variables expressed in real and nominal terms. Elasticity estimates from the model using real monetary variables are included here. Elasticity estimates from the model using nominal monetary variables are similar to those presented in Al-Faris (1997) below.
Eltony (1994)	GCC	1975–1989	Annual/Panel	Country Fixed Effects /PAM	−0.09 to −0.11	−0.11 to −0.13	0.21 to 0.41	0.23 to 0.48	Paper also includes individual estimates for other OAPEC countries. Per capita models with lagged real price that also included the stock of automobiles and the driving age population.
	GCC Sub-group	1975–1989	Annual/Panel	Country Fixed Effects /PAM	−0.04	−0.05	0.28	0.33	First set of elasticity estimates presented are for the GCC as a whole, which includes the KSA. Second set of elasticity estimates presented are for a GCC sub group (Kuwait, KSA, and Qatar), so again includes the KSA.
Eltony (1996)	GCC	1975–1993	Annual/Panel	Country Fixed Effects /PAM	−0.11	−0.17	0.31	0.48	Per capita model. First set of elasticity estimates presented are for the GCC as a whole, which includes the KSA.
	GCC Sub-group				−0.04	−0.05	0.38	0.43	Second set of elasticity estimates presented are for a GCC sub group (Kuwait, KSA, and Qatar), so again includes the KSA.
Al-Faris (1997)	KSA	1970–1991	Annual/Time Series	OLS / PAM	−0.09	−0.32	0.03	0.11	Monetary variables expressed in nominal (not real) terms. Paper also includes individual estimates for other oil products and other GCC countries.
Al-Sahlawi (1997)	KSA	1971–1995	Annual/Time Series	OLS / PAM	−0.16	−0.80	−0.30	1.50	Per capita model. Paper also includes results for modelling the demand for other oil products in the KSA.
Chakravorty et al. (2000)	KSA	1972–1992	Annual/Time Series	OLS / PAM	−0.08	−0.52	0.10	0.66	Per capita model. Paper also includes results for other oil products and other OPEC countries.
Al Yousef (2013)	KSA	1980–2010	Annual/Panel	Pedroni Panel FMOLS & DOLS Cointegration	n/a	−0.28 to −0.36	n/a	0.55 to 0.56	Per capita model. Paper includes group and individual country estimates for other oil products and other GCC countries. The KSA estimates are presented here. SR elasticity estimates not presented in the paper.
Arzaghi and Squalli (2015)	32 fuel-subsidizing countries	1998–2010	Annual/Panel	Static, Country Fixed and Random Effects /PAM	−0.05	−0.25	0.16	0.81	Per capita model that also attempts to include urbanisation, urban primacy, temperature, temperature squared, temperature variation, and (price ×income) variables. Estimates presented are from the random effects model for the group of 32 countries (which includes the KSA) given these are the results discussed in the conclusion of the paper.

Note: All estimated models used a log-linear specification. SR = Short-run. LR= long-run. KSA = Kingdom of Saudi Arabia. GCC = Gulf Cooperation Council. OPEC = Organization of the Petroleum Exporting Countries. OLS = Ordinary Least Squares. FMOLS = Fully Modified Ordinary Least Squares. DOLS = Dynamic Ordinary Least Squares. PAM = Partial Adjustment Model.
Bhattacharyya and Blake (2009) also modelled the demand for different oil products for countries in the Middle East and North Africa using annual data for the period 1982–2005. However, the estimated equations for gasoline demand for the KSA were generally poorly specified and not statistically reliable (for example, the majority of estimated coefficients are not significantly different from zero and the estimated short- and long-run price elasticities are positive); hence their results are not included in the table.

and Javid (2015) do not directly estimate a gasoline demand relationship for the KSA, nor the associated income and price elasticities; thus, as far as we are aware, the estimation undertaken in this paper is the first attempt to model gasoline demand for the KSA using the STSM/UEDT approach.

2.3. Previous welfare analyses

Many studies have used a general equilibrium approach to model the welfare implications of energy subsidy removal. Balke et al. (2015), for example, found for oil exporting countries the removal of subsidies to be welfare enhancing in their baseline calculation. However, they found that the optimal subsidy from the point of view of oil exporters is not zero. Aune et al. (2016) found that the removal of fuel subsidies in the Organization of the Petroleum Exporting Countries (OPEC) has a negative impact on OPEC consumers, but net welfare in OPEC increases due to higher profits from oil production. Both of the studies focused on modelling the welfare implications of price reform in an oil-exporting bloc, whereas our analysis focuses specifically on Saudi Arabia and its announced increase in the price of gasoline.

On the other hand, a number of studies have tackled the question of energy subsidies and welfare using a partial equilibrium approach. Ahmadian et al. (2007), for example, estimated a gasoline demand function using the STSM/UEDT approach with data for the period 1968–2002, which was subsequently used to estimate the change in social welfare for 2003 and 2004 of a higher gasoline price (a policy being considered by the Iranian authorities around that time). They estimated that social welfare would fall if the gasoline price were higher (ceteris paribus). However, once they also allowed for other variables in the model to change, their results suggested that social welfare would increase because the changes in the other variables would more than compensate for the negative effects of the increased gasoline price. In a more recent study, Davis (2017) analysed the deadweight loss and environmental cost of gasoline and diesel subsidies across a large number of countries for 2010. He found that the total global deadweight loss due to transport fuel subsidies was $26 billion annually, while the external costs were found to be $44 billion. In the case of Saudi Arabia, Davis (2017) estimated a deadweight loss of $3.5 billion and external costs of $7.3 billion annually. These monetary estimates rest on a single price elasticity of −0.6 that was assumed for all deadweight loss and external cost calculations for all countries.

