

The political economy of OPEC*

Gal Hochman[†] and David Zilberman[‡]

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Abstract

Building on the political economy literature, we develop a conceptual model and apply it to explain the OPEC pricing behavior. We model OPEC as a cartel-of-nations where politician use two instruments: production quotas and domestic fuel consumption subsidies. Our model explains the wedge between domestic fuel prices in OPEC countries and in the rest of the world. The empirical estimates show that when OPEC sets the production quotas it places similar weights on consumers and producers welfare. But when OPEC countries set the subsidies some countries place extra weight on consumer benefits from domestic fuel consumption. Our analysis suggests OPEC pricing behavior employs domestic cheap oil policies.

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[†]Energy Bioscience Institute — University of California Berkeley — Berkeley — CA — email:galh@berkeley.edu

[‡]Energy Bioscience Institute and department of Agriculture and Resource Economics — University of California Berkeley — Berkeley — CA — email:zilber11@berkeley.edu

1 Introduction

There is growing interest in the behavior of fuel markets as countries and the global community are establishing climate change and energy security policies. But to understand fuel markets, we need to understand the unique institutional setup that characterizes the oil industry. To this end, the Organization of Petroleum Exporting Countries (OPEC) is not a textbook cartel; it is not run by a group of profit-maximizing firms but by politicians who pursue political, as well as economic, objectives. In the paper we develop a model of OPEC as a cartel-of-nations, where pricing decisions are pursued to achieve political economic objectives. We estimate the weights given to consumers and producers interest in setting the international oil price and the prices of fuel in OPEC countries.

Our model tries to catch two stylized facts about OPEC countries: OPEC has monopoly power in international markets for crude oil, and consumers of gasoline and diesel in OPEC countries pay significantly lower price at the pump compared to the rest of the world. Whereas in 2006 average super gasoline prices in non-OPEC countries were 1.04 US\$ per liter, they averaged only 0.28 US\$ per liter in OPEC countries (Metschies et al., 2007). If OPEC was a one country, we can explain these stylized facts using the classical export tax model (Graaf, 1949-50; Johnson, 1953-54, among others), whereby an exporting country that has market power establishes policies that maximize its social welfare (see also Bhagwati et al. 1998 and references therein). The wedge between the domestic and the international price of oil, which is interpreted in the export tax model as a tax with the domestic price as a benchmark, can be interpreted as a subsidy with the international price as a benchmark, and which is more appropriate in the case of OPEC.

But OPEC is not one country but a group of countries, where OPEC determines certain parameters (production quotas and the average wedge) while OPEC member countries may decide to adjust their domestic fuel subsidies and deviate from the OPEC wide decision. Furthermore, recent studies (Grossman and Helpman, 1994 and 1995; Karp and perloff, 2002; Gawande and Krishna, 2003) suggest that policy is established within a political economic context where different groups have different weights. Thus, we develop a political economic framework for both the OPEC wide and the country-specific decisions – a framework where politicians may place extra weight on consumers in determining the wedge, reflecting the importance of cheap oil polices. These cheap oil policies are akin to cheap food policies, where governments subsidize domestic food consumption to achieve political stability and cheap labor (Lewis, 1955; Schultz, 1968; Johnson, 1975; among others).¹ We coin this framework the “production quota cum domestic fuel subsidy” (PQ-DFS) model. The PQ-DFS model results in a set of equations describing the OPEC pricing behavior, which are used to derive an empirical model that is used to test to what extent politician in OPEC countries place extra weight on consumer welfare when setting fuel policies, and if the political economy of subsidizing fuel consumption is different from that of the allocation of production quotas.

¹In addition to cheap food policies, food production is also substantially altered by export subsidies, a key factor in the failure of the WTO Ministerial Conference in Cancun in late 2003 (Peters 2006).

We assume that two forces affect the wedge: OPEC market power in international oil markets and the importance of domestic cheap oil policies in OPEC countries. Our analysis suggests that the smaller the absolute value of the demand elasticity of imports from OPEC, the larger is the wedge. The analysis also suggests that when similar weights are placed on domestic fuel consumption and on oil production, the PQ-DFS model results in outcomes similar to those derived under the export tax model. When, however, more weight is placed on domestic fuel consumption compared with oil production, the gap between the domestic and the world fuel price is larger than that observed under the standard export tax model. But if the domestic consumption in OPEC countries is very small, then the PQ-DFS model results in outcomes similar to those derived under the cartel-of-firm model. The PQ-DFS model suggests that the decision process leading to the domestic fuel subsidy enables OPEC members to deviate from the quota allocation rule and to accommodate the domestic political economic considerations.

In order to estimate the political economic parameters, we estimated the demand elasticity for fuel in and outside OPEC countries. We find that the elasticity of demand for oil imported from OPEC countries is -1.39, which suggests global demand elasticity of -0.62; an elasticity estimate that is consistent with the existing literature.² We also find that, on average, the demand elasticity for fuel in OPEC countries is -0.58. Finding that the elasticity of demand for fuel in individual OPEC countries is lower than the OPEC import demand elasticity allows to conclude that the wedge between fuel prices in OPEC countries and non-OPEC countries is not a result of third degree price discrimination, because a third degree price discriminating monopoly sets a higher price in the low elasticity region (the opposite of what we observe in reality).

Our empirical analysis shows that consumer surplus may have a larger impact than producers' surplus on the choice of domestic subsidies. Our analysis suggests that although, on average, OPEC countries place about 6% more weight on consumer surplus, in some countries the weight placed on consumer surplus is much larger (e.g., for the period 1993 to 2008 both Iran and Venezuela place more than 60% more weight on consumer surplus). However, under reasonable assumptions on user costs, equal weights are given to the domestic consumer welfare and oil producers profits in making choice of quotas. These conclusions are robust to alternative estimation techniques and to alternative control variables and instruments, and support the hypothesis that OPEC countries employ cheap oil policies.

Despite the enormous amount of research that followed the surge in oil prices during the 1970s and 1980s, OPEC's pricing behavior still elicits considerable puzzlement (Adelman, 1982; Moran, 1982; Teece, 1982; Griffin, 1985; Alhajji and Huettner, 2000a and 2000b, among others). Although the majority of the literature refers to OPEC as a profit-maximizing cartel, some argue that Saudi Arabia acts as the dominant producer (Mabro, 1996; Alhajji and Huettner, 2000a and 2000b). Changes in

²See Graham and Glaister (2002) for a comprehensive survey of existing price and income elasticity estimates.

oil prices during the 1970s are explained by changes in property rights, whereby control in OPEC countries shifted from private to public hands; namely, nationalizations occurred (Johany, 1979; Odell and Rosing, 1983). Other studies suggest political forces increased oil prices, which remained high because of capacity constraints in OPEC countries (Ezzati, 1976 and 1978; Salehi-Isfahani, 1987). Some have also argued that OPEC is a revenue-maximizing entity (e.g., Teece, 1982), or that it is driven mostly by political motives (e.g., Moran, 1982). We contribute to this literature by building on work dating back to the 1950s (Graaf, 1949-50; Johnson, 1953-54, among others) and proposing an alternative framework that integrates these alternative factors into a unified framework, namely, the PQ-DFS model, which will also enable us to evaluate the relative importance of the above-mentioned factors. Our unified framework, unlike the Grossman and Helpman (1994 and 1995) framework which was inspired by the Political Action Committees in the United States, assumes political economy considerations in OPEC countries may include pacifying the urban middle class by providing cheap fuels.³

We introduce a static framework that allows us to highlight the importance of monopoly power in the international oil market, explain the gap between fuel prices in oil-exporting and oil-importing countries, and test the model's predictions empirically. Nevertheless, the empirical results derived in the paper boil down to a decision rule that equates marginal benefits with marginal production and capital costs, which in a more elaborated dynamic model would be considered part of the user costs and which is emphasized in dynamic models viewing oil as a non-renewable resource (Pindyck, 1978; Grin and Teece, 1982, among others).

Section 2 presents the stylized facts that guide the assumptions leading to the PQ-DFS model, which is described in Section 3. We present the game that models the OPEC countries' fuel policy decisions in Section 4, and derive the equilibrium and its implications in Section 5. We, then, turn to the empirical model and begin by describing the data and its limitations (Section 6), followed by a description of the empirical model (Section 7) and the empirical analysis (Section 8). Policy implication, a discussion, and concluding remarks are given in Section 9.

2 OPEC pricing behavior in retrospect

We begin this section by arguing that OPEC is a large player in the international oil markets, and that the OPEC countries benefit substantially from oil exports. We then turn to domestic fuel consumption in OPEC countries, depict the gap between domestic and international fuel prices, and show that domestic consumption in OPEC countries has changed substantially since the inception of OPEC in September 1960.

³Mason and Polasky (2005) show that the benefits of cartel membership are related to the size of remaining reserves, and that if a country weighs consumer interests, and not just profits from the sale of petroleum, then the amount of annual consumption should be negatively related to membership.

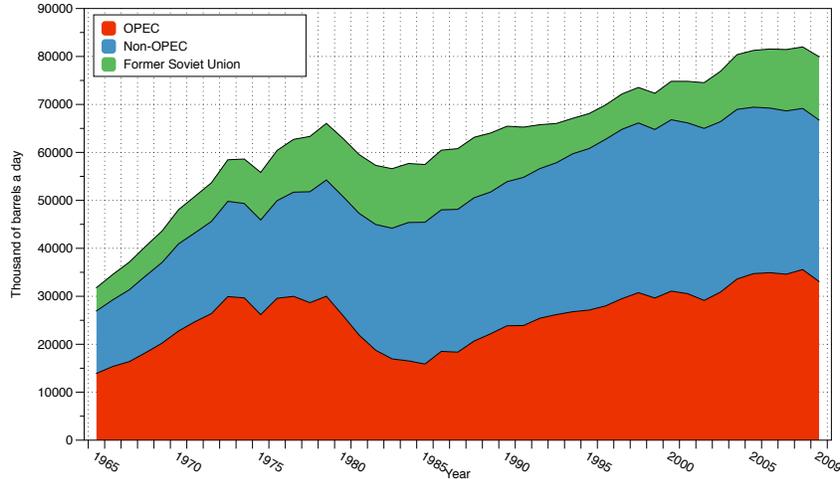


Figure 1: Crude oil extraction and production – OPEC, former Soviet Union, and the rest of the world

In what follows, we use the amount of crude oil produced and consumed to depict the various quantity trends but use crude oil, gasoline, and diesel prices to depict the various price trends. We analyze both oil and fuel prices, assuming simple rules of transition between the two, because of data limitations. We build on Bachmeier and Griffin (2003), who estimated an error-correction model with daily spot gasoline and crude-oil price data over the period 1985–1998 and found no evidence of asymmetry in the response of wholesale gasoline prices to changes in crude oil prices, and assume that gasoline prices respond symmetrically to changes in oil prices. We also build on the technical relation between crude oil and fuels, as described below in Section 6.

