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OPEC and Demand Response to Crude Oil Prices

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Abstract: This paper investigates demand response to crude oil price movements before and during the recent global financial and economic crisis. It employs several market power indices to structurally estimate price elasticities. A newly developed market power index for crude oil markets is implemented. In this approach OPEC is the central player and acts as a dominant producer in the global oil market. We quantify how a change in market structure (such as changes in marginal cost of production) would contribute to market power exercise of OPEC and have an ultimate impact on price elasticity of demand for oil. Our price elasticity predictions fall in a range reported in the literature, however estimates for pre-crisis deviate from the post-crisis ones. In fact, demand response to crude oil prices has almost doubled during the crisis. This severe change in price response can be associated with record price levels caused by supply shortages and surge in alternative renewable energy resources. The key advantages of this methodology over the existing literature are that it is simple to use and estimates price elasticity using a competition framework without specifying demand/supply function(s), and utilizes commonly observable market variables that can be applied to any admissible data frequency.

Keywords: Price elasticity of demand; crude oil; global financial/economic crisis; Brent benchmark; market power; GMM estimation.

JEL Codes: D22; L13; Q35; Q41.

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1. Introduction

The recent events including the global financial crisis of 2008 (which has caused downturn in economic activity all over the world and still endures in Europe and Asia), the shale gas boom, and the surge of green energy initiatives (electric cars, wind and solar energy) have led to turmoil in the oil markets causing unprecedented oil price volatility, record prices (new highs and lows) coupled with significant budget deficits in major oil nations (OPEC, Russia, Norway). In this environment, even a rumor of OPEC's possible production cut could lead to a significant price hike. For example, on Jan 28, 2016 a speculation grew over a possible production cut by OPEC at its upcoming meeting led to 8% price increase in a single day, even though there was a supply glut in excess of 1 million barrel per day.[1] In fact, these events are not unique to this decade. Oil markets have experienced many crises and big shocks in the past (such as low supply of 1970s, the oil glut of 1980s, financial crisis in East Asia in 1998, and positive demand shocks in 2000s due to growth and severe weather). A plethora of studies have examined these issues along with OPEC production behavior and the price formation process in oil markets.

In this study, we investigate demand response to crude oil prices before and during the recent financial/economic crisis using a new technique. The price elasticity estimates provide useful information about the degree of market power and the impact of shocks on the market outcomes (prices, price volatility, outputs, welfare, etc.). It is also essential to project energy demand and outline energy policies. Consequently, the purpose of this paper is to structurally estimate the price elasticity of world demand for crude oil. Although we consider oil production by all nations, the methodology we propose mainly relies on the impact of OPEC's production on demand response.

The demand elasticity estimates in the literature are mainly based on reduced-form models. Different than others this paper considers a game theoretic model and offers structural estimates of price elasticity. While this methodology is unique in the crude oil studies, a similar methodology is implemented by Newbery (2009) and Genc (2016) in electricity context. In this paper we offer a new market power index for crude oil and assume OPEC as a key player in the global crude oil market. The model assumes a flexible quantity competition framework (allows

[1] Source: http://www.theweek.co.uk/oil-price/60838/oil-price-russia-blinks-first-is-this-the-end-of-the-slump Jan 28, 2016.

Cournot or dominant producer(s) with fringe competition) to model the behavior of crude oil producers and then applies an econometric approach to identify the relationship between market power measures of the Lerner Index (LI) and the Residual Supply Index (RSI) to estimate price elasticity of demand for crude oil. The advantages of this approach are *i*) it offers a simple way of structurally estimating price elasticity in a competition framework; *ii*) demand for crude oil need not be specified, it is as general as possible; *iii*) it takes into account of market power of OPEC in price formation process in the crude oil markets; *iv*) it uses a few key variables for which data points are readily available; *v*) it can employ data sets at any admissible data frequency (daily/weekly/monthly/yearly) to calculate market power indices, whereas quarterly or yearly data has been commonly assumed in the literature.

This study investigates crude oil markets in 2002-2014, covering the market outcomes before and after/during the economic crisis of 2008. The goal of the paper is to compare and contrast the change in oil consumption behavior related to the crisis. We find that demand response is about 87% higher after the crisis than the ones estimated before it.

The paper is structured as follows. Section 2 briefly reviews the literature. Section 3 defines the competition model and its solution, and describes the data sets. While Sections 4 provides the results, Section 5 extends to paper for robustness check. It concludes in Section 6 with a short discussion of key findings.

2. Literature Review

Because of the challenges associated with measuring price elasticity of demand for crude oil, a common framework has been utilizing reduced-form demand models. Most of the studies find highly price inelastic demand in the short-run and more elastic demand elasticity (although less than unity) in the long-run. For example, Cooper (2003) provides an extensive coverage for price elasticity estimates for crude oil in 23 countries (mostly in the OECD). Using yearly data Cooper estimates a log-linear equation (oil consumption as a function of price of crude oil and GDP per capita) to measure short- and long-run price elasticities. He finds that short-run elasticities fall in the interval of -0.026 to -0.109. Also, long-run price elasticities for the G7 countries range from -0.18 to -0.45, which is almost within the bounds of -0.2 to -0.6 estimated by the US Federal Energy Office. Krichene (2002) estimates demand and supply elasticities using yearly crude oil data over 1918-1999 using a linear supply and demand model. Krichene finds that the short-run price elasticity is -0.06 in 1918-1999, -0.08 in 1918-1973, and -0.02 in 1973-1999. His long-run elasticity estimates based on a cointegration approach (and also error correction method) are also low: -0.05 in 1918-1999, -0.13 in 1918-1973, and almost zero in 1973-1999. Hamilton (2009) assumes inelastic short-run demand for the study covering 1970-1997.