In this paper, a partial equilibrium approach is used to model the welfare implications of the increase in the administered price of gasoline that occurred in Saudi Arabia on December 29, 2015. Gasoline demand is first modelled using the STSM/UEDT approach. The welfare implications are then considered using the preferred econometrics models, accounting for both the deadweight loss and external costs associated with changes in the gasoline price.

3. Modelling gasoline demand

3.1. Estimation methodology

Per capita gasoline demand in the KSA is modelled as a function of real per capita income, the real gasoline price, and a UEDT:

$$G_t = f\,(P_t,\, Y_t,\, UEDT_t) \tag{1}$$

where;

G_t= Per Capita Gasoline demand;
Y_t= Real Per Capita Income (based on GDP or non-oil GDP per capita);
P_t= Real gasoline price;
$UEDT_t$= Underlying Energy Demand Trend.

Eq. (1) is estimated using a dynamic autoregressive distributed lag specification as follows:

$$g_t = \alpha_1 g_{t-1} + \alpha_2 g_{t-2} + \gamma_0 y_t + \gamma_1 y_{t-1} + \gamma_2 y_{t-2} + \theta_0 p_t + \theta_1 p_{t-1} + \theta_2 p_{t-2} + UEDT_t + \varepsilon_t \tag{2}$$

Where g_t, y_t, and p_t are the natural logarithms of G_t, Y_t, and P_t in year t respectively and ε_t is a random white noise error term. A two-year lag was chosen to capture any possible dynamic effects, since it is considered a reasonable length given the data set being used. The coefficients γ_0 and θ_0 represent the short-run (impact) elasticities for real per capita income and the real gasoline price respectively. The long-run real per capita income and real gasoline price elasticities are given by $\Gamma = \frac{\gamma_0 + \gamma_1 + \gamma_2}{1 - \alpha_1 - \alpha_2}$ and $\Theta = \frac{\theta_0 + \theta_1 + \theta_2}{1 - \alpha_1 - \alpha_2}$, respectively.

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

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

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

where μ_t and β_t are the level and slope of the UEDT respectively. The hyper-parameters 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. The disturbance terms η_t and ξ_t determine the shape of the stochastic trend component (Harvey and Shephard, 1993). Eqs. (2), (3), and (4) are estimated by a combination of maximum likelihood and the Kalman filter using the software package STAMP 8.30 (Koopman et al., 2007).

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 an array of 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). Therefore the estimation strategy involves initially estimating the general model given by Eqs. (2), (3), and (4) and then eliminating insignificant variables and adding interventions but ensuring the model passes an array of diagnostic tests[4] until the preferred parsimonious model is obtained. Furthermore, according to Dilaver and Hunt (2011), the UEDT in the presence of interventions is given by:

$$UEDT_t = \mu_t + \text{irregular interventions} + \text{level interventions} + \text{slope interventions} \tag{5}$$

3.2. Data

This study relies on data for gasoline consumption, gasoline prices, income, and population in the KSA. The nominal gasoline price series was constructed by analysing all gasoline-related royal decrees that were issued in Saudi Arabia since 1979. Each royal decree fixed the gasoline price at a nominal level until the next one. If a royal decree was issued in the middle of the year, then the nominal gasoline price for that year was estimated to be a weighted average of the prices before and after the royal decree, where the weight depended on the number of days each price prevailed. In 2007, Saudi Aramco, the state-owned oil company, began to sell 91-octane gasoline in addition to the already available 95-octane. The lower octane gasoline entered the market at SAR 0.45 SAR, which is 25% cheaper than the higher grade. Consequently, the price of gasoline from 2007 onwards was estimated to be a weighted sum of the two grades, where the weight depended on the share of consumption of each type (see Fig. 1). The consumer price index (CPI) was then used to deflate the gasoline prices. Finally, real GDP and non-oil GDP data were obtained from SAMA (2016), gasoline

[4] With 10% normally being the maximum level to reject the null hypothesis for individual parameter coefficients, interventions, and diagnostic tests.

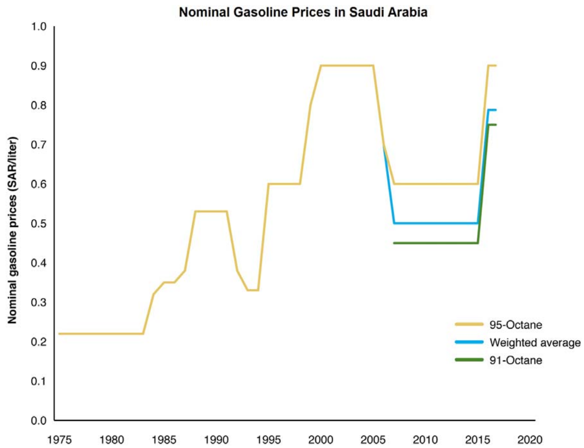

Fig. 1. Nominal gasoline prices in Saudi Arabia.
Saudi Aramco (N.D.) and authors' calculations

consumption data were collected from the MEIM (2016), and population from the World Bank (2016). Total population was used in the analysis instead of only male because women also contribute to the total demand for driving (and thus gasoline) even though they do not currently drive in Saudi Arabia.[5]

