THE JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY
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EMPIRICAL EVIDENCE ON THE OPERATIONAL EFFICIENCY OF NATIONAL OIL COMPANIES

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ABOUT THE POLICY REPORT

THE CHANGING ROLE OF NATIONAL OIL COMPANIES IN INTERNATIONAL ENERGY MARKETS

Of world proven oil reserves of 1,148 billion barrels, approximately 77% of these resources are under the control of national oil companies (NOCs) with no equity participation by foreign, international oil companies. The Western international oil companies now control less than 10% of the world's oil and gas resource base. In terms of current world oil production, NOCs also dominate. Of the top 20 oil producing companies in the world, 14 are NOCs or newly privatized NOCs. However, many of the Western major oil companies continue to achieve a dramatically higher return on capital than NOCs of similar size and operations.

Many NOCs are in the process of reevaluating and adjusting business strategies, with substantial consequences for international oil and gas markets. Several NOCs have increasingly been jockeying for strategic resources in the Middle East, Eurasia, and Africa, in some cases knocking the Western majors out of important resource development plays. Often these emerging NOCs have close and interlocking relationships with their national governments, with geopolitical and strategic aims factored into foreign investments rather than purely commercial considerations. At home, these emerging NOCs fulfill important social and economic functions that compete for capital budgets that might otherwise be spent on more commercial reserve replacement and production activities.

The Baker Institute Policy Report on NOCs focuses on the changing strategies and behavior of NOCs and the impact NOC activities will have on the future supply, security, and pricing of oil. The goals, strategies, and behaviors of NOCs have changed over time. Understanding this transformation is important to understanding the future organization and operation of the international energy industry.

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Empirical Evidence on the Operational Efficiency of National Oil Companies

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I. Introduction

In a related working paper in the study "A Model of the Operation and Development of a National Oil Company," Hartley and Medlock (2007) developed and analyzed a theoretical model of the operation and development of a National Oil Company (NOC). Key conclusions of their analysis are that, relative to an economically efficient producer, a NOC is likely to favor excessive employment and is likely to be forced to sell oil products to domestic consumers at subsidized prices. In addition, as a result of aiming to meet non-commercial objectives, a NOC is likely to under-invest in reserves and shift extraction of resources away from the future toward the present. The analysis in this paper uses a sample of 80 firms over a period of three years (from 2002-2004) to assess whether there is any empirical evidence that is consistent with the predictions of the theoretical model. Namely, we seek to test if the goals and consequent behavior of a NOC are likely to differ from the goals and operating decisions of a privately owned firm exploiting a similar resource base. The theoretical model developed by Hartley and Medlock therefore motivated our selection of variables. The data includes revenue, reserves of natural gas and crude oil, employment, production of natural gas and crude oil and crude oil products, and the share of government ownership. We use both non-parametric Data Envelopment Analysis (DEA) and a parametric Stochastic Frontier Approach to examine the relative operating efficiencies of the different firms in the sample.

Output-oriented technical efficiency (TE) measures construct a production frontier by standardizing measures of inputs and outputs and comparing firms based on these metrics. Specifically, the DEA technique calculates the degree to which a firm maximizes the production of outputs for a given level of inputs on a scale from 0 to 1. By definition, a firm with a technical efficiency measure of 1 fully maximizes production given the inputs it employs. Such firms are classified as operationally efficient and are said to be *on* the frontier. Firms with a TE measure less than 1 are classified as *operationally* inefficient and are said to be *off* the frontier. For example, a firm with a technical efficiency measure of 0.5 is producing only 50% of the output it has the "technical" capability to produce.

The stochastic frontier TE measure uses panel data for the years 2002 through 2004 to estimate a regression equation. In addition to identifying relevant inputs and outputs, this technique has to specify a structural relationship between the inputs and outputs, including how stochastic terms are assumed to arise. If these auxiliary assumptions are inaccurate, the resulting inferences of the underlying model may be compromised. In this sense, the non-parametric DEA approach is more robust. DEA requires no assumptions regarding functional form of the production technology and is not subject to the potential problems of assuming an underlying distribution of the error term. On the other hand, the stochastic frontier method allows for a more direct accounting of various factors that influence firm behavior. It also is more flexible in the types of variables one can include in the analysis and provides a statistical measure of how well the proposed model explains the data. Furthermore, since DEA does not account for statistical noise, estimates of technical efficiency will be biased when stochastic elements (factors characterized by randomness and uncertainty) are a prominent feature of the true production process or the variables used in the analysis are measured with error. Thus, the two analyses are highly complementary.

In this study, we use revenue generated by the firm as the measure of output rather than physical quantities of products produced. The main reason for doing so is that the theoretical model identified revenue as a key objective for both public and private firms. In addition, as noted above, Hartley and Medlock argued that political pressure is likely to reduce the revenue generated by a NOC from given inputs of employment and reserves partly because of pressure to sell products to domestic consumers at subsidized prices. The major effect of such subsidies on net income produced by the firm would not be captured by physical output measures.

It can be problematic to label NOC's as "inefficient" in producing income compared to privately owned oil companies because the NOC's may be maximizing an objective function in which income is only one argument. For example, the model presented in Hartley and Medlock results in a firm that is technically efficient in the sense that it maximizes its objective. Nevertheless, the extent to which firms differ with regard to the amount of revenue they generate for a given vector of inputs can be used to judge the extent to which their objectives truly differ as hypothesized in the theoretical analysis. In fact, to summarize the results, we will demonstrate below that the positions of NOC's and privately owned firms relative to the frontier can be explained in large part by factors that differentiate their respective objective functions. In particular, we identify subsidized domestic oil and gas prices and employment used for political ends as major factors that tend to move firms away from the frontier.

It is important to stress that the TE measures we calculate are consistent with a specific input-output bundle, and therefore they need not correspond to ordinary English language usage of the word "efficient" or even the economic definition of "efficiency" as Pareto optimality. The TE measures merely evaluate the degree to which a firm maximizes revenue for a given level of employment and reserves. The social welfare benefits generated by a NOC are not reflected directly by the measure of technical efficiency so constructed. Nevertheless, in so far as this analysis supports the theoretical framework developed in Hartley and Medlock, we can be more confident using that framework to understand how NOC's are likely to behave in response to various shocks. Such an understanding is becoming more critical to analyzing global oil market outcomes as NOC's become more dominant players in the world oil market.

This chapter is organized as follows: Section II provides a brief summary of the methods used to estimate technical efficiency, and section III analyzes the previous literature on the efficiency of NOC's. The data is described in section IV. The results are presented and discussed in section V, followed by some concluding remarks.

II. ESTIMATING ECONOMIC EFFICIENCY

Farrell (1957) defined output-oriented technical efficiency (*TE*) as a firm's ability to maximize output for a given set of inputs. If a firm's observed output for a given level of inputs is best in practice, the firm is defined to be *on* the frontier. In order to identify the best practice, Farrell suggested constructing a piecewise-linear convex hull of observed input-output bundles. Afriat (1972) and Boles (1966) later used non-parametric mathematical programming (later termed DEA) to identify such a piecewise linear convex hull. To illustrate the concept, consider a simple example in which constant returns to scale technology uses one input, denoted x, to produce one output, denoted y. Also, suppose the production function can be written as $y = f(x)$. This function defines the production frontier as it describes the maximum output achievable from a given input. Moreover, it permits the direct calculation of technical efficiency.

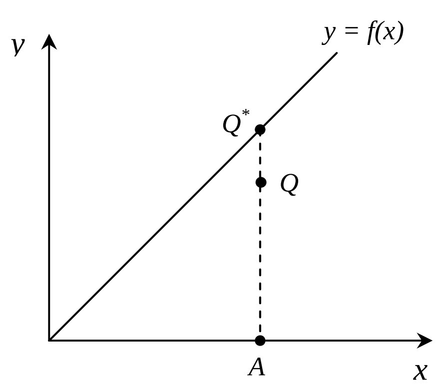

Figure 1 – A graphical description of technical efficiency

As illustrated in Figure 1, a firm producing at point Q can increase production to point Q^* on the efficient production frontier without increasing the use of input x. This distance can be written as QQ^*. Output-oriented technical efficiency measures the ratio of output actually achieved to the efficient output, so that $TE = AQ/AQ^*$. If $TE = 1$ we say the firm is producing the most it can given its inputs, and is therefore technically efficient.