OPEC’s dominant position in the international oil markets is becoming more prominent over time. OPEC countries are rich in crude oil reserves, and their share of global proven reserves in 2009 amounted to 77.2%.⁴ Furthermore, OPEC extracted and produced roughly 45% of global crude oil production in 2008 (Fig. 1). At the same time, although the growth rate of oil consumption in the rest of the world has been on the rise, oil extraction and production has declined. The Energy Information Administration (EIA) predicts that although non-OPEC liquids supply grew by 630,000 barrels per day (bbl/d) in 2009, in 2010 the growth rate will probably be only 420,000 bbl/d, and that rate is likely to decline to 140,000 bbl/d in 2011. World liquids demand, on the other hand, are expected to grow by 2.55 million bbl/d between 2009 and 2011.⁵

The increase in global demand for crude oil from 2000 to 2008 led to a significant increase in the OPEC per capita oil export revenues (Fig. 2). Nevertheless, oil revenues benefited some countries more than others: although OPEC per capita oil export revenues in 2008 amounted to 2,378 US\$ (real 2005 US\$), it reached 36,060 US\$ in Qatar while only 446 US\$ in Nigeria. These revenue gains resulted from a rapid increase in the price of crude oil during the same period (Fig. 3). Although

⁴British Petroleum Statistical Review of World Energy 2010 (available at <http://www.bp.com/>).

⁵Available at <http://www.eia.doe.gov/>.

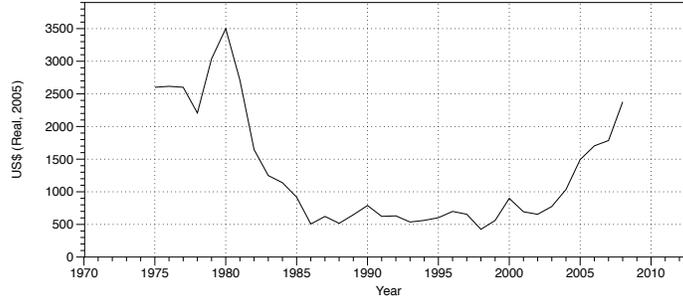


Figure 2: OPEC per capita oil export revenues

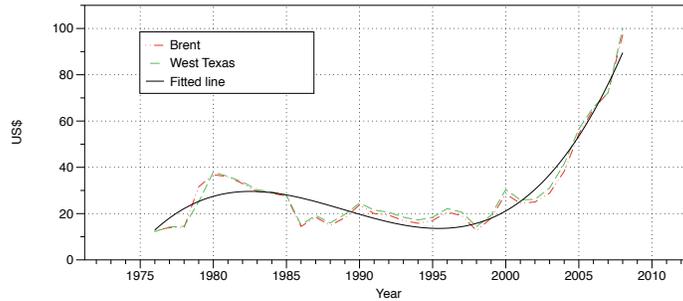


Figure 3: World oil prices

prices more than quadrupled, OPEC production during 1998-2010 increased by an average of only 0.6% a year and the exports grew by only 0.2% a year – suggesting a relatively inelastic supply curve.⁶

OPEC countries are thriving on oil export revenues but in many cases are (significantly) subsidizing domestic fuel consumption. Using data collected by Metschies et al. (2007), we computed the subsidy or tax equivalence levied on gasoline and diesel prices at the fuel pump. The concept of subsidization and taxation relates to a benchmark whereby fuel pricing is calculated with respect to world market prices and existing legislation. In this sense, subsidization (taxation) takes place when the actual pump price is below (above) the benchmark price. Since these benchmark prices are very difficult to calculate with precision, gasoline prices in Fig. 4 will be classified as subsidized (taxed) when they are below (above) the average US price-level, after deducting a highway tax of 10 US cents per liter on average. The subsidy or tax equivalence levied on gasoline prices at the fuel pump are depicted in Fig. 4, which illustrates that between 2002 and 2006 nominal subsidies in OPEC countries increased, while crude oil prices grew by more than 500% (Trostle, 2008) and gasoline prices in the rest of the world surged. A similar pattern can be depicted for diesel prices. During the surge in oil prices from 2000 to 2006, and in reaction to this surge, Saudi Arabia reduced its own fuel prices by 30% – officially out of benevolence to its own population (Metschies et al., 2007).

Figure 5 depicts gasoline and diesel prices both in OPEC countries and in the rest of the world.

⁶See EIA web site at <http://www.eia.doe.gov/>.

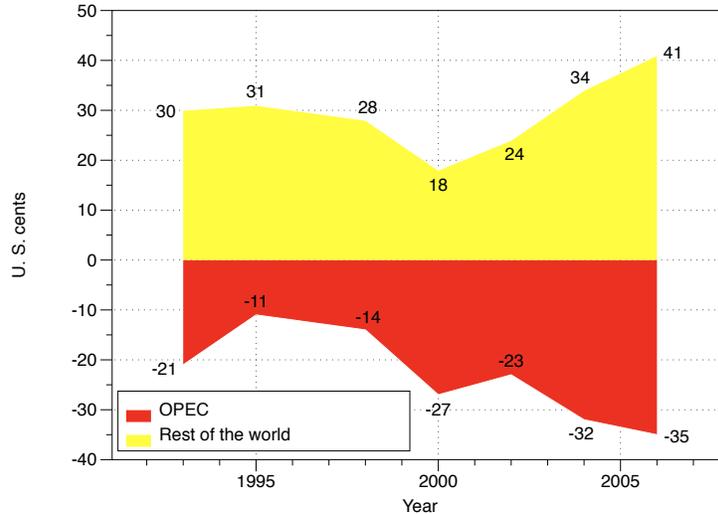


Figure 4: Subsidizing petroleum fuel consumption in OPEC countries

Although from 1993 to 2000 the gap between prices in OPEC countries and the rest of the world was stable, after 2000 the gap began to grow at an increasing rate (see Fig. 5). The popular press attributed the increase in oil prices in 2000 to the OPEC production cuts agreed upon in the OPEC ministerial meetings of March 1999. Alhajji and Huettner (2000a), on the other hand, argued that low oil prices in 1998 and early 1999 led to lower upstream investment and lack of maintenance. World oil production consequently declined and many oil fields suffered from severe technical problems, which, in turn, lowered production capacity.

Fuel consumption in OPEC countries has been increasing since the 1970s, in absolute terms (Fig. 6), as well as with respect to OPEC production (Fig. 7) and to world consumption (Fig. 8). At the beginning of the 1970s, consumption in OPEC with respect to OPEC production was about 5% but with respect to world consumption was less than 3%. During the 1990s when crude oil prices hovered between 10 and 20 US\$ the ratio of consumption to production (or to world consumption) was relatively stable at 15% (or 6%). From 2000 the ratio, however, did increase substantially as did crude oil prices. Oil revenues contributed significantly to disposable income in OPEC countries, which probably contributed to the increase in domestic fuel consumption in OPEC countries.

In sum, OPEC has monopoly power in international oil markets, and OPEC countries use domestic fuel subsidies to (significantly) reduce the domestic price of fuel. However, this domestic policy is used in some OPEC countries more than in others. Building on these empirical observations, we depict in the next section our PQ-DFS model and derive the implications to international oil markets from OPEC domestic fuel consumption.

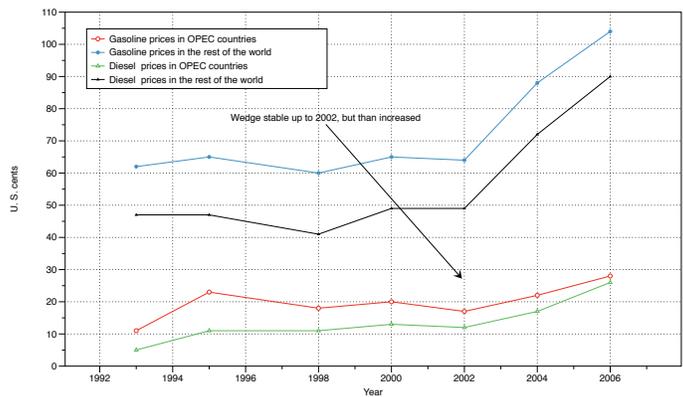


Figure 5: The gap between fuel prices in OPEC countries and in the rest of the world

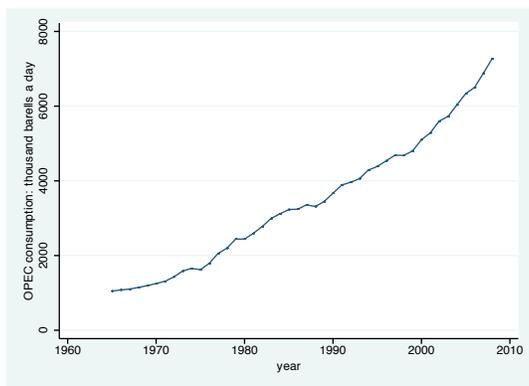


Figure 6: OPEC consumption

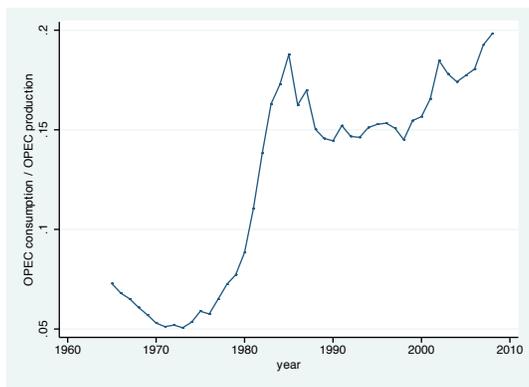


Figure 7: OPEC consumption relative to OPEC production

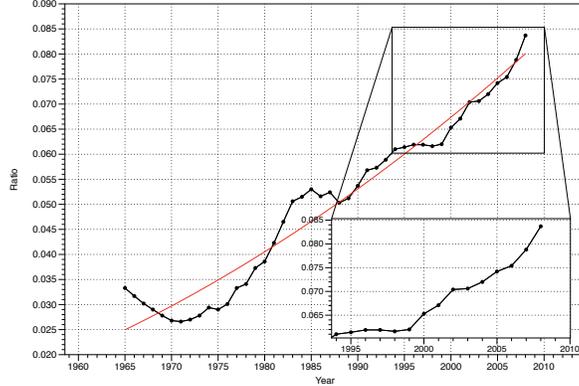


Figure 8: Oil consumption in selected OPEC countries (Algeria, Indonesia, Iran, Kuwait, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela) relative to the rest of the world

3 The production quota cum domestic fuel subsidy model

Many models have been developed to predict the OPEC pricing behavior and to model the world oil market based on the assumption that OPEC behaves like a profit-maximizing cartel.⁷ These models, however, could not explain the gap between fuel prices in OPEC countries and in the rest of the world. We now develop an alternative approach, using a theoretical static trade framework, and assume politicians (not firms) run OPEC.

