

THE FUTURE OF OIL IN MEXICO

/ EL FUTURO DEL SECTOR PETROLERO EN MÉXICO



The Revenue Efficiency of Pemex: A Comparative Approach

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THE REVENUE EFFICIENCY OF PEMEX:
A COMPARATIVE APPROACH

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The Revenue Efficiency of Pemex: A Comparative Approach

ABOUT THE STUDY: THE FUTURE OF OIL IN MEXICO/ EL FUTURO DEL SECTOR PETROLERO EN MÉXICO

The energy industry plays an important role in the Mexican economy, and energy trade is a major component to the U.S.-Mexico relationship. The Mexican government relies on the oil industry for 35 percent of total government revenues, including taxes and direct payments from Petróleos Mexicanos (Pemex), the state oil company. Mexico is the third-largest foreign crude oil supplier to the United States. However, with declining production and rising demand, Mexico could become a net oil importer in the coming decade. President Calderón pushed for energy sector reform in Mexico, but more reforms will be needed for Mexico to reverse its current path toward importer status. This study identifies the dynamics of the political trends in Mexico that will impact future energy policy. The aim of this study is to promote a better understanding of the challenges facing Mexico's oil sector and to enhance the debate among policymakers, the media and industry on these important issues.

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ABOUT THE MEXICAN STUDIES PROGRAMME AT NUFFIELD COLLEGE, OXFORD UNIVERSITY

Since its establishment in 2002, Oxford's Mexican Studies Programme has conducted research and promoted graduate teaching in Mexico's external relations; democratization and the functioning of democratic institutions in Mexico; and on various Mexican public policy issues, including economic and energy policies.

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Medlock's research covers a variety of topics in energy economics, including domestic and international natural gas markets; energy commodity price relationships; transportation; modeling national oil company behavior; economic development and energy demand; and energy use and the environment. Medlock is member of the International Association for Energy Economics (IAEE), the American Economic Association and the Association of Environmental and Resource Economists. In

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2001, he won (joint with Ron Soligo) the IAEE's "The Energy Journal" Campbell Watkins Best Paper Award.

Medlock served as an adviser to the U.S. Department of Energy and the California Energy Commission in their respective energy modeling efforts. He also was the lead modeler of the modeling subgroup of the 2003 National Petroleum Council (NPC) study of long-term natural gas markets in North America, and was a contributing author to the California Energy Commission and Western Interstate Energy Board's "Western Natural Gas Assessment" in 2005. He also contributed to the 2007 NPC study "Facing the Hard Truths" and is involved in the ongoing NPC study, "North American Resource Development."

Previously, Medlock held the Baker Institute's M.D. Anderson Fellowship and was a corporate consultant at El Paso Energy Corporation. He received his Ph.D. in economics from Rice.

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I. Introduction

The operational efficiency of Pemex (Petróleos Mexicanos) is a critical issue in analyzing the contribution of energy resources to economic growth and prosperity in Mexico. If Pemex costs are unnecessarily high, its ability to develop domestic oil and gas resources will be hampered. Furthermore, if Pemex is incapable of generating sufficient revenues from its operations, it will have diminished ability to invest in the exploration and development activities that are essential to its long-run viability.

In this paper, we examine the technical efficiency¹ of Pemex by comparing it with a large sample of oil and natural gas companies from around the world. The sample encompasses firms operating in many different countries under many different geological, fiscal, and market environments. In addition, the firms in the sample range from national oil companies that are fully government-owned to publicly traded firms with no government ownership. The firms in the sample also differ in the extent to which they specialize in the production of oil and/or natural gas, and the degree to which they are vertically integrated. Including a wide range of firms with different characteristics allows a more robust measure of the revenue-efficient frontier for oil and gas firms.

Since Pemex is a fully government-owned company, we examined its operations through the lens of a recently developed theoretical model (Hartley and Medlock 2008) of the operation and development of a national oil company (NOC). In our 2008 paper, we argued that the political overseers of an NOC are likely to require it to pursue various non-commercial objectives, which compete with commercial goals such as profit maximization. For example, an NOC is likely to favor excessive employment while under-investing in reserves and shifting resource extraction away from the future toward the present. In addition, an NOC may be forced to sell oil products to domestic consumers at subsidized prices. Thus, NOCs are likely to appear inefficient relative to firms that do not face similar constraints, especially at generating revenue from given inputs of labor and reserves.

¹ The phrase “technical efficiency” is used to mean getting more output from given inputs. This need not correspond to the economic notion of “efficiency” as Pareto optimality. In particular, revenue maximization is in general neither necessary nor sufficient for a firm to be economically efficient.

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Although we have cited Hartley and Medlock (2008) as motivation for the specific hypotheses we test, there is a substantial body of theory and evidence suggesting that state-owned firms are less efficiently managed than their private sector counterparts.² Recent theoretical analyses of relative firm efficiency have focused on the principal-agent paradigm, whereby firm inefficiency can result when controls are insufficient to prevent managers (agents) from maximizing their own utility at the expense of the owners (principals).³ Theory and evidence suggest that institutional features of private ownership, such as tradable ownership shares, the threat of takeover, and the possibility of bankruptcy, help align managerial objectives with those of the owners. Conversely, the absence of such institutional features in state-owned firms can help explain relative inefficiency of such firms. More to the point, while the owners of a private firm all desire the managers to maximize the firm's market value, the political overseers of managers of state-owned enterprises generally have a less well-defined objective aimed to increase political support. Policies aimed at furthering such goals are likely to hinder conventional measures of firm efficiency.

We examine revenue efficiency of oil and gas firms using a sample of 62 firms over the period 2001–2009. We rely on data from the *Energy Intelligence* annual publication “Ranking the World's Oil Companies,” and, when available, company annual reports were used to verify published data and provide missing information. After accounting for mergers and restricting the sample to firms with complete data for the full period 2001–2009, the sample size was reduced from 150 firms to just 62 companies.⁴ The average values for key variables are presented in Table 1.

By definition, the observed input-output bundle of an efficient firm is on the production frontier, whereas an inefficient firm will be inside the production frontier. We use two broad methods to calculate efficiency to demonstrate our results are robust to the choice of specification. Non-

² Villalonga (2000) provides a thorough discussion of theoretical and empirical studies of the efficiency of publicly versus privately owned firms, as well as the efficiency implications of privatization.

³ The principal-agent paradigm was introduced by Jensen and Meckling (1976) and Harris and Raviv (1978). Property rights theory was originally developed by Alchian (1965). Other notable work on privatization includes Laffont and Tirole (1991) and Schmidt (1996).

⁴ This compares with 78 firms analyzed in Eller, Hartley, and Medlock (2011) for a shorter time period covering 2002–2004. Since we included an additional variable of refinery capacity, and data needed to be available for a longer period, more firms were eliminated from the current sample.

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parametric data envelopment analysis (DEA) uses linear programming techniques to construct a non-parametric piecewise-linear convex hull of observed input-output bundles. Stochastic frontier analysis (SFA) involves estimating a parametric production frontier from observed input-output bundles.

As in a previous analysis (see Eller, Hartley, and Medlock 2011), we measure technical efficiency by the ability of the firm to generate *revenue*⁵ from a given bundle of inputs and output prices. Revenue efficiency not only requires an energy company to be technically efficient in the way it uses its reserves of oil and natural gas, capital, and labor inputs to produce outputs. It also has to produce the appropriate *mix* of outputs given market prices.

We find that the technical efficiency of Pemex ranks it around 35th of the 62 firms in our sample in terms of generating revenue from the resources under its control. Its relative performance was noticeably better in 2006, but noticeably worse in 2002 and 2008. All of the firms in the sample generally showed productivity gains over the period of observation, but the net productivity *change* for Pemex was greater than the corresponding sample average of firms in only two years. In fact, from 2007 to 2008 productivity in Pemex declined while it increased for the sample average of firms. Indeed, there is considerable evidence that 2008 was a particularly bad year for Pemex relative to other firms in our sample.

More generally, we find that the relative inefficiency of Pemex over this period stems from its status as a government-owned firm, a result that was also true in the analysis in Eller, Hartley, and Medlock (2011). There is strong evidence of over-employment by Pemex, and the analysis suggests that Pemex would have been able to earn more than 48% additional revenue, on average, in each year by more efficiently employing the resources at its disposal.