More specifically, the DEA linear programming problem constructs a non-parametric frontier that envelops the set of observations such that no input-output bundle lies above the production frontier. Suppose we have data for N firms each using K inputs and producing M outputs. Defining X as the $K \times N$ matrix of inputs and Y as the $M \times N$ matrix of outputs, let x_n and denote the use of K inputs in the production of M outputs for firm n. The output-oriented technical efficiency of each firm is then calculated by solving the following linear program:

$$\max_{\lambda,\theta} \theta$$

subject to:

$$-\theta y_n + Y\lambda \geq 0$$

$$x_n - X\lambda \geq 0$$

$$\lambda \geq 0$$

where $1 \le \theta \le \infty$ is a scalar and λ is an $N \times 1$ vector of constants. The technical efficiency score is then defined as $1/\theta$, and, by definition, θ^{-1} is the maximum proportional increase in outputs possible for a given set of inputs.

The other method employed in this paper, stochastic frontier analysis, was introduced simultaneously by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977).[1] To begin, we specify a single output production function with *k* inputs $(k = 1, ..., K)$ for *n* firms $(n = 1, ..., N)$ across *t* time periods $(t = 1, ..., T)$ to be given as $y_{n,t} = f\left(x_{1,n,t}, ..., x_{K,n,t}\right)$. If we suppose the production technology can be represented as Cobb-Douglas, then we can linearize the production function by taking the natural logarithm, and write it as

$$\ln y_{n,t} = \alpha + \sum_{k=1}^{K} \beta_k \ln x_{k,n,t} .$$

This specification, however, does not allow for random factors that could arise, for example, from unusual weather or other natural events, unmeasured inputs for a given form that are randomly distributed over time, or measurement errors for the inputs or outputs. More specifically, however, it also does not allow for variation in technical efficiency across firms. Therefore, we allow for a random shock, denoted as $v_{n,t}$, and firm-specific time-invariant technical inefficiency, denoted as u_n $(0 \le u_n \le 1)$, to obtain the following equation to be estimated

$$\ln y_{n,t} = \alpha + \sum_{k=1}^{K} \beta_k \ln x_{k,n,t} + v_{n,t} + u_n .$$

[1] See Kumbhakar and Lovell (2000) for a thorough survey of stochastic frontier analysis.

Once a distribution for the error terms has been specified, this particular expression can be estimated using maximum likelihood, and provides a direct estimate of technical inefficiency.[2] The additional term in the regression equation, $v_{i,t} + u_i$, allows for firms to be some distance from the frontier. In particular, when $u_i \neq 0$ firm *i* is technically inefficient, or *off* the frontier.

III. PREVIOUS LITERATURE

While the economic literature is rich with examples of estimating technical efficiency in many different industries, such as the airline industry, we know of only one article by Al-Obaidan and Scully (1991), which examined the relative efficiencies of NOC's using parametric techniques. We could not find any studies using non-parametric techniques to investigate the relative efficiencies of NOC's. One potential explanation is the paucity of data on non-publicly traded firms. Regardless of the reason, this paper is relatively novel in its application.

Using data for 44 firms in a single year, 1981, Al-Obaidan and Scully construct a production frontier using multiple parametric methods: (1) an Aigner-Chu deterministic frontier, (2) a stochastic frontier, and (3) a maximum likelihood gamma frontier.[3] Specifically, they examined the ability of firms to use assets and employees to produce output, where output was defined as either revenue earned or the quantity of crude oil

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[2] The equation is estimated using maximum likelihood. In our analysis, we assume that u_i is i.i.d. truncated-normal at zero with mean μ and variance σ_u^2, $v_{i,t}$ is i.i.d. normal with mean zero and variance σ_v^2, and u_i and $v_{i,t}$ are independently distributed from each other.

[3] The Aigner-Chu deterministic frontier assumes no random component to the error term, but is one-sided. The stochastic frontier is exactly as discussed in the preceding section. The maximum likelihood gamma frontier is similar to the stochastic frontier, but the terms u_i and $v_{i,t}$ are gamma distributed.

produced plus the quantity of crude oil processed. They found that NOCs are only 63% to 65% as technically efficient relative to private firms.

Although we find results that are generally consistent with those of Al-Obaidan and Scully, our study differs in many respects. Most differences involve the data used in the analysis and will be highlighted in the next section. One crucial departure is that they omit all OPEC nations, whereas we do not.[4] In addition, their study considers only vertically integrated firms, omitting firms that have operations only in the downstream or upstream sectors. In contrast, we omit only firms that specialized in the downstream sector.[5] The other key difference that bears mention here is that our study uses panel data rather than the cross-section approach used by Al-Obaidan and Scully. Since the publication of the Al-Obaidan and Scully article, significant advances have been made in the estimation of stochastic production frontiers. Specifically, Battese, Coelli and Colby (1989) developed a framework to estimate a stochastic production frontier for a set of panel data where technical efficiency is assumed to be time-invariant. The use of panel data adds information to the estimation, when compared to a cross-section approach, by increasing the sample size in the time dimension. It also increases consistency in estimating technical efficiency (see Kumbhakar and Lovell (2000)).

IV. DATA ANALYSIS

This paper focuses on technical efficiency in generating revenue from employees, oil reserves, and natural gas reserves. The analysis covers 80 firms worldwide, including

[4] In fact, they eliminate OPEC members arguing that the demonstrated efficiency of those firms is "related more to the accident of geography than to the allocation of resources within the firm."

[5] We omitted such firms because the theoretical paper by Hartley and Medlock that motivated our analysis assumed that all the firms had mining operations.

9 of OPEC's 11 member nations. Iraq is omitted due to ongoing domestic and petroleum industry turmoil and Libya is omitted due to a lack of relevant data. Since OPEC's role in the international oil markets cannot be overstated, the inclusion of these firms is important when estimating efficiency in the petroleum industry.

As inputs to production, we use oil and gas reserves (measured separately) and total employment. We do not include total assets as an input measure, as in Al-Obaidan and Scully. One reason is that data on total assets is not available for many national oil companies, especially for members of OPEC. Thus, we are able to increase our sample by eight influential firms, including Saudi Aramco, by using total reserves. Another reason for not using total assets is that the value of total assets reported by a firm reflects the book (or accounting) value rather than the true (or economic) value. Although the value of oil and gas reserves is included in the calculation of total assets, cumulative depreciation of non-reserves assets is an accounting measure correlated with the age of the assets, but not necessarily with their productive capability. The accounting measure of asset value is also seriously distorted by inflation, which is important for many of the countries in our sample. Thus, the book value of total assets may be over or understated relative to their economic value as an input to production. Consequently, using asset book value would impact the estimation of technical efficiency in a way that would be difficult to interpret. We avoid this problem by using oil and gas reserves, but potentially introduce another one. Specifically, we must correct for vertical integration since firms engaging in both the upstream (exploration and production) and downstream (refining) operations will record revenue from both the sale of products produced from crude oil along with the external sale of crude to other parties.

Table 1 – Companies with selected statistics

Company	Revenue per Employee *$/employee*	Revenue per Reserves *$/boe*	Government Ownership *%*	Country
		NOCs		
Adnoc	205	0.20	100%	UAE
CNOOC	2,656	2.97	71%	China
EcoPetrol	824	2.26	100%	Colombia
Eni	1,056	10.50	30%	Italy
Gazprom	103	0.16	51%	Russia
INA	187	11.70	75%	Croatia
KMG	n/a	n/a	100%	Kazakhastan
KPC	1,650	0.34	100%	Kuwait
MOL	635	42.37	25%	Hungary
NIOC	283	0.11	100%	Iran
NNPC	1,460	0.56	100%	Nigeria
NorskHydro	673	11.37	44%	Norway
OMV	2,214	8.90	32%	Austria
ONGC	298	2.11	84%	India
PDO	1,591	0.98	60%	Oman
PDVSA	1,985	0.66	100%	Venezuela
Pemex	506	4.01	100%	Mexico
Pertamina	453	0.73	100%	Indonesia
Petrobras	773	3.39	32%	Brazil
PetroChina	111	2.52	90%	China
Petroecuador	1,026	1.25	100%	Ecuador
Petronas	1,202	1.45	100%	Malaysia
PTT	2,896	16.68	100%	Thailand
QP	1,800	0.10	100%	Qatar
Rosneft	86	0.19	100%	Russia
SaudiAramco	2,261	0.40	100%	Saudi Arabia
Sinopec	192	19.76	57%	China
Socar	n/a	n/a	100%	Azerbaijan
Sonangol	755	1.37	100%	Angola
Sonatrach	688	0.93	100%	Algeria
SPC	375	1.71	100%	Syriac
Statoil	1,910	10.85	71%	Norway
TPAO	154	1.53	100%	Turkey
Average	*1,000.27*	*5.23*		
		Major IOCs		
BP	2,788	15.68	0%	UK
Chevron	2,606	12.78	0%	US
ConocoPhillips	3,368	14.03	0%	US
ExxonMobil	3,148	12.26	0%	US
Shell	2,418	21.67	0%	Netherlands
Average	*2,865.48*	*15.28*		

Table 1 (cont.)