The question of what income variable to use, GDP or non-oil GDP, is important. Given the prominence of the oil sector in the KSA, there is a positive relationship between real GDP and the international oil price (Algahtani, 2016). Increases in the oil price generally lead to increases in real GDP, while decreases in the oil price exert the opposite effect. Non-oil real GDP is likely to be less sensitive to fluctuations in the oil price, although even non-oil economic sectors depend on oil revenues to some extent. If the aim were to model energy demand at the whole economy level then the argument for using real non-oil GDP would appear to be relatively strong, an approach taken by Hasanov et al. (2016) for modelling Azerbaijan aggregate electricity demand. However, the argument is less strong when considering gasoline consumers. Therefore, although non-oil GDP may be a better stable measure of gasoline consumers' income for the KSA, it is not completely obvious this is the case at this level; consequently, both measures are considered for the income variable in the analysis below.

3.3. Estimation results

Following the estimation strategy outlined above, the estimated equations were reduced to two parsimonious specifications, one for when income is based on GDP per capita and the other on non-oil GDP per capita, as shown in Table 2, which also shows the required interventions to ensure that the models passed the tests (detailed below). In particular, both models required an intervention for the year 1990 during which the Gulf War occurred and the oil price spiked.

The estimation period for the two models is 1981–2015 in order to allow for the two lags discussed in the previous section. Table 2 presents a number of summary statistics and diagnostics tests. These include p.e.v. (the prediction error variance), AIC (the Akaike information criterion), R^2 (the coefficient of determination), and R_d^2 (the coefficient of determination based on differences). All the normality tests are based on the Bowman-Shenton test distributed approximately as χ_2^2, while $H_{(h)}$ is the test for heteroscedasticity, distributed approximately as $F_{(h,h)}$. These are complemented by the Durbin-Watson statistic (DW), the residual autocorrelation coefficient at lag 1 $r_{(1)}$, distributed approximately as N(0, 1/T), and $Q_{(p,d)}$, which is the Box-Ljung statistic based on the first p residuals' autocorrelations and distributed approximately as χ_d^2.[6] Finally, there is the Predictive Failure test χ_f^2 for the last eight years of the estimation period distributed approximately as χ_8^2. Importantly, Table 2 shows that the two preferred models pass all of these diagnostic tests.

Table 2
The two preferred econometric models of gasoline demand.

	Income based on GDP	Income based on non-oil GDP
Estimated Coefficients		
α_1	0.3685***	–
α_2	–	–
γ_0	–	–
γ_1	0.0936***	0.6149***
γ_2	–	–
θ_0	−0.0975***	−0.0871***
θ_1	–	–
θ_2	–	–
Long-Run Elasticity Estimates		
Γ (Income)	0.1482	0.6149
Θ (Price)	−0.1544	−0.0871
Hyper-Parameters		
Irregular	0.000124631	0.000000000
Level	0.000000000	0.000309639
Slope	0.000001264	0.000009683
Interventions	Lvl1983*** Lvl1987*** Irr1989*** Irr1990***	Lvl1983*** Irr1989*** Lvl1990*
Goodness of Fit		
p.e.v.	0.0001448	0.0002956
AIC	−8.2687	−7.6695
R^2	0.997	0.992
R_d^2	0.941	0.870
Residual Diagnostics		
Std Error	0.012	0.017
Normality	0.22	1.02
$H_{(h)}$	$H_{(8)} = 1.04$	$H_{(9)} = 0.24$
$r_{(1)}$	−0.13	0.03
DW	2.20	1.45
$Q_{(p,\ d)}$	$\chi_4^2 = 4.62$	$\chi_4^2 = 6.54$
Auxiliary Residuals:		
Normality – Irregular	0.85	1.52
Normality – Level	1.32	0.20
Normality – Slope	2.58	0.47
Pred. Failure χ_f^2	$\chi_8^2 = 9.86$	$\chi_8^2 = 3.99$

Notes: The *, **, and *** represent significance at the 10%, 5%, and 1% level.

Furthermore, at the time of writing preliminary data from MEIM (N.D.) suggest that gasoline consumption in the KSA in 2016 grew by less than 1%, thus disrupting the trend over the last ten years in which gasoline demand had been growing at more than 6% on average. Using provisional 2016 GDP and non-oil GDP data from SAMA (2016) and population growth estimates from CDSI (2010), the preferred models in Table 2 also forecast gasoline demand growth of less than 1% in 2016. The closeness of the forecasts with the preliminary actual figures demonstrates the robustness of the income and, more importantly, price elasticity estimates.

The estimated demand model (or curve) based on real non-oil GDP per capita as the income driver has limited dynamics, with only the income variable lagged one year, whereas the estimated demand curve based on real GDP has greater dynamics given the presence of the lagged gasoline demand variable. This is discussed further below in the welfare analysis section. The resulting estimated long-run income and price elasticities are 0.15 and −0.15, respectively, when real GDP per capita is used as a measure of income, and 0.61 and −0.09,

[5] It was recently announced that women would be allowed to drive in Saudi Arabia starting June 2018 (Reuters, 2017).

