

A Structural Econometric Model of the Dynamic Game Between Petroleum Producers in the World Petroleum Market*

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Abstract

In this paper, we develop and estimate a structural econometric model of the dynamic game among petroleum-producing firms in the world petroleum market. Our model allows firms that are at least partially state-owned to have objectives other than profit maximization alone. We use the structural econometric model to analyze the effects of changes in OPEC membership, a ban on mergers, the privatization of state-owned oil companies, and demand shocks on the petroleum industry. Our modeling outcomes can be used to help inform decision-making and policy design. The results of our research will be of interest to academics, policy-makers, entrepreneurs, and business practitioners, including oil companies, alike.

JEL Codes: L71, L13, L78, Q41

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1 Introduction

Fossil fuels supply more than 80 percent of the energy consumed in the world (U.S. Energy Information Administration, 2013). Oil and natural gas provide a large share of energy consumption, and getting access to secure sources of oil and natural gas is of huge importance for any economy (Finley, 2012). The production and consumption of oil and natural gas raise concerns about climate change, fossil fuel price volatility, energy security, and possible fossil fuel scarcity.

In this paper, we develop and estimate a structural econometric model of the dynamic game among petroleum-producing firms in the world petroleum market. Our model allows firms that are at least partially state-owned to have objectives other than profit maximization alone. We apply this model to panel data on firm-level oil and gas exploration, development, production, mergers, acquisitions, and reserves along with data on oil and gas prices to study the behavior of the top 50 oil and natural gas producing companies in the world.

We then use the parameters estimated from our structural econometric model to simulate counterfactual scenarios to analyze the effects of changes in OPEC membership, a ban on mergers, the privatization of state-owned oil companies, and demand shocks on the petroleum industry.

There are several advantages to using a dynamic structural model to analyze the investment, production, merger, and acquisition decisions of petroleum-producing firms. First, unlike reduced-form models, a structural approach explicitly models the dynamics of these decisions. The production decisions of oil and gas producers are dynamic because petroleum is a nonrenewable resource; as a consequence, current extraction and production affect the availability of reserves for future extraction and production. The exploration, development, merger, and acquisition decisions of petroleum producers are dynamic because they are irreversible investments, because their payoffs are uncertain, and because petroleum producers

have leeway over the timing of these investment decisions. Since the profits from investment and production decisions depend on market conditions such as the oil price that vary stochastically over time, an individual firm operating in isolation that hopes to make dynamically optimal decisions would need to account for the option value to waiting before making these irreversible investments (Dixit and Pindyck, 1994).

A second advantage of our structural model of the dynamic game between petroleum producers is that it models the strategic nature of the decisions of petroleum-producing firms. Petroleum producers consider not only future market conditions but also their competitors' investment and production activities when making their current decisions. Since the production decisions of other firms affect the prices of oil and natural gas, and therefore affect a firm's current payoff from production, and since the investment and production decisions of other firms affect future values of state variables which affect a firm's future payoff from producing and investing, petroleum-producing firms must anticipate the production and investment strategies of other firms in order to make a dynamically optimal decision. As a consequence, there are strategic interactions between petroleum-producing firms. In addition, the uncertainty over the production and investment strategies of other firms is another reason there is an option value to waiting before investing (Dixit and Pindyck, 1994).

A third advantage of our structural model is that it enables us to estimate the effect of each state variable on the expected payoffs from exploration, development, production, merger, and acquisition decisions, and therefore enables us to estimate parameters that have direct economic interpretations. Our dynamic model accounts for the continuation value, which is the expected value of the value function next period. With the structural model we are able to estimate parameters in the payoffs from exploration, development, production, merger, and acquisition, since we are able to structurally model how the continuation values relate to the payoffs from each of these decisions.

A fourth advantage of our structural model is that we are able to model the interdepen-

dence of petroleum-producing firms' value functions. When one firm merges with or acquires another firm, the value of the other firm with which it merges or acquires is given by that other firm's value function, which is the present discounted value of the entire stream of per-period payoffs of that other firm, and which accounts for the options that that other firm has to explore, develop, produce, merge, and acquire. Thus, a firm's value function depends on the expected value of other firms with which it has the option to merge or acquire. As a consequence, the firms' value functions are interdependent.

A fifth advantage of our structural model is that we can use the parameter estimates from our structural model to simulate various counterfactual scenarios. We use our estimates to simulate counterfactual scenarios to analyze the effects of changes in OPEC membership, a ban on mergers, the privatization of state-owned oil companies, and demand shocks on the petroleum industry.

The results of our research will be of interest to academics, policy-makers, entrepreneurs, and business practitioners, including oil companies, alike. Our modeling outcomes can be used to help inform decision-making and policy design. This model will also help petroleum firms better respond to government policies, and will help policy-makers better design sustainable energy policies.

The balance of our paper proceeds as follows. Section 2 reviews the previous literature. Section 3 presents our structural econometric model. We describe our data in Section 4. We present our results in Section 5. Section 6 presents our counterfactual simulations. Section 7 concludes.

2 Literature Review

2.1 Models of the world petroleum market

We build on the empirical literature on the world petroleum market, much of which is from over three decades ago (Adelman, 1962; Kennedy, 1974; Nordhaus, 1980; Gately, 1984; Griffin, 1985; Lin, 2011; Espinasa et al., 2017). Cremer and Salehi-Isfahani (1991) provide a survey of models of the oil market. Many previous empirical studies of world petroleum market use a static model; one exception is Lin Lawell (2018). Unlike previous empirical studies of the petroleum market that use a static model, we estimate a dynamic model of the world petroleum market.

We also build on the literature analyzing strategic behavior in the world petroleum market, and particularly the behavior of OPEC (Griffin, 1985; Matutes, 1988; Golombek et al., 2014; Gulen, 1996; Farzin, 1985; Alhajji and Huettner, 2000a,b; Kaufmann et al., 2004; Almoguera et al., 2011; Fang et al., 2014; Hochman and Zilberman, 2015; Okullo and Reynès, 2016; Baumeister and Kilian, 2017; Genc, 2017; Lin Lawell, 2018; Asker et al., 2017; Ghodusi et al., 2017). For detailed background information on the world energy industry, see the classic text by Dahl (2015). For a detailed review of the literature on oil market modeling and OPEC's behavior, see Al-Qahtani et al. (2008).

Our dynamic model of oil production builds on the theoretical model of optimal nonrenewable resource extraction that was first examined by Hotelling (1931), and then expanded upon by many others (see e.g., Solow and Wan (1976); Hanson (1980); Pesaran (1990); Pindyck (1978, 1980); Farzin (1992, 1995); Young and Ryan (1996); Lin and Wagner (2007); Lin (2009b); Lin et al. (2009); Gao et al. (2009); Leighty and Lin (2012); Almansour and Insley (2016); Zhang and Lin Lawell (2017); Ghandi and Lin Lawell (2018a); Anderson et al. (2017); Brown et al. (2017)).

2.2 Models of mixed oligopoly and state-owned firms

The second strand of literature upon which we build is that on mixed oligopoly and state-owned firms. A mixed oligopoly is defined as an oligopolistic market structure with a relatively small number of firms for which the objective of at least one firm differs from that of other firms (de Fraja and Delbono, 1990), as opposed to a private oligopoly in which all firms have the objective of profit maximization. Usually in a mixed oligopoly there is a public firm competing with a multitude of profit-maximizing firms (Poyago-Theotoky, 2001). A market in which there are both private and public firms is then a mixed oligopoly because the firms owned by private agents aim to maximize profits, whereas the publicly owned firms are interested in optimizing social targets (de Fraja and Delbono, 1990).

de Fraja and Delbono (1989) study a situation in which private and public firms pursue different objectives and compete both using only market instruments. Fjell and Pal (1996) consider a mixed oligopoly model in which a state-owned public firm competes with both domestic and foreign private firms. White (1996) and Poyago-Theotoky (2001) analyze output subsidies in the presence of a mixed oligopoly. de Fraja and Valbonesi (2009) find that behavior which would be deemed anti-competitive for a profit maximizing oligopolist may be in line with the objective function of a public, welfare-maximizing supplier. Lutz and Pezzino (2010) show that mixed competition is always socially desirable compared to a private duopoly regardless of the type of competition in the short run and the equilibrium quality ranking. Bennett and La Manna (2012) find that whenever a mixed oligopoly is viable, then aggregate output, aggregate costs, and welfare are the same with and without the public firm. Haraguchi and Matsumura (2016) compare price and quantity competition in a mixed oligopoly in which one state-owned public firm competes against private firms.

In comparing private and state-owned oil firms, Ohene-Asare et al. (forthcoming) find that private oil companies outperform state-owned oil companies and that state-owned firms suffer from scale inefficiencies. Cabrales et al. (forthcoming) assess the impact of domestic

fuel subsidies and employment on the performance of national oil companies by developing a model that clarifies the trade-offs among non-commercial objectives and the market value, production, and reinvestment of national oil companies.

A related literature is that on the objectives of state-owned firms. Chen and Lin Lawell (2018) develop and estimate a random coefficients mixed oligopolistic differentiated products model to analyze supply, demand, and the effects of government policy in the Chinese automobile market. Their structural econometric model of a mixed oligopolistic differentiated products market allows different consumers to vary in how much they like different car characteristics on the demand side, and state-owned automobile companies to have different objectives than private automobile companies on the supply side.

Ghandi and Lin (2012) model the dynamically optimal oil production on Iran's offshore Soroosh and Nowrooz fields, which have been developed by Shell Exploration through a buy-back service contract. In particular, they examine the National Iranian Oil Company's (NIOC) actual and contractual oil production behavior and compare it to the production profile that would have been optimal under the conditions of the contract. They find that the contract's production profile is different from optimal production profile for most discount rates, and that the NIOC's actual production rates have not maximized profits.

2.3 Dynamic structural econometric models

Structural econometric models of dynamic behavior have been applied to bus engine replacement (Rust, 1987), nuclear power plant shutdown decisions (Rothwell and Rust, 1997), water management (Timmins, 2002), air conditioner purchase behavior Rapson (2014), wind turbine shutdowns and upgrades (Cook and Lin Lawell, 2018), copper mining decisions (Aguirregabiria and Luengo, 2016) long-term and short-term decision-making for disease control (Carroll et al., 2018a); supply chain externalities (Carroll et al., 2018b); agricultural productivity (Carroll et al., 2018c); and the spraying of pesticides (Sambucci et al., 2018).

Structural econometric models of dynamic games include the model developed by Pakes, Ostrovsky, and Berry (2007), which has been applied to the multi-stage investment timing game in offshore petroleum production (Lin, 2013), to ethanol investment decisions (Thome and Lin Lawell, 2018), and to the decision to wear and use glasses (Ma et al., 2018); and the model developed by Bajari et al. (2015), which has been applied to ethanol investment (Yi and Lin Lawell, 2018a,b). Structural econometric models of dynamic games have also been applied to fisheries (Huang and Smith, 2014), dynamic natural monopoly regulation (Lim and Yurukoglu, 2018), and Chinese shipbuilding (Kalouptsidi, forthcoming).

Lin (2013) develops and estimates a structural model of the multi-stage investment timing game in offshore petroleum production. When individual petroleum-producing firms make their exploration and development investment timing decisions, positive information externalities and negative extraction externalities may lead them to interact strategically with their neighbors. If they do occur, strategic interactions in petroleum production would lead to a loss in both firm profit and government royalty revenue. The possibility of strategic interactions thus poses a concern to policy-makers and affects the optimal government policy. Lin (2013) examines whether these inefficient strategic interactions take place on U.S. federal lands in the Gulf of Mexico. In particular, she analyzes whether a firm's production decisions and profits depend on the decisions of firms owning neighboring tracts of land. The empirical approach is to estimate a structural econometric model of the firms' multi-stage investment timing game. Lin (2009a) uses a reduced-form model to examine whether strategic interactions take place during petroleum exploration.

In this paper, we apply the structural econometric model of a dynamic game that was developed by Bajari, Benkard, and Levin (2007). This model has been applied to the cement industry (Ryan, 2012; Fowlie et al., 2016), to the production decisions of ethanol producers (Yi et al., 2018), to migration decisions (Rojas Valdes et al., 2018, 2017), to climate change policy (Zakerinia and Lin Lawell, 2018), and to the global market for solar panels (Gerarden,

2017).

Ryan (2012) uses a structural econometric model to measure the welfare costs of the 1990 Clean Air Act Amendments on the US Portland cement industry. Unlike typical static cost analyses, which ignore the sunk costs of entry and investment, Ryan (2012) explicitly accounts for the dynamic effects resulting from a change in the cost structure resulting from the regulation. His results show that the Clean Air Act Amendments increased the sunk costs of entry, which negatively affected potential entrants and partially benefited incumbents because of lower ex post competition. Fowlie et al. (2016) build on this structural econometric model to analyze market-based emissions regulation.

Yi, Lin Lawell, and Thome (2018) use a structural econometric model of a dynamic game to analyze the effect of government subsidies and the Renewable Fuel Standard (RFS) on the US ethanol industry. They use the estimated parameters to evaluate three different types of subsidy: a production subsidy, an investment subsidy, and an entry subsidy, each with and without the RFS. While conventional wisdom and some of the previous literature favor production subsidies over investment subsidies, and while historically the federal government has used production subsidies to support ethanol, their results show that, for the ethanol industry, investment subsidies and entry subsidies are more cost-effective than production subsidies for inducing investment that otherwise would not have occurred.

3 Methodology

We model the dynamic game among the top 50 petroleum producers in the world. Each period, each petroleum producer decides how much oil and natural gas to produce; how much to spend on each type of capital expenditure (exploration, development, and acquisition); whether to acquire another firm or be acquired by another firm; and whether to merge with another firm. The actions a_i of each firm i are assumed to be functions of a set of state

variables and private information:

$$a_i = \sigma_i(s, \varepsilon_i), \quad (1)$$

where s is a vector of publicly observable state variables and ε_i is a vector of private information shocks to firm i which are not observed by either other firms or the econometrician.

We include the following firm-specific state variables: oil and natural gas reserves; cumulative oil and natural gas output; cumulative exploration, acquisition, and development expenditure; percentage of state ownership; whether the firm is a member of OPEC; whether the firm merged in the previous year; and whether the firm acquired another firm in the previous year. We include the following global state variables: average industry rate of return on capital for mining and quarry; average capital compensation on other machinery and equipment; world population; world GDP; world motor vehicles; world road sector gasoline fuel consumption; and world electricity production from oil and natural gas sources.