Company	Revenue per Employee *$/employee*	Revenue per Reserves *$/boe*	Government Ownership *%*	Country
		Others		
Amerada Hess	1,532	16.07	0%	US
Anadarko	1,838	2.52	0%	US
Apache	2,019	2.71	0%	US
BG	1,547	3.64	0%	UK
Burlington	2,537	2.74	0%	US
Chesapeake Energy	1,577	3.22	0%	US
CNR	4,606	3.85	0%	Canada
Devon	2,356	4.33	0%	US
Dominion	847	13.81	0%	US
EnCana	2,915	4.48	0%	Canada
EOG	1,844	2.38	0%	US
ForestOil	1,841	4.02	0%	US
HuskyEnergy	2,149	9.53	0%	Canada
Imperial	2,838	35.72	0%	Canada
Kerr-McGee	1,263	4.15	0%	US
Lukoil	233	1.68	0%	Russia
Maersk	60	2.90	0%	Denmark
Marathon	1,757	39.14	0%	US
Murphy	1,436	21.60	0%	US
Newfield	2,114	4.45	0%	US
Nexen	1,048	4.25	0%	Canada
NipponOil	2,690	131.74	0%	Japan
Noble	2,433	2.54	0%	US
Novatek	220	0.21	0%	Russia
Occidental	1,577	4.46	0%	US
PennWest	1,577	2.53	0%	Canada
Petro-Canada	2,370	9.24	0%	Canada
PetroKazakhstan	546	4.12	0%	Kazakhstan
Pioneer	1,183	1.76	0%	US
Pogo	5,088	4.38	0%	US
RepsolYPF	1,561	10.79	0%	Spain
Santos	789	1.92	0%	Australia
Sibneft	189	1.81	0%	Russia
Suncor	1,447	78.50	0%	Canada
Surgutneftegas	121	1.01	0%	Russia
Talisman	2,207	3.26	0%	Canada
TNK	63	1.66	0%	Russia
Total	1,406	14.33	0%	France
Unocal	1,259	4.63	0%	US
Vintage	1,136	1.76	0%	US
Woodside	758	2.11	0%	Australia
XTO	1,437	1.94	0%	US
Average	*1,628.94*	*11.24*		

As noted in the introduction, we use revenue as a measure of output because this allows us to capture potential inefficiencies specific to some NOC's. Specifically, since it is common for NOC's to subsidize domestic energy prices, analyzing output as physical quantities of energy production does not capture the inefficiency induced by selling output below market equilibrium prices. Revenue, however, will reflect the degree to which a given quantity of output is sold at below market prices.

We collected data for the top 100 oil firms for the years 2002 through 2004. "Ranking the World's Oil Companies" by *Energy Intelligence* is published annually and served as our primary data source, although company annual reports were used to verify the published data and provide some missing data. After eliminating firms that are primarily engaged in downstream actives and for which relevant data is unavailable, 80 firms remain for our analysis. Table 1 lists the 80 firms in the study, the country of origin, and the percent share of government ownership, and some statistics on revenue per employee and revenue per reserves[6] for the year 2004.

Revenue per employee and revenue per unit reserves are included as indicators of how efficiently each firm produces revenue. Closer examination of the data reveals that the major international oil companies (BP, Chevron, ConocoPhillips, ExxonMobil, and Shell collectively denoted *major* IOC's) fall near the top of all the firms in the sample in both measures. In addition, although NOC's are sprinkled throughout, the bottom 20% is dominated by NOC's. The averages of revenue per employee and revenue per unit reserves, also given in Table 1, indicate a relative ranking in both measures, in descending order, of (1) major IOCs, (2) other firms, and (3) NOCs. All together, the

[6] Reserves are defined as the sum of crude oil reserves and natural gas reserves on a barrel of oil equivalent (boe) basis.

data in Table 1 is consistent with the notion that NOC's tend to engage in over-employment and that resource rents are redistributed away from the NOC.

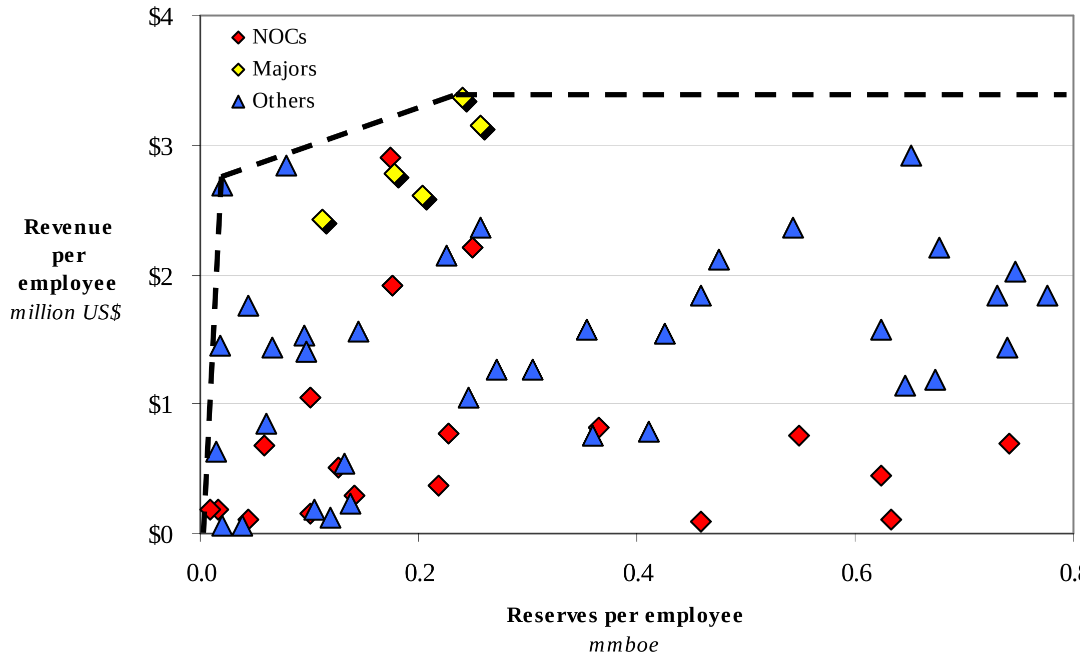

Figure 2 – An illustration of a production frontier

The data from Table 1 is plotted in two dimensions in Figure 2. Also depicted is a piece-wise linear production function constructed by creating the convex hull of observed input-output bundles. This graphic is a simplification of the DEA approach used only for the purpose of illustration. As stated above, our analysis assumes there are three inputs: employees, oil reserves, and natural gas reserves. In order to present the data in only two dimensions the reserves input is defined as the sum of oil and natural gas reserves in barrels of oil equivalent and is normalized, along with revenue, on the number of employees. Using the frontier depicted in Figure 2, technical inefficiency can be calculated using the *vertical* distance of the firm from the frontier.

While Figure 2 is not meant to exactly describe the DEA approach used in this paper, it is informative. For example, a prominent feature of Figure 2 is that the frontier is established by firms with publicly held shares, with the five major IOC's lying near the production frontier.

On average it appears that technical efficiency for NOC's is lower than for privately owned firms, but there is a high degree of diversity among all firms. Such diversity results because the frontier constructed in Figure 2 does not account for the different objectives and strategies of petroleum firms. For example, the data includes companies that are vertically integrated to varying degrees. In the subsequent formal analysis, we shall measure vertical integration, or the degree to which a firm is involved in both upstream and downstream activities, by petroleum product sales divided by total liquids production. Vertical integration can influence a firm's estimated technical efficiency because a vertically integrated firm that refines most of its own production obtains additional revenue from the value added by the internal sale of raw crude oil to its refining unit. Furthermore, since we are not measuring the capital employed in the refining, transporting and marketing operations as inputs, a vertically integrated firm would appear to be technically efficient relative to other firms since it would appear to be able to generate the higher valued output using additional employees alone.

Most critical to our purpose of testing the theoretical framework of Hartley and Medlock (2007), government ownership (indicated in Table 1) may also affect measured technical efficiency in producing revenue from employees and reserves. NOCs are diverse due to the wide range of government control of the petroleum industry.