⁵ We examine revenue generation for several reasons. As Hartley and Medlock (2008) emphasize, revenue is a key objective for both public and private firms, although political pressure is likely to force an NOC to sell products to domestic consumers at subsidized prices. Physical output measures would not capture the full effect of such subsidies. In addition, most firms in the sample produce products ranging from crude oil and natural gas to refined products. The natural way to aggregate these outputs is to measure their relative value at market prices, and hence take revenue as the output measure. Finally, physical outputs of different commodities were not available for some firms in our sample.

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Table 1. Averages of Key Variables

Firm	Headquarter Country	Government Ownership Share	Oil Reserves (million barrels)	Nat. Gas Reserves (billion ft ³)	Refining Capacity (thousands barrels/day)	Employees	Revenue (US\$ million)	Revenue per Employee	Vertical Integration (products/oil prod)
Adnoc	UAE	1	54590.6	138424.0	633.1	85000	27260.3	0.321	0.230
Anadarko	US	0	1366.2	9650.2	0	5812	10208.1	2.000	0
Apache	US	0	925.7	6323.4	0	2826	6865.9	2.295	0
BG	UK	0	591.1	9164.3	0	5075	11412.4	2.166	0
BHPBilliton	Australia	0	586.7	4917.8	0	36287	32934.9	0.882	0
BP	UK	0	9817.8	46815.3	2963.9	100354	245861.0	2.511	2.662
CNOOC	China	0.68	1483.7	5009.8	0	2735	10896.9	3.551	0.047
CNPC	China	0.93	15887.0	62646.4	2391.4	450057	90987.8	0.194	0.687
CNR	Canada	0	1943.2	3024.9	0	2661	7565.9	2.845	0
Chesapeake	US	0	87.2	6778.6	0	3792	5028.3	1.379	0
Chevron	US	0	8320.0	24730.4	2197.2	66478	167549.0	2.566	1.967
ConocoPhillips	US	0	6070.6	24388.3	2690.7	41245	132733.0	3.663	1.990
Devon	US	0	903.8	8010.9	0	4418	8896.7	1.981	0
ENI	Italy	0.30	3694.2	18261.1	719.3	74978	92411.8	1.227	1.015
EOG	US	0	143.7	5793.0	0	1476	3233.1	2.074	0
Ecopetrol	Colombia	0.96	1232.7	2928.2	320.4	6516	8126.7	1.271	0.787
EnCana	Canada	0	765.1	10280.7	50.2	4394	13724.9	2.933	0.376
ExxonMobil	US	0	11851.0	62626.4	6300.9	86356	295090.0	3.496	2.948
Gazprom	Russia	0.48	13370.7	855000.0	631.3	386580	66477.9	0.170	0.594
Hess	US	0	819.4	2580.4	255.3	11882	23420.9	1.938	1.613
Husky	Canada	0	513.6	1749.0	106.8	3525	10138.9	2.686	0.641
KPC	Kuwait	1	98771.7	58474.1	1077.6	19426	47983.8	2.686	0.446
Lukoil	Russia	0.02	13974.4	21893.3	1091.6	147056	47998.7	0.321	0.810
Maersk	Denmark	0	728.6	1572.2	0	3500	6005.2	1.716	0
Marathon	US	0	792.1	3230.3	991.2	27395	48842.1	1.765	6.588
Mol	Hungary	0.11	119.7	943.1	303.8	17279	11585.6	0.692	6.307
MurphyOil	US	0	330.9	519.7	211.8	6237	12490.6	1.824	3.783
NIOC	Iran	1	127229.0	950214.0	1517.9	114956	43765.0	0.381	0.426
Nexen	Canada	0	682.0	597.9	0	3371	4096.4	1.165	0
Nippon	Japan	0	110.9	1334.0	1252.6	13729	50212.7	3.684	19.751
Noble	US	0	258.1	2528.7	0	1043	2171.0	2.064	0
OMV	Austria	0.36	555.4	2359.3	458.2	30627	18972.7	0.839	3.217
ONGC	India	0.77	3768.9	15692.6	155.9	35893	11553.9	0.332	0.329

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Firm	Headquarter Country	Government Ownership Share	Oil Reserves (million barrels)	Nat. Gas Reserves (billion ft ³)	Refining Capacity (thousands barrels/day)	Employees	Revenue (US\$ million)	Revenue per Employee	Vertical Integration (products/oil prod)
Occidental	US	0	2254.0	3839.6	0	8863	14626.4	1.624	0
PDO	Oman	0.6	3194.4	18958.1	65.0	4446	9793.3	2.167	0.107
PDV	Venezuela	1	83753.9	158427.0	3073.9	53391	76195.7	1.506	0.968
PTT	Thailand	0.79	144.1	4795.1	315.9	7530	28706.1	3.463	8.558
Pemex	Mexico	1	14341.1	14126.8	1705.3	139787	82189.8	0.585	0.467
Pertamina	Indonesia	1	2765.0	46753.2	1035.3	28578	29054.2	1.037	5.168
Petrobras	Brazil	0.42	9410.8	11219.8	2105.7	57381	63511.6	1.038	1.434
Petroecuador	Ecuador	0.89	3063.7	611.0	175.9	4011	4609.0	1.150	0.715
Petronas	Malaysia	1	7036.2	104663.0	386.3	30874	44752.2	1.383	0.856
Pioneer	US	0	422.1	2756.4	0	1467	1475.7	1.000	0
Plains	US	0	367.0	1156.3	0	816	1630.0	1.959	0
QP	Qatar	1	12703.1	603147.0	177.8	6976	21946.7	3.140	0.148
Repsol YPF	Spain	0	1415.7	12686.6	1226.8	35208	59294.7	1.665	2.412
Rosneft	Russia	0.83	11091.3	51326.7	493.8	88611	26398.1	0.253	0.645
Santos	Australia	0	147.4	2522.3	0	1743	1741.8	0.986	0
Saudi Aramco	Saudi Arabia	1	263055.0	246052.0	2309.7	53475	175363.0	3.282	0.301
Shell	Netherlands	0	6424.2	41434.7	3993.0	107828	277173.0	2.591	3.315
Sinopec	China	0.68	3147.9	4286.1	3316.0	387585	113067.0	0.309	2.594
Sonangol	Angola	1	2978.3	1158.4	34.1	5611	7810.3	1.409	0.082
Sonatrach	Algeria	1	11003.6	151148.0	471.1	45922	43917.8	0.996	0.429
Statoil Hydro	Norway	0.62	2636.8	20784.3	340.3	49439	77736.0	1.852	0.497
Suncor	Canada	0.02	2075.1	2456.7	407.1	10274	24282.9	2.228	1.159
Surgutneftegas	Russia	0	7289.6	13584.3	358.6	95346	15712.8	0.160	0.287
TNK-BP	Russia	0	5524.2	6002.9	415.7	83285	25509.9	0.380	0.358
Talisman	Canada	0	589.8	3970.7	0	2178	5361.1	2.389	0
Total	France	0	6527.0	24123.4	2648.0	107115	148744.0	1.435	2.221
Wintershall	Germany	0	484.6	3329.8	9.4	1736	10819.2	5.955	0.116
Woodside	Australia	0	224.3	3817.0	0	2698	2307.7	0.824	0
XTO	US	0	222.1	6694.6	0	1824	3906.1	1.850	0

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In the next section of the paper, we summarize some relevant facts about Pemex. Then, we present the efficiency analysis, focusing first on DEA and then SFA. The final section of the paper summarizes our conclusions.

II. Some Background on Pemex

Pemex—Mexico’s national oil company—holds exclusive rights to exploit and manage the nation’s oil and gas resources. Pemex was established in 1938 when domestic oil production was nationalized, and, as one of the largest oil companies in the world, has subsidiaries that manage both upstream and downstream activities in Mexico, ranging from exploration and production to petrochemicals and refining. In sum, Pemex accounts for about 15% of Mexican export revenue and some 40% of the government’s total revenues.