We model the oil market as a world market. The world demand for oil is given by:

$$\begin{aligned} Q_{oil} &= D_{oil}(p_{oil}) \\ &= \alpha_{10} + \alpha_{11}p_{oil} + X'_{oil}\alpha_{1x} + \nu_1, \end{aligned} \quad (2)$$

where Q_{oil} is world oil quantity; p_{oil} is world oil price; X_{oil} is a vector of demand shifters for world oil; and ν_1 is a shock to oil demand.

Unlike the oil market, the natural gas market is not necessarily a world market. Due to the lack of a global pipeline network, the market for natural gas is mostly defined by proximity to supply sources and the availability of a pipeline. We consider 6 separate regional markets r for natural gas: Africa; Asia and Oceania; Eurasia; Europe; the Middle East; and the Americas. The regional demand for natural gas in each region r is given by:

$$\begin{aligned}
 Q_{ng_r} &= D_{ng_r}(p_{ng_r}) \\
 &= \alpha_{20_r} + \alpha_{21_r} p_{ng_r} + X'_{ng_r} \alpha_{2x_r} + \nu_{2_r},
 \end{aligned} \tag{3}$$

where Q_{ng_r} is regional natural gas quantity for region r ; p_{ng_r} is regional natural gas price for region r ; X_{ng_r} is a vector of demand shifters for regional natural gas in region r ; and ν_{2_r} is a shock to regional natural gas demand in region r .

The prices of oil and natural gas are determined by the following inverse demand functions:

$$\begin{aligned}
 p_{oil} &= D_{oil}^{-1}(Q_{oil}) \\
 &= -\frac{\alpha_{10}}{\alpha_{11}} + \frac{1}{\alpha_{11}} Q_{oil} - \frac{1}{\alpha_{11}} X'_{oil} \alpha_{1x} - \frac{1}{\alpha_{11}} \nu_1
 \end{aligned} \tag{4}$$

$$\begin{aligned}
 p_{ng_r} &= D_{ng_r}^{-1}(Q_{ng_r}) \\
 &= -\frac{\alpha_{20_r}}{\alpha_{21_r}} + \frac{1}{\alpha_{21_r}} Q_{ng_r} - \frac{1}{\alpha_{21_r}} X'_{ng_r} \alpha_{2x_r} - \frac{1}{\alpha_{21_r}} \nu_{2_r}.
 \end{aligned} \tag{5}$$

We assume the costs of oil and natural gas production for each company i are given by the following production cost functions:

$$c_{i,oil}(q_{i,oil}, z_{i,oil}; \delta_{11}, \delta_{12}, \delta_{13}, \delta_{14}) = \delta_{11} q_{i,oil} + \delta_{12} q_{i,oil}^2 + \delta_{13} z_{i,oil} + \delta_{14} q_{i,oil} \cdot z_{i,oil} + \delta_{15} q_{i,oil} \cdot q_{i,ng} \tag{6}$$

$$c_{i,ng}(q_{i,ng}, z_{i,ng}; \delta_{21}, \delta_{22}, \delta_{23}, \delta_{24}) = \delta_{21} q_{i,ng} + \delta_{22} q_{i,ng}^2 + \delta_{23} z_{i,ng} + \delta_{24} q_{i,ng} \cdot z_{i,ng} + \delta_{25} q_{i,ng} \cdot q_{i,oil}, \tag{7}$$

where $q_{i,oil}$ and $q_{i,ng} = \sum_{r=1}^6 q_{i,ng_r}$ are firm i 's oil and natural gas production, respectively;

$z_{i,oil}$ and $z_{i,ng}$ are firm i 's oil and natural gas reserves, respectively; and δ_{11} , δ_{12} , δ_{13} , δ_{14} , δ_{21} , δ_{22} , δ_{23} , δ_{24} , and $\delta_5 \equiv (\delta_{15} + \delta_{25})$ are among the parameters θ to be estimated.

The per-period production profit $\bar{\pi}_i(s, a; \theta)$ for company i from the production of oil and natural gas is thus given by:

$$\begin{aligned} \bar{\pi}_i(s, a; \theta) &= \underbrace{\left(D_{oil}^{-1}(Q_{oil}) q_{i,oil} - \delta_{11} q_{i,oil} - \delta_{12} q_{i,oil}^2 - \delta_{13} z_{i,oil} - \delta_{14} q_{i,oil} \cdot z_{i,oil} - \delta_{15} q_{i,oil} \cdot q_{i,ng} \right)}_{\text{Profit from production of oil}} \\ &+ \underbrace{\left(\sum_{r=1}^6 D_{ng_r}^{-1}(Q_{ng_r}) q_{i,ng_r} - \delta_{21} q_{i,ng} - \delta_{22} q_{i,ng}^2 - \delta_{23} z_{i,ng} - \delta_{24} q_{i,ng} \cdot z_{i,ng} - \delta_{25} q_{i,ng} \cdot q_{i,oil} \right)}_{\text{Profit from production of natural gas}}. \end{aligned} \quad (8)$$

In addition to producing oil and natural gas, firms can invest in capital using three forms of capital expenditure: exploration, development, and acquisition capital expenditure.¹ Let x_i be the total capital expenditure of firm i , which is given by:

$$x_i = x_{i,exp} + x_{i,dvp} + x_{i,acq}, \quad (9)$$

where $x_{i,exp}$, $x_{i,dvp}$, and $x_{i,acq}$ are firm i 's exploration, development, and acquisition capital expenditures, respectively.

In addition to production and investment, petroleum-producing firms also make decisions about mergers and acquisitions. There are several possible reasons for mergers and acquisitions in the petroleum industry that are captured by our model. First, owing to nonlinearities with respect to both output and reserves in the production profit function in

¹Acquisition capital expenditures include expenditures for acquiring machinery and any other type of asset.

equation (8), oil and natural gas production may exhibit increasing or decreasing returns to scale, or both. As a consequence, firms may benefit from changing their scale via mergers and acquisitions. Second, there may be other synergies between firms as well, including cost synergies, knowledge synergies, organizational synergies, and management synergies. As we explain below, these additional synergies are captured in our policy functions and transition densities. Third, firms may benefit from any increase in market power as a result of a merger or acquisition. Market power motivations are captured in part by the inverse demand function and any resulting markup from market power. Fourth, some firms may be particularly well suited for mergers and acquisitions, as captured in our model by idiosyncratic private information shocks to the costs and benefits of mergers and acquisitions that firms receive.

Firm i 's payoffs $\Phi_i(s, a_i, \sigma_{-i}, \varepsilon_i; \theta)$ from mergers and/or acquisition are given by:

$$\Phi_i(s, a_i, \sigma_{-i}, \varepsilon_i; \theta) = \begin{cases} -\Gamma_i^B + EV_j(s; \sigma, \theta) \cdot \eta_1 & \text{if firm } i \text{ acquires firm } j \\ \Gamma_i^S & \text{if firm } i \text{ is acquired by firm } j \\ -\Lambda_i + EV_j(s; \sigma, \theta) \cdot \eta_2 & \text{if firms } i \text{ and } j \text{ merge into one firm,} \end{cases}$$

where σ_{-i} are the strategies played by all firms other than firm i ; Γ_i^B is the fixed cost to firm i of acquiring other firm; Γ_i^S is the fixed benefit to firm i of being acquired; Λ_i is the fixed cost to firm i of merging; and $EV_j(s; \sigma, \theta)$ is the expected value of the value function $V_j(s; \sigma, \theta)$ for firm j , which depends on the strategies σ played by all firms. Firm i 's idiosyncratic fixed payoffs Γ_i^B , Γ_i^S , and Λ_i of acquiring, being acquired, and merging, respectively, are private information to firm i , and are thus included in the vector ε_i of private information shocks to firm i .

Using the inverse demand for oil and natural gas given by equations (4) and (5), we calculate the consumer surplus from oil and natural gas consumption, respectively, as follows:

$$\begin{aligned}
 CS_{oil} &= \int_0^{Q_{oil}} D_{oil}^{-1}(x)dx - p_{oil}Q_{oil} \\
 &= \left(\frac{-\alpha_{10} - X'_{oil}\alpha_{1x} - \nu_1}{\alpha_{11}} \right) Q_{oil} + \frac{1}{2\alpha_{11}}Q_{oil}^2 - p_{oil}Q_{oil}
 \end{aligned} \tag{10}$$

$$\begin{aligned}
 CS_{ng_r} &= \int_0^{Q_{ng_r}} D_{ng_r}^{-1}(x)dx - p_{ng_r}Q_{ng_r} \\
 &= \left(\frac{-\alpha_{20_r} - X'_{ng_r}\alpha_{2x_r} - \nu_{2_r}}{\alpha_{21_r}} \right) Q_{ng_r} + \frac{1}{2\alpha_{21_r}}Q_{ng_r}^2 - p_{ng_r}Q_{ng_r}.
 \end{aligned} \tag{11}$$

Total consumer surplus from oil and natural gas consumption is therefore given by:

$$CS = CS_{oil} + \sum_{r=1}^6 CS_{ng_r}. \tag{12}$$

World consumer surplus is not the same as the consumer surplus faced by firms that are at least partially state-owned. We define the consumer surplus for oil faced by firm i as the world consumer surplus for oil times firm i 's oil production as a fraction of world oil production (where world oil production is total oil production over the top 50 firms).

For each natural gas region, we define consumer surplus for natural gas in that region faced by firm i as the world consumer surplus for natural gas in that region times firm i 's natural gas production in that region as a fraction of total natural gas production in the region (where total natural gas production in a region is the natural gas production in that region summed over the top 50 firms).

The consumer surplus CS_i faced by firm i is therefore given by the following weighted sum of the consumer surplus from oil and the consumer surplus from natural gas in each

region, where the weights are given by firm i 's respective share in the total production of oil and regional natural gas:

$$CS_i = CS_{oil} \frac{q_{i,oil}}{Q_{oil}} + \sum_{r=1}^6 CS_{ngr} \frac{q_{i,ngr}}{Q_{ngr}}. \quad (13)$$

We assume that private firms care solely about profit, while firms that are at least partially state-owned may put some weight on the consumer surplus faced by that firm as well.

The per-period payoff $\pi_i(s, a, \varepsilon_i; \theta)$ for each firm i is therefore as follows:

$$\begin{aligned} \pi_i(s, a, \varepsilon_i; \theta) = & \underbrace{\bar{\pi}_i(s, a; \theta)}_{\text{production profit}} + \omega_1 O_{i,state} + \omega_2 O_{i,OPEC} + \underbrace{\Phi_i(s, a_i, \sigma_{-i}, \varepsilon_i; \theta)}_{\text{M\&A}} - \underbrace{x_i}_{\text{capex}} + \\ & \rho_\pi O_{i,state} \bar{\pi}_i + \rho_{CS} O_{i,state} CS_i + \delta_0, \end{aligned} \quad (14)$$

where $O_{i,state}$ denotes the fraction of state ownership in firm i ; $O_{i,OPEC}$ denotes a dummy variable for whether firm i is an OPEC member; and δ_0 is a constant. We impose that for firms that are at least partially state-owned, the weights on production profit and consumer surplus add up to 1. We thus assume that $1 + \rho_\pi O_{i,state} + \rho_{CS} O_{i,state} = 1$, which implies that $\rho_{CS} = -\rho_\pi$.

Assuming the per-period payoff is linear in parameters θ , we can write the per-period payoff as the following:

$$\pi_i(s, a, \varepsilon_i; \theta) = \Psi_i(s, a, \varepsilon_i) \cdot \theta. \quad (15)$$

The expected present discounted value of the entire stream of profits for firm i is given

by the following value function $V_i(s; \sigma, \theta)$:

$$\begin{aligned}
 V_i(s; \sigma, \theta) &= \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \pi_i(s, a, \varepsilon_i; \theta) \right] \\
 &= \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \Psi_i(\sigma(s_t, \varepsilon_t), s_t, \varepsilon_{it}) \right] \cdot \theta \\
 &= W_i(s; \sigma) \cdot \theta,
 \end{aligned} \tag{16}$$

where the vector of terms W_i does not depend on the vector of parameters θ .

The value function $V_i(s; \sigma, \theta)$ can be expanded out into its constituent terms as follows:

$$\begin{aligned}
V_i(s; \sigma, \theta) = & \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t P_{t,oil}(s_{it}, Q_{t,oil}) \cdot q_{it,oil} \right] \\
& - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t q_{it,oil} \right] \cdot \delta_{11} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t q_{it,oil}^2 \right] \cdot \delta_{12} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t z_{it,oil} \right] \cdot \delta_{13} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t z_{it,oil} \cdot q_{it,oil} \right] \cdot \delta_{14} \\
& + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \sum_{r=1}^6 p_{ngr}(s, Q_{ngr}) q_{i,ng_r} \right] \\
& - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t q_{it,ng} \right] \cdot \delta_{21} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t q_{it,ng}^2 \right] \cdot \delta_{22} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t z_{it,ng} \right] \cdot \delta_{23} - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t z_{it,ng} \cdot q_{it,ng} \right] \cdot \delta_{24} \\
& - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t q_{it,oil} \cdot q_{it,ng} \right] \cdot \delta_5 \\
& + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} \right] \cdot \omega_1 + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,OPEC} \right] \cdot \omega_2 \\
& - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_M(s_{it}) \cdot (\lambda_1 p_M + \lambda_2 p_B^2 + \lambda_3 p_S^2 + \lambda_4 p_M^2) \right] + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_M(s_{it}) \cdot EV_j(s; \sigma, \theta) \right] \cdot \eta_1 \\
& - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_B(s_{it}) \cdot (\gamma_{11} p_B + \gamma_{12} p_B^2 + \gamma_{13} p_S^2 + \gamma_{14} p_M^2) \right] + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_B(s_{it}) \cdot EV_j(s; \sigma, \theta) \right] \cdot \eta_2 \\
& + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_S(s_{it}) \cdot (\gamma_{21} p_S + \gamma_{22} p_B^2 + \gamma_{23} p_S^2 + \gamma_{24} p_M^2) \right] - \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t x_{it} \right] + \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \right] \delta_0 \\
& - \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} P_{t,oil}(s_{it}, Q_{t,oil}) \cdot q_{it,oil} \right] + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} q_{it,oil} \right] \cdot \delta_{11} + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} q_{it,oil}^2 \right] \cdot \delta_{12} \\
& + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} z_{it,oil} \right] \cdot \delta_{13} + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} z_{it,oil} \cdot q_{it,oil} \right] \cdot \delta_{14} \\
& - \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} \sum_{r=1}^6 p_{ngr}(s, Q_{ngr}) q_{i,ng_r} \right] + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} q_{it,ng} \right] \cdot \delta_{21} + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} q_{it,ng}^2 \right] \cdot \delta_{22} \\
& + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} z_{it,ng} \right] \cdot \delta_{23} + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} z_{it,ng} \cdot q_{it,ng} \right] \cdot \delta_{24} + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t p_{it,oil} \cdot q_{it,ng} \right] \cdot \delta_5 \\
& + \rho_{CS} \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t O_{it,state} CS_{it} \right], \tag{17}
\end{aligned}$$

where p_B , p_S , and p_M are the probabilities of acquiring another firm, being acquired by another firm, and merging with another firm, respectively.