[6] Although technically, the Durbin-Watson statistic and the Box-Ljung statistic are biased for the model using income based on GDP given the lagged dependent variable.

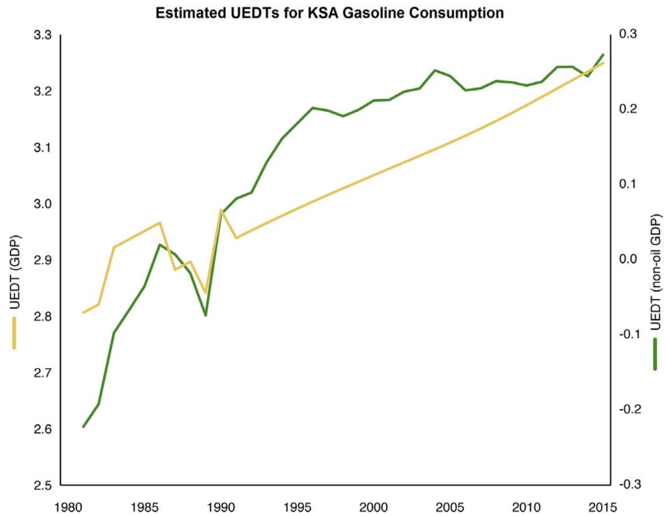

Fig. 2. Estimated UEDTs for gasoline consumption in Saudi Arabia.

respectively, when real non-oil GDP per capita is used instead. Although a considerable difference arises between the two income elasticities depending on which measure of GDP is used, the gasoline price elasticity is consistently small across all models. Therefore, gasoline demand in the KSA is generally found to be price inelastic, which is not dissimilar to the previous KSA estimates discussed in Section 2, despite the differing methodologies. For the welfare analysis, the estimates of the change in total surplus (i.e., social welfare) rest on the size of the price elasticity. Therefore, the estimated price elasticity's robustness translates into robustness for the welfare analysis.

The estimated gasoline UEDTs using both measures of income are shown in Fig. 2 and exhibit a generally upward sloping trend for the majority of the estimation period. An upward sloping UEDT implies that if price and income were held constant, then gasoline consumption per capita in Saudi Arabia would have increased due to the upward force exerted on it by this trend. If improvements in the energy efficiency of passenger cars were to outweigh other exogenous factors then the UEDT would be expected to be generally downward sloping, reflecting how increased efficiency leads to a decrease in consumption holding everything else constant (see, for example, the estimated UEDTs for the majority of OECD countries in Al-Rabbaie and Hunt, 2006). In contrast, the upward sloping UEDTs for gasoline demand in the KSA suggest that either the energy efficiency of passenger cars decreased over the study period, or that it did increase, but was outweighed by behavioural changes that ceteris paribus encouraged greater gasoline consumption per capita.

4. Welfare analysis

4.1. Methodology for calculating welfare

The welfare analysis revolves around the following thought experiment: Suppose the Saudi government decided on the first hour of January 2015 that the nominal prices for 91- and 95-octane gasoline would rise from 0.45 and 0.60 SAR per liter to 0.75 and 0.90 respectively. In reality, this price increase occurred on December 29, 2015 and had almost no effect on total gasoline consumption in 2015. Our analysis, however, looks at what would have happened to gasoline consumption and annual welfare in the short and long run if the administered price increase occurred at the start of 2015 instead. The calculation of this change in social welfare rests on the demand and supply curves for gasoline in the KSA, which are considered in more detail below.

4.1.1. The gasoline demand curve and consumer surplus

Two preferred estimates for the demand curve were presented in the previous section using the two different income variables, which in the short run, can be expressed as follows:

$$\hat{G}_t = G_{t-1}{}^{0.369} \bullet P_t^{-0.098} \bullet Y_{t-1}{}^{0.094} \bullet e^{U\hat{E}DT_t} \quad (6A)$$

$$\hat{G}_t = P_t^{-0.087} \bullet Y_{t-1}{}^{0.615} \bullet e^{U\hat{E}DT_t} \quad (6B)$$

where Eq. (6A) has real GDP per capita as the income variable (Y) while Eq. (6B) has real non-oil GDP per capita.

As mentioned above, the estimated demand curve based on real non-oil GDP per capita as the income driver, Eq. (6B), has limited dynamics with a contemporaneous real price variable and a one-year lagged income variable. This suggests that the adjustment by gasoline consumers to a change in price is completed within a year, whereas the adjustment to a change in income does not start until the year after the income changes, but is completed within that year. However, the estimated demand curve based on real GDP per capita as the income driver, Eq. (6A), has more dynamics with lagged per-capita gasoline demand present in the preferred model, thus giving a greater distinction between the short- and long-run price and income elasticities. That said, given the small size of the estimated coefficient on lagged per capita gasoline demand, the adjustment is still quick, with almost all the adjustment coming through after two years for a real price change and after three years for an income change.

The long-run demand curves for both preferred models can be expressed as follows:

$$\hat{G}_t = P_t^{-0.154} \bullet Y_t^{0.148} \bullet \left(e^{U\hat{E}DT_t}\right)^{1.584} \quad (7A)$$

$$\hat{G}_t = P_t^{-0.087} \bullet Y_t^{0.615} \bullet e^{U\hat{E}DT_t} \quad (7B)$$

Eq. (7A) is the preferred long-run model based on real GDP per capita, whereas Eq. (7B) is the preferred long-run model based on real non-oil GDP per capita. In the case of the latter, the long-run model is similar to the short-run model due to its limited dynamics.