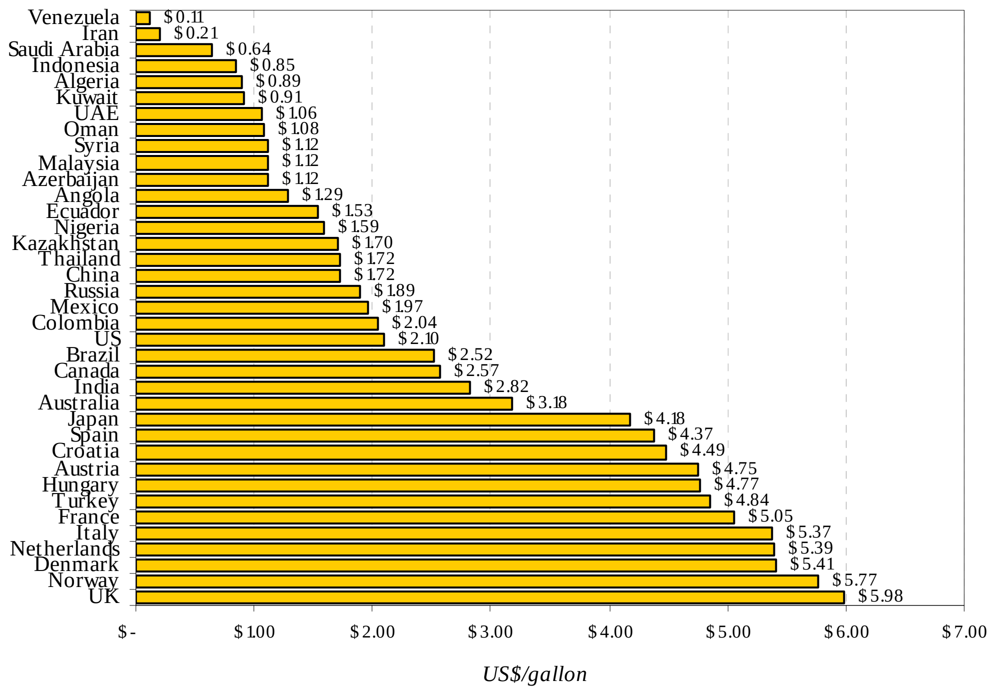

Figure 3 – Simple average of domestic motor fuel prices

The theoretical paper by Hartley and Medlock identified that subsidizing domestic prices of oil products (sometimes referred to as two-tier pricing) may be one way in which government ownership of a NOC could compromise its ability to produce revenue. Figure 3 ranks the domestic pump prices of automotive super gasoline and diesel fuel obtained from the World Bank's *World Development Indicators Online* for 2002 and 2004. The data reveal that exporting countries with a NOC generally have the lowest domestic price of gasoline, which is indicative of the host government using the country's resource position to garner favor among its domestic constituency. The price indicated in Figure 3 is the simple average of the two prices in 2004. We use the information in Figure 3 to define an indicator variable for two-tier pricing to indicate which countries subsidize domestic prices. While a rough approximation, every country with price below the United States is assumed to engage in two-tier pricing.

V. RESULTS

Non-parametric data envelopment analysis

The output-oriented technical efficiency measure of each firm is calculated by constructing the piecewise linear convex hull of the observed input-output bundles for each year.[7] Revenue is used as the measure of output and employees, oil reserves, and natural gas reserves are included as inputs for 76 firms covering the years 2002 through 2004. Figure 4 graphs the average technical efficiency score for each firm across the three years. In summary, the IOC's are clustered near the frontier, while the NOC's tend to be clustered near the bottom. For the NOC's the average technical efficiency measure is about 0.27. This compares to a sample average for all firms of 0.40 and 0.73 for the five major IOC's.

There are various factors that can influence the relative rankings of such a wide variety of firms, especially when the generation of revenue is the only measured objective. For instance, if the objective function of the NOC includes political variables apart from revenue, as outlined in Hartley and Medlock, then that firm might be expected to be *off* the revenue frontier when compared to a firm with no such objectives.

[7] Calculations were performed using Coelli's software program *DEAP Version 2.1*.

Therefore, we included two additional input variables, vertical integration and share of government ownership, in the DEA analysis to see whether they can account for deviations from the frontier.

Recall, the technical efficiency measure in this application is aimed at showing how well the firm combines inputs to generate revenue. Vertical integration and government ownership share are structural and institutional features of the firm, respectively, that may each play a role in determining how well the firm is able to transform employees and reserves into revenue. There may be other factors that also matter in individual cases, but the point of this exercise is to attempt to explain systematic influences on technical efficiency and more specifically to understand if there are any systematic differences between NOC's and other firms.

Figure 5 illustrates the cumulative effects of the included structural and institutional variables on the measured technical efficiency of each firm. Specifically, including measures of vertical integration in Model 2 and vertical integration and the share of government ownership in Model 3, we see that, for many firms, the inefficiency observed in Model 1 can to a large extent be explained. As we move from Model 1 to Model 2 to Model 3, an increasing number of firms move to the estimated technically efficient frontier, increasing from 2 to 12 to 25, respectively. The sample average technical efficiency measures are summarized in Table 3.