We assume that each firm optimizes its behavior conditional on the current state variables, other firms' strategies and its own private shocks, which results in a Markov perfect equilibrium (MPE). The optimal strategy $\sigma_i^*(s)$ for each firm i should therefore satisfy the

following condition that, for all state variables s and alternative strategies $\tilde{\sigma}_i(s)$, the optimal strategy $\sigma_i^*(s)$ yields an expected present discounted value of the entire stream of per-period payoffs at least as high as the expected present discounted value of the entire stream of per-period payoffs from any alternative strategy $\tilde{\sigma}_i(s)$:

$$V_i(s; \sigma_i^*(s), \sigma_{-i}, \theta, \varepsilon_i) \geq V_i(s; \tilde{\sigma}_i(s), \sigma_{-i}, \theta, \varepsilon_i). \quad (18)$$

In our dynamic game, a firm's decisions may depend on the decisions of other firms through several channels. First, aggregate output of oil and natural gas affect the prices of oil and natural gas faced by each firm; as a consequence, owing to market power, each firm's production decisions affect the prices faced by all firms. Second, aggregate output, aggregate reserves, and aggregate capital expenditures affect each firm's policy functions. Thus, each firm's decisions depend on the aggregate output and capital expenditure of all other firms, and on the aggregate reserves of all other firms. Third, aggregate output affects the transition densities for the global state variables. Thus, production decisions of each firm affect future values of the state variables, which then affect the payoffs and decisions of all firms.

There are several sources of uncertainty in our model of a dynamic game. First, future values of the state variables are stochastic. Second, each firm i receives private information shocks ε_i . Third, there are shocks to oil demand and regional natural gas demand. Fourth, merger and acquisition costs are private information to each firm i , and are not observed by either other firms or the econometrician.

In our transition densities for oil and natural gas reserves, we do not assume any fixed finite amount for the reserves. This is consistent with the common practice in the natural resource economics literature of modeling potential reserves as infinite; potential reserves are probably infinite, although the amount that is economical to extract is finite, and technolog-

ical progress and new discoveries will always make more reserves available and feasible for extraction (Farzin (1992); Lin (2009b)). Thus, for the transition densities for oil and natural gas reserves, we allow the distribution of reserves the next period to depend on the reserves, output, capital expenditures, state ownership, and merger and acquisitions this period, and we let the data tell us what the transition density is. Our econometric model allows for reserves to increase or decrease over time.

The structural parameters θ to be estimated include the parameters in the per-period payoff function; and the distributions of the fixed payoffs to merging, acquiring, and being acquired.

Finding a single equilibrium is computationally costly even for problems with a simple structure. In more complex problems – as in the case of our dynamic game between petroleum producers in the world petroleum market, where many agents and decisions are involved – the computational burden is even more important, particularly if there may be multiple equilibria. Bajari, Benkard, and Levin (2007) propose a method for recovering the dynamic parameters of the payoff function without having to compute any single equilibrium. The crucial mathematical assumption to be able to estimate the parameters in the payoff function is that, even when multiple equilibria are possible, the same equilibrium is always played.

We estimate the structural econometric model in two steps. In the first step, we characterize the equilibrium policy functions for the firms' decisions regarding exploration, development, production, merger, and acquisition as functions of state variables by using reduced-form regressions correlating actions to states. We also estimate the transition density for the state variables. We then calculate value functions using forward simulation following methods in Hotz et al. (1994) and Bajari, Benkard, and Levin (2007). In the second step, using the condition for a Markov perfect equilibrium in equation (18), we find the parameters θ that minimize any profitable deviations from the optimal policy as given by the policy functions estimated in the first step.

An innovation we make in our econometric method arises since a firm's own value function $V_i(s; \sigma, \theta)$ depends on the expected value of the value function $EV_j(s; \sigma, \theta)$ of other firms that the firm may acquire or with which the firm may merge. We address the endogeneity of value functions using a fixed point algorithm.

4 Data

We construct a panel data set on the top 50 oil and natural gas producing companies. The original source of data is the Petroleum Intelligence Weekly published by Energy Intelligence Group, which reports annual information on different operational criteria as well as financial and other measures of size for each of the top 50 oil and natural gas producing companies. This data set includes firm-level data on oil and natural gas output, oil and natural gas reserves, product sales, distillation capacity, revenue, net income, total assets, and percentage of state ownership. Each year, the top 50 firms are determined by production as reported in the Petroleum Intelligence Weekly.

The top 50 oil and natural gas producing firms in our data set supply a significant share of global supply of oil. As seen in Figure A.1 in Appendix A, on average over 70% of the global supply is produced by the top 50 oil and natural gas producing firms in our data set.

We use membership information from the Organization of Petroleum Exporting Countries (OPEC) to construct a dummy variable that takes the value of 1 for a firm if it is a state-owned company owned by an OPEC member country.

We obtain annual oil and natural gas prices from the U.S. Energy Information Administration. We obtain average hourly earning of workers in oil and gas extraction industry from the U.S. Bureau of Labor Statistics.

We also use data on financial indicators averaged over 10 OECD countries as reported in the EU KLEMS database. These indicators include industry rate of return on capital

in mining and quarry; average capital compensation on transport equipment in mining and quarry; average capital compensation on other machinery and equipment in mining and quarry; average capital compensation on total non-residential investment in mining and quarry; and average capital compensation on other assets in mining and quarry. Capital compensation is the price of capital times the quantity of capital, which under constant returns to scale is the value added minus labor compensation. We use capital compensation as our measure of capital costs, including costs of drilling rigs and production platforms, in the oil and gas industry.

We use data on world GDP, world population, world electricity production from oil and natural gas, world road sector fuel consumption, and world motor vehicle from the World Bank.

Unlike the oil market, the natural gas market is not necessarily a global market. Due to the lack of a global pipeline network, the market for natural gas is mostly defined by proximity to supply sources and the availability of a pipeline. In order to estimate separate natural gas demand functions for 6 different regional markets, we collect and construct regional natural gas prices using data from the EIA, and regional population and GDP data from the World Bank. Our 6 regional natural gas markets are the following:

- Africa: The share of global natural gas consumption from Africa is about 2.8%, the lowest share out of all our 6 regions. Africa is a net importer of natural gas. We use natural gas price data along with natural gas export and import data from Algeria, Egypt, Equatorial Guinea, Libya, Mozambique, and Nigeria to construct an average natural gas price for Africa.
- Asia and Oceania: This region accounts for just below 15% of the global natural gas consumption, and is a net importer of natural gas. We use natural gas price data along with natural gas export and import data from Australia, Brunei, Burma, China,

Indonesia, and Malaysia to construct an average natural gas price for Asia and Oceania.

- Eurasia: This region consumes over 20% of the global natural gas consumption and is home to a significant share of natural gas resources, which makes this region a net natural gas exporter. We use natural gas price data along with natural gas export and import data from Azerbaijan, Georgia, Kazakhstan, Russia, Turkmenistan, Ukraine, and Uzbekistan to construct an average natural gas price for Eurasia.
- Europe: EU countries consume about 20% of the global natural gas consumption with relatively small production, which makes them a net importer. Russia is the major supplier of EU natural gas imports. We use natural gas price data along with natural gas export and import data from EU members and Turkey to construct an average natural gas price for Europe.
- Middle East: The Middle East on average consumes just below 10% of the global natural gas consumption but it is home to a significant natural gas resources in the world, which makes the region a net exporter of natural gas. We use natural gas price data along with natural gas export and import data from Iran, Iraq, Oman, Qatar, UAE, and Yemen to construct an average natural gas price for the Middle East.
- Americas: The North and South America together consume about 32% of the global natural gas consumption, and aside from the insignificant liquefied natural gas imports from outside of the continent, it is disconnected from natural gas markets in other parts of the world. Over the last decade the North American natural gas market has been experiencing a boom as a result of the boost in shale gas extraction in the United States. We use natural gas price data along with natural gas export and import data from Canada, Mexico, United States, Argentina, Bolivia, Brazil, Colombia, Peru, and Trinidad and Tobago to construct an average natural gas price for the Americas.

Our data includes all acquisitions made by the top 50 firms, even if the firm being acquired by a top 50 firm was itself not among the top 50 firms. In addition, during the time period of our data set, any top 50 firms that were acquired were only ever acquired by other top 50 firms. We therefore observe and model all acquisition activity of the top 50 firms, even if the acquiree was not a top 50 firm.

During the time period of our data set, there were 3 mergers among the top 50 firms. Conoco and Phillips merge in 2000 to become ConocoPhillips. Exxon and Mobil merge in 1998 to become ExxonMobil. Sidanco and Tyumen Oil merge in 2002, after which they drop out of the top 50 firms.

While we do not observe and therefore do not explicitly model mergers between a top 50 firm and a firm that is not among the top 50 firms, we do observe and model the resulting effects of these unobserved mergers on the state variables (including reserves) and actions of the top 50 firm involved in the merger. In particular, unobserved mergers with non-top 50 firms are captured by the error terms in our policy functions and transition densities, and their effects on state variables and actions are therefore accounted for in our model. Although mergers with a firm that is not among the top 50 firms are not directly included in our per-period payoff function, but only indirectly through their effects on state variables and actions, this is justified by our assumption that, conditional on the state variables and actions we do observe, the expected value of the opportunity to merge with a non-top 50 firm is negligible relative to the other terms we include in the per-period payoff function, as the expected value of non-top 50 firms is smaller than those of top 50 firms, and, when weighted by the probability of merging with a non-top 50 firm, is even smaller still.

Summary statistics for the action variables, firm-level state variables, and price variables over the years 2000-2005 are presented in Tables 1 to 3; summary statistics for the same variables over the entire period of the data set are in Tables A.1 to A.3 in Appendix A. Summary statistics for the regional and global state variables are in Table 4.

5 Results

5.1 Oil demand

We use annual oil production data of the top 50 producers over the period 1987-2011 along with oil price data to estimate the oil demand equation (2).

Because observed equilibrium prices and quantities are simultaneously determined in the supply-and-demand system, instrumental variables are needed to address the endogeneity problem (Angrist et al., 2000; Goldberger, 1991; Lin, 2011; Manski, 1995). We instrument for oil price using either real average weekly earnings for support activities in oil and gas extraction or lagged real average weekly earnings for support activities in oil and gas extraction. These variables are supply shifters that affect the costs of producing oil but not demand for oil, and therefore serve as good instruments for oil price. The first-stage F-statistics are over 12 in both specifications of oil demand, and the instruments pass tests of underidentification and weak-instrument-robust inference.

Estimation results for oil demand are reported in Table A.4 in Appendix A. The coefficient on crude oil price is significant and negative in both specifications of the model, which makes sense as it indicates a downward sloping demand curve for crude oil. Demand for oil is increasing with world GDP per capita, which has a significant coefficient in both specifications of the model.²

We use specification (2) for our structural model, since using the lagged real average weekly earnings for support activities in oil and gas extraction as an instrument may more convincingly satisfy the exclusion restriction.

²When included, natural gas prices do not have any significant effect on oil demand. Thus, because we are limited in the number of regressors we can include owing to our small sample size, we do not include natural gas prices in our specification of oil demand.

5.2 Regional natural gas demand

Unlike the global market for oil, natural gas markets are more regional due to lack of a global natural gas pipeline networks and natural gas prices change regionally. We estimate regional natural gas demand functions for 6 regions: the Americas, Europe, Eurasia, the Middle East, Africa, and Asia & Oceania. We use data on regional natural gas prices and quantity along with regional GDP and population to estimate the regional natural gas demand equation (3) for each region.

We instrument for natural gas prices using average capital compensation and lagged real average weekly earnings for oil and gas extraction as well as support activities in oil and gas extraction, and total natural gas reserves. These variables are supply shifters that affect the costs of producing natural gas but not demand for natural gas, and therefore serve as good instruments for natural gas price.

Tables A.5- A.10 in Appendix A report the estimated results for regional natural gas demand for each region respectively. The first-stage F-statistics as well as the p-values for underidentification, weak-instrument-robust inference, and overidentification tests are also reported. The specifications used in our structural model are indicated with an asterisk.

While regional natural gas demand is weakly downward sloping for each region, there is variation in the demand parameters across regions, which provides support for our estimating separate regional natural gas demand for each of the 6 regions. As seen in the first column of Table A.7, the coefficient for natural gas price is negative and significant for the Eurasian natural gas market. The coefficient on regional GDP is also positive and significant for all regions.

The weak instrument robust inference tests test whether the coefficient on price (the endogenous regressor) is significant. The null hypothesis tested is that the coefficient on price in the structural equation is equal to zero, and, in addition, that the overidentifying restrictions are valid. Thus, when we pass both the weak instrument robust inference test

(p-value ≤ 0.05) and the overidentification test (p-value > 0.05), as is the case with Eurasia, the Middle East, and the Americas, the coefficient on price is significant.³

Taken together, our results show a significant negative elasticity of demand for regional natural gas in Eurasia, the Middle East, and the Americas.

5.3 Policy functions

Each period, each petroleum producer decides how much oil and natural gas to produce and how much to spend on each type of capital expenditure. Using our panel data on the top 50 petroleum producers, we estimate policy functions for these decision variables which correlate actions to states. We include dummies for having merged or acquired in the previous year as regressors to capture any synergies or returns to scale in production and/or investment resulting from mergers and acquisitions. The estimation results are reported in Table A.11 in Appendix A. Since OPEC firms may have different production policies from non-OPEC firms, we estimate the oil and natural gas production policy functions for OPEC firms separately; these results are reported in Table A.12 in Appendix A.

Each firm also decides whether to acquire another firm or be acquired by another firm, and whether to merge with another firm. In order to estimate the policy function for merger and acquisition decisions, we define a merger and acquisition action variable which takes the value of 1 for merger, 2 when a firm acquires another firm, and 0 otherwise. We use a multinomial logit regression model to estimate this policy function. Since OPEC firms and firms that are 100% state-owned never merge or acquire, we exclude these firms from the estimation. Estimation results for policy function on merger and acquisition are reported in Table A.13 in Appendix A. We use specification (4) in the structural estimation.