To estimate the change in consumer surplus that follows an increase in the administered price of gasoline, the area underneath the demand curve between the prices before and after the change are calculated. Thus, if the administered price changes from P_t to P_{t*} then the change in consumer surplus in the short run for both models is:

$$\Delta CS_t = \int_{P_t}^{P_t^*} G_{t-1}{}^{0.369} \bullet P_t^{-0.098} \bullet Y_{t-1}{}^{0.094} \bullet e^{U\hat{E}DT_t} \bullet POP_t \, dP_t \quad (8A)$$

$$\Delta CS_t = \int_{P_t}^{P_t^*} P_t^{-0.087} \bullet Y_{t-1}{}^{0.615} \bullet e^{U\hat{E}DT_t} \bullet POP_t \, dP_t \quad (8B)$$

where POP_t is the total population at time t. In the long run, the change in consumer surplus is:

$$\Delta CS_t = \int_{P_t}^{P_t^*} P_t^{-0.154} \bullet Y_t^{0.148} \bullet \left(e^{U\hat{E}DT_t}\right)^{1.584} \bullet POP_t \, dP_t \quad (9A)$$

$$\Delta CS_t = \int_{P_t}^{P_t^*} P_t^{-0.087} \bullet Y_t^{0.615} \bullet e^{U\hat{E}DT_t} \bullet POP_t \, dP_t \quad (9B)$$

The welfare analysis assumes that income, average efficiency of passenger cars, and driver behaviour and other factors (all of which are captured in the UEDT) remain unaffected by the price increase. In mathematical terms, the variables Y_t and $UEDT_t$ do not depend on the gasoline price.

4.1.2. The gasoline supply curve and producer surplus

The actual data needed to calibrate a supply curve are not available; however, it can be constructed by examining the structure of refining in the KSA. Saudi Arabia has invested heavily in refining throughout the

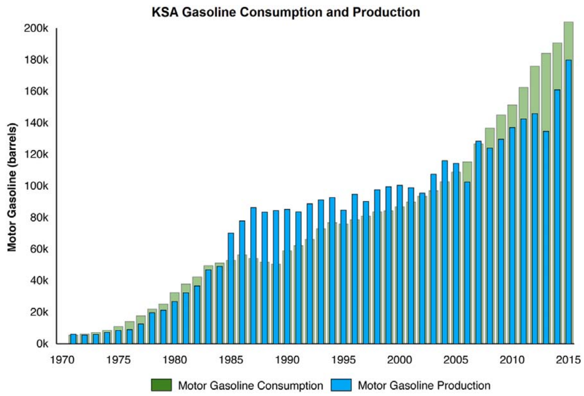

Fig. 3. Gasoline consumption and production in Saudi Arabia.
Source: MEIM (2016).

past several decades in order to meet demand, diversify the economy, and create job opportunities (MEP, 2015b). However, domestic supply of gasoline has not always met demand and, between 1971 and 2015, Saudi Arabia shifted from being a net importer of gasoline to a net exporter and back again (see Fig. 3). According to the IEA (2016), Saudi Arabia has consistently exported and imported some gasoline throughout this period, the existence of seasonality in domestic demand being one reason.

In 2013, there were seven refineries operating in the KSA (MEP, 2015b; Saudi Aramco, 2015). Four were wholly owned by Saudi Aramco, while the other three were joint ventures between Saudi Aramco and different international oil companies (see Table 3). In 2014, SATORP, another Saudi Aramco joint venture, came on stream in the KSA. The following year witnessed YASREF, a fifth joint venture, deliver its first shipment of refined petroleum products. Both SATROP and YASREF contributed to making refining the fastest growing sector in the Saudi economy in 2014 (MEP, 2015b). Furthermore, Saudi Aramco expects to begin commissioning its Jazan Refinery and Terminal in 2017. This push to increase domestic refining capacity is part of Saudi Aramco's broader strategy to expand across the entire hydrocarbon value chain. It also allows the company, which currently imports gasoline at international market prices but sells them at lower prices domestically, to cut its import bill (Argaam, 2015; Krane, 2015b).

The refining sector is characterized by indivisibility of capital (Bhattacharyya, 2011). In other words, increments in the supply of refined petroleum products occur in discrete steps, as shown in Table 3.

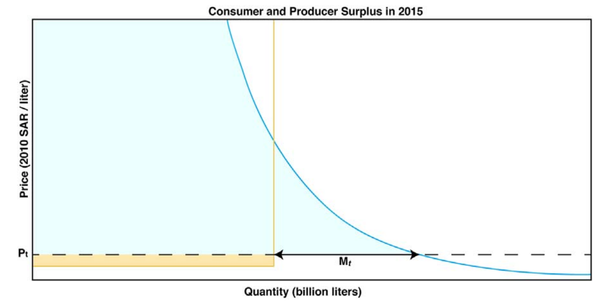

Fig. 4. Consumer and producer surplus in Saudi Arabia in 2015. Note: Distances and areas are illustrative.