We assume two types of countries, Home (h) and Foreign (f), and follow the convention used in the international trade literature whereby a country f 's variables are denoted with an asterisk (*) (Bagwell and Staiger, 2002). For tractability and without loss of generality and given that we want to explain the political economy of OPEC countries, we normalize the number of countries of type Foreign-but-not-Home to 1, and denote the country of type Foreign by F . In addition, we assume two products: fuel, denoted by subscript 1, and a numeraire good, denoted by subscript 0. These assumptions not only simplify the analysis but also enable us to focus on cheap fuel policies in OPEC countries.

Country $h \in \{1, \dots, H\}$ and country F are endowed, respectively, with L_h and L^* units of the numeraire good 0, where $L = \sum_h L_h$. We assume the country h produces q_h units of oil, with x_h units sold domestically and m_h units sold abroad (i.e., $q_h = x_h + m_h$), and we let $X = \sum_h x_h$, $M = \sum_h m_h$, and $Q = \sum_h q_h$. Country F , on the other hand, exports the numeraire good 0. For simplicity and without loss of generality, we assume that country F does not produce fuel. In principle, the model may allow country F to produce and import oil. Then, if the oil-importing country behaves

⁷This assumption was used in numerous studies on the international oil market that investigated OPEC's pricing behavior in a static framework (Adelman 1982; Gately, 1984; Griffin 1985; Loderer, 1985; Dahl and Yucel, 1991; Gulen, 1996; Griffin and Xiong 1997; Alhajji and Huettner, 2000a and 2000b; Horn, 2004, among others). All of those studies focused on the oil market, i.e., a partial equilibrium analysis, and asked whether the international price of crude oil was the cartel (monopoly) price. Moreover, all of those papers assumed oil is extracted by profit-maximizing firms but only Griffin (1985) found statistical support for the classic cartel-of-firms model.

competitively, country h 's decision should simply incorporate into the calculation the residual import demand of oil *net* of production in country F . We also assume balanced trade and that markets clear.

We normalize the population in each country to 1. Following the literature on the political economy of international trade (e.g., Grossman and Helpman 1994 and 1995), preferences for a consumer in country h are captured by the following quasi-linear utility:

$$U_h = c_{0h} + u_h(c_{1h}), \quad (1)$$

where c_{0h} denotes the numeraire good, c_{1h} denotes fuel, and where $\partial u_h / \partial c_{1h} > 0$ and $\partial^2 u_h / \partial c_{1h}^2 < 0$. We normalize the price of the numeraire good 0 to 1. Now, let p_{ch} denote the consumer price of fuel in country h , and let p^* denote the price of fuel in country F . The consumers' total expenditure (income) in country h is I_h . With these preferences and assumptions, country h 's per capita inverse demand equals $\partial u_h / \partial c_{1h}$. The consumer in country h devotes the remainder of his total expenditure to the numeraire good, i.e., $c_{0h} = I_h - p_{ch} \cdot c_{1h}$, thereby attaining an utility level of:

$$V_h = I_h + cs_h,$$

where $cs_h = u_h(c_{1h}(p_{ch})) - p_{ch} \cdot c_{1h}$ is the consumer surplus from fuel consumption and $CS = \sum_h cs_h$. In equilibrium, supply equals demand, i.e., $c_{1h} = x_h$ and $c_1^* = M$. We similarly define preferences in F ; namely, country F 's per capita inverse demand equals $\partial u^* / \partial c_1^*$, and $V^* = I^* + cs^*$.

Country h 's cost function is $tc_h(q_h)$. Its derivative, $mc_h = \partial tc_h / \partial q_h > 0$, is the marginal cost function of country h which is increasing in q_h , i.e., $\partial^2 tc_h / \partial q_h^2 > 0$. The cost function of a finite resource can also include components like user costs. Because the dynamic aspects of oil extractions are beyond the scope of this paper, we remain agnostic with respect to the different cost components. The oil cost function of OPEC as a whole is $TC(Q) = TC(X + M)$. Its derivative, $MC = \partial TC / \partial Q > 0$, is the marginal cost curve of OPEC and is increasing in Q , i.e., $\partial^2 TC / \partial Q^2 > 0$. We assumed that the aggregate quota, Q , is allocated efficiently among OPEC countries and not allow differences in mc_h among $h \in H$, i.e., in equilibrium $mc_h = MC$ for all $h \in H$. The reason is that we do not have data on differential costs of oil production among OPEC countries. Although other quota allocation rules may be assumed (each will result in a different aggregate cost function), we elected to choose an efficient one since it allows us to compare the PQ-DFS model's wedge with the wedge obtained under an optimal export tax model.

A key stylized fact guiding the analysis is that the domestic consumer prices in OPEC countries, p_{ch} for $h \in H$, are lower than the price paid by consumers in the oil-importing countries, p^* , and that domestic fuel prices vary among OPEC countries. This wedge, which equals $p^* - p_{ch}$, is the domestic fuel consumption subsidy in country h and can be decomposed into two elements: a common subsidy among OPEC countries, $p^* - MC$, and a country-specific differential subsidy, $MC - p_{ch}$. Because it

is more intuitive to carry out the conceptual, as well as the empirical analysis while employing the ad valorem subsidies, we define these subsidies next. That is, the difference between the international price and the price in country h is the ad valorem fuel subsidy sub_h to consumers in country h , (i.e., $sub_h = (p^* - p_{ch})/p^*$), which we decomposed to two elements: a *common ad valorem subsidy*, $\varphi = (p^* - MC)/p^*$, and a *differential ad valorem subsidy*, $s_h = (MC - p_{ch})/p^*$; in other words, $sub_h = (\varphi + s_h)$. Assuming that OPEC as a whole sets production quotas efficiently results in a common ad valorem subsidy, φ , which leads to a wedge between international prices and marginal costs, $MC = (1 - \varphi) \cdot p^*$. We gain by focusing on the common ad valorem subsidy because it allows us to estimate the elasticity of import demand from OPEC – a key parameter used in policy analysis – and to relate this elasticity to the difference between production costs and the world oil prices. Note that both the common ad valorem subsidy and the differential ad valorem subsidy are defined relative to the world price p^* .

Subsidizing domestic fuel results in lower prices and more consumption domestically, but less oil exports. When politicians in country h subsidize fuel and support the domestic price p_{ch} , they create a wedge between the international and the domestic price of fuel, i.e., $p^* - p_{ch} > 0$. Using the wedge, we define the subsidization cost as the forgone revenues from selling fuel domestically and not exporting it. That is, the ad valorem fuel subsidy generates a cost of

$$r_h^s = sub_h \cdot p^* \cdot x_h$$

to country h , where $R^s = \sum_h r_h^s$ is the cost of subsidization for OPEC as a whole. The aggregate social welfare of the economy, W_h , is a function of the endowment (i.e., L_h), the nationalized oil firm's profits (i.e., $\pi_h = p^* \cdot q_h - tc_h(q_h)$), the cost of subsidization (i.e., r_h^s), and the monetary benefits from fuel consumption (i.e., cs_h):

$$W_h = L_h + \pi_h - r_h^s + cs_h.$$

We similarly define welfare in country F , given that country F has only one source of income: endowment L^* . In other words,

$$W^* = L^* + cs^*.$$

4 Modeling the OPEC decision process

Although, theoretically, large oil-consuming countries can exercise their monopsony power and impact the international price of crude oil (for example, by levying an import tariff or quota), the reality is that most oil-consuming countries have a limited scope for adjusting oil supply or demand in the short to medium run, particularly as oil demand becomes increasingly concentrated in the transportation sector

(International Energy Agency, 2005)⁸ and the demand for oil in the light-duty vehicle sector becomes increasingly inelastic (Hughes et al., 2008).⁹ We thus maintain the assumption that oil-importing countries act competitively and do not exercise their market power. Our assumption follows the line of argument set forth in the literature on international trade, which assumes that countries that have market power establish policies that maximize their social welfare, taking the behavior of the rest of the world as a given. The optimal tariff literature is one branch of this literature; the literature on optimal export tax is another (see Bhagwati et al., 1998 and references therein).

We focus here on two instruments used by OPEC countries to achieve domestic cheap oil policies: production quotas and fuel consumption subsidies. Because we do not empirically observe a clear sequential decision process that results in domestic cheap oil policies, we assume that the decisions are made simultaneously. We assume an OPEC wide decision and a country specific decision. OPEC decision is about the production quota and the common ad valorem subsidy while the country specific decision is on the deviation from the common ad valorem subsidy – it is about the differential ad valorem subsidy.

When modeling the OPEC production allocation decisions, we focus on a focal equilibrium and assume politicians in countries $h \in H$ collectively design the production quotas to maximize the weighted sum of the producers and consumers welfare in the OPEC countries; that is,

$$Max_Q G = \sum_h W_h + \gamma_{OPEC} \cdot CS \quad (2)$$

given the differential subsidies in OPEC countries, i.e., $\{s_h\}_{h=1}^H$. Whereas the OPEC countries welfare is $\sum_h W_h = \sum_h U_h + p^*M - TC(Q)$. We assume that politicians weigh consumer surplus differently than they weigh oil producers' profits, and let γ_{OPEC} measure the extra weight they place on consumer surplus relative to the oil sector's welfare. If $\gamma_{OPEC} > 0$, then the politicians place additional weight on consumer surplus, whereas if $\gamma_{OPEC} < 0$, then politicians care more about the oil sector's profits. Furthermore, when politicians care only about the oil companies' profits, then $\gamma_{OPEC} = -1$, and we revert to the classic cartel-of-firms model without domestic cheap fuel policies. The estimated value of γ_{OPEC} can, therefore, be used to assess the plausibility of the alternative models.

Similarly, we assume that politicians, when setting the differential country-specific ad valorem fuel subsidies, weigh consumer surplus differently than they weigh oil producers' profits and revenue. Formally, let γ_h measure the extra weight politicians place on consumer surplus relative to the oil sector's welfare. That is, politicians in country h maximize

$$Max_{s_h} G_h = W_h + \gamma_h \cdot cs_h, \quad (3)$$

⁸Available at <http://www.iea.org/>.

⁹That said, Leiby (2007) calculates that the oil import premium is \$13.60 per barrel (in 2004 dollars) with a wide 90% confidence interval (\$6.70 - \$23.25).

by choosing non-cooperatively the differential country-specific ad valorem fuel subsidy s_h – they choose s_h given the allocation of production quotas, $\{q_h\}_{h=1}^H$, and thus the common ad valorem subsidy, φ , and given the differential country-specific ad valorem subsidies set by other OPEC countries, $\{s_j\}_{j \neq h}$. Although OPEC countries cooperate when deciding on the allocation of production quotas, domestic policy is subject to domestic scrutiny and may be viewed as a sign of sovereignty.