For firms that do not merge or acquire, these firms may choose to be acquired by another

³When included, oil price does not have any significant effect on natural gas demand. Thus, because we are limited in the number of regressors we can include owing to our small sample size, we do not include oil price in our specifications of regional natural gas demand.

firm. We use a logit regression model to estimate this policy function, once again excluding OPEC firms and firms that are 100% state-owned, since they are never acquired by others, and also excluding firms that merge or acquire. Estimation results for policy function for being acquired are reported in Table A.14 in Appendix A. We use specification (2) in the structural estimation.

5.4 Transition densities

The transition densities for each state variables depend on the lagged value of that state variable and also potentially on the lags of other state variables and lagged actions.

We estimate the transition densities for firm-level oil reserves and natural gas reserves by regressing reserves on lagged reserves, lagged output, lagged capital expenditures, lagged percent state ownership, lagged dummy for merger, and lagged dummy for acquisition, all at the firm level. Similarly we estimate a transition density for percentage of state ownership. The results are presented in Table A.15 in Appendix A.

In our transition densities for oil and natural gas reserves, we do not assume any fixed finite amount for the reserves. This is consistent with the common practice in the natural resource economics literature of modeling potential reserves as infinite; potential reserves are probably infinite, although the amount that is economical to extract is finite, and technological progress and new discoveries will always make more reserves available and feasible for extraction (Farzin (1992); Lin (2009b)). Thus, for the transition densities for oil and natural gas reserves, we regress reserves on lagged reserves, lagged output, lagged capital expenditures, lagged percent state ownership, lagged dummy for merger, and lagged dummy for acquisition, and we let the data tell us what the transition density is. Our econometric model allows for reserves to increase or decrease over time.

The results for the transition density for world population, which depends on lagged world population, are presented in Table A.16. The results for the transition density for

world GDP per capita, which depends on lagged world GDP per capita, are presented in Table A.17 in Appendix A.

The results for the transition density for regional population, which depends on lagged regional population, for each of the 6 regions of the world are presented in Table A.18. The results for the transition density for regional GDP, which depends on lagged regional GDP, for each of the 6 regions of the world are presented in Table A.19 in Appendix A.

The transition densities for average industry rate of return on capital, average capital compensation on other machinery and equipment, average capital compensation on total non-residential investment, world road sector gasoline fuel consumption, world motor vehicles, world electricity production from natural gas sources, and world road sector gasoline from oil sources are in Tables A.20 to A.26, respectively, in Appendix A. For each of these state variables, we regress the state variable on the lagged value of the state variable, as well as on the lagged values of other relevant state variables and lagged values of aggregate reserves and aggregate production variables. In some cases, relevant state variables were dropped due to collinearity.

The lagged values of aggregate reserves and aggregate production are significant in most transition densities, which means that the investment and production decisions of other firms affect the future values of state variables which affect a firm's future payoff from producing and investing, and therefore that firms must anticipate the production and investment strategies of other firms in order to make a dynamically optimal decision. There is thus an important strategic component in firms' production and investment decisions.

5.5 Structural parameters

The structural parameters θ we estimate include the parameters in the per-period payoff function, and the distributions of the fixed payoffs to merging, acquiring, and being acquired. We set the discount factor β to 0.9.

Our estimates of the parameters in the per-period payoff function are presented in Table 5. Our estimated parameters in the per-period payoff function show that there are nonlinearities with respect to both output and reserves in the production profit function. Thus, oil and natural gas production may exhibit increasing or decreasing returns to scale, or both. As a consequence, firms may benefit from changing their scale via mergers and acquisitions.

The coefficient δ_5 in oil and natural gas production cost on the interaction between oil and natural gas output is significant and negative, which is evidence of cost synergies between oil and natural gas production, which may include joint production and other supply-side links in oil and gas (Roberts and Gilbert, 2016).

Both the percentage of state ownership and being an OPEC member have a significant positive effect on the per-period payoff. However, while our model allows firms that are at least partially state-owned to have different objectives from private firms, we find that state-owned firms do not put any weight on consumer surplus, as we estimate ρ_{CS} to be a precise zero.

Our estimates of the distribution of fixed payoffs to merger and acquisition are presented in Table 6. The fixed benefits from being acquired, the fixed costs of acquiring another firm, and the fixed costs of merging each have a significant and positive mean, but a large significant standard deviation as well. Thus, the idiosyncratic fixed payoffs to merger and acquisition vary greatly by firm and year.

Welfare statistics, including firm payoffs for all firms, OPEC firms, and non-OPEC firms; and consumer surplus are presented in Table 7. The expected firm payoff is significant and positive on average, but can be negative for some firms in some years. Expected total consumer surplus is several orders of magnitude larger than expected total firm payoff.

Summary statistics of the action variables predicted by our structural econometric model for the period 2000-2005 are presented in Table A.27 in Appendix A. When compared with the summary statistics of the actual values of the action variables observed in the data in

Table 1, it appears that our structural econometric model does a fairly good job matching the actual data.

6 Counterfactual Simulations

We use the estimated parameters from our structural econometric model to run counterfactual simulations to analyze the effects of changes in OPEC membership, a ban on mergers, the privatization of state-owned oil companies, and demand shocks on the petroleum industry over the period 2000-2005. For each counterfactual scenario, we compare the results from that counterfactual scenario with the results from the base-case status quo simulation of no counterfactual change using two-sample t-tests.

6.1 OPEC membership scenarios

We simulate two counterfactual OPEC membership scenarios. In one counterfactual OPEC membership scenario, all firms are members of OPEC. In the other counterfactual OPEC membership scenario, no firms are members of OPEC.

Table 8 presents results of two-sample t-tests comparing the welfare from the OPEC membership scenarios to the welfare from the base-case status quo simulation. Table 9 presents results of two-sample t-tests comparing each of the action variables (output, capex, and mergers and acquisitions) from the OPEC membership scenarios to the action variables from the base-case status quo simulation. Table 10 presents results of two-sample t-tests comparing oil and natural gas prices from the OPEC membership scenarios to the prices from the base-case status quo simulation.

According to the results, including all firms in OPEC increases the average firm payoff, decreases oil production, increases oil price, and decreases consumer surplus.

The other extreme of not including any firms in OPEC increases oil production and

decreases oil price, as expected; and increases natural gas production and decreases regional natural gas prices. When no firms are in OPEC, average firm payoff increases, but by less than it would if all firms were members of OPEC; and consumer surplus decreases.

Our result that including all firms in OPEC increases average firm payoff is consistent with OPEC’s mission 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’ (Organization of Petroleum Exporting Countries [OPEC], 2017).

6.2 Ban on mergers

We also simulate a counterfactual scenario in which mergers between top 50 firms are banned.⁴

Table 11 presents results of two-sample t-tests comparing the welfare from the merger ban scenario to the welfare from the base-case status quo simulation. Table 12 presents results of two-sample t-tests comparing each of the action variables (output, capex, and mergers and acquisitions) from the merger ban scenario to the action variables from the base-case status quo simulation. Table B.1 in Appendix B presents results of two-sample t-tests comparing oil and natural gas prices from the merger ban scenario to the prices from the base-case status quo simulation.

According to the results, banning mergers would decrease oil and natural gas output, increase oil price, decrease investment, increase acquisitions, decrease average firm payoff for both OPEC and non-OPEC firms, and decrease consumer surplus. We also find that the

⁴As we do not observe and therefore do not explicitly model mergers between a top 50 firm and a firm that is not among the top 50 firms, we are unable to run a counterfactual simulation banning mergers between a top 50 firm and a firm that is not among the top 50 firms. Unobserved mergers with non-top 50 firms are captured in our structural model by the error terms in our policy functions and transition densities.

negative effect of a merger ban on average firm payoff is more severe for non-OPEC firms than for OPEC firms, in both absolute and percentage change terms.

The result that banning mergers has a larger negative effect on non-OPEC firms than on OPEC firms is likely because OPEC firms do not engage in mergers, so banning mergers by non-OPEC firms imposes a constraint on non-OPEC firm decision-making that has a larger negative effect on non-OPEC firms.

6.3 Privatization scenarios

We simulate three counterfactual privatization scenarios. In the first privatization scenario, we simulate all firms having 0% state ownership (i.e., all firms privatized). In the second privatization scenario, we simulate all firms as being 50% state-owned. In the third privatization scenario, we simulate all firms being 100% state-owned.

Table 13 presents results of two-sample t-tests comparing the welfare from the privatization scenarios to the welfare from the base-case status quo simulation.

According to the results, privatizing all firms decreases average firm payoff for both OPEC and non-OPEC firms. Since the percentage of state ownership has a significant positive effect on a firm's per-period payoff, privatizing all firms decreases the average firm payoff.

Making all firms 50% state-owned decreases average firm payoff for OPEC firms and increases average firm payoff for non-OPEC firms. Since the percentage of state ownership has a significant positive effect on a firm's per-period payoff, decreasing the percentage state ownership of OPEC firms from 100% to 50% decreases the average firm payoff for OPEC firms. In contrast, since the average state ownership of non-OPEC firms in our data set is 36.69%, making all firms 50% state-owned increases the average state ownership of non-OPEC firms in our data set, thus increasing average firm payoff for non-OPEC firms.

Making all firms 100% state-owned increases has no significant effect on the average firm payoff for OPEC firms, but increases the average firm payoff for non-OPEC firms.

Since OPEC firms are already all 100% state-owned, making all firms 100% state-owned does not change the percentage state ownership of OPEC firms. Since the percentage of state ownership has a significant positive effect on a firm's per-period payoff, increasing the percentage state ownership of all non-OPEC firms to 100% increases the average firm payoff for non-OPEC firms.

6.4 Demand shock

We also simulate counterfactual shocks to oil demand and natural gas demand. For example, demand shocks may arise due to disruptive technologies, such as shale oil and gas and new batteries for electric vehicles. We specify these shocks as shocks that change the constant in the oil and natural gas demand functions.

In the first counterfactual scenario, the constant in oil demand decreases by 10% and the constant in regional natural gas demand decreases by 10% for each region. In the second counterfactual scenario, the constant in oil demand decreases by 25% and the constant in regional natural gas demand decreases by 25% for each region. In the third counterfactual scenario, the constant in oil demand decreases by 10%. In the fourth counterfactual scenario, the constant in oil demand decreases by 25%.

We also simulate a set of counterfactual scenarios, one for each region, in which the constant in regional natural gas demand decreases by 25% for that region only; and another set of counterfactual scenarios, one for each region, in which the constant in regional natural gas demand increases by 25% for that region only.

Tables B.2-B.4 in Appendix B present results of two-sample t-tests comparing the welfare from the demand shock scenarios to the welfare from the base-case status quo simulation.

According to the results, whether they increase or decrease demand, shocks to oil and/or natural gas demand may increase or decrease firm payoffs, and tend to decrease consumer surplus.

7 Conclusions

In this paper, we develop and estimate a structural econometric model of the dynamic game among petroleum-producing firms to analyze the effects of economic factors, strategic factors, and government policy on the world petroleum market. It is important to account for both the dynamic and strategic nature of decision-making by petroleum producers.

According to the results of our structural econometric model, oil and natural gas production may exhibit increasing or decreasing returns to scale, or both. As a consequence, firms may benefit from changing their scale via mergers and acquisitions. In addition, we find evidence of cost synergies between oil and natural gas production, which may include joint production and other supply-side links in oil and gas (Roberts and Gilbert, 2016).

We also find that both the percentage of state ownership and being an OPEC member have a significant positive effect on the per-period payoff. However, while our model allows firms that are at least partially state-owned to have different objectives from private firms, we find that state-owned firms do not put any weight on consumer surplus.

We use the estimated parameters from our structural econometric model to run counterfactual simulations to analyze the effects of changes in OPEC membership, a ban on mergers, the privatization of state-owned oil companies, and demand shocks on the petroleum industry.

According to the results from our counterfactual OPEC membership scenarios, including all firms in OPEC increases the average firm payoff. This result is consistent with OPEC's mission to 'coordinate and unify the petroleum policies of its Member Countries and ensure ... a steady income to producers' (Organization of Petroleum Exporting Countries [OPEC], 2017).

According to the results from our counterfactual merger ban scenario, a ban of mergers would decrease average firm payoff for both OPEC and non-OPEC firms, and also decrease

consumer surplus. We find that banning mergers has a larger negative effect on non-OPEC firms than on OPEC firms, likely because OPEC firms do not engage in mergers, so banning mergers by non-OPEC firms imposes a constraint on non-OPEC firm decision-making that has a larger negative effect on non-OPEC firms.

According to the results from our counterfactual privatization scenarios, privatizing all firms decreases the average firm payoff for both OPEC and non-OPEC firms. Making all firms 50% state-owned decreases the average firm payoff for OPEC firms, but increases the average firm payoff for non-OPEC firms. Making all firms 100% state-owned has no significant effect on the average firm payoff for OPEC firms, but increases the average firm payoff for non-OPEC firms. The intuition for our privatization results is as follows: since the percentage of state ownership has a significant positive effect on a firm's per-period payoff, increasing the percentage state ownership increases the average firm payoff.

We also find that, whether they increase or decrease demand, shocks to oil and/or natural gas demand may increase or decrease firm payoffs, and tend to decrease consumer surplus. We hope to further analyze the effects of demand shocks on the world petroleum market in future work.

There are several potential avenues for future work that we hope to pursue. First, as mentioned, we hope to further analyze the effects of demand shocks on the world petroleum market in future work. Second, we hope in future work to complement our analysis of mergers and acquisitions by further analyzing other forms of cooperation between firms, including production sharing or service-type contracts between state-owned oil companies and international oil companies (Ghandi and Lin, 2012, 2014; Ghandi and Lin Lawell, 2018b). Third, as we found that firms that are at least partially state-owned do not put any weight on consumer surplus, we hope to further analyze other alternative objectives for state-owned firms in future work. Fourth, in future work we hope to further analyze the strategies and behavior of OPEC and OPEC firms.

The results of our research will be of interest to academics, policy-makers, entrepreneurs, and business practitioners, including oil companies, alike. Our modeling outcomes can be used to help inform decision-making and policy design. This model will also help petroleum firms better respond to government policies, and will help policy-makers better design sustainable energy policies.