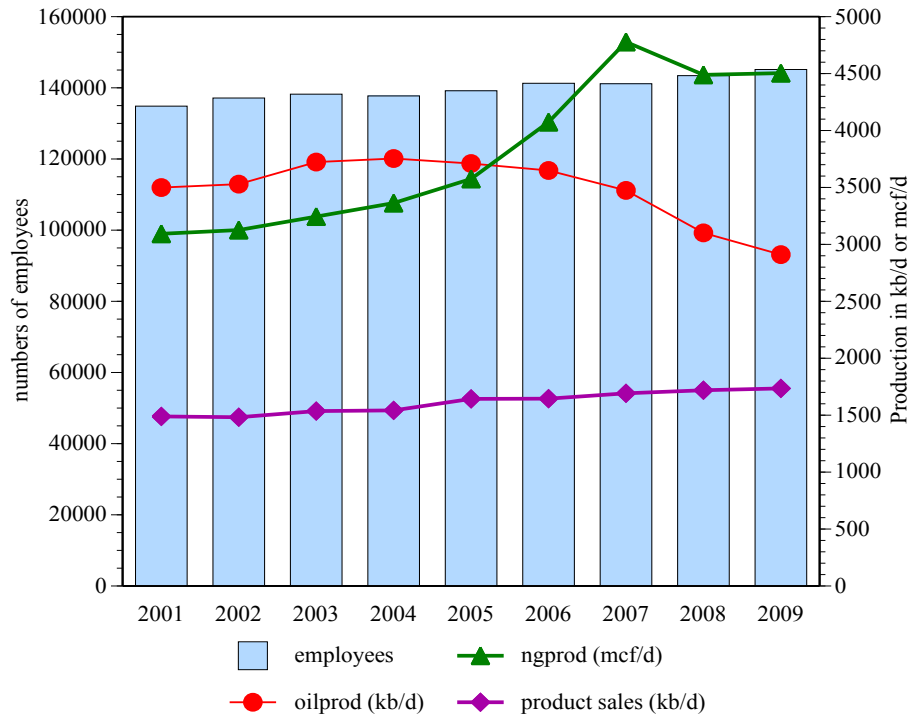
Pemex crude oil production is predominantly of the heavy variety, with the high sulfur Maya crude (API° 22) accounting for more than half of total crude production. The lighter Isthmus (API° 34) and Olmecca (API° 39) crudes account for about one-third and one-fifth of total Mexican production, respectively. Pemex generally exports its heavy crudes to the U.S. Gulf Coast for refining, while the lighter streams are used for domestic consumption.

Basic production data for Pemex taken from our sample is graphed in Figure 1. The decline in oil production following its peak in 2004 is particularly evident. The production declines have been especially steep at the giant Cantarell Field, which had been responsible for the majority of Mexico’s oil production. Cantarell production declined precipitously from a peak of 2.136 million barrels per day (b/d) in 2004 to only 685,000 b/d in 2009 and 558,000 b/d in 2010.⁶ Pemex has said it has slowed the rate of decline at Cantarell, but it is not clear can be sustained as Pemex attempts to bring new fields into production. The declines to date have been partially offset by increases at the Ku-Maloob-Zaap (KMZ) field, whose production of 808,000 b/d in 2009 was about 500,000 b/d higher than its 2004 level. Pemex had hoped that production at Chicontepec would offset some of the declines from Cantarell, but production there has been disappointing and is only forecast to be about 70,000 b/d in 2011 (Rodriguez 2010).

⁶ Secretaria de Energía, Sistema de Información Energética, <http://sie.energia.gob.mx/sie/bdiController>.

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Figure 1. Pemex Oil and Natural Gas Production, Product Sales, and Employment



Source: Petroleum Intelligence Weekly

Note: kb/d stands for thousand barrels per day, and mcf/d is million cubic feet per day.

Roughly 50% of Mexican crude oil was exported in 2009 (Pemex Investor Relations 2010), but *net* exports of liquid hydrocarbons are lower due to substantial imports of finished products. Nevertheless, crude oil exports are an important source of national income. In 2010, crude oil exports accounted for US\$35.918 billion (Sistema de Información Energética). Mexico's international trade partners include the United States, Canada, Spain, India, Great Britain, the Netherlands, and Japan, among others, according to the Energy Information Administration (EIA). However, the United States is the main destination for Mexican crude oil, acquiring 84% of Mexico's total crude oil exports in 2010.

From 2001 to 2009, Mexican demand for refined products increased at an average annual pace of about 0.27% (EIA). Over the same period, total gasoline consumption increased from almost 552,000 b/d in 2001 to more than 775,000 b/d in 2009. According to our data set, Pemex refining

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capacity (including capacity owned outside Mexico)⁷ increased in two steps from 1.692 million b/d at the beginning of the sample to 1.710 million b/d at the end. This means that domestic refining capacity is insufficient to meet domestic demand, which forces Pemex to import refined products (Pemex Preguntas frecuentes generales). In fact, according to EIA data, gasoline imports almost doubled over the period of our analysis, rising from around 153,000 b/d in 2001 to more than 307,000 b/d in 2009.

Declining production in the face of rising domestic demand is symptomatic of the problems originating in Mexico's upstream sector. According to data from our sample, Pemex's proven reserves of oil declined from 18,767 million barrels of oil and 16,256 billion cubic feet (bcf) of natural gas in 2001 to 11,691 million barrels of oil and 11,966 bcf of natural gas in 2009. It is widely acknowledged that Pemex has numerous issues that contribute to declining production and reserves. Investment is one major area of concern. The government, which establishes Pemex's budget each year, does not give Pemex the flexibility to change its budget in response to new market conditions, and Pemex has had trouble allocating capital due to bureaucratic delays (Coleman et al, 2003).

Furthermore, since Pemex must give a large portion of its revenues to the government—62% in 2006—it has generally had less cash flow available to allocate to upstream investments (Solache 2007). The government, in turn, relies on Pemex for upwards of 40% of its revenues, which makes it very challenging to change the fiscal regime without harming government services or dramatically raising other taxes (Longmire and Martin 2011).

The difficulties that Pemex faces with regards to declining reserves and production are symptomatic of other issues related to firm efficiency, relative to its peers. In particular, Pemex produces much less revenue per employee than most of the firms in our sample, ranking 52nd out of 62 in this measure (see Table 1). The large employment relative to revenue further reduces the capital available for investments, but very strong labor unions help protect the large workforce. As of 2003, approximately 79% of Pemex employees were unionized (Coleman et al.

⁷ Pemex has a 50% investment in the Deer Park refinery in Houston, Texas, a joint venture with Shell Oil Company. The venture sells 35,000 to 45,000 b/d of unleaded gasoline to Pemex, which is about half of the country's import requirement (Center for Energy Economics).

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2003). The large payroll translates into very high costs for Pemex; from the years 2000-2002, operating expenses were nearly 55% of net sales (Coleman et al. 2003). The large number of employees has also resulted in large pension obligations that totaled US\$34 billion as of 2007 (Solache 2007).

Pemex also suffers from a lackluster safety record. A fire at a Pemex plant in Mexico City in 1984 killed more than 500 people. A gasoline pipeline explosion in 1992 killed more than 200, and at least seven people died in various other accidents from 2003 through 2005 (Sullivan 2005).

Despite all these hurdles, Pemex has recently almost doubled its total investment from 122.8 billion pesos in 2004 to 251.9 billion pesos in 2009, of which about 90% was for upstream activity (Statistical Yearbook 2009). Historically, however, much of this upstream capital has been spent on enhancing production from existing fields rather than focusing on exploration. This may stem from the fact that Pemex suffers from lack of access to advanced technology (Shields 2006), a point borne out by the fact that, as of 2009, Pemex still had not produced in waters deeper than 300 feet, while the frontier of the industry is in waters in other parts of the world more than one mile deep (Bogan 2009).

With the support of the current president of Mexico, Felipe Calderón, the country has partially reformed the Mexican oil industry, but whether or not the reforms can stimulate dramatic external private investment or improvement in company performance remains to be seen. The reform, passed in October 2008, “improves Pemex’s corporate governance, increases management’s execution capacity in investment decisions, allows the company to provide incentives or make modifications to awarded contracts and stipulates the issuance of citizen bonds (debt securities which may be acquired by small investors and whose return is linked to Pemex’s performance)” (Energy 2009).

The reform also reduces the “ordinary hydrocarbon duty” from 79% to 71.5% by 2012 and gives the company some additional financial flexibility. Another change involves adding four “independent professional commissioners” to the board of directors (Doing Business 2009).

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However, insiders say the reforms that added these board members have not been effective, instead adding another layer of political overburden to the company's deliberations.