At the equilibrium: The solution to Eq. (2) will result in the optimal allocation of the production quotas given the level of the domestic fuel subsidies set by OPEC countries, and the solution to Eq. (3) will result in the optimal ad valorem fuel subsidy set by an OPEC country given the allocation of quotas among OPEC countries and given the subsidies set by other OPEC countries.

5 The equilibrium outcome and its implications

We derive and characterize the equilibrium, while assuming countries' endowments are large enough. We begin with the OPEC wide quota allocation decision (i.e., (2)) and then characterize the country-specific ad valorem subsidy decision (i.e., (3)). Beginning with the OPEC wide decision, we characterize the first order condition of the maximization problem (2) but also rewrite this condition to obtain an equation for the common ad valorem subsidy, φ . Next, we characterize the first order condition of the country h maximization problem (3), and use this latter condition to derive a relation between the international price of fuel, p^* , and the domestic price of fuel in country h , p_{ch} . When characterizing the equilibrium, the implications are discussed and the equilibrium outcome is contrasted with the outcome derived under the cartel-of-firms and the export tax models.

When modeling the OPEC wide decision, we assumed that OPEC as a whole solves (2) while taking domestic subsidies as given (Section 4). This optimization problem results in the following first order condition:

$$\frac{\partial TR}{\partial Q} + (1 + \gamma_{OPEC}) \cdot \frac{\partial CS}{\partial Q} = MC + \frac{\partial R^s}{\partial Q}, \quad (4)$$

where $TR = p^* \cdot Q$. Equation (4) is composed of four components, two that capture the marginal benefit from a small increase in aggregate production (left-hand side of Eq. (4)) and two that capture the marginal cost (right-hand side of Eq. (4)). The former includes the marginal revenue $\partial TR/\partial Q$ and the weighted marginal consumer surplus $(1 + \gamma_{OPEC}) \cdot \partial CS/\partial Q$. Whereas the latter includes the marginal production cost MC and the marginal subsidization cost $\partial R^s/\partial Q$. In contrast to the PQ-DFS model, the cartel-of-firms model suggests that at equilibrium the marginal revenue equals the marginal production cost, i.e., $\partial TR/\partial Q = MC$. On the other hand, if we employ the export tax model, then

$$\frac{\partial TR}{\partial Q} + \frac{\partial CS}{\partial Q} = MC + \frac{\partial R^s}{\partial Q}.$$

That is, domestic fuel consumers, as well as fuel producers, affect the OPEC pricing decisions. When compared to the export tax model, the PQ-DFS model enriches the OPEC pricing behavior and introduces the importance of domestic cheap oil policies. Furthermore, while the export tax model focuses on one country, the PQ-DFS model focuses on a group of countries.

We can further simplify the first order condition of (2), i.e., Eq. (4), and derive an equation that we use to estimate γ_{OPEC} ; i.e.,

$$\varphi = -\frac{1 - J_1}{\varepsilon^* + J_0} \quad (5)$$

where

$$\begin{aligned} J_0 &\equiv \gamma_{OPEC} \sum_h \frac{c_{1h}}{M} \text{ and} \\ J_1 &\equiv \sum_h \frac{c_{1h}}{M} \cdot (\varepsilon_h(c_{1h}, p_{ch}) \cdot s_h + \gamma_{OPEC} \cdot (1 - s_h)), \end{aligned}$$

and where $\varepsilon_h(z, y)$ denotes the elasticity of z with respect to y in country h and $\varepsilon^* = \frac{p^*}{M} \frac{\partial M}{\partial p^*} < 0$ denotes the elasticity of import demand from OPEC. Using Eq. (5), we can show that if OPEC *does not* place extra weight on domestic fuel consumption (i.e., $\gamma_{OPEC} = 0$) and there are no domestic fuel subsidies (i.e., $s_h = 0$ for all $h \in H$), then $J_0 = J_1 = 0$ and the common ad valorem subsidy φ is only a function of the OPEC market power; i.e.,

$$\varphi = -1/\varepsilon^*.$$

However, if there are no domestic subsidies but OPEC *does* place extra weight on domestic fuel consumption (i.e., $\gamma_{OPEC} > 0$), then $J_1 = J_0$,

$$\varphi = -\frac{1 - J_0}{\varepsilon^* + J_0},$$

and domestic cheap oil considerations affect φ through J_0 . Finally if, in addition to cheap oil considerations, we introduce domestic fuel subsidies (i.e., $s_h > 0$), then $J_1 \neq J_0$,

$$\varphi = -\frac{1 - J_1}{\varepsilon^* + J_0},$$

and domestic fuel subsidies, not only cheap oil considerations, affect φ .

Next, we discuss the implications from changes in the various factors that determine J_0 and J_1 on φ . We discuss the effect of a change in the extra weight placed on OPEC consumption, γ_{OPEC} , the demand elasticity in OPEC countries, $\varepsilon_h(c_{1h}, p_{ch})$, the import demand elasticity, ε^* , and domestic fuel subsidies, s_h , on the common ad valorem subsidy φ .

Proposition 1 *If the importance of cheap oil policies, measured by γ_{OPEC} , is sufficiently small (i.e.,*

if $0 < J_0 < -\varepsilon^*$ and $J_1 < 0$), then

- a decrease in the absolute value of the price elasticity of the import demand curve, i.e., ε^* , and
- an increase in the absolute value of the price elasticity of the domestic fuel demand, i.e., $\varepsilon_h(c_{1h}, p_{ch})$,

results in a larger common ad valorem subsidy, φ . If, in addition, the import demand is not too elastic, i.e., $-\varepsilon^* < 1/(1 - s_h)$, and the domestic demand for fuel in country h is sufficiently elastic, i.e., $\gamma_{OPEC} \cdot \frac{1-s_h}{s_h} < -\varepsilon_h(c_{1h}, p_{ch})$, then

- an increase in the extra weight placed on consumer surplus, γ_{OPEC} and
- an increase in the ratio of domestic fuel consumption to exports, i.e., c_{1h}/M , (caused by an increase in the differential ad valorem subsidy, i.e., s_h)

also results in a larger common ad valorem subsidy, φ .

According to Proposition 1, the OPEC monopoly power in international markets affects the optimal pricing rule, where a lower import demand elasticity in absolute value (i.e., $|\varepsilon^*|$ is smaller) results in a larger common ad valorem subsidy φ . While oil demand is becoming increasingly concentrated in the transportation sector (World Energy Outlook, 2005),¹⁰ and the demand for oil in the light-duty vehicle sector is becoming increasingly inelastic (Hughes et al., 2008), the wedge between prices in OPEC and non-OPEC countries is increasing.

Proposition 1 also states that, under certain conditions, an increase in the ratio of OPEC consumption to exports (i.e., $\Sigma_h c_h/M$) results in a larger common ad valorem subsidy φ . During the latest surge in both net oil export revenues and oil prices, which began in 2000 (see Fig. 2 and Fig. 3, respectively), we observed an increase of subsidies in OPEC countries together with an increase in c_h/m_h (Fig. 4 and Fig. 7, respectively).

Next, when modeling the country-specific decision, we assumed that an OPEC member country solves (3) while taking the allocation of the production quotas and the fuel subsidization in other OPEC countries as given (Section 4). This optimization problem results in the following first order condition:

$$q_h \cdot \frac{\partial p^*}{\partial s_h} + (1 + \gamma_h) \cdot \frac{\partial c s_h}{\partial s_h} = \frac{\partial r_h^s}{\partial s_h}. \quad (6)$$

Equation (6) suggests that politicians compare the gains from subsidizing domestic fuel consumption with the cost. Whereas an increase in the ad valorem subsidy makes the production quotas more

¹⁰Available at <http://www.iea.org/>.

valuable (i.e., $q_h \cdot \frac{\partial p^*}{\partial s_h}$) and increases the consumer surplus (i.e., $(1 + \gamma_h) \cdot \frac{\partial cs_h}{\partial s_h}$), it also increases the wedge and the associated cost of domestic fuel subsidization (i.e., $\frac{\partial r_h^*}{\partial s_h}$). We assumed that the quota is given when setting the differential ad valorem subsidy, and thus an increase in the ad valorem subsidy results in more domestic consumption, c_{1h} , but less exports, m_h . The increase in the ad valorem subsidy results in a gain to consumer surplus but a loss in revenues from oil exports.

In Appendix A we show that the first order conditions of (3), i.e., Eq. (6), can be further simplified and rewritten as

$$p^* = \frac{(1 - \Gamma_c)}{(1 + \Gamma_m)} \cdot p_{ch}, \quad (7)$$

where

$$\begin{aligned} \Gamma_c &\equiv \frac{\gamma_h}{\varepsilon_h(c_{1h}, p_{ch})} < 0 \text{ and} \\ \Gamma_m &\equiv \frac{1}{\varepsilon_h(m_h, p^*)}, \end{aligned}$$

and where

$$\varepsilon_h(m_h, p^*) = \frac{\partial m_h}{\partial p^*} \frac{p^*}{m_h} = \frac{\partial m_h}{\partial M} \frac{\partial M}{\partial p^*} \frac{p^*}{M} \frac{M}{m_h}$$

denotes the import response elasticity. If the relative allocation of exports among OPEC countries is constant and does not vary with the volume of exports, then the import response elasticity $\varepsilon_h(m_h, p^*)$ equals the import demand elasticity ε^* ; that is, if $\partial m_h / \partial M = m_h / M$ then $\varepsilon_h(m_h, p^*) = \varepsilon^*$ for all $h \in H$. Furthermore, if $|\varepsilon_h(m_h, p^*)| > 1$ then $(1 + \Gamma_m) > 0$ and thus $(1 - \Gamma_c) / (1 + \Gamma_m) > 0$. We use Eq. (7) to derive an estimate for γ_h .

Equation (7) implies, while using $p_{ch} = (1 - sub_h) \cdot p^*$, that the ad valorem fuel subsidy is

$$sub_h = \frac{-\Gamma_m - \Gamma_c}{1 - \Gamma_c}.$$

That is, if country h places equal weights on producers and consumers of fuel (i.e., $\gamma_h = 0$), then

$$sub_h = -\Gamma_m \text{ and } s_h = -\Gamma_m - \varphi.$$

If we also assume that $\partial m_h / \partial M = m_h / M$, then $s_h = 0$ and OPEC countries do not deviate from the OPEC wide decision. Otherwise, the domestic fuel subsidy is a function of both the inverse elasticity of the import response, Γ_m , and the weighted inverse domestic demand elasticity Γ_c (Eq. (5)), and the differential ad valorem subsidy is

$$s_h = -\frac{\Gamma_m + \Gamma_c}{1 - \Gamma_c} - \varphi.$$

Proposition 2 *The differential ad valorem subsidy, s_h , increases monotonically with the extra weight placed on domestic fuel consumption, i.e., γ_h . But it decreases monotonically with the absolute value*

of the elasticity of the domestic fuel demand, i.e., $|\varepsilon_h(c_{1h}, p_{ch})|$, and the absolute value of the import response elasticity, i.e., $|\varepsilon_h(m_h, p^*)|$.