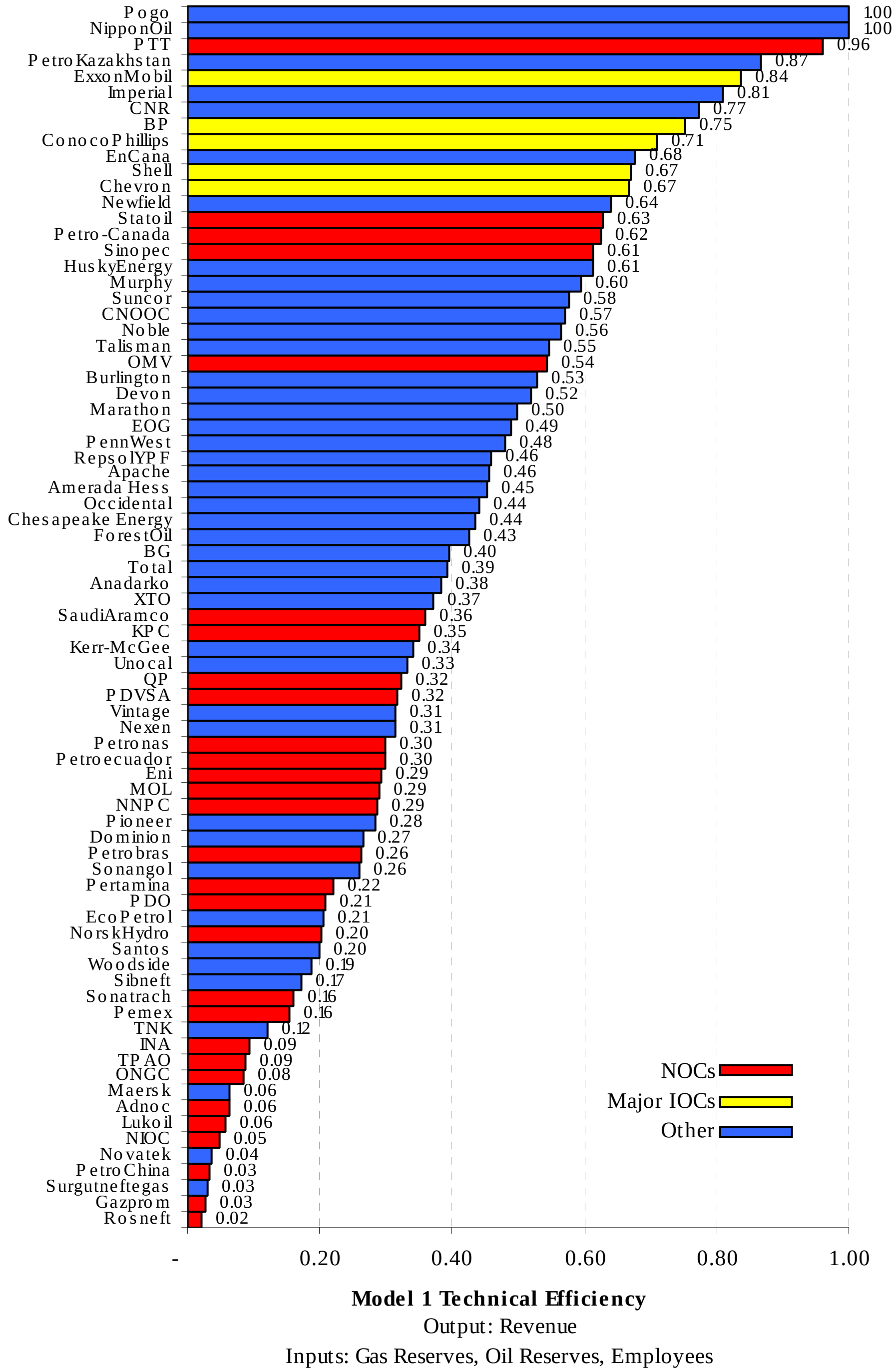

Figure 4 – Firm-specific technical efficiency (average) by model

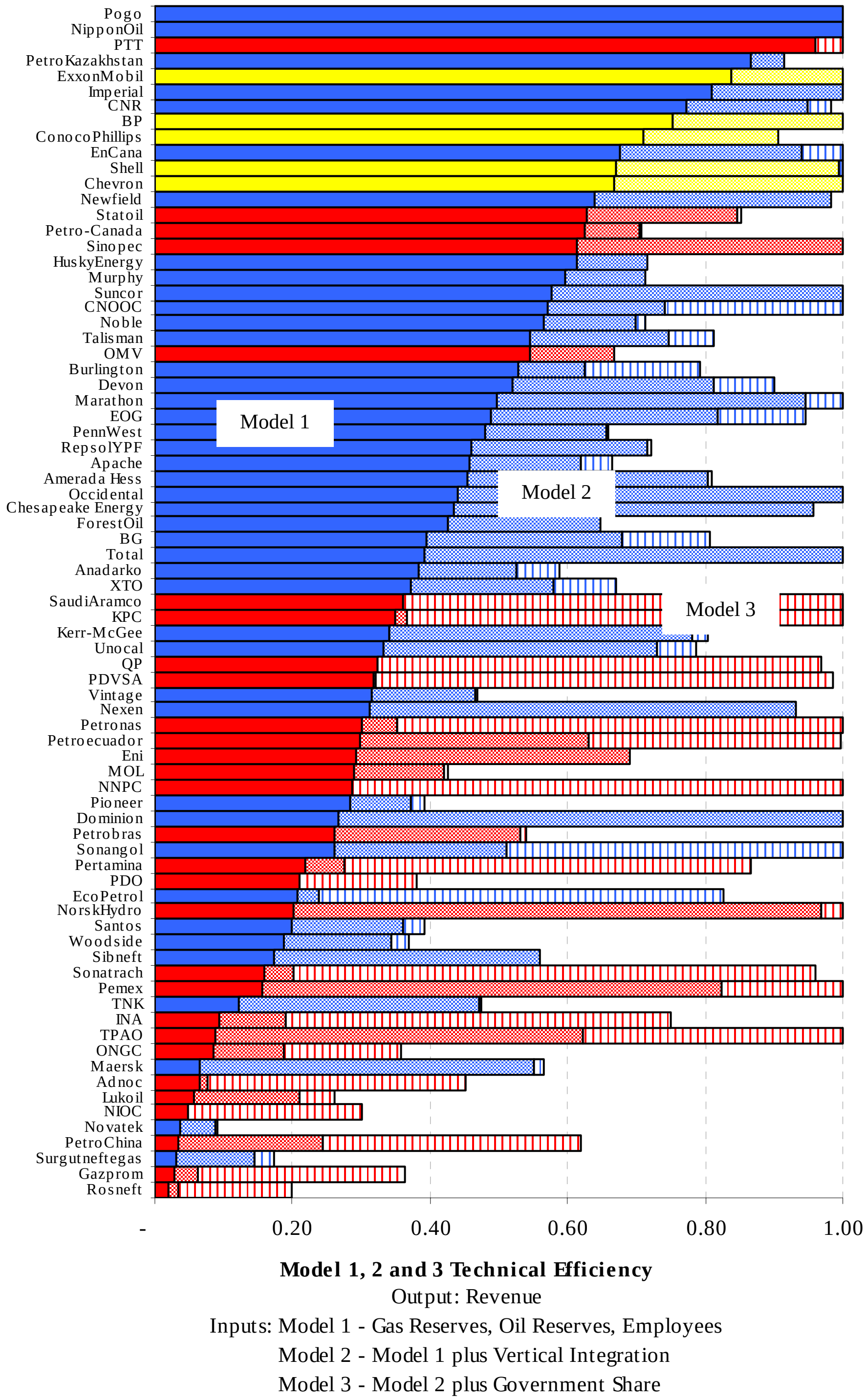

Figure 5 – Cumulative effects of structural variables on technical efficiency

Table 3 – Summary of firm technical efficiency (averages)

	All firms	NOC	Major IOC	Others
Model 1	0.398	0.280	0.728	0.452
Model 2	0.621	0.441	0.980	0.721
Model 3	0.767	0.755	0.981	0.750

By including a measure of vertical integration in Model 2, we are correcting for a measurement issue introduced by the manner in which we have defined inputs and outputs, as discussed above. Of note is the fact that accounting for vertical integration moves the five major IOC's toward the frontier. Thus, the data indicates that the corporate structure of a firm is an important feature in the production of revenue.

Adding the government ownership share in Model 3 identifies that variable as being responsible for a large amount of the measured technical inefficiencies that remain in Model 2. Thus, the data suggest that government ownership reduces the ability of a firm to produce revenues for a given quantity of inputs. In fact, the NOC's tend to move the most when government ownership is considered as an explanatory variable for the relationship between their inputs and output. In Model 3, the average technical efficiency measure for NOC's improves to 0.79, up from 0.27. This compares to a sample average for all firms of 0.77 and 0.98 for the five IOC's. This is consistent with the notion that government objectives skew the objective of the NOC away from pure commercial motives.

Parametric analysis (stochastic frontier estimation)

Parametric analysis of technical efficiency through the estimation of a stochastic frontier yields similar results. We begin by estimating a fairly simple model (Model 1sf) in which revenue is produced using oil reserves, natural gas reserves and employees as inputs. Thus, Model 1sf is similar in specification of inputs and output as Model 1 in the DEA analysis. Time effects are included in the panel estimation of Model 1sf because the price of oil and gas is not constant across years, and the revenue generated in each year will depend on the prevailing market price. If price increases from one year to the next, holding all other inputs constant, a firm will appear more productive because it generated more revenue. It should be noted that time effects were unnecessary in the DEA approach because technical inefficiency is calculated as the distance from the frontier for each year. We reported the average technical efficiency measure for each firm over the three year sample to describe the firm's efficiency over the time horizon. In contrast, estimated technical efficiency in the stochastic panel frontier model is assumed to be constant over the three years.

Departing from Model 1sf, we add variables to determine whether they can explain the estimated deviations from the technically efficient frontier. For example, Model 2sf includes measures of both government share and vertical integration, much as was done in the DEA analysis. Model 3sf then adds a dummy variable ($2TierP$) for those countries that subsidize domestic prices. Model 4sf includes an interaction term between the share of government ownership and total employment. Table 4 presents the results of various models of the stochastic revenue frontier.

Consistent with the results for the DEA analysis, Model 2sf shows that both government share and vertical integration are significant in explaining why firms are estimated to be technically inefficient. A negative coefficient on the government share variable indicates that government ownership tends to limit the ability of the firm to produce revenue for a given quantity of inputs. A positive coefficient on the vertical integration variable indicates that a firm's ability to generate revenue is enhanced when it is vertically integrated. In addition, a larger estimated coefficient on oil reserves, than was the case for Model 1sf, is more consistent with oil reserves being a significant input into the production of revenue. This may suggest that an estimated frontier that does not account for these institutional and structural variables in the production of revenue, such as was estimated in Model 1sf, is misspecified.

Table 4 – Panel estimation of stochastic frontier[a]

	Model 1sf	**Model 2sf**	**Model 3sf**	**Model 4sf**
$\ln L$	0.4847*** *0.0666*	0.6459*** *0.0504*	0.5648*** *0.0637*	0.6077*** *0.0362*
$\ln OilRsv$	0.0463 *0.0415*	0.0666 *0.0462*	0.1188*** *0.0459*	0.1524*** *0.0396*
$\ln NGRsv$	0.1695*** *0.0493*	0.2091*** *0.0485*	0.2069*** *0.0471*	0.2035*** *0.0415*
GovShare		-0.5970*** *0.1398*	-0.3109** *0.1607*	2.7912*** *0.8316*
VertInt		0.0737*** *0.0203*	0.0969*** *0.0198*	0.0824*** *0.0198*
2*TierP*			-0.5435*** *0.1570*	-0.6654*** *0.1382*
$GovShare * \ln L$				-0.3099*** *0.0824*
*year*2003	0.3022*** *0.0307*	0.2950*** *0.0325*	0.2877*** *0.0331*	0.2872*** *0.0335*
*year*2004	0.4767*** *0.0312*	0.4626*** *0.0330*	0.4633*** *0.0334*	0.4652*** *0.0339*
constant	4.3644*** *0.6561*	1.5483*** *0.3474*	1.9375*** *0.4860*	1.2476*** *0.2894*
$\chi^2(d)$	451.33	1112.72	992.72	1643.43
d	5	7	8	9
Log Likelihood	-111.300	-100.041	-94.109	-87.427
# Observations	236	236	236	236

[a] Estimated standard errors included beneath each coefficient estimate.