Among earlier studies, Pindyck (1979) estimated long-run price elasticity for crude oil in the OECD countries in the industrial sector. He found that price elasticity fell into the interval of [-0.22, -1.17]. Dahl and Sterner (1991) found that the short run price elasticities for gasoline demand were in between -0.22 and -0.31; the long run price elasticities ranged -0.8 to -1.01. Pesaran et al. (1998) estimated long-run price elasticities for a group of Asian countries. They reported that the price elasticity for energy demand was -0.33 in aggregate; -0.52 for industry; -0.36 for transport; -0.47 for residential; -0.08 for commercial. Graham and Glaister (2002) provided a survey of demand for gasoline. They reported motorists' response to gasoline price movements: the short-run price elasticities ranged from -0.2 to -0.5, and the long-run price elasticities fell in the interval [-0.23, -1.35] in the OECD countries. Variations in estimations in these studies mainly stem from estimation method, the frequency and form of data (time series or cross-sectional), and model specifications.

The studies examining the production behavior of OPEC and/or Saudi Arabia have also assumed low price elasticity. Examples include Mixon (1982) who assumed price elasticity of -0.5, and De Santis (2003) who assumed -0.45 in their simulations. A number of papers investigated different issues (such as supply elasticity, determinants of prices, and degree of competitiveness) in the world oil markets. For instance, Ramcharran (2002) estimated price elasticity of supply employing the log-linear supply model of Griffen (1985) using yearly production and price data in 1973-1997. He estimated negative price elasticity of supply for OPEC countries (offering support for the target revenue hypothesis) and positive supply elasticity for most non-OPEC countries (an evidence for the competitive market hypothesis). Kaufmann et al. (2008) tested the hypothesis of whether crude oil prices were determined in part by refinery capacity, non-linearities in supply conditions, and expectations during the price rises in 2004-2006. They reported that all of these factors explained the price increases. Dees et al. (2007) specified crude oil prices as a function of OPEC capacity, OECD crude oil stocks, OPEC quotas and cheating on

OPEC quotas, and its model performed well in sample 1986-2003, but under-predicted real oil prices out of sample.

Recent papers on oil markets also examine a number of interesting issues including estimation of long term oil prices (Haugom et al., 2016), the impact of fuel subsidies on crude oil prices and welfare (Balke, et al., 2015), pricing behavior and political economy of OPEC (Hochman and Zilberman, 2015), predicting growth in OPEC and non-OPEC production and real oil prices (Ratti and Vespignani, 2015). These papers also stress the importance of magnitude of price elasticities on market outcomes and assume the previously reported elasticity estimates in their models. As explained by Haugom et al. (2016) the price elasticity information is vital for oil exporting countries, especially OPEC countries which rely on oil revenues. Cuddington and Dagher (2015) criticize the priori restrictions of demand functions for estimating short and long-run elasticities for energy products. They emphasize that the restrictions on coefficients are testable and can be avoided. We also argue in this paper that demand and/or supply functions need not be restricted for elasticity estimations. Therefore, we offer a simple, tractable, and comprehensive approach of estimating crude oil demand elasticity in a structural model taking into account of imperfect competition in oil markets.

3. Model and Data

We will model the competition in the global crude oil market by assuming that oil nations/producers choose how much oil to produce. The solution of the competition model will yield to a theoretical relationship between two market power measures: the Residual Supply Index (RSI) and the Lerner index (LI), which encompass information for price, marginal cost, productions and world consumption of crude oil. Using this relation and the computed monthly values of these indices we will structurally estimate the price elasticity of demand for crude oil before and during the recent economic/financial crisis.

3.1 Model

In line with the literature we assume that OPEC is a dominant producer in the global crude oil market as it supplies over 40% of the world production. After the first oil shock of 1973-74, the OPEC has proven its power and leadership in impacting international markets. Since then many studies (Kalymon, 1975; Fisher et al., 1975; Ezzati, 1976; Hnyilicza and Pindyck, 1976; Newbery, 1981; Griffen, 1985; Jones, 1990; Mabro, 1992; Gately, 1995; Gulen, 1996; Dees et al., 2007; Alkhathlan et al., 2014, among others) have examined OPEC's production and pricing behavior using econometric models, game theoretic approaches and exhaustible resource theories.

Econometric studies show that the oil market outcomes largely deviate from perfect competition. A common belief is that the behavior of OPEC swings between the dominant producer model and pure cartel (Griffen, 1985; Jones, 1990; Alhajji and Huettner, 2000; Ramcharran, 2002). Johany (1980) utilized dominant producer model in which OPEC acted as a dominant player, imposing the price that the others (non-OPEC countries) accept. Market observers and economic studies suggest that Saudi Arabia is the most powerful swing producer in OPEC and in the global market (Griffen and Teece, 1982; Mabro, 1991; De Santis, 2003), and this hypothesis is supported by econometric evidence (Alhajji and Huettner, 2000). In OPEC, Saudi Arabia's high share of world production (over 10%), exports (over 16%), and proven reserves (over 24%) supports its role as a dominant producer (OPEC 2001). Dahl and Yucel (1991) argue that OPEC behavior is consistent with an oligopoly model, and Adelman (1982) predicts its behavior swinging between dominant producer and market share models. Although OPEC's crude oil export share has declined from 63.1% in 1980 to 46.4% in 2000 (OPEC 2001), its share of world production stood at 41.8% in 2014 (OPEC 2015), and it is still the game changer in oil markets. However, OPEC countries heavily need oil export revenues, and supply and/or demand shocks in the market largely impact their economies.