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8 Figures and Tables

Table 1: Summary statistics for action variables (2000-2005)

Variable	# Obs	Mean	Std. Dev.	Min	Max
Oil output (KBD)	300	1214.441	1466.5487	11	11035
Natural gas output (MCFD)	300	3445.546	7242.888	44	53135
Exploration capex (million 2005 US\$)	94	595.9822	453.5993	-13.232	1828.14
Development capex (million 2005 US\$)	94	2640.832	2268.744	0	9045
Acquisition capex (million 2005 US\$)	93	1133.271	2651.709	-142.899	17625
Dummy for M&A at time t					
merging with another firm	300	.0133	.1149	0	1
acquiring another firm	300	.0233	.1512	0	1
being acquired by another firm	300	.0167	.1282	0	1
OPEC firms' production only					
Oil output (KBD)	67	2445.269	2324.396	135	11035
Natural gas output (MCFD)	67	3419.313	2687.751	112	8485
Non-OPEC firms' production only					
Oil output (KBD)	233	860.5119	819.4949	11	3754
Natural gas output (MCFD)	233	3453.09	8096.542	44	53135

Table 2: Summary statistics for firm level state variables (2000-2005)

Variable	# Obs	Mean	Std. Dev.	Min	Max
OPEC membership at time t (dummy)	300	.2233333	.4171758	0	1
State ownership (in percentage)	300	48.48641	45.74817	0	100
Oil reserves (million barrels)	300	19820.82	44090.61	50	264200
Natural gas reserves (BCF)	300	85529.82	207369.9	420	1320000

Table 3: Summary statistics for prices of oil and natural gas (2000-2005)

Variable	# Obs	Mean	Std. Dev.	Min	Max
Crude oil price, Brent (2005 US\$/bbl)	6	35.98517	9.791585	28.7883	54.4341
Natural gas price, US (2005 US\$/mmbtu)	6	5.756597	1.755797	3.97939	8.91567
Regional natural gas price (2005 US\$/mmbtu)					
Africa	5	5.643	2.4304	3.3171	9.679
Asia & Oceania	5	9.7815	1.4431	8.2034	11.764
Eurasia	5	0.9509	0.2714	0.7106	1.3715
Europe	5	7.1918	1.8749	5.1571	9.7842
Middle East	5	6.263	1.0773	5.3768	8.1295

Table 3: (continued)

Variable	# Obs	Mean	Std. Dev.	Min	Max
America	5	5.8928	1.8119	3.9221	8.5541

Table 4: Summary statistics for state variables

Variable	# Obs	Mean	Std. Dev.	Min	Max
Avg capital compensation (million 2005 US\$)					
on transport equipment	24	132.322	57.204	21.891	243.422
on other machinery and equipment	24	2086.081	870.891	415.203	4141.958
on total non-residential investment	24	4078.227	2371.123	847.457	10639.06
Average industry rate of return on capital	24	.144	.04	.08	.232
World GDP per capita (2005 US\$)	25	6475.482	691.679	5456.522	7642.35
World population (million people)	25	5970.799	575.621	4985.892	6942.765
World electricity production (kWh)					
from oil sources	25	1.04e+12	1.02e+11	8.08e+11	1.19e+12
from natural gas sources	25	2.71e+12	1.17e+12	8.28e+11	4.85e+12
World road sector gasoline					
fuel consumption (kt of oil equivalent)	18	827537.6	50057.57	730584	898004
World motor vehicles (per 1,000 people)	10	156.73	11.225	142.4	180.18
Average weekly earnings (2005 US\$)					
for oil and gas extraction	25	892.2796	65.31246	803.238	1023.57
for supporting activities in oil and gas	22	789.4748	92.58307	681.1732	978.1636
Regional GDP (trillion 2005 US\$)					
Africa	25	0.817	0.507	0.408	2.13
Asia and Oceania	25	9.19	4.3	3.81	20.7
Eurasia	25	0.871	0.691	0.0722	2.6
Europe	25	11.9	4.68	5.59	20.8
Middle East	25	0.885	0.622	0.304	2.52
Americas	25	13.3	5.15	6.1	23.2
Regional population (million people)					
Africa	25	797	144	578	1050
Asia and Oceania	25	3340	321	2780	3820

Table 4: (continued)

Variable	# Obs	Mean	Std. Dev.	Min	Max
Eurasia	25	287	2.548955	281	291
Europe	25	574	18.6	540	604
Middle East	25	168	30.2	120	221
Americas	25	823	80.3	689	948

Table 5: Estimated parameters in per-period payoff function

Description		Estimated parameters
Coefficient in oil production cost on:		
Oil production (KBD*1e-4)	δ_{11}	-20.0970 *** (1.1779)
Oil production squared	δ_{12}	-0.1591 *** (0.0093)
Oil reserves (bbl)	δ_{13}	1.1744 *** (0.0688)
Oil production \times Oil reserves	δ_{14}	-0.7277 *** (0.0426)
Coefficient in natural gas production cost on:		
NG production (MCF*1e-4)	δ_{21}	0.0200 *** (0.0012)
NG production squared	δ_{22}	-0.0140 *** (0.0008)
NG reserves (KCF)	δ_{23}	-0.2700 *** (0.0158)
NG production \times NG reserves	δ_{24}	-0.0772 *** (0.0045)
Coefficient in oil and natural gas production cost on:		
Oil production \times NG production	δ_5	-11.4587 *** (0.6716)
Coefficient in per-period payoff on:		
Percentage of state ownership	ω_1	0.3787 *** (0.0222)
OPEC member (dummy)	ω_2	2.8945 *** (0.1696)
EV of other firm if acquire (billion \$)	η_1	0.1710 *** (0.0100)
EV of other firm if merge (billion \$)	η_2	0.3976 *** (0.0233)
Percent state ownership \times Consumer surplus (billion \$)	ρ_{CS}	0.0000 *** (0.0000)
Constant	δ_0	0.0000 *** (0.0000)

Notes: Per period payoffs are in billion dollars. Standard errors in parentheses.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6: Estimated distribution of fixed payoffs to merger and acquisition

	Mean	Standard Deviation
Fixed benefits from being acquired	0.0487 *** (0.0031)	0.0724 *** (0.0048)
Fixed costs of acquiring	0.1037*** (0.0062)	0.1401*** (0.0083)
Fixed costs of merging	0.0588*** (0.0035)	0.0767*** (0.0045)

Note: Per period payoffs are in billion dollars. Standard errors in parentheses.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 7: Welfare

Variable	All firms	OPEC firms	Non-OPEC firms
Expected total firm payoff	63.0721 *** (11.2308)	37.0672 *** (4.4646)	26.0049 *** (6.7669)
Expected avg. firm payoff	1.2614 *** (0.2246)	3.3048 *** (0.3960)	0.6719 *** (0.1749)
Min firm payoff	-3.9834 *** (0.2105)	-3.9834 *** (0.2105)	-0.6357 * (0.2554)
Max firm payoff	14.3074 *** (0.9821)	14.3074 *** (0.9821)	10.3077 *** (0.9953)
Expected total consumer surplus	3.12e+10 *** (6.48e+09)		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 8: Changes in welfare from base case under different OPEC membership cases

All firms	
OPEC membership case where all firms are members of OPEC	
Expected total firm payoff	53.6844 ***
Expected avg firm payoff	1.0737 ***
Min firm payoff	0.0620 ***
Max firm payoff	0.1101
Expected total consumer surplus	-4.90e+09***
OPEC membership case where no firms are members of OPEC	
Expected total firm payoff	13.5019 ***
Expected avg firm payoff	0.2700 ***
Min firm payoff	3.5639 ***
Max firm payoff	-2.0790 ***
Expected total consumer surplus	-6.77e+09***

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 9: Change in action variables from base case under different OPEC membership cases

	All firms
OPEC membership case where all firms are members of OPEC	
Oil output (KBD)	-317.1271***
Natural gas output (MCFD)	-1728.641 ***
Exploration capex (2005 US\$)	-138.822 ***
Development capex (2005 US\$)	-392.5024 ***
Acquisition capex (2005 US\$)	-261.2711***
OPEC membership case where no firms are members of OPEC	
Oil output (KBD)	97.3434***
Natural gas output (MCFD)	2494.8607 ***
Exploration capex (2005 US\$)	56.0369 ***
Development capex (2005 US\$)	99.4664 ***
Acquisition capex (2005 US\$)	-0.9552
merging	0.0293***
acquiring another firm	-0.0017 ***
being acquired by another firm	0.0011 ***

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 10: Change in prices from base case under different OPEC membership cases

OPEC membership case where all firms are members of OPEC	
Crude oil price, Brent (2005 US\$/bbl)	12.8777 ***
Regional natural gas price (2005 US\$/mmbtu)	
Africa	0.08129 ***
Asia & Oceania	0.2989
Eurasia	0.0494***
Europe	-0.1537 **
Middle East	-0.3151 ***
America	0.2871*
OPEC membership case where no firms are members of OPEC	
Crude oil price, Brent (2005 US\$/bbl)	-4.7371 ***
Regional natural gas price (2005 US\$/mmbtu)	
Africa	-0.4736***
Asia & Oceania	-0.3654 *
Eurasia	-0.2450 ***
Europe	-0.2945***
Middle East	-0.3802***
America	-0.6612 ***

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 11: Changes in welfare from base case under merger ban

	All firms	OPEC firms	Non-OPEC firms
Expected total firm payoff	-6.9851 ***	-1.1974 ***	-5.7876 ***
Expected avg firm payoff	-0.1397 ***	-0.1092 ***	-0.1497***
Min firm payoff	0.0000	0.0000	-0.3014 ***
Max firm payoff	-0.1662 *	-0.2494 ***	1.9774 ***
Expected total consumer surplus	-3.60e+09 ***		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 12: Change in action variables from base case under merger ban

	All firms	OPEC firms	Non-OPEC firms
Oil output (KBD)	-282.7638***	-43.2392 **	-179.203 ***
Natural gas output (MCFD)	-706.1913***	-38.5162*	-1001.348 ***
Exploration capex (2005 US\$)	-112.7563***	12.7991 *	-72.2011 ***
Development capex (2005 US\$)	-337.2594***	31.7296 *	-226.6801***
Acquisition capex (2005 US\$)	-63.2232***	3.404179 **	-132.3239 ***
merging			
acquiring another firm	.0154 ***		0.01997 ***
being acquired by another firm	.0059 ***		0.0076 ***

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 13: Changes in welfare from base case under different privatization scenarios

	All firms	OPEC firms	Non-OPEC firms
State ownership=0%			
Expected total firm payoff	-15.1576 ***	-4.8248 ***	-10.3328 ***
Expected avg firm payoff	-0.3032 ***	-0.3737 ***	-0.2700 ***
Min firm payoff	-0.1173 ***	-0.1173 ***	-0.4109 ***
Max firm payoff	0.0627	0.0627	-2.2536 ***
Expected total consumer surplus	2.00e+10***		
State ownership=50%			
Expected total firm payoff	-7.0886 ***	-10.5162 ***	3.4276 ***
Expected avg firm payoff	-0.1418 ***	-0.8911 ***	0.0828 ***
Min firm payoff	-0.1764 ***	-0.1764 ***	0.1763 ***
Max firm payoff	-1.2226 ***	-1.2226 ***	-1.7623 ***
Expected total consumer surplus	2.26e+10 ***		
State ownership=100%			
Expected total firm payoff	19.6248 ***	-0.2815	19.906 ***
Expected avg firm payoff	0.3925 ***	0.0393	0.5053 ***
Min firm payoff	0.1348 ***	0.1348 ***	0.3734 ***
Max firm payoff	0.0798	0.0798	2.4763 ***
Expected total consumer surplus	3.26e+10 ***		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

A Appendix A

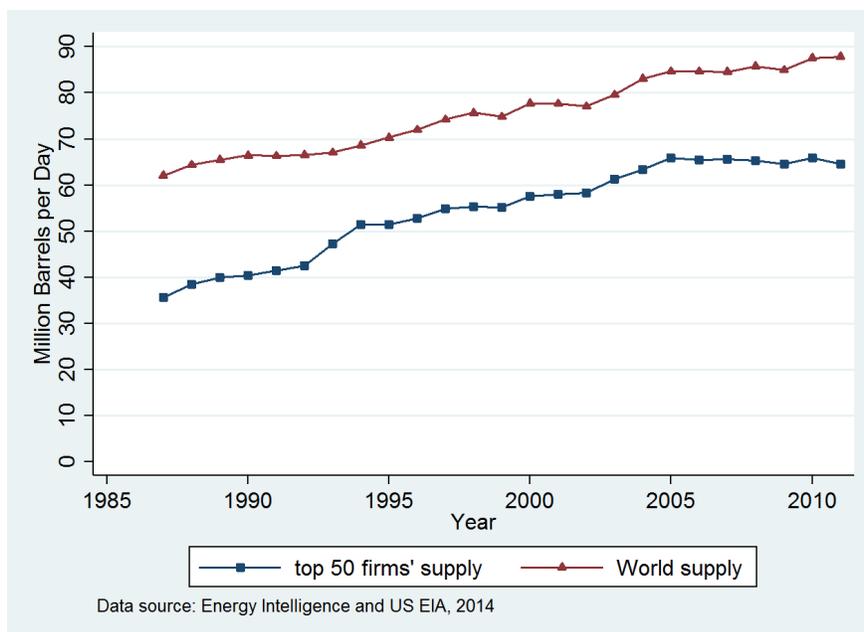


Figure A.1: World oil supply vs top 50 producers supply in MMBD

Table A.1: Summary statistics for action variables

Variable	# Obs	Mean	Std. Dev.	Min	Max
Oil output (KBD)	1250	1089.934	1407.45	4	11035
Natural gas output (MCFD)	1250	2951.507	6528.964	0	55901.06
Exploration capex (million 2005 US\$)	300	520.385	596.664	-13.232	2760.085
Development capex (million 2005 US\$)	300	1743.55	2043.468	0	9045
Acquisition capex (million 2005 US\$)	295	531.016	1720.282	-142.899	17625
Dummy for M&A at time t					
merging with another firm	1296	.005	.067	0	1
acquiring another firm	1296	.012	.11	0	1
being acquired by another firm	1296	.009	.095	0	1

Table A.2: Summary statistics for firm level state variables

Variable	# Obs	Mean	Std. Dev.	Min	Max
OPEC membership at time t (dummy)	1316	.211	.408	0	1
State ownership (in percentage)	1316	49.858	46.344	0	100
Oil reserves (million barrels)	1250	19473.12	45401.37	22	296501
Natural gas reserves (BCF)	1250	72399.95	177989.3	0	1320000

Table A.3: Summary statistics for prices of oil and natural gas

Variable	# Obs	Mean	Std. Dev.	Min	Max
Crude oil price, Brent (2005 US\$/bbl)	25	35.6445	23.3058	13.6616	90.5464
Natural gas price, US (2005 US\$/mmbtu)	25	3.6833	2.14151	1.5439	8.9157
Regional natural gas price (2005 US\$/mmbtu)					
Africa	9	6.0782	2.2554	3.3171	9.6790
Asia & Oceania	9	12.1561	3.2825	8.2034	18.1676
Eurasia	9	1.3760	0.5569	0.7106	2.1370
Europe	9	10.2351	4.0633	5.1570	16.6824
Middle East	9	8.8214	3.4490	5.3768	15.1544
America	9	6.8508	2.2628	3.9221	10.7228