***- statistically significant at the 1% level; **- statistically significant at the 5% level; *- statistically significant at the 10% level

The coefficient on government ownership share in Model 2sf summarizes the influence of government ownership. However, government ownership can influence the ability of the firm to generate revenue in a number of different ways. Thus, in order to distinguish between alternative government objectives Model 3sf includes a dummy variable for those companies operating in countries where domestic prices are subsidized.[8] This enables us to capture the effect of a lower average sales price for firms operating in countries with subsidized domestic oil prices, which would impact revenues adversely. As discussed in Hartley and Medlock, such subsidies might be imposed to garner political support from a broad constituency. The coefficient on this so-called "two-tier pricing" variable is negative and highly significant indicating that domestic price subsidies have an adverse impact on the firm's ability to produce revenues. Nevertheless, the government ownership variable remains significant, meaning there are other facets of government control that reduce the firm's ability to generate revenue. In addition, the coefficient on oil reserves further increases in both magnitude and significance, thus indicating that oil reserves do indeed matter, but institutional features of the firm and its operating constraints must be taken into account to measure their effect accurately.

The fact that the government share variable remains significant despite the inclusion of a two-tiered pricing dummy begs the question of whether the negative influence of government share can be separated into other identifiable effects. The model

[8] Those countries for which a 2-tiered pricing dummy was implemented are: Colombia, Mexico, Russia, China, Thailand, Kazakhstan, Nigeria, Ecuador, Angola, Azerbaijan, Malaysia, Syria, Oman, UAE, Kuwait, Algeria, Indonesia, Saudi Arabia, Iran, Venezuela.

developed in Hartley and Medlock indicates that many of the effects of government ownership are likely to lead to more employment than is necessary to achieve a given production or revenue target. In Model 4sf, therefore, we add an interaction term between employment and government share.[9] The estimated coefficient is strongly negative and highly statistically significant. In addition, the three physical variable inputs have a strong and statistically significant positive effect on the production of revenue, while the influence of the vertical integration and two-tier pricing variables remain virtually the same as in Model 3sf.

The results from Model 4sf indicate that government control impacts revenue in multiple ways. First, in countries where governments tend to redistribute resource rents to consumers through subsidized domestic prices, domestic firm's revenues will be impacted negatively. This follows directly from the coefficient on the two-tiered pricing dummy. Model 4sf also indicates that the revenues of firms will be adversely affected if they tend to use a larger workforce than necessary to meet purely commercial objectives as a means of redistributing resource rents. This follows from the coefficients on government share and the interaction term. In particular, if government share is zero, then these variables drop out of the equation. However, the combined effect of government share and the interaction term can be written

$$GovShare * (2.7912 - 0.3099 * \ln L),$$

[9] We also examine the interaction between *GovShare* and reserves of oil and natural gas. We found these interaction terms to be insignificant. This is consistent with the theoretical model presented in Hartley and Medlock, which predicts ambiguous effects of government ownership in the level of reserves, conditional on the age of the resource.

which is negative for most firms with a positive government share.[10] The negative coefficient on the interaction term can also be interpreted as implying increased employment has less of a positive effect on revenue (or a lower marginal revenue product) the higher is the government share in ownership.[11]

Figure 6 summarizes the influence of domestic price subsidies and over-employment. Depicted is revenue as a function of employees for firms with[12]:

i. no government ownership;

ii. full government ownership and subsidized domestic prices; and

iii. full government ownership and no domestic price subsidies.

The points illustrated along the horizontal axis correspond to the employment for each of the 80 firms over the three year sample. The general tendency is that revenue tends to decrease with an increase in the exercise of government controls. For example, as a firm is forced to sell into a subsidized market, its revenues are impacted negatively. In addition, although an increase in the number of employees tends to increase revenues, firms with full government ownership will generate less revenue for a given level of employment. The largest three firms – PetroChina, Sinopec, and Gazprom – are each fully owned by the government and domestic prices are subsidized. Figure 7 illustrates the effects of increasing government ownership with domestic price subsidies.[13]

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[10] Among all firms with a positive government share, CNOOC has the lowest number of employees (2047 in 2002), which would give a positive coefficient of 0.4284 on *GovShare*, but one which would not be statistically significantly different from zero.

[11] We also examined the case in which *GovShare* was allowed to differ for importing and exporting firms. The coefficients were not statistically different from each other or the *GovShare* variable in Model 4sf.

[12] To construct the curves oil and gas reserves are held constant at the sample average.

[13] To construct the curves, employment is held constant at the sample average. In addition, as in Figure 8, oil and gas reserves are held constant at the sample average.