Our modeling framework also assumes a quantity competition in the global crude oil market, in which the major player is OPEC.[2] The model is flexible enough to accommodate the other (non-OPEC) oil producing nations (such as, Russia, Brazil, Norway, the USA, China, Mexico, Canada, Australia) as Cournot competitors or fringe suppliers. That is, these oil producers could behave like strategic producers or price-taking competitive fringe. Among the non-OPEC producers, there are very small producers such as Germany, Italy, France, Spain, Netherland, Turkey, Peru, which should be price-takers as their tiny productions (less than 1% of total

[2] See also Breton and Zaccour, 1991 who use Cournot framework to analyze competition in oil and gas industries.

production) cannot even meet their own crude oil demand. All producers strive to maximize their profits non-cooperatively while meeting the world demand for crude oil, which is differentiable and downward sloping function of the wholesale price p and is denoted $Q_t(p)$ at time t. [3]

Each strategic producer i maximizes its profit function for each time t,

(1) $\pi_{it} = p_t(Q_t)q_{it} - c_{it}(q_{it})$.

If some of non-OPEC nations are price takers then the residual demand for strategic producer i as a function of market price p is $q_{it} = [Q_t(p) - S_t(p) - q_{-it}]$, where $S_t(p)$ is the aggregate supply of fringe producers, q_{-it} is the quantity produced at price p by other strategic producers (-i), and $c_{it}(q_{ih})$ is the total production cost function for producer i at time t.

If the non-OPEC nations are all strategic then each strategic producer j, including OPEC, maximizes its profit function for each time as in expression (1), but the residual demand faced by producer j will be equal to $q_{jt} = [Q_t(p) - q_{-jt}]$, where q_{-jt} is the total quantity supplied at price p by the rivals of producer j.

Production from each producer is bounded by the capacity K_{it} for producer i at time t. The production cost function $c_{it}(q)$ is convex and differentiable.

Although marginal production costs and total cost functions are confidential, some estimates, which can greatly vary over OPEC and non-OPEC nations, are available. For example, in OPEC in 2014 Saudi Arabia's marginal cost of production is reported \$3 per barrel, and Nigeria's marginal cost is reported \$15/b.[4] Overtime technological changes have reduced the marginal cost of crude oil production (Alazard and Champlon, 1999). Oil producers can also use innovative approaches to cut costs in the oil rigs. For example, in Texas a top shale oil producer (Pioneer National Resources Co) uses treated municipal wastewater for fracking.[5]

3.2 Model Solution

[3] In the literature mentioned above, it is commonly assumed that OPEC's residual demand is either a stable function or shifting at a known (exogenous) growth rate. Here we do not impose such restrictions.

[4] http://knoema.com/vhzbeig/oil-statistics-production-costs-breakeven-price. The data comes from IMF, Deutsche Bank, Citi Research and Reuters.

[5] See http://www.reuters.com/article/us-pioneer-natl-rsc-fracking-water-idUSKCN0QQ0CA20150821

To estimate crude oil price elasticity we first need to compute market power indices (which will show up as equilibrium conditions in the profit maximization problem of each producer). Using oil data we will compute the Residual Supply Index (RSI) and the Lerner Index (LI), which are commonly used market power indices for electricity market studies. We will adopt these indices to crude oil industry and offer new definitions. To our knowledge, the RSI as a market power index has not been implemented for crude oil market studies before.[6] The RSI includes quantity information such as global market demand and oil productions. The LI, which is more common in measuring market power, will be a function of market price and marginal cost.

The RSI can be calculated for any oil producing nation. A producer's RSI is defined as the ratio of residual market supply (excluding this nation's production) to the world demand quantity at a given time. Therefore, it measures pivotal status of the oil nation and determines whether this country's production is needed to meet the global demand. In general there exists a negative relation between the RSI and the LI (as observed in the US and European electricity markets): the lower the RSI the higher is the producer's market power. We will test whether this relation holds for oil markets. In the situations in which marginal cost information is not readily available, the RSI can be computed to determine the level of market power held by the producer. We will use these indices to structurally estimate price elasticity of demand for crude oil.

We define oil nation i's RSI at time t as follows:

(2) $$RSI_i(t) = [K(t) - q_i(t)]/D(t).$$

Namely, it is equal to world crude oil production minus country i's production divided by global consumption.

If the country i has any bilateral contractual obligations, the total contracted quantity can be subtracted from this country's production to calculate its RSI. If $0 < RSI_i(h) < 1$, then

[6] The RSI was first designed by the California Market Surveillance Committee. Sheffrin (2002) shows that there is a negative relationship between the RSI and Lerner Index (LI) in the California electricity market in summer 2000. As a market power measure, the RSI has been used in the US and European electricity markets (see Genc, 2016, and the references therein).

producer i's production is needed to meet market demand, and therefore it is pivotal and has a market power. Otherwise, the competitors of country i can meet the demand.

The Lerner Index (LI) as a market power measure indicates the proportional markup of price over marginal cost. Formally,

(3) $$LI_i(t) = [p(t) - mc_i(t)]/p(t)$$

for country i given the world price p at time t. $LI_i\ (t)$ indicates country i's ability to raise the market price to p given that its marginal cost of production at the supplied output is mc_i, which varies over time.