If the extra weight is larger than 0, i.e., $\gamma_h > 0$, then country h deviates from the common subsidy and sets domestic fuel price that is lower than that implied by the OPEC wide decision, i.e., $sub_h = (p^* - p_{ch})/p^* > (p^* - MC)/p^*$ and $p_{ch} < MC$. An OPEC country consumes more fuel domestically but exports less oil than suggested by the OPEC wide decision. On the other hand, if $\gamma_h < 0$ then country h deviates from the common subsidy and sets higher domestic prices than implied by the OPEC wide decision, i.e., $sub_h = (p^* - p_{ch})/p^* < (p^* - MC)/p^*$. The country specific decision is on the deviation from the common subsidy and it adjusts the OPEC wide decision to the domestic political economy.

Next, we show how the PQ-DFS model compares with existing models. We begin by depicting conditions whereby the outcome of the PQ-DFS model is the one obtained under the export tax model:

Proposition 3 *OPEC sets the aggregate production quota, Q , such that the common ad valorem subsidy equals the optimal export tax (i.e., $\varphi = -\frac{1}{\varepsilon^*}$), when fuel consumption in OPEC countries equals zero (i.e., $c_{1h} = 0$ for all $h \in H$). Furthermore, if we assume country h 's share of total exports is constant (i.e., $\partial m_h / \partial M = m_h / M$ for all $h \in H$), then the ad valorem fuel subsidy equals the wedge obtained under the optimal export tax (i.e., $sub_h = -\frac{1}{\varepsilon^*}$) and the differential ad valorem subsidy equals zero (i.e., $s_h = 0$) if*

1. *there is no extra weight placed on fuel consumers at the country-specific level (i.e., $\gamma_h = 0$ for all $h \in H$)*
2. *and*
 - *there is no extra weight placed on fuel consumers at the OPEC wide level (i.e., $\gamma_{OPEC} = 0$),*
or
 - *fuel consumption in OPEC countries equals zero (i.e., $c_{1h} = 0$ for all $h \in H$).*

When OPEC decisions are limited to setting the production quotas that maximize aggregate welfare (no differential subsidies), then the common ad valorem subsidy defined above equals the optimal export tax, i.e., $\varphi = -\frac{1}{\varepsilon^*}$.¹¹ The only difference is in the interpretation: When the optimal export tax is derived, the reference price is the domestic price and the international price is the domestic price *plus* the export tax. When setting a production quota, on the other hand, the reference price is the international price and the domestic price is the international *minus* the common ad

¹¹Similar results are obtained in Grossman and Helpman (1995), when the government sets trade policy that maximizes aggregate welfare and does not place extra weight on the special interest groups.

valorem subsidy. The PQ-DFS model not only expands the cartel-of-firms model but also extends the export tax model by allowing OPEC to place different weights on the various groups when setting the aggregate quota.

Empirical papers on OPEC from the 1970s and 1980s (e.g., Griffin, 1985) concluded that OPEC is a cartel-of-firms while neglecting to incorporate into the analysis domestic fuel consumption in OPEC countries. But if the domestic consumption in OPEC countries is very small, as indeed was the case in the 1970s and 1980s, then the predictions derived in those papers can be replicated while employing the PQ-DFS model and the analysis done in this paper does not contradict the results obtained in those papers. Formally, if

- domestic demand in country h is inelastic, i.e., $\varepsilon_h(c_{1h}, p_{ch}) \rightarrow 0$, or
- consumption in country h is very small, i.e., $c_{1h} \rightarrow 0$, or
- demand in country F is very elastic, i.e., $\varepsilon^* \rightarrow \infty$,

then $\frac{dp^*}{ds_h} \rightarrow 0$ (see Appendix B). This suggests that if domestic demand in OPEC countries is very inelastic, i.e., large changes in prices result in very small changes in quantities, then it is reasonable to assume that domestic fuel subsidies in OPEC countries do not affect world fuel prices. However, as argued in the Introduction and in Section 2, and as our empirical estimates validate, these conditions do not capture the real world in which OPEC countries set both production quotas *and* domestic fuel subsidies. But if fuel consumption in OPEC countries is very low, then the link between the domestic fuel subsidy and OPEC pricing behavior is of little importance. This was true in the 1970s (see Figures 6, 7, and 8), where empirical work on OPEC concluded that OPEC is a cartel-of-firms (e.g., Griffin, 1985). However, it is not true in the 21st century, where consumption in OPEC countries amounts to more than 20% of the amount OPEC produces and to almost 10% of world consumption.

Building on the PQ-DFS model developed above, we derive an empirical model which we then estimate. We estimate the demand elasticities, and then use these estimates together with the estimated subsidy equation parameter (which builds on Eq. (7)) to compute the extra weight placed on consumers when setting domestic fuel subsidies. Finally, we use the quota allocation rule derived above (which builds on Eq. (5)) to compute the weight placed on consumers when setting production quotas.

We begin the empirical analysis by describing the data and its limitations (Section 6). Then, we incorporate the data constraints into our empirical model (Section 7). The empirical findings are reported in Section 8, in which we also assess the validity of the alternative models discussed in the literature.

6 The data

We estimate the empirical model using data on annual quantities of crude oil taken from the British Petroleum Statistical Review.¹² Although we aim to explain differences in fuel prices among oil-exporting and oil-importing countries, we have global data only on oil production and consumption, but not on gasoline and diesel consumption. However, using data from the EIA website¹³ we can show that although crude oil is used to produce several products ranging from gasoline and diesel to asphalt and oil lubricants, 65% to 67% of every barrel of crude oil in the United States from 1993 to 2008 was allocated to the production of gasoline and diesel. These two products, characterized by relatively high profit margins compared with other crude products, are the main source of income of downstream refineries.¹⁴ This creates strong incentives for refineries to maximize the amount of gasoline and diesel produced from crude, an amount that is constrained by technology.¹⁵ We, therefore, assume a fixed-proportion relationship between crude oil and fossil fuel consumed, i.e., the quantities of fossil fuel consumed can be derived from the quantities of crude oil and the optimal quantity of fuel consumed determines the quantity of crude oil demanded.

Building on these assumptions, we construct the price and quantity data utilized to estimate the various parameters. When estimating the domestic fuel demand in OPEC countries the prices used are fuel prices at the pump (in constant 2005 US\$) taken from Metschies et al. (2007) and from the GTZ International Fuel Prices, 6th Edition.¹⁶ A barrel of crude oil yields 19.5 gallons of gasoline and 8.5 gallons of diesel, on average. This represents 67% of a barrel of crude oil, with the remaining volume used to produce kerosene-type jet fuel, liquefied refinery gases, still gas, coke, asphalt and road oil, and petrochemical feedstock.¹⁷ We use this ratio to convert barrels of crude oil to fuel consumed, and to compute the weighted average price of fuel at the pump, i.e., $p_{ch} = 19.5/28 \times \text{gasoline price} + 8.5/28 \times \text{diesel price}$.¹⁸ We focus on aggregate fuel consumption (gasoline and diesel) because we believe that both types of fuel affect demand for crude oil, and thus the composite model better captures the interactions between crude oil and the downstream fuel market. However, when estimating the import demand equation, the prices used are the OPEC Reference Basket prices. The reason is that official documentation on the OPEC website suggests OPEC Reference Basket prices guide OPEC's production ceiling decisions (i.e., quota allocation).

¹²Available at <http://www.bp.com/>

¹³See http://tonto.eia.doe.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_m.htm

¹⁴According to Tom Campbell, a commercial manager at BP, this ratio is used to approximate the highly valuable fuel content of crude oil.

¹⁵The evolution of the petroleum refinery industry is one in which the main objective of technological innovations, dating back to the 1940s, is to maximize the amount of gasoline and diesel produced from a barrel of crude oil. See, for example, Leffler (1985) and Jones and Pujado (2008).

¹⁶The data presented in these two sources is for 1993, 1995, 1998, 2000, 2002, 2004, 2006, and 2008.

¹⁷<http://www.txoga.org/articles/308/1/WHAT-A-BARREL-OF-CRUDE-OIL-MAKES>.

¹⁸Although we could adjust these weights using global data on refined fuels, with the objective of capturing changes in the composition of a barrel of crude oil over time (available from Oil & Gas), we elected to maintain the weights presented above, because the year-specific weights are computed based on global refining capacity (not only OPEC oil) and introducing these year-specific weights does not change the results much.

To estimate our empirical model we had to control for other effects, while correcting the estimation procedures for endogeneity problems. Thus, when estimating domestic demand in the OPEC countries we expanded our price and quantity data set to include OPEC-country-level data, i.e., purchasing power parity, electricity production from oil sources, and car ownership. When estimating the import demand, we included data on world GDP per capita, GDP per capita for developed countries and for emerging countries, GDP growth rates, OPEC capacity, OPEC production quotas, and OPEC reference basket price. The different variables and the sources used are summarized in Appendix C.

7 The empirical model

To understand the political economy of OPEC and to quantify the extra weight placed on consumer surplus when allocating production quotas and when setting domestic fuel subsidies, we assume constant elasticity of demand.¹⁹ Furthermore, to transition from the conceptual model discussed above to the empirical model estimated below, we introduced additive error terms and specified their distribution.

The empirical model used to estimate and compute the various parameters is composed of four equations: The domestic demand equation, the import demand equation, the subsidy equation, and the quota allocation equation. These equations are described below, starting with the domestic demand equation for fuel in country h , which is given by

$$\ln(p_{ch}) = \phi_0 - \phi_1 \cdot \ln(c_{1h}) + \Gamma_c Z_{c_h} + \varsigma_{Ch}. \quad (8)$$

The vector Z_{c_h} denotes the log of control variables such as GDP per capita (which controls for income) and purchasing power parity (which controls for real exchange rate fluctuations), and ς_{Ch} denotes the error term. We expect that the estimated parameters will be positive, i.e., $0 < \phi_0, \phi_1$, suggesting that prices decline with the quantity of fuel consumed and that the price elasticity in country $h \in H$, on average, is $\varepsilon^D = -1/\phi_1 < 0$.

The OPEC import demand equation is given by

$$\ln(M) = \beta_0 - \beta_1 \ln(p^*) + \Gamma_M Z_M + \varsigma_M, \quad (9)$$

where the vector Z_M denotes the log of the control variables such as world GDP per capita, and where ς_M denotes the error term. We expect that $0 < \beta_0, \beta_1$, suggesting that the price declines with the quantity and that the price elasticity in country F is $\varepsilon^* = -\beta_1 < 0$.