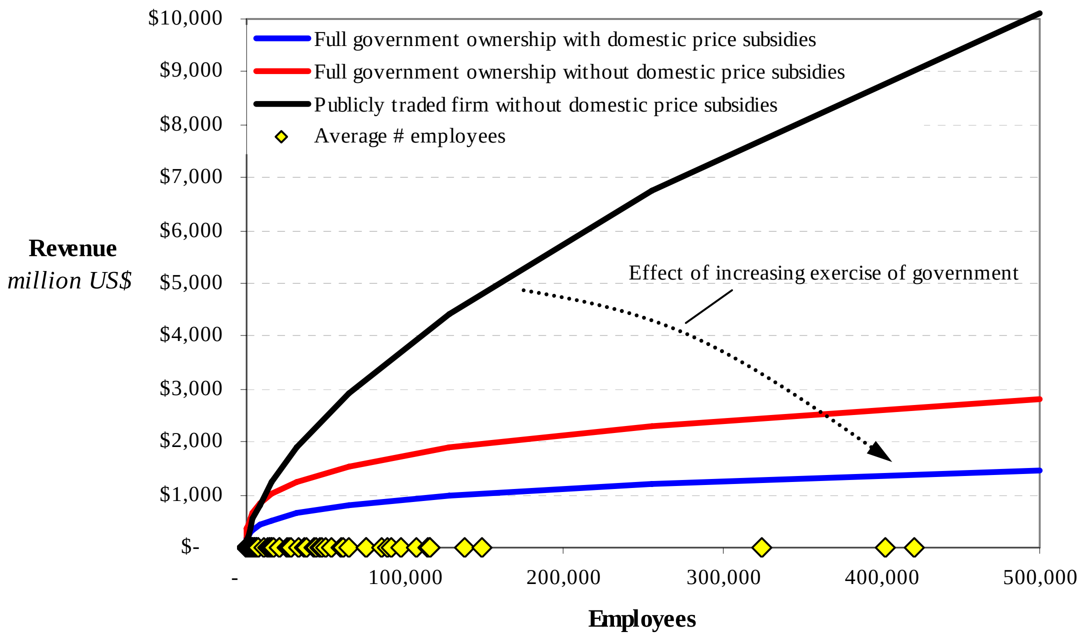

Figure 6 – Revenue as a function of government control

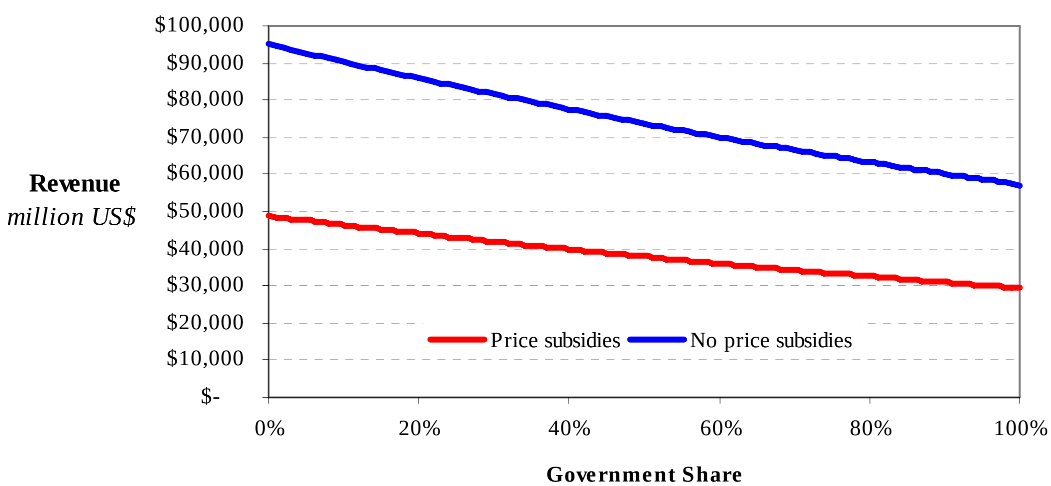

Figure 7 – Revenue as a function of government ownership

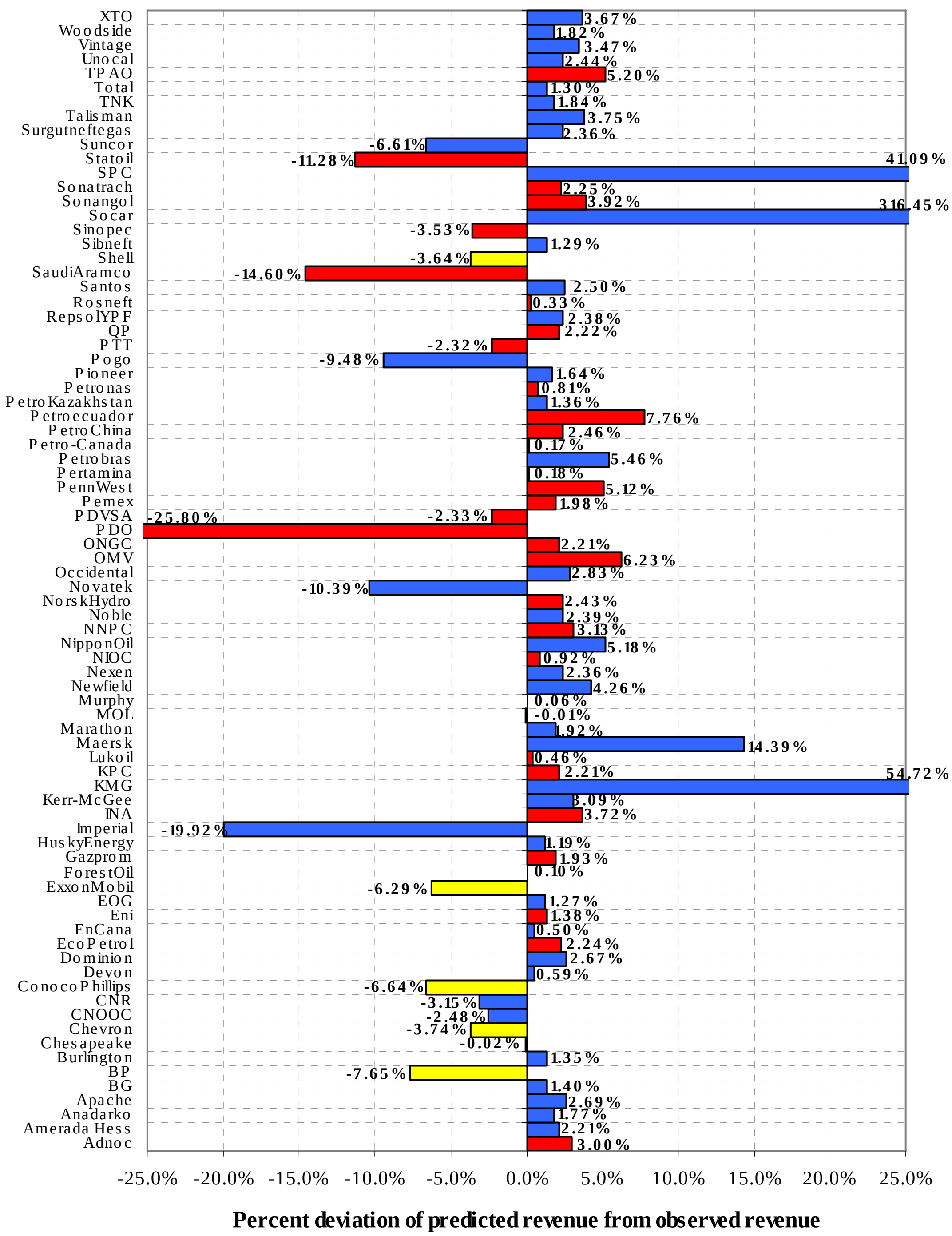

Figure 8 – Predicted versus actual revenues by firm

Figure 8 shows the average percent deviation of predicted from actual revenues for each firm. Three points corresponding to the firms Syrian Petrolem Company (SPC), the State Oil Company of Azerbaijan (Socar), and KazMunayGaz (KMG) are outliers with regard to goodness of fit. Interestingly, these three companies also happen to be the firms for which the data does not cover all three years. Thus, the fact that the model does not fit these firms very well is likely related to insufficiency of the data set.

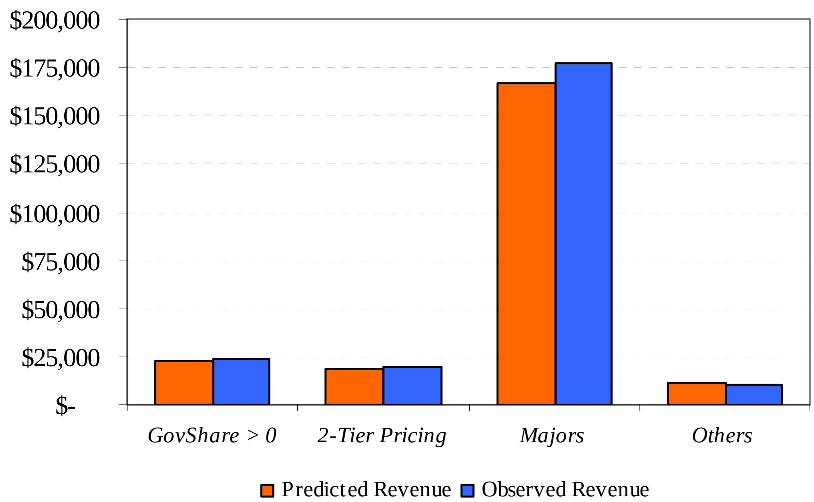

Figure 9 – Predicted versus actual revenues (group averages)

Figure 9 compares the average predicted and actual values of revenue, by four categories of firms, across all three years. The four categories are:

(1) firms with positive government share ownership,

(2) firms that operate in domestic markets with subsidized prices,

(3) the five major IOCs, and

(4) all other firms.

We see that the model provides a fairly accurate representation of the relative abilities of the different types of firms to produce revenues using the defined set of inputs.

Figure 10 provides the estimated technical efficiency for the 80 firms in our sample in Model 1sf. The firms with government ownership are now more dispersed than in Model 1 from the DEA approach. Nevertheless, the five major IOCs tend to be clustered near the frontier, just as in the DEA approach.

Figure 11 is similar to Figure 5 above, but, unlike in the DEA we are able to control for a greater number of factors through the use of dummy variables. By focusing on Model 1sf and Model 4sf, Figure 11 illustrates the effects of controlling for the various structural and institutional variables that influence revenues. Prior to controlling for vertical integration, firms that are heavily invested in downstream activities will appear to be more technically efficient at generating revenue. As noted above, this is due to the fact that we are not accounting for (i) capital as an input in a firm's refining and marketing operations, and (ii) the internal use of crude to produce higher valued products. For example, when we move to Model 4sf, NipponOil, which is heavily integrated in downstream activities, actually moves away from the estimated frontier.

We also see in Figure 11 that government ownership accounts for a substantial proportion of the measured technical inefficiency of the NOCs. Thus, consistent with the DEA, institutional factors are explaining a large proportion of the differences between NOCs and IOCs. Again, this is consistent with the theoretical framework presented in Hartley and Medlock that the measured technical inefficiency of NOCs may be largely the result of the influence of non-commercial objectives.