In Figure 1 we plot the relationship between the Lerner Index (LI) and the Residual Supply Index (RSI) before and during/after the global crisis of 2008 using OPEC's LI and RSI. The solid line indicates a linear fit for the data after the crisis; the dotted line shows the linear fit before the crisis. Clearly, the market power indices in crude oil industry are highly correlated and higher the RSI the lower is the LI. An economic interpretation of this figure is that as OPEC's residual demand goes down or the supply or market share of rival countries goes up, OPEC's market power or its ability to increase crude oil price over and beyond its marginal cost diminishes. Alternatively, the slope of the fitted curve (which is explicitly discussed in the Results section below) can be interpreted as an influence of oil market structure on markups.

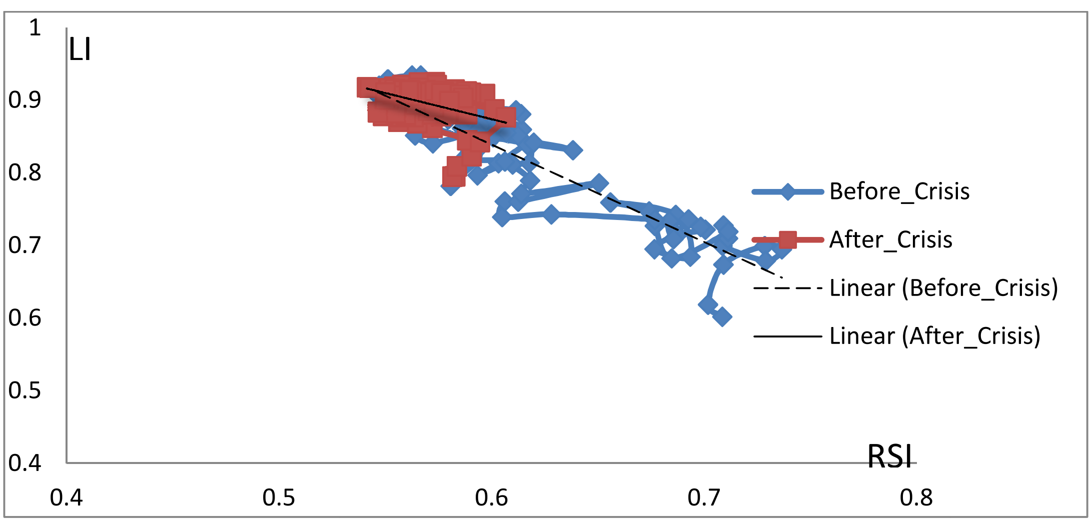

Figure 1: The inverse relationship between the LI and the RSI in the global crude oil market before and during/after the global financial crisis of 2008.

Next we show that the market power indices in (2) and (3) emerge as an equilibrium outcome. Specifically, the RSI and LI which are dynamic indices and change for each time period with respect to the changes in market conditions are obtained by the profit maximization problem of OPEC. The interplay between these indices will provide price elasticity estimates for crude oil.

In the short run demand response to the oil/gas prices can be very low, but consumers may resort to alternative energy resources in the long-run. Policy makers and governments have recently developed policies and incentives that are intended to create aversion from oil-based outputs. The public conscious on environmental awareness and the recent initiatives for electric car developments and green energy investments (solar and wind based generation facilities) may be considered as divergence from traditional energy resources such as oil and coal. These efforts may help create price responsive demand for crude oil.

The objective function of country/producer i is to maximize its profit function to choose the amount of crude oil q_{it}:

$$\pi_{it} = p_t(Q_t)q_{it} - c_{it}(q_{it}).$$

The actual oil data (monthly, quarterly or yearly data published by the IEA and EIA and JODI) shows that crude oil production is always higher than consumption. The overproduction is meant to be reserve/inventory. Therefore, total crude oil supply is equal to total production less reserve quantity. Formally,

(4) $Q_t = \sum_i (q_{it} - \sigma_{it}),$

where $q_{it} \geq 0$ is the crude oil production and $\sigma_{it} \geq 0$ is reserve quantity/inventory held by country i at time t. Q_t is equal to the world consumption of (refined) crude oil and/or crude oil derivatives (such as gasoline, jet fuel, fuel oil, etc). Let $\sigma_t = \sum_i \sigma_{it}$ be total reserves at time t. Alternatively, σ_{it} could be interpreted as the amount of crude oil wasted in the refinement process. Also let q_{-it} denote total production by country i's rivals (denoted $-i$).

The optimum output for an interior solution for problem (1) satisfies

(5) $\frac{\partial \pi_{it}}{\partial q_{it}} = p_t - c'_{it} + q_{it}\, \partial p_t / \partial Q_t = 0.$

The terms are re-arranged to obtain

(6) $$p_t - c'_{it} = -q_{it}\frac{p_t}{p_t}\frac{Q_t}{Q_t}\partial p_t/\partial Q_t = q_{it}\frac{p_t}{Q_t}\frac{1}{\varepsilon_t} = (Q_t - q_{-it} + \sigma_t)\frac{p_t}{Q_t}\frac{1}{\varepsilon_t} = \left(1 + \frac{\sigma_t}{Q_t} - \frac{q_{-it}}{Q_t}\right)\frac{p_t}{\varepsilon_t} = (1 + \frac{\sigma_t}{Q_t} - RSI_{it})\frac{p_t}{\varepsilon_t},$$

where the second equality comes from the definition of price elasticity of demand $\varepsilon_t = -(p_t/Q_t)\,\partial Q_t/\partial p_t$, the third equality comes from the expression (4), and the last equality is based on the definition of RSI for oil producer *i*: $RSI_{it} = q_{-it}/Q_t$. Using the definition of LI in (3), the expression (6) becomes