Table A.4: Estimated demand function for oil

	<i>Dependent variable is:</i>	
	Oil quantity (KBD)	
	(1)	(2)
Crude oil price, Brent (2005 US\$/bbl)	-274.6** (102.1)	-495.3* (205.8)
World GDP per capita (2005 US\$)	17.66* (8.427)	36.69* (16.35)
World population (million people)	1.936 (9.522)	-19.40 (18.09)
World electricity production from oil sources (kWh)	-1.11e-08 (1.60e-08)	-4.02e-08 (2.89e-08)
Constant	-50081.5 (27851.5)	-7019.2 (45755.7)
Instruments used:		
Average weekly earning		
for support activities in oil and gas extraction	Y	
for support activities in oil and gas extraction (lagged)		Y
First stage F-statistic	21.62	12.44
p-value of underidentification test	0.0035	0.0488
p-value of weak-instrument-robust inference tests	0.0092	0.0002
N	22	21
R^2	0.951	0.888
Root MSE	1810	2516

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.5: Estimated regional demand function for natural gas for Africa

	<i>Dependent variable is:</i>			
	Regional natural gas consumption (MCFD)			
	(92-1*)	(92-3)	(92-4)	(91-33)
Natural gas regional price,(US\$/mmbtu)	-2.213 (20.03)	-7.540 (19.93)	-14.97 (20.66)	-5.894 (21.04)
Regional GDP (US\$)	1.14e-09*** (1.14e-10)	1.15e-09*** (1.13e-10)	1.17e-09*** (1.15e-10)	4.64e-10 (5.66e-10)
Regional population				0.00000456 (0.00000355)
Constant	1688.1*** (133.4)	1706.9*** (133.0)	1732.9*** (135.4)	-1742.0 (2713.4)
Instruments used:				
Lagged average weekly earnings (2005 US\$)				
for oil and gas extraction	N	Y	Y	Y
for supporting activities in oil and gas	Y	Y	Y	N
Avg capital compensation (million 2005 US\$)				
on other machinery and equipment	Y	N	Y	N
on transport equipment	Y	Y	N	N
on total non-residential investment	Y	Y	Y	Y
Avg industry rate of return on capital	Y	Y	Y	Y
Aggregate gas reserve (BCF)	Y	Y	Y	N
First stage F-statistic	17.61	74.20	2.60	5.38
p-value of underidentification test	0.1777	0.1746	0.2017	0.0478
p-value of weak-instrument-robust inference tests	0.3282	0.0001	0.0068	0.3675
p-value of Sargan-Hansen overidentification test	0.5603	0.2362	0.3701	0.3350
<i>N</i>	9	9	9	9
<i>R</i> ²	0.932	0.932	0.931	0.945
Root MSE	114.8	114.5	115.7	103.4

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.6: Estimated regional demand function for natural gas for Asia and Oceania

	<i>Dependent variable is:</i>				
	Regional natural gas consumption (MCFD)				
	(91-39*)	(91-46)	(91-30)	(91-32)	(91-45)
Natural gas regional price,(US\$/mmbtu)	-76.94 (189.6)	-30.18 (206.8)	-195.4 (304.2)	-22.75 (178.2)	-355.8 (353.0)
Regional GDP (US\$)	5.77e-10* (2.53e-10)	5.46e-10* (2.52e-10)	6.56e-10* (3.20e-10)	5.41e-10* (2.41e-10)	7.63e-10* (3.81e-10)
Regional population	0.0000135* (0.00000637)	0.0000129* (0.00000625)	0.0000151 (0.00000772)	0.0000129* (0.00000608)	0.0000171 (0.00000922)
Constant	-39914.4 (20404.5)	-37989.0 (20014.5)	-44790.6 (24743.0)	-37683.5 (19447.4)	-51393.2 (29540.3)
Instruments used:					
Avg capital compensation (million 2005 US\$)					
on other machinery and equipment	N	N	Y	N	N
on transport equipment	N	N	N	Y	N
on total non-residential investment	N	N	N	N	Y
Avg industry rate of return on capital	Y	Y	N	Y	N
Aggregate gas reserve (BCF)	Y	N	Y	Y	N
First stage F-statistic	2.67	2.38	0.71	1.79	1.31
p-value of underidentification test	0.0437	0.0275	0.2103	0.0906	0.0667
p-value of weak-instrument-robust inference tests	0.8001	0.8813	0.6690	0.2002	0.0939
p-value of Sargan-Hansen overidentification test	0.6459	NA	0.7563	0.2290	NA
<i>N</i>	9	9	9	9	9
<i>R</i> ²	0.984	0.985	0.979	0.985	0.970
Root MSE	337	323.8	381.5	322	459.8

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.7: Estimated regional demand function for natural gas for Eurasia

	<i>Dependent variable is:</i>	
	Regional natural gas consumption (MCFD) (91-34*)	(91-29)
Natural gas regional price,(US\$/mmbtu)	-5960.0*** (420.7)	-6039.3*** (482.2)
Regional GDP (US\$)	4.99e-09*** (3.57e-10)	5.06e-09*** (4.07e-10)
Regional population	-0.00135*** (0.0000574)	-0.00135*** (0.0000581)
Constant	408719.2*** (16435.4)	409082.8*** (16636.3)
Instruments used:		
Lagged average weekly earnings (2005 US\$)		
for supporting activities in oil and gas	Y	Y
for oil and gas extraction	Y	N
Avg capital compensation (million 2005 US\$)		
on transport equipment	Y	Y
Avg industry rate of return on capital	N	Y
First stage F-statistic	13.23	1.76
p-value of underidentification test	0.0350	0.0826
p-value of weak-instrument-robust inference tests	0.0000	0.0000
p-value of Sargan-Hansen overidentification test	0.2582	0.0755
<i>N</i>	9	9
<i>R</i> ²	0.990	0.990
Root MSE	126.9	128.2

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.8: Estimated regional demand function for natural gas for Europe

	<i>Dependent variable is:</i>	
	Regional natural gas consumption (MCFD) (91-21**)	(91-40)
Natural gas regional price,(US\$/mmbtu)	-169.9 (165.2)	-344.7 (185.5)
Regional GDP (US\$)	5.15e-10*** (1.44e-10)	6.11e-10*** (1.55e-10)
Regional population	-0.0000783 (0.0000679)	-0.0000361 (0.0000730)
Constant	59235.9 (38457.1)	34714.0 (41355.9)
Instruments used:		
Lagged average weekly earnings (2005 US\$)		
for supporting activities in oil and gas	Y	N
for oil and gas extraction	Y	Y
Avg capital compensation (million 2005 US\$)		
on total non-residential investment	N	Y
Avg industry rate of return on capital	Y	N
Aggregate gas reserve (BCF)	Y	N
First stage F-statistic	9.36	7.63
p-value of underidentification test	0.0738	0.0243
p-value of weak-instrument-robust inference tests	0.0000	0.0014
p-value of Sargan-Hansen overidentification test	0.0451	0.1406
<i>N</i>	9	9
<i>R</i> ²	0.833	0.817
Root MSE	331	346.8

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.9: Estimated regional demand function for natural gas for Middle East

	<i>Dependent variable is:</i>			
	Regional natural gas consumption (MCFD)			
	(92-33*)	(92-38)	(92-40)	(92-45)
Natural gas regional price,(US\$/mmbtu)	-12.14 (47.81)	11.55 (49.62)	-38.25 (50.26)	-37.77 (50.23)
Regional population	0.000146*** (0.0000126)	0.000140*** (0.0000130)	0.000152*** (0.0000132)	0.000152*** (0.0000132)
Constant	-18265.8*** (2027.4)	-17372.0*** (2094.2)	-19250.5*** (2118.4)	-19232.7*** (2117.0)
Instruments used:				
Lagged average weekly earnings (2005 US\$) for oil and gas extraction	Y	Y	Y	N
Avg capital compensation (million 2005 US\$) on total non-residential investment	Y	N	Y	Y
Avg industry rate of return on capital	Y	Y	N	N
First stage F-statistic	49.67	61.88	57.38	103.23
p-value of underidentification test	0.0478	0.0228	0.0241	0.0063
p-value of weak-instrument-robust inference tests	0.0019	0.8	0.4334	0.4296
p-value of Sargan-Hansen overidentification test	0.0612	0.5473	0.3753	NA
<i>N</i>	9	9	9	9
<i>R</i> ²	0.990	0.990	0.989	0.989
Root MSE	177.1	179.7	180.7	180.6

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.10: Estimated regional demand function for natural gas for Americas

	<i>Dependent variable is:</i>				
	Regional natural gas consumption (MCFD)				
	(92-33*)	(92-26)	(92-20)	(92-12)	(91-9)
Natural gas regional price,(US\$/mmbtu)	-85.00 (85.49)	-67.54 (86.38)	-80.89 (85.30)	-74.39 (84.32)	-39.23 (108.8)
Regional GDP (US\$)	3.17e-10*** (6.64e-11)	3.08e-10*** (6.65e-11)	3.15e-10*** (6.63e-11)	3.12e-10*** (6.58e-11)	2.37e-10 (3.12e-10)
Regional population					0.00000594 (0.0000288)
Constant	26750.5*** (849.0)	26792.2*** (844.7)	26760.3*** (847.4)	26775.8*** (844.9)	22518.3 (20904.6)
Instruments used:					
Lagged average weekly earnings (2005 US\$)					
for supporting activities in oil and gas	N	N	N	Y	Y
for oil and gas extraction	Y	Y	Y	Y	N
Avg capital compensation (million 2005 US\$)					
on other machinery and equipment	N	N	N	N	Y
on transport equipment	N	N	N	N	Y
on total non-residential investment	Y	N	Y	Y	Y
Avg industry rate of return on capital	Y	Y	Y	Y	Y
Aggregate gas reserve (BCF)	N	Y	Y	Y	N
First stage F-statistic	16.65	10.48	10.13	8.36	4.15
p-value of underidentification test	0.0369	0.0418	0.0750	0.1236	0.1305
p-value of weak-instrument-robust inference tests	0.0135	0.0001	0.0000	0.0000	0.0000
p-value of Sargan-Hansen overidentification test	0.1309	0.0426	0.0727	0.1195	0.0614
<i>N</i>	9	9	9	9	9
<i>R</i> ²	0.785	0.787	0.785	0.786	0.788
Root MSE	386.6	384.3	385.9	385	383

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.11: Estimation results for policy functions

	<i>Dependent variable is:</i>				
	Oil output	Natural gas output	Exploration capex	Development capex	Acquisition capex
Avg capital compensation (million 2005 US\$)					
on transport equipment	0.761 (2.655)	4.030 (7.666)	2.246 (5.110)	7.716 (14.23)	10.85 (21.58)
on other machinery and equipment	0.0934 (0.172)	0.491 (0.496)	0.177 (0.331)	0.520 (0.921)	0.546 (1.397)
on total non-residential investment	0.131 (0.208)	0.549 (0.602)	0.219 (0.401)	0.162 (1.117)	0.127 (1.694)
on other assets	0.0225 (0.238)	-0.148 (0.688)	-0.190 (0.459)	-0.810 (1.278)	0.0379 (1.938)
Oil reserves (million Barrels)	0.102*** (0.00475)	-0.0298* (0.0137)	0.000859 (0.00914)	-0.00840 (0.0254)	-0.0380 (0.0386)
Natural gas reserves (BCF)	0.0111*** (0.00163)	0.0996*** (0.00470)	0.0205*** (0.00313)	0.0490*** (0.00872)	0.0184 (0.0132)
Avg weekly earning (2005 US\$)					
on oil and gas extraction	1.260 (2.339)	5.709 (6.753)	3.450 (4.501)	4.734 (12.53)	-6.329 (19.01)
on supporting activities in oil and gas	0.874 (2.373)	4.311 (6.852)	3.434 (4.567)	7.274 (12.72)	-0.546 (19.29)
Cumulative oil output (KBD)	0.0113* (0.00474)	-0.0779*** (0.0137)	0.0101 (0.00912)	0.0408 (0.0254)	-0.00104 (0.0385)
Cumulative gas output (MCFD)	-0.000100 (0.00167)	0.0240*** (0.00481)	-0.00340 (0.00321)	-0.00831 (0.00893)	0.00561 (0.0135)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.11: (continued)

	<i>Dependent variable is:</i>				
	Oil output	Natural gas output	Exploration capex	Development capex	Acquisition capex
Aggregate oil output (KBD)	-0.00424 (0.0252)	-0.0315 (0.0727)	-0.00614 (0.0485)	0.000890 (0.135)	-0.0116 (0.205)
Aggregate gas output (MCFD)	-0.000200 (0.00625)	0.00737 (0.0180)	0.00407 (0.0120)	0.00377 (0.0335)	-0.0120 (0.0508)
Cumulative					
Exploration capex (2005 US\$)	0.0340 (0.0183)	-0.0343 (0.0528)	0.186*** (0.0352)	0.0371 (0.0980)	0.109 (0.149)
Development capex (million 2005 US\$)	-0.00169 (0.00608)	0.0727*** (0.0176)	-0.0547*** (0.0117)	0.0487 (0.0326)	-0.0420 (0.0495)
acquisition capex (million 2005 US\$)	0.00137 (0.00404)	0.0315** (0.0117)	-0.0186* (0.00778)	0.0191 (0.0217)	0.0314 (0.0329)
Aggregate					
exploration capex (million 2005 US\$)	0.0143 (0.0733)	0.0732 (0.212)	-0.0168 (0.141)	0.0104 (0.393)	0.181 (0.596)
development capex (million 2005 US\$)	0.00849 (0.0114)	0.0224 (0.0329)	0.00821 (0.0219)	-0.0103 (0.0611)	0.00210 (0.0926)
acquisition capex (million 2005 US\$)	-0.00572 (0.0109)	-0.0300 (0.0315)	-0.00720 (0.0210)	0.00700 (0.0584)	-0.0250 (0.0886)
Aggregate oil reserves (million barrels)	-0.00480 (0.00553)	-0.0198 (0.0160)	-0.00717 (0.0106)	-0.00923 (0.0296)	-0.00395 (0.0449)
Aggregate gas reserves (BCF)	0.000108 (0.000218)	0.000539 (0.000630)	0.000304 (0.000420)	0.000799 (0.00117)	0.000647 (0.00177)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.11: (continued)