Significantly, despite the reforms, Pemex still cannot enter into joint ventures or partnerships, and foreign companies who could provide much needed capital and technology will be reluctant to do so because they cannot secure an equity stake in the upstream projects allowing them to book reserves. In addition, Pemex still does not determine its own budget. With these limitations still in place, Pemex will likely have difficulty vastly improving its position.

III. Measuring the Technical Efficiency of Pemex

As in Eller, Hartley, and Medlock (2011), we use two methods to assess the relative technical efficiency of the firms in different years. The first technique is non-parametric data envelopment analysis (DEA).⁸ The second is a parametric stochastic frontier analysis (SFA).⁹

An advantage of using DEA is that it requires no assumptions regarding the functional form of the production technology, and it is not subject to the potential problems of assuming an inappropriate distribution of the error term. In this sense, the non-parametric DEA approach is more robust than SFA. However, since DEA does not account for statistical noise, estimates of efficiency will be biased when stochastic elements are a prominent feature of the true production process or the variables used in the analysis are measured with error. SFA, by contrast, provides a statistical measure of how well the proposed model explains the data. A potential weakness, however, is that one has to specify a structural relationship between inputs and outputs and assume distributions for the stochastic terms. If these auxiliary assumptions are inaccurate, the resulting inferences about the underlying model may be compromised. In addition, the one-sided technical efficiency error can be difficult to identify if the statistical noise has a high variance.

⁸ We used the program DEAP 2.1 written by Tim Coelli. For the reported results, we assumed that the technology displays constant returns to scale. While variable returns to scale allows for wider variations in technologies across firms, and more firms then are measured as maximally efficient, firms also are harder to compare. Nevertheless, the qualitative features of the results are not sensitive to this assumption. In particular, under both assumptions, Pemex is slightly less efficient than the average firm in our sample.

⁹ We primarily used the program FRONT 4.1, also written by Tim Coelli, for the stochastic frontier analysis, although we also used STATA for data manipulation and some of the basic analysis.

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Both DEA and SFA have been used extensively to analyze productive efficiency. Comparison of methods is available in Gong and Sickles (1992), Banker (1993), Cooper and Tone (1997), and Ruggiero (2007), to name a few. Our intention is not to examine the relative merits of DEA and SFA as methods for measuring efficiency. Rather, we explore both approaches to ensure as much as possible that our conclusions do not simply reflect the limitations of our mode of analysis.¹⁰

Data Envelopment Analysis

In brief, DEA uses a sample of firms to define a “frontier” of maximum outputs that can be obtained by combining the different inputs. Firms that determine the frontier of maximum outputs are assigned a DEA score of 1. All other firms are then given a score between zero and 1 that represents their distance from the frontier measured in such a way as to maintain their relative mix of inputs constant.

We use as inputs into the production of revenue (millions of current US\$), reserves of oil (millions of barrels) and natural gas (billions of cubic feet), distillation capacity (thousands of b/d), employees (head count at the end of the year), and prices of oil (current US\$ per barrel) and natural gas (current US\$ per million British thermal units or MMBTU).¹¹

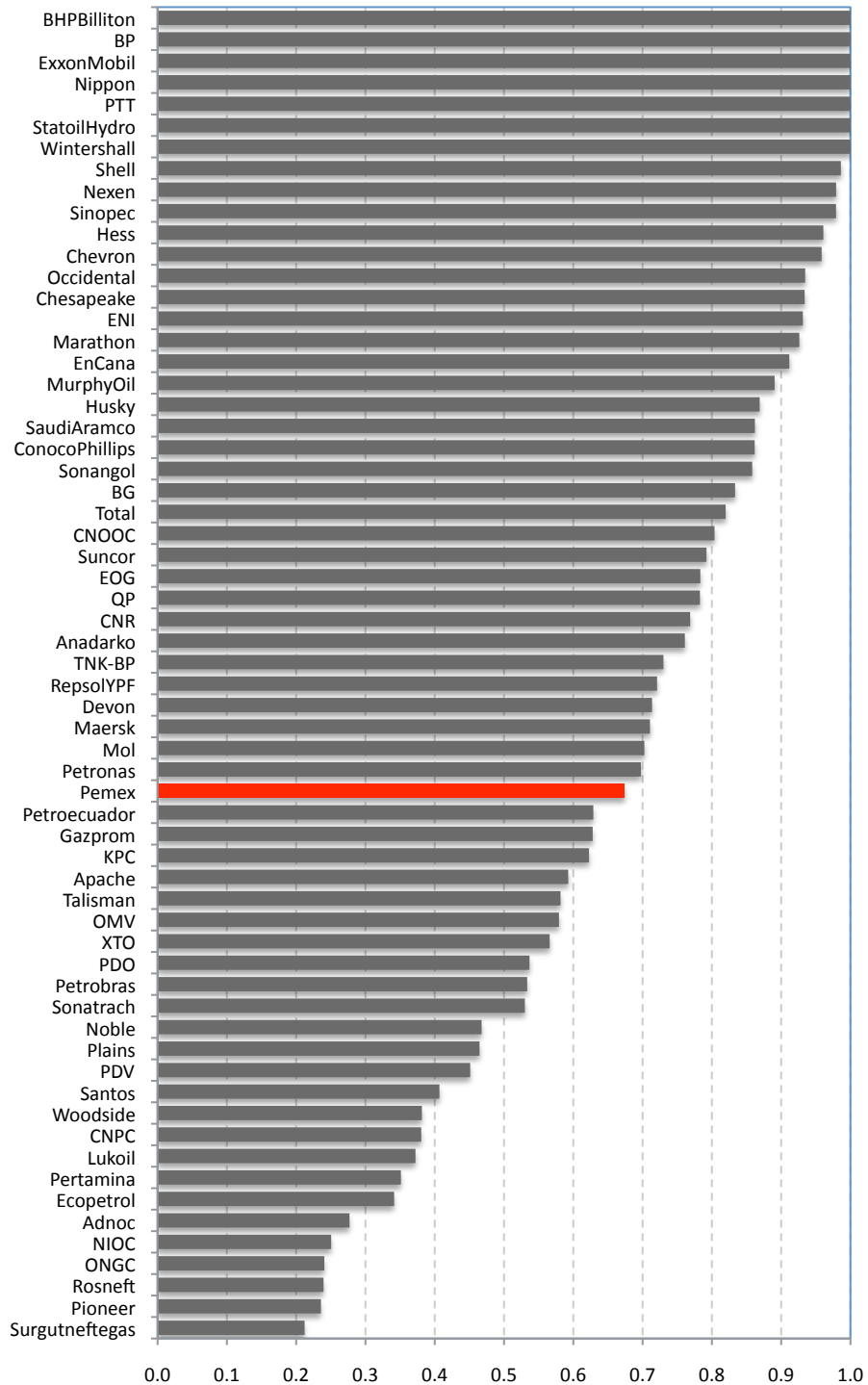
Figure 2 depicts the average of the DEA scores for each firm across the nine years of observation. By definition, there is an upper bound of 1 on the measured technical efficiency of a firm. The figure arranges the firms in decreasing order of technical efficiency with names alphabetized when scores are tied. As we found in our previous study, the majors are near the top of this ranking, while the national oil companies and smaller private firms are spread throughout the range. Pemex is ranked 37th from the top in terms of average efficiency in this sample of 62 firms.

¹⁰ More recent econometric literature has attempted to bridge the gap between the two methods by, on the one hand, introducing statistical noise into DEA and, on the other hand, by using a non-parametric formulation for inefficiency in SFA. Grosskopf (1996) provides an early survey of literature on statistical inference in DEA models. Desai et al. (2005) modified the constraints in DEA so they only needed to hold probabilistically. Tsionas (2003) discusses using DEA estimates of efficiency as priors for the one-sided errors in an SFA model, which then are derived as posterior estimates in a Monte Carlo Bayesian analysis.

¹¹ The price series were obtained from the Energy Information Administration (EIA). We used the average annual U.S. import price for North American firms, the average annual OPEC price for OPEC members, and the average non-OPEC price for other firms in the sample. The natural gas prices were the average annual prices at the Henry Hub. OPEC is the Organization of the Petroleum Exporting Countries.