(7) $$LI_{it} = (1 + \frac{\sigma_t}{Q_t})\frac{1}{\varepsilon_t} - RSI_{it}\frac{1}{\varepsilon_t},$$

This expression indicates the theoretical relationship between market power index and the residual supply index for producer *i*. Using data for L_{it} and RSI_{it} we intend to run the regression

(8) $$LI_{it} = \alpha + \beta RSI_{it} + e_t,$$

where e_t is the error term. The inverse of the coefficient of RSI gives the estimate of price elasticity. We expect to obtain negative sign for the estimate of β which would imply that the higher the producer i's residual supply index (therefore lower production and market share) the lower the relative markup is. Furthermore, from the relation in (7) $\alpha \neq |\beta|$ should hold. That is, they should be statistically different and this is what is observed from the regression estimates below. More specifically, $\alpha > |\beta|$ as long as $\sigma_{it} > 0$ holds.

The main advantage of this way of estimating demand elasticity is that there is no need to explicitly define a market demand function to measure the price response. The competition model directly provides price elasticity as a solution of strategic interactions.

3.3 Data

We use monthly data of Brent oil prices (\$/barrel), marginal production cost of crude oil for OPEC (\$/barrel), world crude oil production, OPEC crude oil production including condensate, and world crude oil demand from January 2002 to December 2014. We divide the data into two parts: before the economic/financial crisis covering 2002-2008, and during/after the crisis covering 2009-2014.[7] We purposely do not include 2015-2016 data, as the macroeconomic indicators have shown recovery in the US economy (and elsewhere) which is followed by the first interest rate hike by the Fed in December 2015. The data are freely available and comes from the websites of multiple sources (US Energy Information Administration, JODI, and International Energy Agency). Although there are more than 160 types of traded crude oil (Brent, WTI, Dubai, Maya, Canadian Lloyd Blend, Nigerian, Algerian Blend, Ural, Sahara, etc.) depending on quality (viscosity and sulfur content) and location, nearly all oil traded outside the USA and the Far East Asia is priced using Brent as a benchmark.[8] As OPEC is the main focus of our modeling, we utilize Brent oil prices.

During our study period the members of OPEC are Algeria, Iran, Iraq, Kuwait, Qatar, Saudi Arabia (the de facto leader), United Arab Emirates, Libya, Nigeria, Venezuela, Indonesia (was a member between 1962-2008, rejoined to the organization in 2016), Ecuador (was a member between 1973-1992, rejoined in 2007), Angola (became member in 2007). We take this entry and exit information into account in calculating OPEC's production. OPEC's mission is "to coordinate and unify the petroleum policies of its member countries and ensure the stabilization of oil markets, in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers, and a fair return on capital for those investing in the petroleum industry".[9]

Brent spot price is available at the US Energy Information Administration (EIA) website.[10] Reuters provides marginal production cost estimate for OPEC which is estimated to be between \$10 and \$17 per barrel in 2015. These estimates are based on a survey of banks, oil consultancies and independent analysts.[11] In our calibrations we assume three scenarios of marginal costs: low cost (=\$10/b), medium cost (=\$14/b), and high cost (=\$17/b) in 2015. Therefore, we account for

[7] The global financial crisis or known as 2008 financial crisis is considered by many economists to have been the worst financial crisis since the Great Depression of 1930s (source: Wikipedia.org). Because the major shocks (such as bank bailouts, housing market crashes, firm bankruptcies) hit the markets in mid-2008, and spread all over the world as a form of recession, we assume the periods of 2009-2014 as during/after the crisis.

[8] The oil traded in the USA is priced at the benchmark West Texas Intermediate (WTI).
[9] www.opec.org
[10] https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=M
[11] http://uk.reuters.com/article/opec-budget-idUKL6N0QL1VY20140815

different marginal costs in OPEC countries. We deflate each cost at the interest rate of 2%, which is a target CPI in several developed countries, to estimate marginal costs for the preceding years in the study period. Therefore, the marginal cost changes every year in the regressions.

The data for world and OPEC crude oil production including lease condensate (thousand barrels per day) comes from the US EIA. The world consumption data (demand for finished products) is obtained from JODI.[12] In Table 1 we present the descriptive statistics of price, marginal cost, production, demand, and market power indices for OPEC.

< Table 1>

4. Results

We aim to pinpoint how crude oil consumption behavior has changed during the economic crisis by measuring price elasticity of demand. In Table 2 we present the OLS estimation results for the model in (8) using OPEC's market power indices RSI and LI for the entire sample (2002-2014) and subsamples covering the periods of before the economic crisis (2002-2008) and during the crisis (2009-2014). We report our estimates of demand responses to crude oil price changes over a range of OPEC weighted marginal cost of production. The low cost estimate corresponds to \$10/b marginal cost (which is denoted LI1 in the table), the high cost estimate corresponds to \$17/b (denoted LI3), and the medium cost reflects \$14/b (denoted LI2) in 2015. Note that the marginal costs that are used in the LI computations change every period as a given marginal cost is deflated by the inflation rate for the remaining periods.

< Table 2>

The results in Table 2 demonstrate that all regression coefficients are significant, mainly with p values less than 0.01. The R-square is very high (0.82) for the entire sample indicating high explanatory power of the RSI for the LI. The F statistics are also high and significant. The number of monthly observations is almost symmetric before and during the economic crisis. The sign of the RSI coefficient $\hat{\beta}$ is always negative for all time intervals in all regressions, confirming the theoretical prediction in (7). This implies that as the RSI increases (i.e., non-

[12] https://www.jodidata.org/oil The JODI Oil World Database provides extensive data coverage including world demand for oil. Nevertheless, the US EIA only provides demand in the US and the OECD countries.