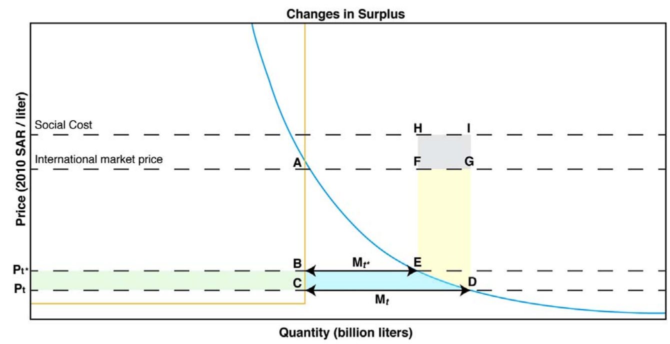

Fig. 5. Changes in surplus following the 2015 gasoline price increase. Note: Distances and areas are illustrative.

Consider the case of a single refinery with a given capacity. The marginal cost of supply is assumed constant up to the capacity constraint. So long as the domestic price is below the long-run marginal cost, there will be no incentive to invest in further refining capacity. This in turn gives rise to a vertical domestic supply curve at the capacity constraint. Because of the existence of low domestic fuel prices in Saudi Arabia, particularly over the last decade, we assume that the domestic gasoline supply curve is vertical at the capacity constraint (see Fig. 4). Although we do not know the fixed marginal cost of refining in the KSA, its exact value has no impact on the change in producer surplus that we wish to estimate.

The capacity constraint allows us to express the domestic supply that is provided in year t, whenever there are imports, as follows:

Table 3
The production of gasoline in refineries in the KSA in 2015.
Source: Saudi Aramco (2015) and MEP (2015b).

In-Kingdom Refineries	Saudi Aramco share of gasoline produced (million barrels)	Saudi Aramco Ownership Share (%)	Total gasoline produced (million barrels)
100% Saudi Aramco owned refineries			
Jeddah (1976)	3.738	100%	3.738
Yanbu (1979)	10.485	100%	10.485
Riyadh (1981)	11.379	100%	11.379
Ras Tanura (1986)	42.304	100%	42.304
Jazan (under construction)		100%	
Sub-Total	**67.906**		**67.906**
Saudi Aramco joint ventures			
SAMREF (1983)	23.766	50%	47.532
SASREF (1986)	2.255	50%	4.510
Petro Rabigh (1990)	4.566	37.5%	12.176
SATORP (2014)	15.639	62.5%	25.022
YASREF (2015)	14.222	62.5%	22.755
Sub-Total	**60.448**		**111.995**
Total	**128.354**		**179.901**

$$S_t = G_t \cdot POP_t - M_t \quad (10)$$

where S_t is the supply of gasoline by domestic producers and M_t the imports.

To estimate the change in producer surplus that results from the administered price increase, the area of the following rectangle is calculated:

$$\Delta PS = S_t \cdot (P_{t*} - P_t) \quad (11)$$

Because of the position of the domestic supply curve, Saudi Arabia's status as a net importer of gasoline in 2015, and the not so large increase in price, domestic supply is not affected. Instead, imports fall from M_t to M_{t*} to ensure that total supply and demand are balanced (see Fig. 5). For very large increases in price, however, it may be possible for domestic gasoline demand to fall to the point where imports would no longer be needed and excess domestic supply could be exported. However, the administered price increase examined in this paper is not large enough to make Saudi Arabia a net exporter of gasoline.

According to our GDP-based model, the roughly 60% increase in the administered price of gasoline would have reduced gasoline demand from the actual value of 32.4 billion liters in 2015 to 31.0 billion liters in the short run and 30.2 billion liters in the long run. Our non-oil GDP-based model predicts that the administered price increase would have reduced gasoline demand from 32.4 to 31.2 billion liters in both the short and the long run (since in this model the estimated short- and long-run price elasticities are the same). Given that the domestic supply of gasoline in 2015 was around 28.6 billion liters, both models demonstrate that the KSA would continue to be a net importer of gasoline following the administered price increase.

4.1.3. External costs

Increasing the gasoline price leads to a reduction in gasoline demand and the distances travelled by passenger cars. This in turn leads to an additional welfare gain through reduced air pollution, greenhouse gas emissions, congestion, and accidents. These external costs have been measured for over 100 countries, including Saudi Arabia, by Parry et al. (2014). To measure the total external costs, EC_t, avoided by the announced gasoline price increase, the change in gasoline demand predicted by the preferred models is multiplied by the total marginal damages, τ, due to air pollution, emissions, congestion, and accidents, all measured in 2010 SAR per liter of gasoline, as shown below:

$$EC_t = (G_t(P_t) - G_t(P_{t*})) \cdot POP_t \cdot \quad \tau \quad (12)$$

4.1.4. The price-gap approach

The welfare analysis is conducted using the standard price-gap approach (Koplow, 2009), which considers the gap between a good's price and its opportunity cost, which in the case of gasoline is the international market price.[7] Domestically produced gasoline is implicitly subsidized because the domestic price is considerably lower than the international market price, even if the domestic price is higher than production costs. This subsidy reflects foregone revenues. On the other hand, the subsidy on imports is explicit since they are purchased at international market prices then sold at much lower prices domestically, giving rise to what we call the 'import bill'. Since the subsidy cut considered only affects the demand for imports, the focus falls on the welfare gains from reducing this import bill.