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Figure 2. Average DEA Efficiency Scores



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We can also look at the rankings in each of the years in the sample. Of particular interest is the manner in which the ranking of Pemex changes through time. Its ranking in each year is given in Table 2. Three years stand out. Pemex efficiency was significantly lower compared with the other firms in the sample in 2002 and 2008, while in 2006 it was significantly higher. We discuss below some of the factors that may help us understand reasons for these changes in relative rankings.

Table 2. DEA Pemex Ranking by Year

	Pemex Ranking (Out of 62 firms)
2001	34
2002	42
2003	37
2004	34
2005	35
2006	30
2007	33
2008	40
2009	34

Since we are interested in understanding any systematic factors that may explain differences in measured efficiency, we examined the relationship between the DEA measures of inefficiency and several potential explanatory variables. In particular, as in Eller, Hartley, and Medlock (2011), we found that the annual DEA efficiency scores for all firms in the sample were systematically related to the extent of government ownership and a measure of the extent to which the firm was vertically integrated.¹² In addition, we tested for the effect of retail fuel subsidies on the DEA inefficiency scores.¹³

¹² As in Eller et al. (2011), we used the ratio of product sales (in thousands of b/d) to annual liquids production (also measured in thousands of b/d) to measure the extent to which the firm is involved in downstream markets.

¹³ Retail gasoline and diesel fuel prices were obtained from the Metschies surveys of international fuel prices. For countries where the retail prices were lower than in the U.S., the extent of subsidy was measured by the average percent that the price was below the corresponding price in the U.S. in the same year. Since the Metschies data is biannual, we used the average of the two percentage subsidies from the two adjacent years to proxy the percentage subsidy in the missing years. For countries with average retail prices above those of the U.S., including the U.S. itself, the subsidy variable was set to zero. In Eller et al (2011), we used the same data but coded the subsidy variable 0–1 to indicate whether the country had an average gasoline and diesel price below the corresponding average of the two prices in the U.S.

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The current data set also contained a significant number of mergers and acquisitions, a difficulty encountered due to the longer time series. In order to obtain a balanced panel data set with a fixed number of firms, we added the inputs and revenues of the merged parties in the years prior to the merger. We then defined an indicator variable that took the value of 1 for firms in the years prior to a subsequent merger and a value of zero after the merger took place. Estimating a panel Tobit regression¹⁴ with firm specific random effects we obtained (with estimated standard errors in parentheses):¹⁵

$$RevEff_{n,t}^{DEA} = 0.848 + 0.021 VertInt_{n,t} - 0.209 GovSh_{n,t} - 0.347 Subsidy - 0.129 PreMerg \quad (1)$$

(0.051)
(0.010)
(0.083)
(0.127)
(0.047)

All variables are estimated with the hypothesized sign and are statistically significant. We find that government-owned enterprises are on average significantly less efficient at producing revenue. Firms headquartered in countries where retail gasoline and diesel prices are subsidized relative to the U.S. also are significantly more likely to have lower revenue. Firms that have a larger ratio of final product sales to crude oil production also are measured as more efficient. Such firms also are likely to have significant downstream assets used as capital inputs that we are not measuring.¹⁶ Finally, we find that mergers are likely to significantly increase the measured efficiency of the resulting firm.

Using the estimated regression relationship in equation (1) and the values of the right-hand-side variables for Pemex, the predicted values for the DEA efficiency score for Pemex along with the corresponding actual values are presented in Table 3. Since the actual and predicted DEA scores

¹⁴ We use a Tobit regression since the DEA score is truncated at a maximum value of 1 for 158 out of 558 observations (62 firms for nine years).

¹⁵ The effect of government ownership share on the DEA efficiency score is slightly smaller, but not statistically significantly different from the effect obtained in Eller et al. (2011). While the effect of the vertical integration measure is about 40% of the corresponding effect found in Eller et al., since the inclusion of distillation capacity as an input variable in the current study already controls somewhat for vertical integration, this result is not unexpected.

¹⁶ While the *Energy Intelligence* data includes a measure of total assets we did not use it for two reasons. First, the measure is missing for many government-owned firms, and especially some of the important OPEC members. Including the variable would therefore have excluded these important firms from our data. Second, the value of assets is measured at historical cost and depreciated at what are often artificial conventional discount rates, making the reported asset values poor representations of the true economic values of the assets.

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are very similar, we conclude that Pemex in particular suffers around the average penalty for being a national oil company.

Table 3. Pemex Efficiency Scores Compared with Predicted Values

	Predicted DEA Score	Actual DEA Score
2001	0.648	0.636
2002	0.648	0.599
2003	0.648	0.619
2004	0.611	0.683
2005	0.649	0.685
2006	0.649	0.763
2007	0.649	0.748
2008	0.651	0.643
2009	0.652	0.691

The year-by-year DEA analysis provides a substantial amount of additional information about why Pemex generates less revenue from the resources at its disposal than do the most efficient firms in the sample. Specifically, for each year in the sample, the DEAP program specifies the maximally efficient firms (those on the “frontier” with a DEA score of 1) that are “closest” to each inefficient firm in terms of the proportions of their input mix. In a sense, these are the frontier firms in that year that the inefficient firm could most easily emulate.

In 2001, Pemex had three frontier peer firms. The closest (with a weight of 0.642) was Marathon, followed by BP (weight of 0.306), and BHPBilliton (weight of 0.037). The measured inefficiency of Pemex in 2001 implied that it should have been able to produce around 57% more revenue from its existing inputs and prices had it been able to emulate more closely one of its peers. There is also evidence that changing the mix of inputs could have generated additional revenue. Specifically, the comparisons with the remaining firms suggest that Pemex could have used only about 37% of the actual number of employees and held substantially lower oil reserves to produce the same 2001 revenue.

In 2002, the peer frontier firms were Statoil (weight 0.364), Shell¹⁷ (weight of 0.355), and BHPBilliton (weight of 0.254). Once again, the comparisons suggest that Pemex should have been able to generate round 67% more revenue from its existing inputs and prices. Furthermore,

¹⁷ Shell was not a frontier firm in 2001 but was in all subsequent years.

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it was again estimated to have excess employees and oil reserves for the revenue that it produced. The excess reserves and employee numbers were lower in 2002 than in 2001.

In 2003, the peer frontier firms were Nippon Oil (weight of 0.602), BP (weight of 0.288), and Marathon (weight of 0.088). The additional revenue Pemex should have been able to generate without changing its mix of inputs fell to around 61%, and once again there were indications that the actual revenue earned in 2003 could have been produced using substantially fewer employees and lower oil reserves.

In 2004, the peer frontier firms were again Marathon (now with a weight of 0.473), Shell (weight of 0.295), and BHPBilliton (weight of 0.227). The same mix of inputs as Pemex used in 2004 should have been able to generate an additional 46% of revenue, while the actual revenue generated once again could have been obtained using substantially fewer employees and lower oil reserves.

In 2005, Chevron became a peer frontier firm for the first time¹⁸ (weight of 0.574). Other peer frontier firms for Pemex in 2005 were Marathon (weight of 0.261) and Nippon Oil (weight of 0.160). Had Pemex been on the frontier with the same mix of inputs it actually deployed in 2005, it should have been able to generate over 45% more revenue. Once again, the comparisons suggest that the actual revenue that Pemex earned in 2005 should have needed only about 31% of the employees actually used. Now, however, the *excess* oil reserves (relative to the revenue produced) declined noticeably compared with previous years.

Chevron was once again was a peer frontier firm for Pemex in 2006 (weight of 0.581), but TNK-BP (weight of 0.318) and Sinopec (weight of 0.092) became two new peer frontier firms for Pemex in this year.¹⁹ After being stable for a few years at 137,000 to 138,000, Pemex employment increased to more than 141,000 in 2006. Excess employment measured by peer

¹⁸ Chevron did not become a frontier firm until 2004 following its merger with Texaco.

¹⁹ In 2001, TNK was among the lowest performing firms, with a DEA technical efficiency score of just 0.077. Its measured efficiency then improved dramatically to 0.779 in 2003 following the formation of TNK-BP with further improvement to 0.860 in 2004. TNK-BP became a frontier firm in 2005, and remained there in 2006 and 2007, but then fell back to a score of 0.995 in 2008 and 0.726 in 2009. Sinopec was a frontier firm in every year except 2002, when its DEA score was 0.813. Apparently, its input mix in 2001 and 2003-2005, however, was sufficiently different from Pemex that it did not become a peer frontier firm for Pemex until 2006.