OPEC supply per market demand goes up) the price-cost markup decreases (i.e., OPEC's market power alleviates). The coefficient β in (8) represents an estimate of the influence of market structure (through consumption and market shares) on markups.

In expression (8) the relationship between the LI and the RSI captures OPEC's ability to exercise market power implied by the market power of non-OPEC countries whose productions along with market demand determine OPEC's profit margin. As both market power indices are correlated, the RSI which involves observable market outcomes can be used to measure the variation in OPEC markups and profits.

The RSI coefficient or the slope term $\hat{\beta}$ in Table 2 is in the range of (-2.38, -1.22) when the high marginal cost estimate (i.e., $17/b in 2015) is used in the LI computations: the lowest (in absolute value) is obtained during the economic crisis period, and the highest (in absolute value) is observed in the entire sample. Note that the inverse of beta corresponds to price elasticity in expression (8), which can be seen from (7). Before the economic crisis the estimate of beta is -2.28 and it is -1.22 during the crisis. The economic implication of this result is that crude oil price response has almost doubled, from -0.44 to -0.82, during the economic crisis, as the inverse of this slope gives rise to the price elasticity of demand estimation. We also report the elasticity estimates with standard errors in Table 3, and observe that these estimates are statistically significant. We also observe from Table 2 that the marginal impact of the RSI on the LI increases in the marginal costs. This implies that the decrease in OPEC's markup will be accompanied with larger increase in its RSI, implying lower residual demand for OPEC. Therefore, market power of OPEC alleviates as its marginal cost of production increases. Alternatively, the rise in production cost of OPEC will impact the market structure in favor of non-OPEC nations by increasing OPEC's RSI. Therefore, the higher the RSI for OPEC, the more competitive the crude oil market is.

< Table 3>

As reported in Table 3, because marginal costs impact prices in any competition model the price elasticity estimates are sensitive to marginal costs of production used to calculate OPEC's LI: for the entire sample (01.2002-12.2014) the elasticity estimation is equal to -0.715 with the low

OPEC marginal cost, -0.511 with the medium marginal cost, and -0.42 with the high marginal cost. Note that these elasticity estimates are congruent with the ones reported in the literature. Observe that the price elasticity figures before the global financial crisis (encompassing 01.2002-12.2008) are similar to the ones in the whole sample (of 01.2002-12.2014). However, they have increased during the crisis (covering 1.2009-12.2014). For any marginal cost of production level (either low, or medium, or high), the rate of change in price responsiveness is about %86.5 higher during the crisis. Moreover, the volatility (measured by standard deviation) of price response rates have increased tenfold. This acute change in demand response can be partially explained by the descriptive statistics in Table 1. Comparing before crisis figures to the ones during the crisis, Brent oil price has increased 75%, from $54.4 to $95.3, on average. Interestingly, demand for oil after the crisis has kept its increasing pace (raised about 12% relative to before the crisis level). To meet this demand increase world production has gone up about 5%. While developed countries have contracted after the crisis, the increase in demand for crude oil has been due to growth in China, India and other emerging countries. While OPEC production has increased after the crisis, its market power has improved: on average its LI has increased from 0.74 to 0.85 and its RSI has decreased from 0.62 to 0.57. All of these factors (increase in prices, consumption quantities, and OPEC market power) contribute to higher price responsiveness for crude oil consumption after the crisis. On top of that, the public consciousness on environmental issues, the rise of hybrid and electric cars, and the green energy investments could have contributed to create price responsive demand for crude oil.

To sum up, we find that price elasticity of demand for crude oil is inelastic (Table 3) and is in the range of [-0.755, -0.438] before the crisis for all marginal costs. This result is in line with the literature. The vitality of crude oil (products) for economies, given that it is the key input for production of almost all goods and has near zero substitutes, would result in low demand response to crude oil price changes. However, we find that the price response has almost doubled and tended to become almost elastic during the crisis. We argue that this high response rate would have been propelled by green energy initiatives and record high crude oil and gasoline prices. Furthermore, we quantify how a change in market structure (such as changes in marginal cost of production) would contribute to market power exercise (through the LI and the RSI) and have an ultimate impact on the consumption behavior.

5. Robustness Check

In this section we perform robustness check of our results by considering possibility of endogeneity between the LI and the RSI in expression (8). We suspect that the error term in (8) could be correlated with the RSI. The reason for a possible endogeneity issue is that the dependent variable (the LI) is a function of price, and so is the consumption which is captured by the right hand side variable (the RSI). If the endogeneity issue would be significant in (8), we would expect to obtain different elasticity estimations. Therefore, we will run a GMM regression with a valid instrumental variable and compare results to the OLS results reported in Table 2.