¹⁹Numerous papers set forth these assumptions, including Chakravorty et al. (1997) and Kaufmann et al. (2008).

If we assume $\partial m_h / \partial M = m_h / M$ then $\varepsilon_h(m_h, p^*) = \varepsilon^*$,²⁰ and we can estimate the extra weight placed on consumer surplus using the subsidy equation (Eq. (7)). Although the theory predicts differences among OPEC countries and preliminary analysis indeed supports this heterogeneity, we do not estimate the country-specific parameters since the number of observations per country is too small (less than 10) but assume $\gamma_h = \bar{\gamma}$ for all h and estimate Eq. (10) using instrumental variable techniques:

$$p^* = \kappa \cdot p_{ch} + \varsigma_{sh}. \quad (10)$$

This suggests that

$$\bar{\gamma} = \left(1 - \left(1 + \frac{1}{\varepsilon^*} \right) \cdot \frac{1}{\kappa} \right) \cdot \varepsilon^D.$$

An alternative to estimating the subsidy equation (i.e., Eq. 10) would be to use Eq. (7) and directly calculate the extra weight placed on the consumer surplus, i.e., calculate γ_h . Using the elasticity estimates of the import demand curve, ε^* , and of the domestic demand in an OPEC country, ε^D , as well as the average of the observed domestic fuel subsidy in an OPEC country, $\bar{s}ub_h$, we can calculate (not estimate) the extra weight placed on consumer surplus from fuel consumption; that is,

$$\gamma_h = \frac{\bar{s}ub_h + 1/\varepsilon^*}{1 - \bar{s}ub_h} \cdot |\varepsilon^D|. \quad (11)$$

The parameter γ_h determines the sign of the difference $\bar{s}ub_h + 1/\varepsilon^*$ (recall that $\varepsilon^* < 0$). Then, because we observe $\bar{s}ub_h$ not γ_h and because we estimated ε^* and ε^D , we can use Equation (11) to calculate γ_h , where if the observed ad valorem fuel subsidy $\bar{s}ub_h$ is larger than $|1/\varepsilon^*|$ then $\gamma_h > 0$.

Building on Eq. (5), while using the estimates for the demand elasticity derived below and the cost estimates listed in the EIA (2008), we employed non-linear estimation techniques and estimated the extra weight OPEC gives fuel consumers when allocating quotas; i.e., we estimated

$$\varphi = -\frac{A_1 - \gamma_{OPEC} \cdot A_2}{\varepsilon^* + \gamma_{OPEC} \cdot A_0}, \quad (12a)$$

where

$$A_0 = \sum_h \frac{c_{1h}}{M}, \quad (12b)$$

$$A_1 = 1 - \sum_h \frac{c_{1h}}{M} \cdot \varepsilon^D \cdot s_h, \text{ and} \quad (12c)$$

$$A_2 = \sum_h \frac{c_{1h}}{M} \cdot (1 - s_h) \quad (12d)$$

where the parameter estimated is γ_{OPEC} and where φ , (12b), (12c), and (12d) are calculated using

²⁰As implied by a constant elasticity structure, while assuming OPEC countries adhere to the production quota set at the OPEC ministerial meetings and that the OPEC countries production shares are very stable throughout the investigated period with quotas for most countries changing by less than 1%.

the data and the estimate of the domestic demand elasticity. The parameter ε^* is the estimate of the elasticity of the import demand from OPEC.

The fundamental requirement for consistency of least square estimators is that the error terms are unrelated to the regressors. However, the empirical model presented above is one in which price and quantity are determined jointly, suggesting that the error term embodies factors not explained by the regressors and that some of the unobserved factors that are captured by the error term may be correlated with the regressors. Thus, we resort to instrumental variable techniques, which introduce variables that are associated with the regressors but not with the error term. Furthermore, since raw data on prices and quantities taken over time may have an internal non-stationary structure, the data is tested for non-stationarity and de-trended when needed. We also convert all nominal variables to constant 2005 US\$.

Our set of equations relies on two different data sets. Whereas Eq. (9) is estimated using aggregate data at the OPEC level, Eqs. (8), (10), and (12) rely on country-level data. We thus apply techniques using limited information estimation methods, which ignore information contained in other equations.²¹ Focusing on two-stage least square (2SLS) techniques will enable us to compare our estimates to those obtained using limited information maximum likelihood (LIML) estimators, which are asymptotically equivalent to 2SLS but have different finite-sample properties – thus checking the robustness of our estimates. The difference between LIML and 2SLS in finite samples stems from the difference in the weights placed on instruments. These differences result in smaller biases under LIML, especially when the instruments are weak (Cameron and Trivedi, 2010).

8 The empirical analysis

The estimated parameters, and the steps taken to justify the estimation methods used, are presented next beginning with the domestic demand for fuel in an OPEC country (i.e., Eq. (8)) – see Table 3.

We added to Eq. (8) control variables that capture the income effect on demand for fuel, namely, GDP per capita in country h , and the value of money in OPEC countries measured by the purchasing power of country h . Additional control variables, which we introduced to control for other unobserved factors that are correlated with the regressors, include population and electricity production from oil. Furthermore, we use cost shifters such as production and quota variables to identify the demand equation's regressors.

²¹Although the system methods [e.g., three-stage least square (3SLS)] are asymptotically better, the advantage is not clear when the analysis is confined to a finite sample. The finite sample variation of the estimated covariance matrix is transmitted throughout the system, and may result in the 3SLS having a larger finite sample variance than that of the 2SLS or the LIML. In addition, the limited information methods not only limit the variation of the parameters in a finite sample, but also confine any structural problem in a particular equation to the equation in which it appears.

Test	Statistic	P-value
Durbin (score)	9.98	p=0.0016
Wu-Hausman	11.47	p=0.0025

Table 1: Durbin and Wu-Hausman tests for the domestic demand for fuel

Test	Statistic	P-value
Sargan (score)	0.92	p=0.34
Basman	0.73	p=0.39

Table 2: Testing for overidentification for the domestic demand for fuel in an OPEC country

The post estimation steps taken to justify the domestic demand parameters included testing for endogeneity using two alternative tests: the Durbin test and the Wu-Hausman test. We reject the null hypothesis, conclude that we have an endogeneity problem, and summarize the results in Table 5. However, even if the instrumental variables are consistent, they may be weak in which case the asymptotic theory provides a poor guide to actual finite-sample distribution (Davidson and MacKinnon, 2004). Here, we use Stock and Yogo’s (2005) methodology and apply two complementary test approaches. The first approach addresses the concern that the estimation bias of the instrumental variable estimators from the use of weak instruments can be large, sometimes even exceeding the bias of the OLS. The test statistic for this approach is the F-statistic for joint significance of instruments in the first-stage regression. The statistic was larger than the widely used rule of thumb of 10.00 (Staiger and Stock, 1997). The second approach addresses the concern that weak instruments can lead to size distortions of Wald tests performed on the parameters of finite samples. This latter approach uses Shea’s partial R^2 , which was larger than 0.5. Moreover, the pairwise correlation coefficients were larger than 0.6. We thus concluded that the instruments are not weak. We also tested for over-identification using the Sargan’s (1958) and Basman’s (1960) chi-squared tests, where a statistically significant test statistic indicates that the instruments may not be valid. The test statistic was not significant suggesting the instruments are valid, and the results are summarized in Table 2.

The domestic demand curve in an OPEC country, which was estimated using 2SLS techniques, suggests that, on average, the elasticity of domestic demand for fossil fuels used for transportation, electricity, and heat in OPEC countries is

$$\epsilon^D = \frac{1}{-1.72} = -0.58,$$

whereas the income elasticity is $0.68 = 1.18/1.72$.

These elasticities are consistent with estimations reported in the literature and result in both country level price and income elasticity below 1, in absolute value. To this end, Goodwin (1992)

Variables	OLS estimates	LIML estimates	2SLS estimates
Log of consumption	-0.5876 (0.3878)	-1.8031** (0.6042)	-1.7271** (0.5835)
Log of population	0.4637** (0.1397)	0.5733*** (0.1536)	0.5664*** (0.1505)
Log of electricity production from oil sources	-0.0898 (0.1275)	.2227 (0.1767)	.2031 (0.1713)
Log of GDP (constant 2005 US\$)	0.6390 (0.3280)	1.2151** (0.4065)	1.1791** (0.3960)
Log of PPP	-0.2590*** (0.0649)	-0.2556*** (0.0689)	-0.2558*** (0.0677)
Constant	-12.4176 (7.7847)	-28.3391** (10.0932)	-27.3433** (9.8114)
R^2	0.4903	0.2817	0.3070
Number of observations	30	30	30

^a The standard deviation are reported by the number in parenthesis. Let * denote $p < 0.05$, ** denote $p < 0.01$, and *** denote $p < 0.001$.

Table 3: The domestic demand for fuel in OPEC countries

computes in his review a simple mean value of 120 elasticity estimates of gasoline consumption with respect to fuel prices reported in the literature, which is equal -0.48. We must, however, be careful when making comparison with the literature. First, our focus is on OPEC countries, a set of oil-exporting countries that do not appear in most, if not all, studies. In these countries, large parts of the population receive free electricity that is partly produced from fuel. Although the Qatar government has limited the supply of free electricity to Qatar citizens since 1999, with payment required for consumption above a given threshold, electricity is still heavily subsidized. Second, we use biennial data, suggesting that we are estimating the long-run elasticities.

Next, we report the import demand parameters (Table 4); i.e., Eq. (9). Here, we begin by testing the data for unit-root using the augmented Dickey–Fuller test (Dickey and Fuller, 1979). Different from the data on the prices and the quantities in OPEC countries, when testing the data on the international prices and OPEC exports for a unit-root, we cannot reject the null hypothesis at a 1% significant level. We then generated the Trace statistic (Johansen, 1995) to determine the number of cointegrating equations, and cannot reject the null hypothesis at a 5% significant level that there are one or fewer cointegrating equations. Therefore, we used first differences of the international prices and quantities consumed. In addition, because, while using the Chow test, we identified a structural break in 1998, we introduced a dummy variable that equals 1 for the years 1999 to 2008 and 0 otherwise.