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performance fell in percentage terms, however, to slightly above 36% of actual employment. There was also a further decline in the excess oil reserves needed to earn the actual revenue recorded in 2006. The DEA analysis indicated that had Pemex been on the frontier with the same mix of inputs it actually deployed in 2006, it should have been able to generate more than 31% additional revenue.

The peer frontier firms for Pemex in 2007 were again Chevron (weight of 0.563), Nippon Oil (weight of 0.419) and Sinopec (but now with a weight of just 0.002). The peer frontier firms now indicate that Pemex could reduce employment back toward the levels of 2001-2005 and still earn the same revenue as it actually earned in 2007. However, actual employment levels remained above 141,000, so excess employment increased to almost 70%. Alternatively, keeping the same mix of inputs but improving efficiency to attain the frontier, Pemex should have been able to earn over 33% more revenue in 2007.

Chevron was again the closest peer frontier firm for Pemex in 2008 (weight of 0.483), followed by Suncor (weight of 0.389)²⁰ and Sinopec (weight of 0.125). Actual employment at Pemex increased further in 2008, to exceed 143,000. However, the estimated efficient level of employment also increased again, so the excess employment fell to a little under 43%. The analysis again suggests that Pemex could have produced the same revenue with slightly reduced oil reserves if it operated as efficiently as the frontier firms. Alternatively, using the actual inputs deployed in 2008, the analysis suggests that Pemex could have earned over 55% more revenue.

In the final year of the sample, the efficient level of employment as determined from the peer frontier firms increased dramatically, so excess employment disappeared. In concert with this development, the number of peer frontier firms increased from three to four. BHPBilliton (with weight 0.340) reappears as a frontier peer to Pemex in 2009.²¹ ENI (with weight 0.298) appeared as a frontier peer of Pemex for the first time.²² Sinopec (weight 0.273) remained a frontier peer, while, among the majors, Shell (weight 0.066) again appeared as a frontier peer of Pemex. The analysis again suggested that the oil reserves needed to produce the actual revenue in 2009 were

²⁰ Suncor was a frontier firm only in 2007 and 2008, although it was also quite close to the frontier in 2006.

²¹ Chevron had a DEA score of 0.989 in 2009 and thus dropped back slightly from the frontier.

²² ENI was a frontier firm from 2006–2009, although it was also quite close to the frontier in 2004 and 2005.

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further below actual reserves than in 2008. Alternatively, using the actual inputs deployed in 2009, the analysis suggests that Pemex could have earned over 45% more revenue.

Changes in the DEA efficiency measure

We next examine changes in the DEA efficiency measures from one year to the next by examining a measure of relative efficiency change known as the Malmquist index. To explain this, it is useful to introduce some notation. As observed above, the DEA score for firm i in year t , measures the distance of firm i from the frontier in year t along a ray through the origin. Moving along such a ray varies the level of inputs while keeping the relative proportions of inputs constant. If we use $I_{i,t}$ to denote the inputs used by firm i in period t to produce revenue $R_{i,t}$, then the DEA score for firm i in year t can be written as $D_t(R_{i,t}, I_{i,t})$. One could also ask how efficient firm i would have been had year t technologies been available to firm i in year $t-1$. This is denoted as $D_t(R_{i,t-1}, I_{i,t-1})$. The ratio of these quantities

$$M_1 = \frac{D_t(R_{i,t}, I_{i,t})}{D_t(R_{i,t-1}, I_{i,t-1})} \quad (2)$$

measures productivity growth from year $t-1$ to year t viewed from the perspective of the complete set of technologies available in period t .

We could also measure the productivity gain from year $t-1$ to year t from the perspective of the technologies available in year $t-1$. The productivity gain from year $t-1$ to year t viewed from the perspective of the complete set of technologies available in period $t-1$ can be measured as:

$$M_2 = \frac{D_{t-1}(R_{i,t}, I_{i,t})}{D_{t-1}(R_{i,t-1}, I_{i,t-1})} \quad (3)$$

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The Malmquist index is defined as the geometric mean of M_1 and M_2 :

$$M = \left(\frac{D_t(R_{i,t}, I_{i,t})}{D_t(R_{i,t-1}, I_{i,t-1})} \frac{D_{t-1}(R_{i,t}, I_{i,t})}{D_{t-1}(R_{i,t-1}, I_{i,t-1})} \right)^{\frac{1}{2}} \quad (4)$$

The Malmquist index M in equation (4) can also be written as the product of two components:

$$M = \frac{D_t(R_{i,t}, I_{i,t})}{D_{t-1}(R_{i,t-1}, I_{i,t-1})} \left(\frac{D_{t-1}(R_{i,t-1}, I_{i,t-1})}{D_t(R_{i,t-1}, I_{i,t-1})} \frac{D_{t-1}(R_{i,t}, I_{i,t})}{D_t(R_{i,t}, I_{i,t})} \right)^{\frac{1}{2}} \quad (5)$$

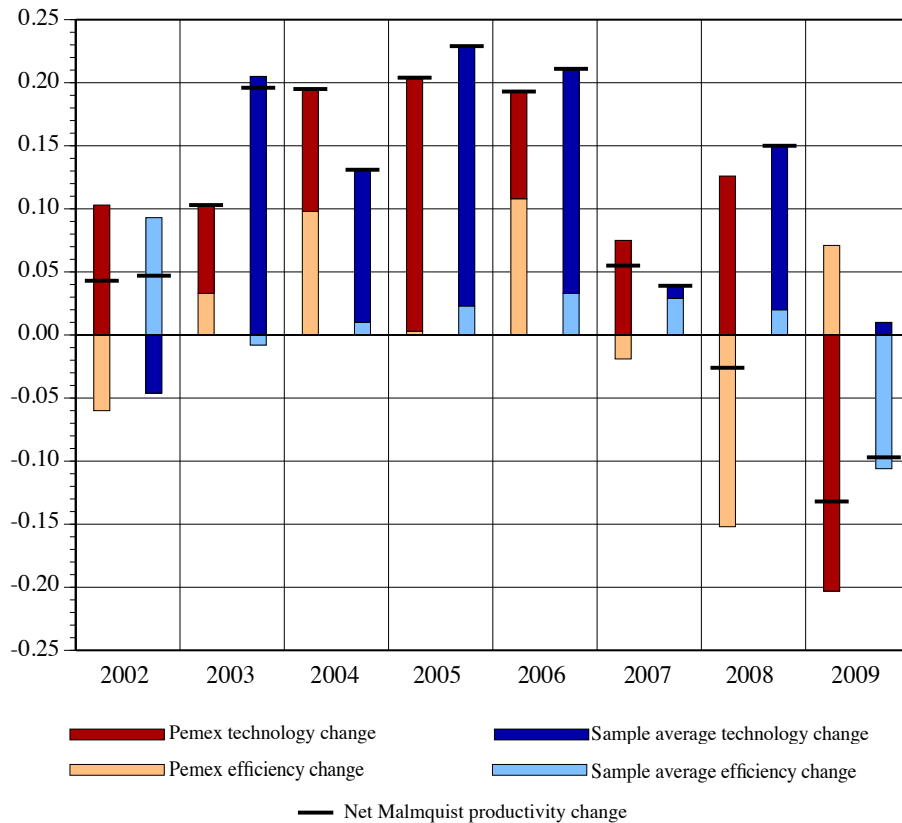
The first ratio (outside the square brackets) is just the ratio of the DEA score in period t to the DEA score in period $t-1$. It measures the proportional change from year $t-1$ to year t in the distance of firm i from the respective frontiers in each period. It is called the *efficiency change*. The first term in square brackets measures the proportional change in the *efficient frontier* at the data observed for firm i in period $t-1$, while the second term measures the change in the *frontier* at the data observed in period t .²³ The geometric average of these two ratios is thus a measure of the change in the *frontier technology* between the two periods.

Figure 3 graphs the natural logarithms of the two components of (5) for Pemex (red) and for the (geometric) average of all the firms in the sample (blue). Since these changes can only be measured for one year to the next, we only have them for 2002–2009. The logarithm of the first term in (5) is graphed in the lighter shade of the respective color, while the logarithm of the second term in square brackets is graphed in the darker shade of the respective color. Since the logarithm of a product is the sum of the logarithms, the logarithm of the overall change in the index is the sum of the logarithms of the two components and is indicated on the graph by the horizontal black lines.