We initially search for several possible instrumental variables that do not influence the LI beyond the influence of the RSI. Some possible instruments are temperature, exports, and imports. In terms of temperature we have applied the world, the Northern Hemisphere, and the USA temperature (including national average, California and New York air temperature) data. We find that there is no significant correlation (less than 10%) between the RSI and the temperature. Therefore, it cannot be used as an instrument. When we have applied the US exports and imports data as a proxy for the world trade (assuming that oil is a major input for production), we obtain a high correlation (over 70%) between the RSI and the trade (for both exports and imports). Next, we run OLS regression between the RSI and the trade data, and obtain the residual. However, the correlation between this residual and the LI, the left hand side variable, is around 40%, which implies that the trade variable (either exports or imports) is not a valid instrument. We have also tried several combinations of trade and temperature data (involving combinations of exports, imports, temperature and temperature square) as instruments. Nevertheless the correlation between the residual and the LI was still high (27%). These results suggest that the candidate instruments are not valid. Next we have tried a lag of the RSI as a possible instrument. We find that the correlation between the RSI and one period lag of it is very high (95%). So, we run a regression between the RSI and a lag of it and obtain the residuals. Then, we measure the correlation between the residual term and the LI. The result is that these two terms are almost perpendicular: the correlation is about -0.09.[13] This suggests that one lag of RSI can be used as a valid instrument and this procedure (Hausman, 1978) justifies the orthogonality condition. We then use it in the GMM estimation to obtain robust coefficients for the regression incorporating the market power indices.

The GMM estimation results reported in Table 4 addresses whether we need to worry about a possible endogeneity issue in the expression (8). In the GMM regressions standard errors are calculated using HAC variance-covariance matrix.[14] The results in Table 4 demonstrate that almost all regression coefficients are highly significant mostly with p values less than 0.01. When we compare the OLS to GMM estimators we observe that the RSI coefficients in both regressions are negative and very close to each other. Only difference arises when the LI is computed based on the high marginal cost scenario (LI3). However, in this case the RSI coefficient is only significant at 10% level. Given that the coefficients are almost identical in both OLS and GMM regressions, we conclude that OLS results are as good as GMM results, and our elasticity estimates in Table 3 are robust.

<Table 4>

6. Concluding Remarks

Compared to previous studies which mainly considered reduced-form models for measuring price elasticity in oil markets, in this paper we offer a very simple and tractable method using a comprehensive approach incorporating economic fundamentals of oil markets along with the dominant role of OPEC in a competition framework. We offer some new demand elasticity estimates for crude oil during the recent economic crisis.

The importance of this work lies in an explicit consideration of the impact of the crisis on oil consumption behavior which directly impacts both oil importing countries and OPEC. The

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[13] We also tried several lags of the RSI combined with temperature data. However, the correlation coefficients between the error term and the LI were again in the same neighborhood. Therefore, one lag of RSI is sufficient.

[14] For all GMM regressions we use the Stata command "ivregress GMM" along with the option "wmatrix(hac nw opt)", where HAC lags and WMat Lags are chosen by the Newey-West method and the HAC VCE uses Bartlett kernel with the optimum lags. In all OLS estimations we use the option "vce(hc3)" to correct for the standard errors.

reflections of OPEC's decreasing influence on oil price formation coupled with its diminishing market share in the presence of supply glut caused mainly by new shale oil developments have significant economic and social consequences including their currencies, budgets, finances, investments, and social order for OPEC and other oil nations. On top of these issues, as we find out in this paper, the increasing demand response to crude oil prices (during the crisis) may become a new hurdle to oil producers.

This paper offers a new approach for estimating crude oil demand response to price changes. Unlike other methods proposed in the literature, this approach relies on market power indices of the Residual Supply Index and the Lerner Index. As we show these indices emerge as an equilibrium condition based on a quantity competition framework, in which OPEC is assumed to be the key producer of crude oil. In this equilibrium model, we do not impose behavioral restriction for non-OPEC nations, which can be treated fringe or strategic producers. There are several advantages of our approach. First, the elasticity estimates are based on an imperfect competition model (which is flexible enough to accommodate dominant producer with fringe or oligopolistic competition). Second, there is no need to specify the functional form of demand (and/or supply) curve(s) to measure price elasticity of demand. Third, one can easily employ data sets at any permissible data frequency (daily/weekly/monthly/yearly) to calculate the RSI and the LI for OPEC, whereas quarterly or yearly data has been commonly utilized in the literature. Fourth, we are able to quantify how a change in market structure (such as changes in marginal costs) would contribute to market power exercise and have an ultimate impact on price elasticity of demand for oil.

We offer a new definition of a market power index (the RSI) for oil industry and show that the LI and the RSI are relevant measures for crude oil markets. These indices are highly correlated and one can be utilized to estimate the other. Our regression results validate the negative relationship between the LI and the RSI predicted by the quantity competition model. Moreover, we estimate price elasticity of demand for crude oil using these indices and find that demand elasticities are mainly in the range of what is predicted in the literature. However, the price response rates are higher during the crisis period. Of course, the high price response rates would alleviate exercise of market power by OPEC and major oil producers. Our robustness check using the GMM estimation together with a valid instrumental variable indicates that our estimated demand response rates are robust: the rate at which consumers' ability to adjust their consumptions with respect to changes in oil prices is invariant to a choice of our estimation procedures.

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Table 1: Descriptive Statistics:

The statistics of average prices, quantities, and market power indices (standard deviation in parenthesis) in 2002-2014. Brent oil spot price FOB dollars; Using Reuters' estimation OPEC marginal cost is assumed to be medium level of $14/b in 2015, and it is discounted 2% for every past year.