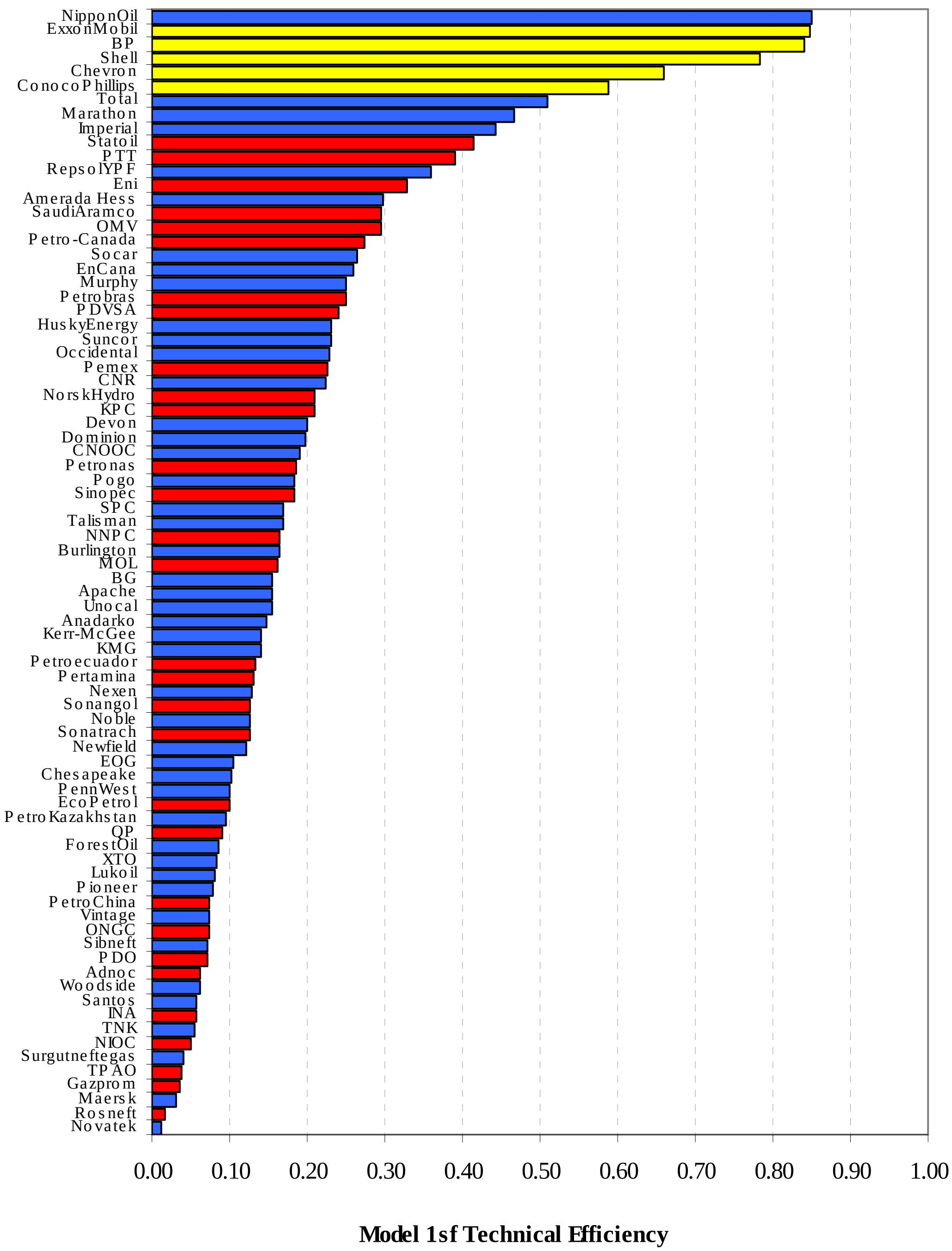

Figure 10 – Stochastic frontier estimated technical efficiency by firm

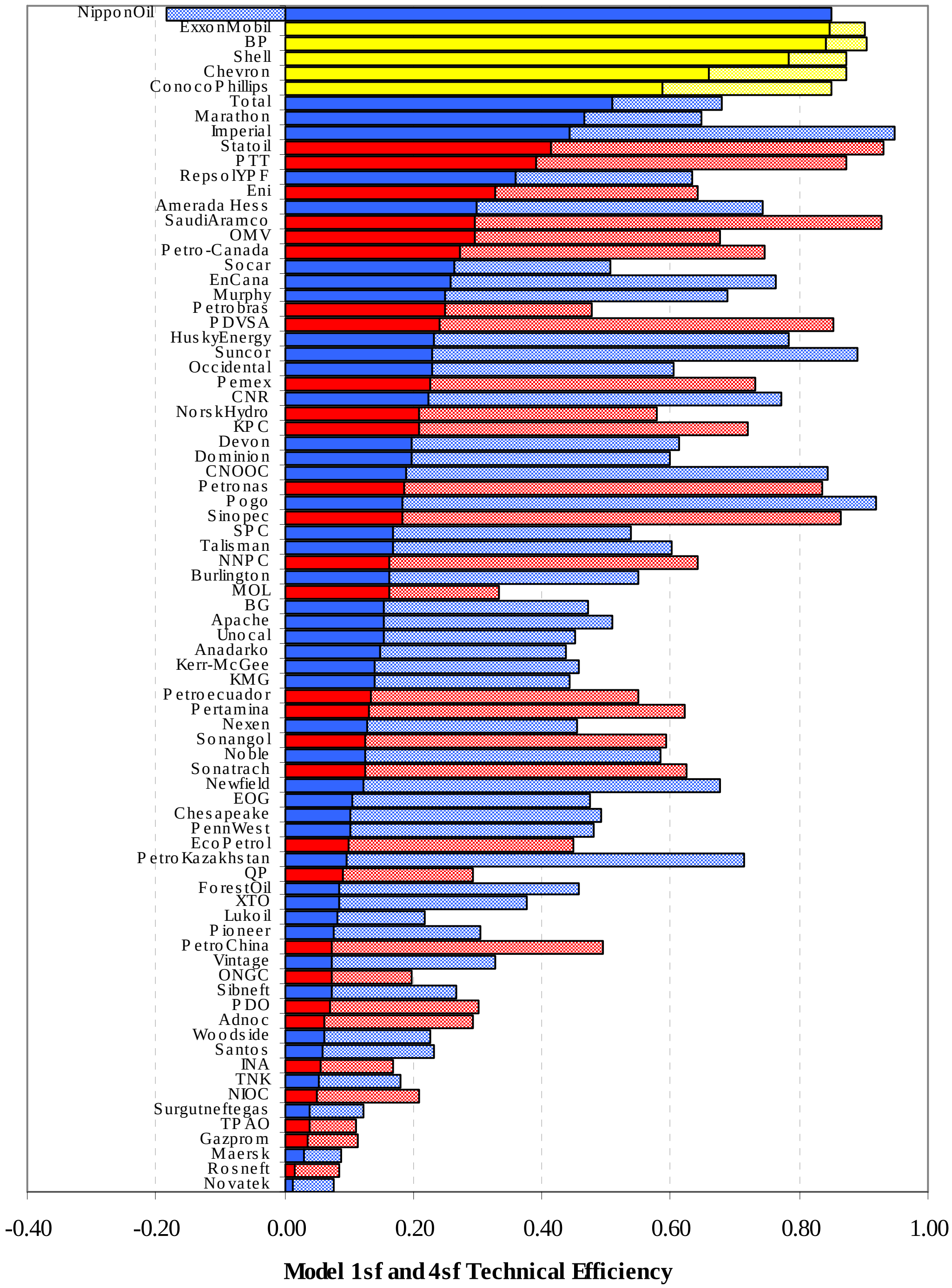

Figure 11 – Cumulative effects of structural variables on technical efficiency

An interesting regularity apparent in Figure 11 is that the Russian firms (regardless of the amount of government ownership) tend to be ranked with low levels of technical efficiency. This suggests that systematic features of doing business in Russia apart from government ownership negatively affect the ability of Russian firms to generate revenue from a given level of reserves and employment.[14]

VI. CONCLUDING REMARKS

The model developed Hartley and Medlock (2007) demonstrates the influences that different government objectives can have on output and revenues of a NOC. In particular, they demonstrate that if the government places weight on the benefits of a particular special interest, resource rents will tend to be redistributed toward that special interest. This alters the investment patterns of the NOC and results in an outcome that can be described as operationally inefficient.

The empirical evidence provided in this paper supports the theoretical framework suggested in Hartley and Medlock. In particular, we have demonstrated, using both non-parametric and parametric techniques, that institutional features reflecting some non-commercial set of objectives facing a firm are important in explaining how well that firm produces revenue for a given set of inputs. Thus, the relative technical inefficiencies of various NOC's, which are observed when one considers only commercial objectives, are largely the result of governments exercising control over the distribution of rents. This is an important finding. If an increasing proportion of global oil and gas resources are under the control of NOC's, it is reasonable to expect that an increasing majority of oil

[14] We examined the case with a dummy variable for Russian companies included in the Model 4sf. It had a coefficient of -1.611 and standard error of 0.216. Including this variable did not change the remaining coefficients significantly. This suggests that the Russian firms are not greatly influencing the sample.

and gas developments will be driven with political objectives in mind. Relative to a commercial outcome, this will result in inefficiencies in the production of revenues, which can manifest through lower levels of production, and higher prices, than would otherwise occur.

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