²³ Note that an increase in these ratios would make it easier for firm i to attain the frontier in period t and thus contribute to measured positive productivity growth for firm i relative to the other firms in the sample.

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Figure 3. Changes in Productivity by Component for Pemex and All Other Firms



Observe first that the net productivity change for Pemex was greater than the corresponding sample average of firms on only two occasions—from 2003 to 2004 and from 2006 to 2007. In all other years, the net change in productivity in Pemex is less than the net change for the sample average of firms. This indicates that for the majority of the last decade, Pemex was moving away from the revenue efficient frontier. In fact, 2007–2008 was particularly bad for Pemex, as its productivity declined while productivity increased for the sample average of firms.

It also is noticeable that the *technology* changes for the sample average of firms (the dark blue bars in the figure) are positive in all years except from 2001-2002, while the technology changes for Pemex (the dark red bars) are positive in all years except 2008-2009. When the frontier moved out at the input combinations applying for Pemex, it also tended to move out for the input mix observed at most of the other firms. In the two periods when these movements are opposite, the sample average changes are quite small, suggesting that the direction of movement of the

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frontier in these years varied at different combinations of inputs. In other words, these were not years of a reasonably uniform shift in productivities across firms and, therefore, also for the frontier at different combinations of inputs.

By contrast, the efficiency changes at Pemex (the light red bars) moved in the opposite direction to the average efficiency changes for the full sample (the light blue bars) for five out of nine years. They moved in the same positive direction for three years, and in the same negative direction in just one year. We therefore conclude that, more often than not, Pemex was moving further from the frontier in those years when the average firm in the sample was moving closer to it. Furthermore, years when Pemex moved “with the crowd” were more likely to be years when firms as a whole were moving closer to the frontier than years when firms as a whole were moving away from the frontier.

In summary, these Malmquist index results suggest that Pemex tended to lag behind the industry as a whole in productivity changes. They also suggest that Pemex did not reflect widespread changes in efficiency changes in most years.

Stochastic frontier analysis (SFA)

As we noted above, unlike DEA, SFA requires parametric assumptions. Specifically, consider a single output production function for a cross-section of N firms with K inputs to be given as $y_n = f(x_{1,n}, \dots, x_{K,n})$. If the production technology can be represented as Cobb-Douglas, the production function can be linearized by taking natural logarithms, yielding

$$\ln y_n = \beta_0 + \sum_{k=1}^K \beta_k \ln x_{k,n} + v_n - u_n \quad (6)$$

where v_n is a stochastic component generally assumed to be normally distributed and u_n captures the nonnegative technical efficiency component. Define ε_n as the composed error such that $\varepsilon_n = v_n - u_n$. Jondrow et al. (1982) proposed estimating individual technical efficiency from the

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expected value of u_n conditional on ε_n using maximum likelihood. Firm-specific efficiency can then be calculated as $e^{-E(u_n|\varepsilon_n)}$. Since $u_n \geq 0$, efficiency will be bounded between zero and one.

Pitt and Lee (1981) extended the maximum likelihood approach for estimating firm-specific technical efficiency to panel data.²⁴ The log-linear Cobb-Douglas production function for panel data is

$$\ln y_{n,t} = \beta_0 + \sum_{k=1}^K \beta_k \ln x_{k,n,t} + v_{n,t} - u_{n,t} \quad (7)$$

for years $t = 1, \dots, T$ and where the efficiency component u_n can depend in a parametric way on time or other measured covariates, but cannot have an arbitrary time dependence.²⁵ In the simplest specification, we assume:

- (i) $v_{n,t} \sim N(0, \sigma_v^2)$,
- (ii) $u_{nt} = e^{-\eta(t-T)} u_n$ with $u_n \sim N^+(\mu, \sigma_u^2)$ and N^+ is the truncated-normal distribution,
- (iii) $v_{n,t}$ and u_n are distributed independently of each other and the regressors.

This allows the efficiency of the *panel* of firms to change over time at the rate η per year, although the deviations u_n of individual firms from the panel average do not change over time.

In our case, y_{nt} is the revenue of firm n in year t , the regressors $x_{k,n,t}$ are oil and natural gas reserves, distillation capacity,²⁶ employees, and oil and natural gas prices.

²⁴ Schmidt and Sickles (1984) also proposed using one-sided fixed-effects and random-effects to measure time-invariant producer-specific technical efficiency. See Kumbhakar and Lovell (2000) for a thorough survey of panel stochastic frontier analysis.

²⁵ The time-varying specifications we shall examine were first proposed by Cornwell, Schmidt, and Sickles (1990), Battese and Coelli (1992, 1995).

²⁶ Since some firms had no distillation capacity we actually used the $\ln(1+\text{capacity})$, which is zero for capacity equal to zero and barely unchanged from $\ln(\text{capacity})$ when capacity is positive since the average of the strictly positive values is around 1000 (in thousands of b/d).

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The estimated equation (with estimated standard errors in parentheses) is:

$$\begin{aligned} \ln Rev_{n,t} = & 3.866 + 0.350 \ln Emp_{n,t} + 0.158 \ln OilRsv_{n,t} + 0.015 \ln NGRsv_{n,t} \\ & + 0.086 \ln RefCap_{n,t} + 0.570 \ln OilP_{n,t} + 0.160 \ln NGP_{n,t} + v_{n,t} - u_{n,t} \end{aligned} \quad (8)$$

0.505 0.043 0.032 0.028
0.017 0.058 0.045

with estimated error structure parameters $\mu = 1.3391$ (0.2035), $\eta = 0.0345$ (0.0055), $\sigma_u^2 = 0.3861$ (0.0882) and $\sigma_v^2 = 0.0533$ (0.0034). All the coefficients have the expected positive signs as each input contributes positively to revenue. All variables except natural gas reserves are statistically significantly different from zero. The point estimate of η implies, as with the DEA estimates discussed above, that firms in the sample were on average becoming more efficient at generating revenue from their inputs over the period 2002-2009. Finally, the much larger value of σ_u^2 relative to σ_v^2 implies that almost 88% of the variation in the composite error term is due to the one-sided systematic efficiency differences between the firms rather than statistical noise or measurement error.

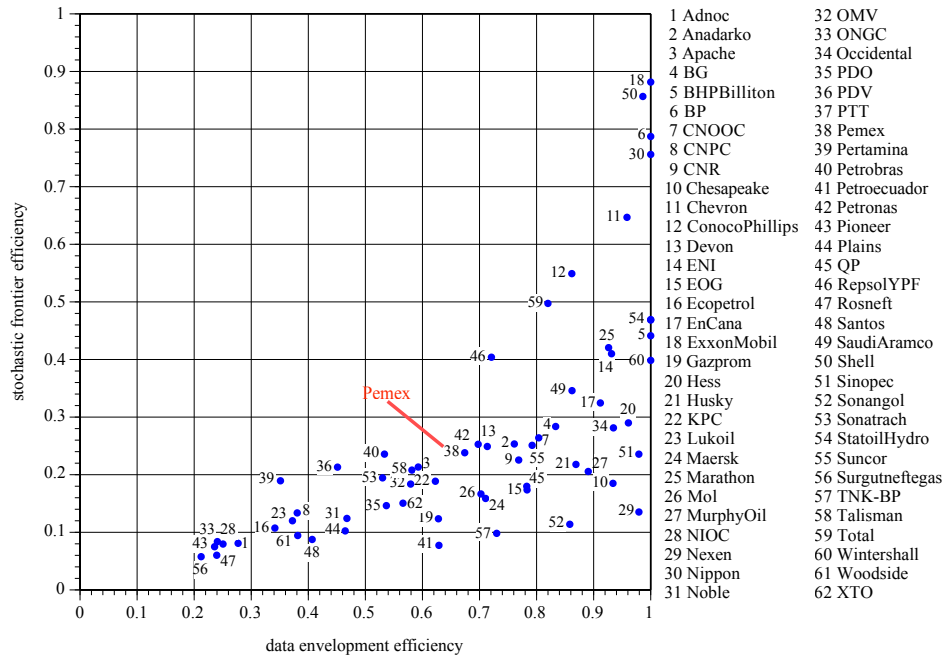
Although the DEA and SFA are very different types of measures, they give reasonably similar efficiency rankings for most of the firms. Estimating a panel Tobit regression with firm specific random effects we obtained (with estimated standard errors in parentheses):

$$RevEff_{n,t}^{DEA} = 0.420 + 1.312 RevEff_{n,t}^{SFA}$$

(0.046) (0.152)

The strong positive correlation between the measures for each firm is also illustrated in Figure 4, which plots the average of the SFA scores over the nine years against the average of the DEA scores over the same years. Of particular relevance to this paper, we find that Pemex is around the middle of the group of firms in terms of measured efficiency in generating revenue regardless of which type of technique we use to measure efficiency.