	Brent oil spot price	OPEC marginal cost	World production	OPEC production	Demand	OPEC LI	OPEC RSI
All sample (2002-14)							
Mean	73.3	12.2	73,576	31,205	71,534	0.79	0.60
Stdev	(31.8)	(0.9)	(2,777)	(2,093)	(6,010)	(0.11)	(0.05)
Max	132.7	13.7	79,894	34,354	79,482	0.91	0.74
Min	19.4	10.8	66,288	25,152	55,422	0.44	0.54
Before the crisis (2002-08)							
Mean	54.4	11.5	71,987	30,299	67,825	0.74	0.62
Stdev	(27.0)	(0.5)	(2,514)	(2,410)	(5,804)	(0.11)	(0.06)
Max	132.7	12.2	75,085	34,354	74,524	0.91	0.74
Min	19.4	10.8	66,288	25,152	55,422	0.44	0.55
After the crisis (2009-14)							
Mean	95.3	13.1	75,431	32,262	75,860	0.85	0.57
Stdev	(21.0)	(0.4)	(1,723)	(821)	(2,054)	(0.04)	(0.01)
Max	125.5	13.7	79,894	33,955	79,482	0.90	0.61
Min	43.3	12.4	72,020	30,484	70,355	0.71	0.54

Table 2: OLS regression results for the relation between LI and RSI: All series (01.2002-12.2014); Before the Economic Crisis (01.2002-12.2008); During the Economic Crisis (01.2009-12.2014). Using the low (\$10/b)=LI1, medium (\$14/b)=LI2, high (\$17/b)=LI3 marginal cost estimates by Reuters for OPEC's Lerner Index.

Model ($LI_{OPEC} \sim RSI_{OPEC}$)

	OLS Estimation				
	Constant	RSI	R^2	F	n
LI1 (01.2002-12.2014)	1.686***	-1.399***	0.815	613.48	156
	(0. 033)	*(0.0565)*			
LI1 (01.2002-12.2008)	1.644***	-1.342 ***	0.824	406.36	84
	(0.0406)	*(0.0666)*			
LI1 (01.2009-12.2014)	1.306***	-0.720**	0.134	9.94	72
	(0.128)	*(0.228)*			
LI2 01.2002-12.2014	1.960***	-1.959***	0.815	613.48	156
	(0.046)	*(0.079)*			
LI2 01.2002-12.2008	1.902***	-1.879***	0.824	406.36	84
	(0.057)	*(0.093)*			
LI2 01.2009-12.2014	1.428***	-1.008**	0.134	9.94	72
	(0.179)	*(0.3197)*			
LI3 01.2002-12.2014	2.166***	-2.379***	0.815	613.48	156
	(0.056)	*(0.096)*			
LI3 01.2002-12.2008	2.095***	-2.281***	0.824	406.36	84
	(0.069)	*(0.113)*			
LI3 01.2009-12.2014	1.520***	-1.224**	0.134	9.94	72
	(0.2176)	*(0.388)*			

Notes: 1) Standard errors are in parentheses. 2) Significance levels are ***p<0.01; ** p<=0.02. All regressions were run using Stata, and all standard errors were corrected for serial correlations with sufficient lags.

Table 3: Price Elasticity of Demand Estimates for Crude Oil: All series (01.2002-12.2014); Before the Economic Crisis (01.2002-12.2008); During the Economic Crisis (01.2009-12.2014). Using the low ($10/b), medium ($14/b), high ($17/b) marginal cost estimates by Reuters for OPEC.

	mc=10	**mc=14**	**mc=17**
01.2002-12.2014	-0.715***	-0.511***	-0.420***
	(0.029)	*(0.021)*	*(0.017)*
01.2002-12.2008	-0.745***	-0.532***	-0.438***
	(0.037)	*(0.026)*	*(0.022)*
01.2009-12.2014	-1.389**	-0.992**	-0.817**
	(0.439)	*(0.315)*	*(0.259)*

Notes: 1) Standard errors are in parentheses. 2) Significance levels are ***p<0.01; ** p<=0.02. All regressions were run using Stata, and all standard errors were corrected for serial correlations with sufficient lags.

Table 4: OLS regression results for the relation between LI and RSI: All series (01.2002-12.2014); Before the Economic Crisis (01.2002-12.2008); During the Economic Crisis (01.2009-12.2014). Using the low ($10/b)=LI1, medium ($14/b)=LI2, high ($17/b)=LI3 marginal cost estimates by Reuters for OPEC's Lerner Index. One period lag of RSI is instrumented for RSI.

	Model ($LI_{OPEC} \sim RSI_{OPEC}$)				
	GMM Estimation				
	Constant	RSI	R^2	Wald	n
LI1 (02.2002-12.2014)	1.721***	-1.457***	0.808	480	155
	(0. 040)	*(0.067)*			
LI1 (02.2002-12.2008)	1.674***	-1.389 ***	0.822	743	83
	(0.033)	*(0.051)*			
LI1 (01.2009-12.2014)	1.635***	-1.298*	0.05	3	72
	(0.411)	*(0.735)*			
LI2 02.2002-12.2014	2.009***	-2.040***	0.808	480	155
	(0.057)	*(0.093)*			
LI2 02.2002-12.2008	1.944***	-1.944***	0.822	743	83
	(0.046)	*(0.071)*			
LI2 01.2009-12.2014	1.889***	-1.817*	0.05	3	72
	(0.576)	*(1.028)*			
LI3 02.2002-12.2014	2.225***	-2.477***	0.808	480	155
	(0.069)	*(0.113)*			
LI3 02.2002-12.2008	2.146***	-2.361***	0.822	743	83
	(0.056)	*(0.087)*			
LI3 01.2009-12.2014	2.079***	-2.207*	0.05	3	72
	(0.699)	*(1.249)*			

Notes: 1) Standard errors are in parentheses. 2) Significance levels are ***p<0.01; ** p<=0.02,* p<=0.10. All regressions were run using Stata, and all standard errors were corrected for serial correlations with sufficient lags.