The ordinary least squares (OLS) estimators are consistent when the regressors are exogenous, and efficient in the class of linear unbiased estimators when the errors are homoscedastic and serially uncorrelated. Therefore, when testing to determine whether endogenous regressors in the model are in fact exogenous, while using the Durbin test (Durbin, 1954) and the Wu-Hausman test (Wu, 1973, and Hausman, 1978), and being unable to reject the null hypothesis that the regressors are exogenous

Variables	OLS estimates	LIML estimates	2SLS estimates
$\log(M_t) - \log(M_{t-1})$	-0.7028 [‡] (0.5814)	-0.5443 (0.6841)	-0.7042 [‡] (0.6636)
$\log(\text{World GDP}_t) - \log(\text{World GDP}_{t-1})$	2.0733 (3.6268)	1.9115 (3.6906)	2.1766 (3.6713)
$t \times$ dummy for 1999 to 2008 equals 1	6.761×10^{-5} (6.853×10^{-5})	$8.770 \times 10^{-5\dagger}$ (6.850×10^{-5})	$8.514 \times 10^{-5\dagger}$ (6.829×10^{-5})
Number of observations	25	18	18

^a The standard deviation are reported by the number in parenthesis. Let [‡] denote variables whose t-statistics is above 1.

^b The number of observations is affected by the data, including the instrumental variables.

Table 4: The domestic demand for fuel in OPEC countries

at a 1% significant level, we elected to report the OLS estimators (recall that the null hypothesis is that the variables are exogenous).

The import demand elasticity ε^* observed by OPEC equals $-1.39 = -1/0.72$.²² Then, following Hochman et al. (forthcoming) and assuming OPEC behave like a leading firm treating the rest of the world as a competitive fringe that takes the international fuel price as given and since in 2006 OPEC produces about 45 percent of world oil consumption (see also Hamilton 2009), the empirical model suggests a world demand elasticity of -0.62 ²³ which is within the range of medium- to long-run price elasticities reported in the literature (Cooper, 2003; Leiby, 2007). Furthermore, Sterner (1990) examines the pricing and consumption of gasoline in OECD countries reported in the literature and concludes that long-run price elasticity falls in the interval -0.65 to -1.0 and for income between 1.0 and 1.3. On the other hand, Ramanathan (1999) found that the long-run income elasticity of gasoline in India is quite high, at 2.68.

When comparing the elasticity of import demand from OPEC to the elasticity of domestic demand in OPEC countries, we conclude that cheap oil policies not third degree price discrimination predominate OPEC pricing decisions. The theory of third degree price discrimination suggests that prices vary by location and that prices are higher in locations with more inelastic demand curves. However, our empirical analysis suggests that, although $p^* > p_{ch}$, $0 < -\varepsilon_h(c_{1h}, p_{ch}) < -\varepsilon^*$.

We estimated the subsidy equation (i.e., Eq. (10)), while using OPEC production and OPEC quota variables as instruments for the international price, p^* .²⁴ The estimated parameter, κ , is then used to compute $\bar{\gamma}$:²⁵

$$\bar{\gamma} = 0.06$$

²²When estimating the import demand function using the West Texas intermediate, as opposed to the OPEC basket price, the elasticity equaled -2.08 . Moreover, due to a potential endogeneity problem we also estimated the elasticity obtained using 2SLS (i.e., -1.42) and LIML (i.e., -1.11).

²³Because the parameters are estimated using first differences, we might be under-estimating the long-run import demand elasticity.

²⁴Equation (10) was estimated using bi-yearly data on fuel prices in OPEC countries, from 1993 to 2008, while excluding Angola, Ecuador, Iraq, Libya, and Nigeria due to missing data.

²⁵Using instrumental variable methods that were extended to panel data, while taking first differences, we can show that $\bar{\gamma} = 0.32$.

Test	Statistic	P-value
Durbin (score)	9.45	p=0.0021
Wu-Hausman	10.74	p=0.0017

Table 5: Durbin and Wu-Hausman tests for the subsidy equation

Test	Statistic	P-value
Sargan (score)	1.935	p=0.164
Basman	1.933	p=0.165

Table 6: Testing for overidentification for the subsidy equation

In other words, the ruling party in an OPEC country places about 6% more weight on consumer welfare from fuel consumption, compared with producer welfare from oil production, when setting domestic ad valorem fuel subsidies. Given the import demand elasticity and the domestic demand elasticity, results in a 95% confidence interval for the $\bar{\gamma}$ parameter of $[-0.05, 0.16]$. Although we cannot reject the assumption that OPEC maximizes aggregate welfare, the t-statistic is larger than 1.²⁶

The post estimation steps taken to justify the subsidy parameters (i.e., Eq. (10)) included testing for endogeneity using two alternative tests: the Durbin test and the Wu-Hausman test. We reject the null hypothesis and summarize the results in Table 5. Next, we use Stock and Yogo’s (2005) methodology and apply two complementary test approaches to test if the instruments are weak. Under the first approach the statistic was larger than the widely used rule of thumb of 10.00 (Staiger and Stock, 1997). Under the second approach Shea’s partial R^2 was larger than 0.5. Moreover, the pairwise correlation coefficients were larger than 0.6. We thus concluded that the instruments are not weak. We also tested for over-identification using the Sargan’s (1958) and Basman’s (1960) chi-squared tests. The test statistic was not significant, and the results are summarized in Table 6.

Although our sample size does not permit us to estimate the extra weights placed on consumer surplus in the various OPEC countries, i.e., γ_h for $h \in H$, we have documented significant differences across countries. To this end, we compute (not estimate) the extra weight placed on consumers in the OPEC countries employing Eq. (11), while using data from 1993 to 2008. Because, while employing the Chow test we identified a structural break in 1998, we also reported the extra weight placed on consumers in the OPEC countries for two sub-samples: (i) 1993 to 1998 and (ii) 2000 to 2008. The results are summarized in Table 7.

The two OPEC “hawkish” countries, i.e., Iran and Venezuela, which usually advocate for smaller quotas compared to other OPEC member countries, are also the countries that place the largest weight on domestic fuel consumption when setting the domestic fuel subsidy. However, some of the OPEC

²⁶The OLS estimates predicted a larger weight placed on consumption of fuel (i.e., $\bar{\gamma} = 0.13$), and the $\bar{\gamma}$ was significantly larger than 0 at a 95% level.

countries place less weight on consumers, and the ad valorem fuel subsidy in those countries is less than $-1/\varepsilon^*$ (recall that under the optimal export tax model, the wedge equals $-1/\varepsilon^*$). Conceptually, when the extra weight placed on consumer surplus is positive (i.e., $\gamma_h > 0$), the ad valorem fuel subsidy is larger than the common subsidy (i.e., $sub_h > \varphi = 0.72$) and the differential ad valorem subsidy is positive (i.e., $s_h > 0$). On the other hand, when $\gamma_h < 0$, $sub_h < \varphi = 0.72$ and $s_h < 0$. (See Table 7.) Furthermore, when comparing the two sub-samples, as net export revenues from oil increased and the international price of oil spiked, more weight was given to consumers when setting domestic fuel subsidies (assuming no change in the import demand and the domestic fuel demand elasticities).

Although, on average, the extra weight placed by an OPEC country on domestic fuel consumption is 0.05 (recall that the average estimated weight was $\bar{\gamma} = 0.06$), some OPEC countries place a much higher weight on consumer surplus when setting domestic fuel subsidies but others favor the oil producers (Table 7). OPEC countries use the domestic fuel subsidies to deviate from the quota allocation rule set at the OPEC ministerial meetings, and to adjust the pattern of domestic consumption and exports to the domestic political economy.

In comparison, work that builds on Grossman and Helpman (1994) and is applied to the United States, suggests that when setting trade policy, governments place only a few extra percentage points on the interest groups' welfare compared with aggregate welfare (Goldberg and Maggi, 1999; Gawande and Bandyopadhyay, 2000). On the other hand, Branstetter and Feenstra (1999) examined trade and Foreign Direct Investment (FDI) in China, and found that the government places on consumer welfare only half the weight that it places on the welfare of state-owned enterprises.

The theory used to derive Eq. (12) predicts that a higher consumption to export ratio results in a higher domestic ad valorem fuel subsidy (i.e., a lower ratio of domestic fuel price to international price). While focusing on 2006, we calculated the ratio of domestic fuel prices to the international price for both gasoline and diesel (Table 8). The table also includes proven reserves and the ratio of consumption to exports for that year. The correlations between the ratio of domestic fuel prices to the international price and the ratio of consumption to exports, for both gasoline and diesel, are -0.54 and -0.48 , respectively.²⁷ That is, and in line with Eq. (12), a higher ratio of domestic to international price, and thus a lower ad valorem fuel subsidy, is negatively correlated with consumption to exports.

Although outside the scope of the paper, we also computed the correlation coefficient between proven reserves and the ratio of domestic fuel prices to the international price, for both gasoline and diesel. Here, we get -0.52 and -0.43 for gasoline and diesel, respectively.²⁸ This seems to suggest that OPEC countries view crude oil reserves as an endowment, and use this endowment to transfer

²⁷Data for 2006 available for Iran, Venezuela, Saudi Arabia, UAE, Algeria, Kuwait, and Qatar

²⁸Where now the list of countries included Angola, Libya, and Nigeria, in addition to the eight countries mentioned above (Iran, Venezuela, Saudi Arabia, UAE, Algeria, Kuwait, and Qatar).

Country	The period 1993 to 2008	The period 1993 to 1998	The period 2000 to 2008
The extra weight placed on consumer surplus (i.e., γ_h)			
Algeria	-0.24	-0.36	-0.03
Angola	-0.26	-0.43	-0.12
Indonesia	-0.21	-0.34	-0.07
Iran	1.08	0.23	1.68
Kuwait	-0.08	-0.28	0.03
Libya	0	-0.35	0.36
Nigeria	-0.09	0.11	-0.18
Qatar	-0.04	-0.28	0.33
SaudiArabia	-0.04	-0.19	0.09
UAE	-0.21	-0.35	-0.15
Venezuela	0.67	0.10	1.58
OPEC	0.05	-0.19	0.32
The ad valorem differential fuel subsidy (i.e., s_h)			
Algeria	-0.20	-0.45	-0.02
Angola	-0.22	-0.82	-0.08
Indonesia	-0.16	-0.40	-0.04
Iran	0.18	0.08	0.21
Kuwait	-0.04	-0.26	0.01
Libya	0	-0.42	0.11
Nigeria	-0.05	0.04	-0.12
Qatar	-0.02	-0.26	0.10
SaudiArabia	-0.02	-0.14	0.04
UAE	-0.16	-0.42	-0.10
Venezuela	0.15	0.04	0.20
OPEC	-0.03	-0.23	0.05
The common ad valorem subsidy φ			
	0.72	0.72	0.72

Table 7: Differences in γ_h and s_h

Country	Gasoline price (World price equals 53 cents per litter)	Diesel price (World price equals 59 cents per litter)	Proven reserves (Thousand million barrels)	exports/production
Indonesia	108%	75%	4.4	.
Angola	94%	61%	9	.
Algeria	60%	32%	12.3	0.15
Qatar	36%	32%	27.4	0.08
Nigeria	96%	112%	36.2	.
Libya	25%	22%	41.5	.
Venezuela	6%	3%	87.3	0.28
UAE	70%	90%	97.8	0.16
Kuwait	42%	36%	101.5	0.11
Iran	17%	5%	138.4	0.67
SaudiArabia	30%	12%	264.3	0.20

Table 8: Differences in prices and quantities

money to (fuel) consumers. Furthermore, if larger reserves suggest lower user costs (i.e., lower cost from extracting oil today as opposed to the future), then, all else being equal, we should observe more subsidization in those countries. We reached a similar conclusion when computing the correlation coefficient between the ratio of the domestic prices to the international price for gasoline and the country's production (-0.365) or the country's net oil export revenues (-0.404). We get similar outcomes for diesel: -0.359 and -0.397 , respectively.