4.2. Welfare results

4.2.1. Total surplus and deadweight loss

The change in social welfare (or total surplus) due to the gasoline price increase comprises the sum of changes that occur to three components: consumer surplus, producer surplus, and government spending, which includes the import bill (Just et al., 1982). Importing gasoline at international market prices and selling it domestically at lower prices results in a negative impact on Saudi Aramco's net profits. If the government provides a transfer to Saudi Aramco to cover this subsidy, then any reduction in the import bill would result in an equivalent reduction in government spending. Nonetheless, even in the absence of any government transfers, Saudi Aramco would simply absorb the losses, which in turn would translate into foregone revenues for the government. In fact, according to the Saudi Ministry of Economy and Planning (MEP, 2015b), oil revenues accounted for 89% of total public revenues in 2014. Therefore, given that Saudi Aramco is state-owned, any changes to the gasoline import bill translate into changes in government spending.

The welfare analysis conducted here compares the total surplus in 2015 to the total surplus that would have existed in the economy if gasoline prices were raised at the start of 2015. Fig. 5 illustrates the breakdown of the net gain in total surplus into three components. First, Fig. 5 illustrates that the gasoline price increase would reduce demand, thereby reducing consumer surplus (shown by the sum of the areas $P_{t*}P_tCB$ and $BCDE$). Second, it would lead to an increase in producer surplus (or profits) for domestic gasoline producers, mainly Saudi Aramco (shown by area $P_{t*}P_tCB$), highlighting how a relatively large portion of the lost consumer surplus would be transferred to domestic gasoline producers. Finally, the original import bill, which was $ACDG$, would fall to $ABEF$, reflecting a reduction in government spending. Part of the reduction in government spending would offset the lost consumer surplus due to imports (shown by the area $BCDE$). The remaining part of the reduction in government spending (shown by the area FEDG) reflects the net gain in total surplus in the Saudi economy following the gasoline price increase. Looked at from another perspective, this net gain in total surplus reflects the deadweight loss that is eliminated by the gasoline price increase.

Table 4
The changes to surplus and government spending following the administered price increase.

	GDP-based model		Non-oil GDP-based model	
	short run	*long run*	*short run*	*long run*
Price elasticity	*−0.098*	*−0.154*	*−0.087*	*−0.087*
Change in consumer surplus	*−7834 (−0.31%)*	*−7907 (−0.31%)*	*−7935 (−0.31%)*	*−7983 (−0.32%)*
Change in producer surplus	*+7147 (0.28%)*	*+7147 (0.28%)*	*+7147 (0.28%)*	*+7147 (0.28%)*
Change in government spending	*−2033 (0.08%)*	*−2639 (0.10%)*	*−1912 (0.08%)*	*−1921 (0.08%)*
Change in total surplus	**+1346 (0.05%)**	**+1879 (0.07%)**	**+1124 (0.04%)**	**+1085 (0.04%)**

Notes: The absolute changes are expressed in million 2010 SAR while the percentage changes, which are expressed relative to real GDP in 2015, are shown between parentheses. The change in total surplus is equal to the change in consumer surplus plus the change in producer surplus minus the change in government spending.

Table 4 presents the calculated annual net gain in total surplus using the two preferred demand models, for both the short and the long run (holding income and the UEDT constant). This shows that the calculated net gain is between one and two billion 2010 SAR annually, and depends strongly on the estimated price elasticity. For the non-oil GDP-based model, with an estimated short- and long-run price elasticity of −0.087, the net gain as a result of the price increase is 1.1 billion 2010 SAR. For the GDP-based dynamic model, with estimated short- and long-run price elasticities of −0.098 and −0.154, respectively, Table 4 shows that the calculated net gain is 1.3 and 1.9 billion 2010 SAR, respectively.

[7] The average 'free on board' (FOB) spot price of 95-octane gasoline at Jebel Ali port in 2015 is used as a proxy for the international gasoline price (Platts, 2016).

Table 5
The welfare gains from reducing deadweight loss and external costs.

	GDP-based model		Non-oil GDP-based model	
	short run	*long run*	*short run*	*long run*
Price elasticity	*−0.098*	*−0.154*	*−0.087*	*−0.087*
Reduction in deadweight loss	+1346 (0.05%)	+1879 (0.07%)	+1124 (0.04%)	+1085 (0.04%)
Reduction in external costs	*+2784 (0.11%)*	*+4351 (0.18%)*	*+2493 (0.10%)*	*+2493 (0.10%)*
Net Welfare Gain	**+4130 (0.17%)**	**+6231 (0.26%)**	**+3617 (0.15%)**	**+3577 (0.14%)**

Notes: The absolute changes are expressed in million 2010 SAR while the percentage changes, which are expressed relative to real GDP in 2015, are shown between parentheses. The net welfare gain is equal to the sum of the reductions in deadweight loss and external costs.

4.2.2. External costs

As mentioned previously, increasing the gasoline price leads to a reduction in gasoline demand and the distances travelled by passenger cars. This in turn leads to an additional welfare gain through reduced air pollution, greenhouse gas emissions, congestion, and accidents (shown by the area HIGF in Fig. 5). Using estimates of these external costs for Saudi Arabia and the estimated gasoline demand models in Table 2, the welfare gain delivered by reduced external costs can be calculated. Table 5 shows these results, revealing that accounting for both the welfare gain from the reduction in deadweight loss and the welfare gain from lower external costs results in a total welfare gain of between 3.6 and 6.2 billion 2010 SAR, which is between 0.14% and 0.26% of Saudi Arabia's real GDP in 2015.