	<i>Dependent variable is:</i>				
	Oil output	Natural gas output	Exploration capex	Development capex	Acquisition capex
World GDP per capita (2005 US\$)	-1.234 (2.275)	-6.065 (6.567)	-3.163 (4.377)	-5.290 (12.19)	7.063 (18.49)
Percentage of state ownership	1.158** (0.426)	-7.148*** (1.230)	-3.318*** (0.820)	-6.515** (2.283)	-2.339 (3.463)
Lag dummy for merger	204.3 (161.0)	1617.3*** (464.7)	-145.3 (309.7)	-421.1 (862.5)	-234.9 (1308.1)
Lag dummy for acquiring another firm	177.2 (92.10)	414.5 (265.9)	-119.1 (177.2)	-122.6 (493.5)	4035.3*** (748.5)
Constant	9036.9 (14302.4)	42039.7 (41292.6)	17489.3 (27522.5)	25295.1 (76637.4)	-33943.4 (116237.7)
N	252	252	252	252	252
R^2	0.933	0.950	0.617	0.748	0.255
Root MSE	206.94	597.46	398.22	1108.9	1681.8

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.12: Oil and natural gas production policy functions for OPEC firms

	<i>Dependent variable is:</i>	
	Oil output	Natural gas output
Avg capital compensation (million 2005 US\$)		
on transport equipment	-4.065 (34.87)	-10.62 (42.65)
on other machinery and equipment	-0.204 (1.402)	-0.834 (1.715)
on total non-residential investment	-0.0981 (0.304)	-0.0783 (0.372)
on other assets	0.459 (2.110)	1.415 (2.581)
Oil reserves (million Barrels)	0.0176*** (0.00144)	0.000415 (0.00176)
Natural gas reserves (BCF)	0.000524 (0.000266)	0.00186*** (0.000326)
Avg weekly earning (2005 US\$)		
on supporting activities in oil and gas	-0.586 (7.484)	-2.412 (9.155)
Cumulative oil output (KBD)	0.0386*** (0.00537)	-0.00133 (0.00657)
Cumulative gas output (MCFD)	0.0119*** (0.00346)	0.103*** (0.00423)
Aggregate oil output (KBD)	0.0282 (0.122)	0.0148 (0.149)
Aggregate gas output (MCFD)	-0.00801 (0.0344)	-0.00309 (0.0421)
Aggregate oil reserves (million barrels)	0.000392 (0.0149)	0.00662 (0.0182)
Aggregate gas reserves (BCF)	-0.0000213 (0.00187)	-0.000514 (0.00229)
World GDP per capita (2005 US\$)	2.316 (7.867)	1.402 (9.624)
World population	-8.492 (38.08)	-8.726 (46.58)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.12: (continued)

	<i>Dependent variable is:</i>	
	Oil output	Natural gas output
Aggregate exploration capex (million 2005 US\$)	-0.00534 (0.226)	0.00711 (0.277)
Aggregate development capex (million 2005 US\$)	0.0110 (0.101)	0.0203 (0.123)
Aggregate acquisition capex (million 2005 US\$)	0.00231 (0.0643)	0.0196 (0.0787)
Constant	30697.6 (205966.5)	36317.5 (251941.4)
N	173	173
R^2	0.900	0.863
Root MSE	725.51	887.45

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.13: Multinomial logit regression of decisions on merger and acquisitions for non-OPEC firms that are not 100% state-owned

	(1)	(2)	(3)	(4)	(5)
0: Base outcome					
1: Merge					
Oil reserves (million barrels)	-0.000969 (0.00115)	-0.0184 (16.30)	-0.000678 (0.000923)	-0.000692 (0.000915)	-0.0241 (38.84)
Natural gas reserves (BCF)	0.000171 (0.000191)	0.00623 (2.830)	0.000106 (0.000155)	0.0000843 (0.000147)	0.00625 (8.071)
Cumulative oil output (KBD)	0.000629 (0.000749)	0.00901 (15.23)	0.000477 (0.000681)	0.000389 (0.000558)	0.0142 (20.92)
Cumulative natural gas output (MCFD)	-0.0000306 (0.000259)	0.00313 (10.78)	-0.0000275 (0.000215)	-0.0000449 (0.000151)	
Avg industry rate of return on capital	-95.99 (64.26)		-65.55 (41.02)		
Avg capital compensation (million 2005 US\$) on other machinery and equipment		-0.964 (212.1)			-0.901 (133.0)
on total non-residential investment	0.00105 (0.00119)	0.00532 (4.109)		0.000208 (0.000715)	0.00519 (2.559)
Percentage of state ownership	-3.835 (601.5)	-5.975 (2604.6)	-3.905 (627.0)	-3.359 (464.2)	-5.160 (1581.6)
Lag dummy for merger	-14.09 (308979.2)	222.8 (1682718.4)	-15.09 (213014.2)	-15.77 (126734.6)	210.2 (1829812.3)
Lag dummy for acquiring another firm	-20.97 (46820.3)	-7.690 (399914.3)	-20.86 (54990.4)	-19.15 (37619.4)	-14.89 (564250.7)
Cumulative exploration capex (million 2005 US\$)	-0.00174	-0.0825	-0.00138	-0.000288	-0.0694

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.13: (continued)

	(1)	(2)	(3)	(4)	(5)
	(0.00175)	(42.33)	(0.00148)	(0.000939)	(22.40)
Cumulative development capex (million 2005 US\$)	0.000363 (0.000457)	0.0163 (4.922)	0.000314 (0.000438)	0.0000469 (0.000327)	0.0152 (4.906)
Cumulative acquisition capex (million 2005 US\$)	-0.000364 (0.000451)	-0.00801 (2.525)	-0.000204 (0.000413)	-0.000237 (0.000368)	-0.00782 (1.918)
Constant	4.092 (4.837)	1377.3 (310162.1)	4.216 (4.736)	-4.408 (2.483)	1290.8 (177846.4)
2: Acquire another firm					
Oil reserves (million barrels)	-0.000999 (0.000571)	-0.000756 (0.000500)	-0.00102 (0.000570)	-0.00108* (0.000533)	-0.000132 (0.000384)
Natural gas reserves (BCF)	-0.000236* (0.000109)	-0.000483* (0.000197)	-0.000234* (0.000108)	-0.000224* (0.000101)	-0.0000764 (0.0000697)
Cumulative oil output (KBD)	0.0000650 (0.000293)	0.000553 (0.000395)	0.0000465 (0.000282)	-0.0000236 (0.000245)	-0.000295 (0.000218)
Cumulative natural gas output (MCFD)	-0.000350* (0.000151)	-0.000708** (0.000273)	-0.000343* (0.000146)	-0.000331* (0.000138)	
Avg industry rate of return on capital	-41.81 (34.26)		-37.44 (25.80)		
Avg capital compensation (million 2005 US\$)					
on other machinery and equipment		-0.0109* (0.00513)			-0.00257 (0.00199)
on total non-residential investment	0.000173 (0.000826)	-0.000193 (0.000640)		-0.000366 (0.000586)	-0.000747 (0.000513)
Percentage of state ownership	-0.0203 (0.0534)	-0.0880 (0.0583)	-0.0148 (0.0459)	-0.0129 (0.0448)	-0.00616 (0.0382)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.13: (continued)

	(1)	(2)	(3)	(4)	(5)
Lag dummy for merger	-23.17 (139116.7)	-25.86 (1075955.0)	-22.41 (95709.8)	-21.00 (52089.2)	-26.71 (1071192.3)
Lag dummy for acquiring another firm	-22.49 (53086.1)	-29.56 (369831.2)	-21.74 (37340.2)	-20.94 (26521.0)	-27.23 (503787.3)
Cumulative exploration capex (million 2005 US\$)	0.00136 (0.000854)	0.00127 (0.00101)	0.00142 (0.000802)	0.00162* (0.000792)	0.00170 (0.000945)
Cumulative development capex (million 2005 US\$)	0.0000737 (0.000291)	0.000293 (0.000423)	0.0000560 (0.000276)	0.0000163 (0.000259)	-0.000403 (0.000305)
Cumulative acquisition capex (million 2005 US\$)	0.000314* (0.000146)	0.000376* (0.000162)	0.000329* (0.000133)	0.000326* (0.000141)	0.000186 (0.000103)
Constant	0.817 (2.967)	15.15 (8.012)	0.822 (2.964)	-2.402 (1.901)	2.439 (3.743)
<i>N</i>	244	244	244	244	244
pseudo R^2	0.484	0.724	0.474	0.420	0.553

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.14: Logit regression of decisions on selling (being acquired) for non-OPEC firms that are not 100% state-owned

	(1)	(2)	(3)	(4)	(5)
Oil reserves (million barrels)	-0.000225 (0.000239)	-0.000217 (0.000239)	-0.000198 (0.000239)	-0.000110 (0.000231)	-0.000262 (0.000173)
Natural gas reserves (BCF)	-0.0000643 (0.0000702)	-0.0000640 (0.0000704)	-0.0000706 (0.0000733)	-0.0000816 (0.0000761)	-0.0000576 (0.0000644)
Cumulative oil output (KBD)	0.0000341 (0.000193)	0.0000391 (0.000203)	0.0000279 (0.000204)	0.00000187 (0.000182)	0.0000868 (0.0000807)
Cumulative natural gas output (MCFD)	0.0000140 (0.0000566)	0.0000151 (0.0000587)	0.0000234 (0.0000597)	0.0000277 (0.0000543)	
Avg industry rate of return on capital	-41.99** (15.79)		-31.07* (12.13)		
Avg capital compensation (million 2005 US\$)					
on other machinery and equipment		-0.00365* (0.00159)			-0.00367* (0.00159)
on total non-residential investment	0.000364 (0.000256)	-0.000117 (0.000201)		-0.0000388 (0.000146)	-0.000112 (0.000200)
Percentage of state ownership	-0.00456 (0.0158)	-0.00743 (0.0155)	-0.00152 (0.0153)	-0.00413 (0.0145)	-0.00904 (0.0143)
Constant	0.947 (1.546)	3.846 (2.757)	0.908 (1.507)	-3.035*** (0.703)	3.909 (2.747)
<i>N</i>	574	600	574	600	600
pseudo <i>R</i> ²	0.158	0.171	0.138	0.057	0.171

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.15: Estimated transition densities for oil and natural gas reserves and state ownership

	<i>Dependent variable is:</i>		
	Oil reserves (million barrels)	Natural gas reserves (BCF)	percentage of state ownership
Lag oil reserves (million barrels)	0.774*** (0.0590)	-0.789*** (0.127)	-0.000521 (0.000424)
Lag natural gas reserves (BCF)	-0.00558 (0.0175)	0.941*** (0.0378)	0.000337** (0.000125)
Lag oil output (KBD)	1.785*** (0.460)	7.502*** (0.993)	0.00379 (0.00331)
Lag natural gas output (MCFD)	-0.142 (0.129)	-0.585* (0.278)	-0.00237* (0.000924)
Lag exploration capex (million 2005 US\$)	-0.353 (0.304)	-1.077 (0.655)	-0.00263 (0.00218)
Lag development capex (million 2005 US\$)	-0.0513 (0.113)	0.0464 (0.244)	0.000445 (0.000814)
Lag acquisition capex (million 2005 US\$)	-0.0206 (0.0492)	-0.0896 (0.106)	-0.000134 (0.000354)
Lag Percentage of state ownership	-4.954 (3.254)	-5.762 (7.024)	0.868*** (0.0233)
Lag dummy for merger	4199.2*** (995.3)	13760.5*** (2148.5)	-0.0118 (7.160)
Lag dummy for acquiring another firm	1147.0* (540.3)	6993.3*** (1166.3)	-2.989 (3.886)
Constant	319.1 (184.2)	30.32 (397.6)	1.372 (1.307)
<i>N</i>	249	249	252

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.15: (continued)

	<i>Dependent variable is:</i>		
	Oil reserves (million barrels)	Natural gas reserves (BCF)	percentage of state ownership
R^2	0.913	0.968	0.920
Root MSE	1381.7	2982.8	9.9398

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.16: Estimated transition density for world population

<i>Dependent variable is:</i>	
World population (million people)	
Lag world population (million people)	0.994*** (0.000149)
Constant	116.8*** (0.890)
N	1203
R^2	1.000
Root MSE	2.8701

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.17: Estimated transition density for GDP per capita

<i>Dependent variable is:</i>	
World GDP per capita (2005 US\$)	
Lag world GDP per capita (2005 US\$)	1.003*** (0.00411)
Constant	71.11** (26.59)
N	1203
R^2	0.980
Root MSE	95.064

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.18: Estimated transition densities for regional population

	<i>Dependent variable is:</i> Regional population					
	Africa	Asia and Oceania	Eurasia	Europe	Middle East	Americas
Lag regional population	1.022*** (0.000793)	0.982*** (0.000535)	0.815*** (0.0797)	0.979*** (0.0192)	1.014*** (0.00553)	0.991*** (0.00132)
Constant	2377399.5** (632438.5)	102604406.2*** (1781063.3)	53407212.6* (22869701.1)	14702775.6 (11008355.2)	1865626.2 (927779.4)	18512826.5*** (1082268.0)
N	24	24	24	24	24	24
R^2	1.000	1.000	0.826	0.992	0.999	1.000
Root MSE	5.2e5	8.0e5	9.8e5	1.6e6	7.6e5	4.9e5

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.19: Estimated transition densities for regional GDP

	<i>Dependent variable is:</i> Regional GDP (2005 US\$)					
	Africa	Asia and Oceania	Eurasia	Europe	Middle East	Americas
Lag regional GDP	1.153*** (0.0439)	1.151*** (0.0379)	1.062*** (0.0862)	1.005*** (0.0520)	1.146*** (0.0597)	1.041*** (0.0221)
Constant	-4.48941e+10 (3.83697e+10)	-6.11064e+11 (3.56436e+11)	5.56731e+10 (8.55987e+10)	5.59495e+11 (6.42472e+11)	-3.05928e+10 (5.78489e+10)	1.92957e+11 (3.03131e+11)
N	24	24	24	24	24	24
R^2	0.969	0.977	0.873	0.944	0.944	0.990
Root MSE	9.2e10	6.6e11	2.5e11	1.1e12	1.5e11	5.1e11

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.20: Estimated transition density for avg industry rate of return on capital