Finally, using Eq. (12) and the cost estimates provided by the EIA (2008), we computed γ_{OPEC} . The EIA (2008) reports the lifting costs (also called production costs), which are the costs to operate and maintain existing production wells of oil and natural gas produced by those facilities, after the oil and natural gas reserve have been discovered. To this end, the highest value of the lifting costs reported in 2007 for a region that includes an OPEC country was in Africa and equaled 5.66 US\$.

The calculated γ_{OPEC} depends on the cost component used, and there are different degrees of support among studies to the extent to which the Hotelling Valuation Principle affects oil supply (e.g., Miller and Upton, 1985; Adelman and Watkins, 1995; Lin, 2009; Hamilton, 2009). Therefore, because in principle the cost of extraction and production of oil and fuel should incorporate these Hotelling rents, we choose three plausible costs for the analysis: (i) 5.66 US\$; (ii) $5.66 \times 1.125 = 6.368$ US\$; and (iii) $5.66 \times 1.25 = 7.075$ US\$. These costs generate three different values for γ_{OPEC} (Table 9), which suggest that if OPEC decisions are guided only by current costs, then we cannot reject the hypothesis that OPEC allocates production quotas so as to maximize the aggregate welfare of the OPEC countries.

To evaluate the robustness of our results, and different from the analysis done above, we estimated the MC in OPEC countries for the period of 1993 to 2004, assuming OPEC allocates production quotas so as to maximize the aggregate welfare of the OPEC countries. We assumed $\gamma_{OPEC} = 0$ and used the first order condition of (2) to estimate the MC . These estimates resulted in an average MC

Marginal cost	γ_{OPEC}	95% confidence interval
5.660	0.10	(-0.028, 0.229)
6.368	-0.24	(-0.394, -0.081)
7.075	-0.63	(-0.823, -0.433)

Table 9: The MC and three different values for γ_{OPEC}

of 5.63. That is, using the unit-cost reported by the EIA (2008) and assuming OPEC decisions are guided only by current costs suggests that OPEC maximizes aggregate welfare, whereas assuming that OPEC maximizes aggregate welfare results in MC estimates that are very similar to those reported by the EIA (2008).

9 Discussion and concluding remarks

The economic literature defines a cartel as a group of profit-maximizing firms that coordinate production decisions to maximize joint profits and collectively have large market shares. In this respect, OPEC indeed possesses market power. According to the Energy Information Administration (2007), OPEC produced 41 percent of world liquid supply (i.e., crude oil and liquefied natural gas) in 2004, whereby under plausible assumptions, 65 percent of the total increase in crude oil supply will, in future years, come from OPEC. A similar picture is revealed if, instead of production, proven reserves are examined. More than 900 billion barrels of crude oil, out of a total of 1317.4 billion barrels, are located in OPEC countries (Energy Information Administration, 2007). That said, the analysis presented in this paper illustrates how the PQ-DFS model better captures OPEC’s pricing behavior and how domestic fuel subsidies in OPEC countries affect OPEC’s exports.

In this paper, we developed a framework that captures OPEC’s decision process: the OPEC wide production decision and the country specific fuel subsidy decision. While the conceptual framework shows the implications from introducing domestic fuel subsidies into OPEC’s pricing behavior, the empirical model quantifies the importance of these policies and estimates the extra weight placed on consumer surplus in the OPEC countries. The analysis presented in this paper illustrates how, on average, the standard optimal export tax model (where governments maximize aggregate welfare) describes OPEC’s pricing behavior, and how political economic considerations lead to deviations that vary across countries. The analysis done in this paper supports the hypothesis that OPEC is not an “economic” cartel, but can be viewed as a “political” cartel among big oil-exporting countries; countries that, on average, set fuel policy to maximize aggregate welfare. OPEC’s evolution and durability can thus be explained by understanding the interests of countries, not firms.

World energy demand grew from 1980 to 2007 by 66% and in 2007 equaled 12,013 million ton of oil equivalent (IEA, 2009). Out of the total amount of energy demanded in 2007 34% was supplied using

oil. Furthermore, according to IEA (2008) “oil is the most vital source of energy and will remain so for many years to come, even under the most optimistic set of assumptions on technology development and deployment of alternative technology.” Oil is a commodity that is necessary to our way of life. But to understand the (long-run) price of oil, our analysis suggests that domestic consumption in OPEC countries needs to be incorporated into the analysis. And that an increase in the amount of oil consumed in OPEC countries not only leads to higher international oil prices but also increases the gap between fuel prices in OPEC and in non-OPEC countries.

The last two decades witnessed the emergence of alternatives to crude oil: unconventional oil and biomass. Whereas unconventional oil is projected to reach 5.5 million oil barrels a day by 2020 (i.e., about 5% of the global oil supply in 2008), biomass feedstock currently amount to about 5% of global fuel consumption. Because the OPEC response plays a significant role in determining the global effect of the introduction and expansion of alternatives to crude oil, and because the oil market structure is key to understanding and quantifying this role, our analysis suggests that to evaluate the economic and environmental impact of these various alternatives one should employ the cartel-of-nation model.

This paper is a first pass at assessing the OPEC pricing behavior using the cartel-of-nations model, while confronting data limitations. The analysis suggests that assessment of fuel markets requires quantitative modeling of the behavior of the oil sector, and that further conceptual and empirical analysis of OPEC behavior is needed to support and expand this line of research. As history suggests, the structure of oil and fuel markets may change as the power of OPEC and the composition of fuel supply change with the introduction of new alternative fuel sources. Thus, studies on the international oil and fuel markets need to be updated to detect changes in market structure and behavior as well as their implications on market, quantities, welfare, and the environment.

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10 Appendices

10.1 Appendix A

At equilibrium, the first-order condition of G_h (i.e., 3) with respect to s_h is

$$p_{ch} \frac{\partial c_{1h}}{\partial p_{ch}} \frac{dp_{ch}}{ds_h} + \left(p^* \frac{\partial m_h}{\partial p^*} + m_h \right) \frac{dp^*}{ds_h} - \gamma_h c_{1h} \frac{dp_{ch}}{ds_h} = 0. \quad (\text{B.1})$$

Next, we derive $\frac{dp_{ch}}{ds_h}$ using the market clearing conditions; that is, we total differentiate $c_{1h} + m_h - q_h = 0$ with respect to s_h (recalling that q_h is held fixed):

$$\frac{\partial c_{1h}}{\partial p_{ch}} \frac{dp_{ch}}{ds_h} + \frac{\partial m_h}{\partial p^*} \frac{dp^*}{ds_h} = 0 \quad (\text{B.2})$$

Now, while using Eq. (B.2), we can further simplify Eq. (B.1):

$$p^* - p_{ch} = \frac{p^*}{-\varepsilon_h(m_h, p^*)} + \frac{\gamma_h p_{ch}}{-\varepsilon_h(c_{1h}, p_{ch})} \text{ and } p^* = p_{ch} \frac{\left(1 - \frac{\gamma_h}{\varepsilon_h(c_{1h}, p_{ch})}\right)}{\left(1 + \frac{1}{\varepsilon_h(m_h, p^*)}\right)}. \quad (\text{B.3})$$

10.2 Appendix B

We apply the implicit function theorem to compute $\frac{dp^*}{ds_{ub_h}}$ using the market clearing condition:

$$\sum_h c_{1h}(p_{ch}(p^*, s_h)) + C_1^*(p^*) - Q = 0$$

By total differentiating the market clearing condition, we obtain

$$\left(\underbrace{\sum_h \frac{\partial c_{1h}}{\partial p_{ch}} (1 - sub_h) + \frac{\partial C_1^*}{\partial p^*}}_{\equiv \Delta}, -p^* \frac{\partial c_{1h}}{\partial p_{ch}} \right) \begin{pmatrix} dp^* \\ ds_{ub_h} \end{pmatrix} = 0 \quad (\text{A.1})$$

such that $\Delta < 0$. Therefore,

$$\frac{dp^*}{ds_{ub_h}} = -\frac{-p^* \frac{\partial c_{1h}}{\partial p_{ch}}}{\Delta} > 0$$

Eq. (A.1) can then be rewritten as

$$\left(\sum_h \frac{\partial c_{1h}}{\partial p_{ch}} (1 - sub_h) + \frac{\partial C_1^*}{\partial p^*}, -p^* \frac{\partial c_{1h}}{\partial p_{ch}} \right) \begin{pmatrix} dp^* \\ ds_{ub_h} \end{pmatrix} = 0$$

and

$$\begin{aligned} \frac{dp^*}{ds_{ub_h}} &= \frac{p^* \frac{\partial c_{1h}}{\partial p_{ch}}}{\sum_h \frac{\partial c_{1h}}{\partial p_{ch}} (1 - sub_h) + \frac{\partial C_1^*}{\partial p^*}} \\ &= \frac{\varepsilon_h(c_{1h}, p_{ch}) \frac{c_{1h}}{(1 - sub_h)}}{\sum_h \varepsilon_h(c_{1h}, p_{ch}) \frac{c_{1h}}{p^*} + \varepsilon^* \frac{C_1^*}{p^*}} > 0 \end{aligned}$$

Thus,

- if domestic demand in country h is inelastic, i.e., $\varepsilon_h(c_{1h}, p_{ch}) \rightarrow 0$,
- if consumption in country h is very small, i.e., $c_{1h} \rightarrow 0$, or
- if foreign demand in country F is very elastic, i.e., $\varepsilon^* \rightarrow \infty$,

then $\frac{dp^*}{ds_h} \rightarrow 0$.

10.3 Appendix C

Quantities and price data were complemented with the following variables:

1. OPEC capacity (supplied by Erik Kreil from the US Energy Information Administration).
2. The purchasing power parity. This measures the number of currency units required to buy a basket of goods that is equivalent to what can be bought with one currency unit of the base country (PENN 6.1).
3. OPEC country-level data on electricity production from oil sources, car ownership, and GDP per capita were taken from the World Development Indicators data set.
4. OPEC reference basket price was taken from OPEC's Annual Statistic Report.
5. World real GDP per capita was taken from the US Department of Agriculture Economic Research Services.