4.2.3. Government revenue uplift

In addition to looking at the impact of the gasoline price increase on social welfare, it is also useful to examine its impact on Saudi national revenues. This is especially important given the pressures that have been exerted on the government budget by low international oil prices. In 2015, total actual revenues from gasoline sales were 16.2 billion SAR (calculated by taking the actual gasoline price in 2015 and multiplying it by actual gasoline demand.) In the hypothetical scenario where the price increase occurred at the start of 2015, the total revenues from gasoline sales would have been around 24.3 billion SAR on average across our models. (This is calculated by taking the new gasoline price, accounting for the potential switching of consumers between different grades of gasoline, and multiplying it by our estimates of gasoline demand at the new price, which is obtained from our demand curves.) Therefore, we find that the gasoline price increase would have resulted in a revenue uplift of more than 8 billion SAR, most of which would be a gain in government revenues.

5. Conclusions and policy implications

The KSA is entering a period of substantial economic and social change following the government's announcement of a new vision for the next 15 years; which, according to Alarabiya (2016), involves "deregulating the energy market to make it more competitive". The research undertaken for this paper therefore considers the increase in the gasoline price announced at the end of 2015. In particular, gasoline demand functions for the KSA are estimated, which are then used to calculate the potential welfare effects of the administered price increase.

The estimated GDP-based model suggests that the long-run price and income elasticities of gasoline demand are −0.15 and 0.15, respectively, while the non-oil GDP-based model points to elasticities of −0.09 and 0.61, respectively. Although there are differences in the income elasticity across models, the gasoline price elasticity is consistently small. Furthermore, both models produce an upward sloping UEDT for the KSA, suggesting that the energy efficiency of the stock of passenger cars either decreased over the study period or increased but was outweighed by changes in driver behaviour that ceteris paribus resulted in greater gasoline consumption per capita.

Therefore, if the Saudi government would like to limit future growth in gasoline consumption, then the estimated model has two messages for policymakers. First, even if gasoline prices are raised above those announced on 29 December 2015, the low estimated price elasticity suggests that this would not markedly reduce gasoline consumption in the KSA. An alternative transport mode, particularly within cities, would be needed to make gasoline demand more elastic to price changes. However, if gasoline prices are raised considerably higher so that expenditure on gasoline is a much larger proportion of income, then it is possible that the price elasticity would increase holding everything else fixed, and thus any further increases in price would have a bigger impact on gasoline consumption. Second, the generally upward sloping UEDT suggests that a key way to limit future gasoline consumption would be to improve the energy efficiency of passenger cars and increase energy awareness by drivers through education and marketing campaigns.

Focusing on the welfare analysis, we demonstrate that the increase in administered energy prices in the KSA announced at the end of 2015, which affected both consumers and producers across a number of sectors, could have a significant positive impact on welfare in the KSA. For just the gasoline price increase, our estimates suggest that there would be a welfare increase of between 0.14% and 0.26% of real GDP per annum.

The possible welfare gains are noteworthy, but it is worth considering that there are even longer-term changes that might occur in consumer behaviour that are not captured by the estimated long-run price elasticity. For example, over a number of years an increase in the gasoline price may encourage consumers to live closer to work, thereby altering the urban sprawl of cities across the KSA. It could be argued that the estimated long-run price elasticities (and/or the estimated UEDT) in our models do not adequately capture such changes. Therefore, if this were the case, then the estimates of the net gain in social welfare presented in this paper would be lower bound estimates. Furthermore, the welfare gains would continue to accumulate over time, and grow larger in the event that oil prices return to the higher levels seen in the past.

In summary, the welfare calculations suggest the increase in the administered price of gasoline announced at the end of 2015 in the KSA yields an overall increase in social welfare. Although within this consumers lose surplus as result of the price increase, how they perceive this loss depends on how the government achieves an appropriate balance between redistributing the additional revenues and using them to help alleviate budget deficit problems. It should also be noted that in 2015 roughly 52% of government spending was on public employee salaries and benefits (Argaam, 2016). This suggests that the loss in consumer surplus due to the administered price increase may be offset by the gain in government revenues, estimated to be around 8 billion SAR, which could be redistributed back to consumers.

It could be argued, however, that if international oil prices were to increase then the Saudi government would reinstate the implicit energy subsidies by lowering the administered prices. However, given that one of the Saudi government's many goals is to make the energy sector more competitive, this would seem very unlikely. As noted by Alarabiya (2016), it has been stated "that providing subsidies with no clear eligibility criteria is a substantial obstacle to the energy sector's competitiveness" and that "market prices shall, in the long term, stimulate productivity and competitiveness among utility companies and open the door to investment and diversification of the energy mix in the Kingdom". Therefore, energy prices in Saudi Arabia are expected to rise towards international market prices over the next few years regardless of whether they increase or decrease (SABQ, 2017).

Future work could focus on quantifying the potential welfare gains from the similar price increases in electricity, fuel, and water. Assuming that they will also produce similar welfare enhancements, then together they could yield per annum net welfare increases of up to a few percent of GDP.

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