	<i>Dependent variable is:</i> Avg industry rate of return on capital for mining and quarry
Lag avg industry rate of return on capital for mining and quarry	-1.005*** (0.0295)
Lag aggregate oil reserves (million Barrels)	0.000000987*** (2.86e-08)
Lag aggregate natural gas reserves (BCF)	-5.80e-08*** (2.11e-09)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	-0.0000540*** (0.00000144)
on total non-residential investment	0.00000925*** (0.00000105)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	0.00000241*** (0.000000115)
Lag world population (million people)	-0.000926*** (0.0000281)
Lag world GDP per capita (2005 US\$)	-0.0000776*** (0.00000757)
Lag world electricity production (kWh) from natural gas sources	2.98e-13*** (9.28e-15)
from oil sources	-1.03e-12*** (2.45e-14)
Lag aggregate output of all firms Oil (KBD)	0.000000341 (0.000000325)
Natural gas (MCFD)	-0.00000177*** (0.000000121)
Constant	4.296*** (0.0779)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.20: (continued)

<i>Dependent variable is:</i>	
Avg industry rate of return on capital for mining and quarry	
N	750
R^2	0.970
Root MSE	0.00613

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.21: Estimated transition density for avg capital compensation on other machinery and equipment

	<i>Dependent variable is:</i> Avg capital compensation on other machinery and equipment
Lag avg industry rate of return on capital for mining and quarry	1365.0*** (348.4)
Lag aggregate oil reserves (million barrels)	0.0196*** (0.000348)
Lag aggregate natural gas reserves (BCF)	-0.00105*** (0.0000287)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	0.0439* (0.0188)
on total non-residential investment	-0.0155 (0.0129)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	0.0479*** (0.00123)
Lag world population (million people)	-12.85*** (0.288)
Lag world GDP per capita (2005 US\$)	-4.037*** (0.103)
Lag world electricity production (kWh) from natural gas sources	5.33e-09*** (1.26e-10)
from oil sources	-3.48e-09*** (2.70e-10)
Lag aggregate output of all firms Oil (KBD)	-0.100*** (0.00431)
Natural gas (MCFD)	-0.00540*** (0.00152)
Constant	48009.7*** (1023.5)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.21: (continued)

<i>Dependent variable is:</i>	
Avg capital compensation on other machinery and equipment	
N	799
R^2	0.984
Root MSE	84.461

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.22: Estimated transition density for avg capital compensation on total non-residential investment

	<i>Dependent variable is:</i> Avg capital compensation on total non-residential investment
Lag avg industry rate of return on capital for mining and quarry	-9793.8*** (1027.7)
Lag aggregate oil reserves (million barrels)	0.0238*** (0.00103)
Lag aggregate natural gas reserves (BCF)	-0.00133*** (0.0000847)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	-1.862*** (0.0554)
on total non-residential investment	0.288*** (0.0382)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	0.0913*** (0.00363)
Lag world population (million people)	-18.10*** (0.850)
Lag world GDP per capita (2005 US\$)	2.459*** (0.303)
Lag world electricity production (kWh) from natural gas sources	2.57e-09*** (3.73e-10)
from oil sources	-2.77e-08*** (7.96e-10)
Lag aggregate output of all firms Oil (KBD)	-0.221*** (0.0127)
Natural gas (MCFD)	-0.0479*** (0.00447)
Constant	52944.6*** (3018.8)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.22: (continued)

<i>Dependent variable is:</i>	
Avg capital compensation on total non-residential investment	
N	799
R^2	0.988
Root MSE	249.12

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.23: Estimated transition density for world road sector gasoline fuel consumption

	<i>Dependent variable is:</i> World road sector gasoline fuel consumption (kt of oil equivalent)
Lag avg industry rate of return on capital for mining and quarry	-67174.8*** (7757.0)
Lag aggregate oil reserves (million barrels)	0.0681*** (0.00774)
Lag aggregate natural gas reserves (BCF)	-0.00510*** (0.000639)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	-3.795*** (0.418)
on total non-residential investment	1.360*** (0.288)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	0.656*** (0.0274)
Lag world population (million people)	125.3*** (6.413)
Lag world GDP per capita (2005 US\$)	-40.56*** (2.286)
Lag world electricity production (kWh) from natural gas sources	-5.56e-08*** (2.81e-09)
from oil sources	-8.99e-08*** (6.01e-09)
Lag aggregate output of all firms Oil (KBD)	2.995*** (0.0960)
Natural gas (MCFD)	0.378*** (0.0338)
Constant	-226225.2*** (22785.8)
<i>N</i>	799
<i>R</i> ²	0.998
Root MSE	1880.3

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.23: (continued)

Dependent variable is:
World road sector gasoline fuel
consumption (kt of oil equivalent)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.24: Estimated transition density for world motor vehicles

	<i>Dependent variable is:</i> World motor vehicles (per 1,000 people)
Lag aggregate oil reserves (million barrels)	-0.000708*** (0.000154)
Lag avg capital compensation (million 2005 US\$) on total non-residential investment	0.0283** (0.0102)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	0.000419* (0.000200)
Lag world motor vehicles (per 1,000 people)	1.232*** (0.341)
Lag world electricity production (kWh) from natural gas sources	-1.25e-10*** (3.35e-11)
from oil sources	7.30e-11 (1.53e-10)
Lag aggregate oil output of all firms (KBD)	0.0144*** (0.00355)
Constant	-375.4 (384.0)
N	432
R^2	0.847
Root MSE	4.2212

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.25: Estimated transition density for world electricity production from natural gas sources

	<i>Dependent variable is:</i> World electricity production from natural gas sources (kWh)
Lag avg industry rate of return on capital for mining and quarry	-1.00546e+12*** (5.49455e+10)
Lag aggregate oil reserves (million barrels)	667398.1*** (54844.7)
Lag aggregate natural gas reserves (BCF)	-1946.8 (4529.8)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	-137198427.2*** (2959959.6)
on total non-residential investment	-38581285.1*** (2040441.5)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	-958016.6*** (193818.5)
Lag world population (million people)	1.23760e+09*** (45427800.1)
Lag world GDP per capita (2005 US\$)	447240369.9*** (16189014.5)
Lag world electricity production (kWh) from natural gas sources	-0.391*** (0.0199)
from oil sources	-2.678*** (0.0425)
Lag aggregate output of all firms Oil (KBD)	27159110.5*** (680113.6)
Natural gas (MCFD)	11117179.1*** (239226.4)
Constant	-6.26490e+12*** (1.61399e+11)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.25: (continued)

<i>Dependent variable is:</i>	
World electricity production from natural gas sources (kWh)	
N	799
R^2	1.000
Root MSE	1.3e10

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.26: Estimated transition density for world electricity production from oil sources

	<i>Dependent variable is:</i> World electricity production from oil sources (kWh)
Lag avg industry rate of return on capital for mining and quarry	-1.29705e+12*** (4.12199e+10)
Lag aggregate oil reserves (million barrels)	-554911.8*** (41144.2)
Lag aggregate natural gas reserves (BCF)	48747.4*** (3398.2)
Lag avg capital compensation (million 2005 US\$) on other machinery and equipment	21049440.2*** (2220549.6)
on total non-residential investment	22978949.9*** (1530730.9)
Lag world road sector gasoline fuel consumption (kt of oil equivalent)	-116019.6 (145401.9)
Lag world population (million people)	-70654784.0* (34079749.4)
Lag world GDP per capita (2005 US\$)	127831765.8*** (12144932.3)
Lag world electricity production (kWh) from natural gas sources	-0.186*** (0.0150)
from oil sources	-0.0661* (0.0319)
Lag aggregate output of all firms Oil (KBD)	10355770.0*** (510218.5)
Natural gas (MCFD)	-555873.4** (179466.7)
Constant	1.18372e+12*** (1.21081e+11)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.26: (continued)

	<i>Dependent variable is:</i> World electricity production from oil sources (kWh)
Observations	799
R^2	0.988
Root MSE	1.0e10

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.27: Summary statistics for action variables predicted by structural model (2000-2005)

Variable	All firms		OPEC firms		Non-OPEC firms	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Oil output (KBD)	1503.514 *** (43.788)	1796.073 *** (71.594)	2512.852 *** (160.515)	2562.346 *** (113.881)	1028.842 *** (11.299)	967.779 *** (8.659)
Natural gas output (MCFD)	3874.760 *** (155.890)	7502.254 *** (103.774)	3336.468 *** (231.449)	3383.802 *** (141.766)	4135.609 *** (122.972)	8784.601 *** (124.555)
Capital expenditure on						
Exploration (million 2005 US\$)	679.122 *** (19.319)	897.901 *** (9.175)	1126.927 *** (35.132)	1139.218 *** (10.234)	466.955 *** (20.062)	657.581 *** (11.838)
Development (million 2005 US\$)	1832.241 *** (22.778)	2577.189 *** (21.113)	3091.026 *** (84.241)	3421.532 *** (28.691)	1232.528 *** (15.390)	1766.299 *** (18.242)
Acquisition (million 2005 US\$)	776.833 *** (19.530)	1376.407 *** (26.413)	499.663 *** (8.003)	954.628 *** (8.435)	908.868 *** (27.168)	1517.305 *** (32.139)
Dummy for M&A at time t						
merging	0.174 *** (0.002)	0.379 *** (0.001)			0.225 *** (0.001)	0.418 *** (0.001)
acquiring another firm	0.048 *** (0.004)	0.212 *** (0.009)			0.062 *** (0.005)	0.240 *** (0.010)
being acquired by another firm	0.003 *** (0.000)	0.036 *** (0.002)			0.003 *** (0.000)	0.041 *** (0.003)

Notes: Standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

B Appendix B

Table B.1: Change in prices from base case under merger ban

Crude oil price, Brent (2005 US\$/bbl)	12.8777***
Regional natural gas price (2005 US\$/mmbtu)	
Africa	-0.1626 *
Asia & Oceania	-0.4484 **
Eurasia	0.00437
Europe	-0.0768
Middle East	0.0163
America	-0.0113

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.2: Changes in welfare from base case under different demand shocks

	All firms	OPEC firms	Non-OPEC firms
1: Constant in both oil and all regional natural gas demand functions decreases by 10%			
Expected total firm payoff	-7.8270 ***	-8.3398 ***	0.5129
Expected avg firm payoff	-0.1565 ***	-0.6933 ***	0.0081
Expected total consumer surplus	-1.09E+10 ***		
2: Constant in both oil and all regional natural gas demand functions decreases by 25%			
Expected total firm payoff	-4.5229 ***	-7.2810 ***	2.7582 ***
Expected avg firm payoff	-0.0905 ***	-0.5970 ***	0.0656 ***
Expected total consumer surplus	-5.78E+09 ***		
3: Constant in oil demand function decreases by 10%			
Expected total firm payoff	-4.2786 ***	-5.5973 ***	1.3187 **
Expected avg firm payoff	-0.0856 ***	-0.4439 ***	0.0287 **
Expected total consumer surplus	-1.09E+10 ***		
4: Constant in oil demand function decreases by 25%			
Expected total firm payoff	3.2723 ***	1.8484 ***	1.4239 ***
Expected avg firm payoff	0.0654 ***	0.2330 ***	0.0314 **
Expected total consumer surplus	-3.77E+08		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.3: Changes in welfare from base case under different demand shocks

	All firms	OPEC firms	Non-OPEC firms
5: Constant in natural gas demand function for Africa decreases by 25%			
Expected total firm payoff	-3.1588 ***	-1.6232 ***	-1.5356 ***
Expected avg firm payoff	-0.0632 ***	-0.1475 ***	-0.0395 ***
Expected total consumer surplus	-3.08E+09 ***		
6: Constant in natural gas demand function for Asia & Oceania decreases by 25%			
Expected total firm payoff	8.5882 ***	6.2976 ***	2.2906 ***
Expected avg firm payoff	0.1718 ***	0.6374 ***	0.0537 ***
Expected total consumer surplus	1.01E+10 ***		
7: Constant in natural gas demand function for Eurasia decreases by 25%			
Expected total firm payoff	2.2239 **	-0.0138	2.2377 ***
Expected avg firm payoff	0.0445 **	0.0637	0.0523 ***
Expected total consumer surplus	-9.77E+08		
8: Constant in natural gas demand function for Europe decreases by 25%			
Expected total firm payoff	-3.4513 ***	-1.6069 ***	-1.8444 ***
Expected avg firm payoff	-0.0690 ***	-0.1462 ***	-0.0475 ***
Expected total consumer surplus	-3.38E+09 ***		
9: Constant in natural gas demand function for Middle East decreases by 25%			
Expected total firm payoff	-4.8333 ***	-7.1310 ***	2.2977 ***
Expected avg firm payoff	-0.0967 ***	-0.5834 ***	0.0538 ***
Expected total consumer surplus	-6.08E+09 ***		
10: Constant in natural gas demand function for America decreases by 25%			
Expected total firm payoff	-6.4455 ***	-4.4568 ***	-1.9886 ***
Expected avg firm payoff	-0.1289 ***	-0.4042 ***	-0.0515 ***
Expected total consumer surplus	-5.48E+09 ***		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.4: Changes in welfare from base case under different demand shocks

	All firms	OPEC firms	Non-OPEC firms
11: Constant in natural gas demand function for Africa increases by 25%			
Expected total firm payoff	-10.0762 ***	-6.3787 ***	-3.6974 ***
Expected avg firm payoff	-0.2015 ***	-0.6434 ***	-0.0905 ***
Expected total consumer surplus	-9.88E+09 ***		
12: Constant in natural gas demand function for Asia & Oceania increases by 25%			
Expected total firm payoff	3.3807 ***	0.2934	3.0873 ***
Expected avg firm payoff	0.0676 ***	0.0916 **	0.0741 ***
Expected total consumer surplus	-2.28E+09 ***		
13: Constant in natural gas demand function for Eurasia increases by 25%			
Expected total firm payoff	-1.1374	-0.1513	-0.9862 *
Expected avg firm payoff	-0.0227	-0.0138	-0.0254 *
Expected total consumer surplus	-1.77E+08		
14: Constant in natural gas demand function for Europe increases by 25%			
Expected total firm payoff	-7.2221 ***	-4.8451 ***	-2.3770 ***
Expected avg firm payoff	-0.1444 ***	-0.4386 ***	-0.0615 ***
Expected total consumer surplus	-5.48E+09 ***		
15: Constant in natural gas demand function for Middle East increases by 25%			
Expected total firm payoff	-7.7741 ***	-5.8515 ***	-1.9226 ***
Expected avg firm payoff	-0.1555 ***	-0.5320 ***	-0.0496 ***
Expected total consumer surplus	-1.56E+10 ***		
16: Constant in natural gas demand function for America increases by 25%			
Expected total firm payoff	-1.1550	-3.9475 ***	2.7925 ***
Expected avg firm payoff	-0.0231	-0.2939 ***	0.0665 ***
Expected total consumer surplus	-7.58E+09 ***		

Notes: Firm payoffs and consumer surplus are in billion dollars per year.

Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.