Figure 4. Average SFA versus Average DEA Efficiency Scores



In order to further understand some of the sources of measured inefficiencies in generating revenue, we estimated a series of revised SFA models based on the specification of Battese and Coelli (1995). This specification allows the mean of the firm-specific inefficiency measures $u_{n,t}$ to depend on firm-specific covariates $z_{l,n,t}$, where $l = 1, \dots, L$. Table 4 presents the estimates from a range of such models.

In Model 1, we re-estimate the same frontier as in (8) but allow the mean of $u_{n,t}$ to depend on the extent of government ownership, the previously considered vertical integration measure (final product sales divided by crude production) and the pre-merger indicator variable. This model is analogous to regression (1), which uses the same three variables, along with the percentage fuel subsidy,²⁷ to explain the DEA efficiency measures. As in that analysis, SFA model 1 reveals that firms with higher government ownership are less efficient while firms that have relatively more product sales are more efficient. On the other hand, while (1) revealed that firms that subsequently merged tended to be less efficient prior to their merger, SFA model 1 suggests the

²⁷ In the SFA analysis, the subsidy variable will be entered into the frontier as a discount on the oil price.

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opposite. However, the coefficient is not statistically significantly different from zero. The coefficient on the natural gas price, although positive as hypothesized, is also not statistically significantly different from zero. A possible explanation is that the Henry Hub price is likely to be a poor measure of the domestic natural gas price in most countries.

Table 4. Models of the Efficiency Error Terms

	Model 1	Model 2	Model 3	Model 4
β_0	2.1961 (0.3231)	1.8023 (0.2995)	1.7916 (0.3257)	1.3550 (0.2910)
$\ln OilRes$	0.1272 (0.0298)	0.1136 (0.0300)	0.1159 (0.0285)	0.0880 (0.0239)
$\ln NGRes$	0.1335 (0.0244)	0.1836 (0.0272)	0.1842 (0.0266)	0.1970 (0.0250)
$\ln Refcap$	0.1466 (0.0130)	0.1397 (0.0127)	0.1410 (0.0142)	0.1577 (0.0115)
$\ln Emp$	0.3181 (0.0313)	0.3161 (0.0289)	0.3158 (0.0281)	0.3492 (0.0286)
$GovShare*\ln Emp$		-0.0780 (0.0091)	-0.0773 (0.0090)	-0.0713 (0.0065)
$\ln Oilp$	0.8181 (0.0760)	0.8358 (0.0619)	0.8142 (0.0495)	0.8007 (0.0497)
$\ln NGp$	0.0122 (0.1166)	-0.0335 (0.0929)		
$\ln (1-Subsidy)$		0.1737 (0.0673)	0.1835 (0.0651)	0.1709 (0.0641)
δ_0	1.2469 (0.1208)	1.1481 (0.1874)	1.1200 (0.1960)	0.7107 (0.1659)
$GovShare$	0.8036 (0.0885)	-0.1976 (0.1899)	-0.1713 (0.2046)	
$VertInt$	-0.1321 (0.0237)	-0.2163 (0.0105)	-0.2138 (0.0201)	-0.2341 (0.0389)
$Premerge$	-0.1421 (0.1232)	-0.1399 (0.1748)		
$\sigma_u^2 + \sigma_v^2$	0.4093 (0.0334)	0.4878 (0.0704)	0.4827 (0.0734)	0.6772 (0.1028)
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.9726 (0.0323)	0.9230 (0.0236)	0.9158 (0.0188)	0.9230 (0.0189)
log likelihood	-486.81	-469.05	-469.59	-472.98

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The coefficient on the government share variable in model 1 summarizes the overall effect of government ownership. The model presented in Hartley and Medlock (2008), however, suggests more specifically that, in order to redistribute resource rents, NOCs are likely to be forced to have excess employees and to sell oil products to domestic consumers at subsidized prices (a practice sometimes referred to as two-tiered pricing).

Excessive employment in NOCs is likely to show up as a lower marginal productivity of labor in generating revenue. Hence, to test this hypothesis, we added an interaction term between the share of government ownership and total employment to the explanatory variables for the stochastic frontier in model 1. The coefficient on this variable should then indicate the discount on labor productivity (or equivalently the excess employment) in government-owned firms.

Two-tier pricing would reduce the firm's average selling prices. However, we do not have explicit measures of these for each firm. All we have is the percentage deviation of retail prices of gasoline and diesel below U.S. prices in different *countries*. Nevertheless, the countries where such subsidies are measured²⁸ all have domestic product markets dominated by an NOC, so associating country subsidies with firms based in those countries ought not introduce too much error. Recall that the subsidy variable is the percentage deviation of domestic prices below the U.S. price. Hence, we should multiply the international price by $(1 - \textit{Subsidy})$ to obtain the domestic selling price. Thus, we included $\ln(1 - \textit{Subsidy})$ as a variable in the frontier.

Adding these two variables to Model 1 yields a substantially lower maximized log likelihood ($\chi^2 = 17.76$, p -value less than 0.00014), implying that the two variables together help significantly in further delineating the efficient frontier. Furthermore, the high t -statistics on both variables, and especially the interaction term between government ownership and employment, imply that each variable individually helps delineate the frontier. The coefficient on the employment interaction term implies that labor in a fully government-owned firm is on average almost 25% less productive than an equivalent level of employment in a private firm.

²⁸ These were Algeria, Angola, China, Colombia, Ecuador, Indonesia, Iran, Kuwait, Malaysia, Mexico, Oman, Qatar, Russia, Saudi Arabia, Thailand, UAE, and Venezuela.

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Most of the coefficients on the remaining variables are not significantly affected by the addition of the two new variables. The coefficient on the natural gas price changes from being positive and insignificantly different from zero to being negative and insignificantly different from zero. Similarly, the coefficient on the pre-merger variable retains its unexpected negative sign in Model 2 but becomes even less statistically significant. The coefficient on the vertical integration variable in explaining the mean of $u_{n,t}$ increased in magnitude and statistical significance, implying that once we adjust for subsidies and the lower labor productivity in government-owned firms, the value of product market sales for enhancing revenue (recall that we are not measuring capital employed in retailing operations) increases.

The most interesting change in moving from Model 1 to Model 2, however, is that the coefficient on the government ownership share changes sign and becomes statistically insignificantly different from zero. The implication is that, once we correct for the effects of subsidies and excess employment on the production of revenue, remaining unmeasured characteristics of government-owned firms (such as, for example, the geological characteristics of their deposits or the quality of the oil they produce) tend to make them *more* efficient at producing revenue from the measured inputs than private firms. The fact that the coefficient is not statistically significantly different from zero, however, suggests that there is considerable heterogeneity across firms in these unmeasured characteristics. In other words, there is not a systematic tendency to either raise or lower the efficiency of government-owned, relative to private, firms.

In Model 3, we dropped the natural gas price from the variables describing the efficiency frontier and the pre-merger variable from the terms describing the mean of the one-sided efficiency measure $u_{n,t}$. As the t -statistics in Model 2 would suggest, eliminating these variables leaves the maximized log likelihood virtually unchanged²⁹ confirming that these variables do not help explain inefficiency across firms or over time. Once again, the coefficients on the remaining variables are all virtually unchanged. Generally speaking, however, the estimated standard errors are reduced, implying the statistical significance of most of the coefficients increases. A notable exception again is the coefficient on the government ownership variable in explaining the mean

²⁹ The statistic for measuring their joint significance is $\chi^2 = 0.54$ with a p -value of 0.7645.

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of $u_{n,t}$, which retains its negative sign but declines in magnitude and is estimated with a higher standard error—implying it becomes even less statistically significant.

In Model 4 presented in Table 3, we dropped the government ownership variable from the expression explaining the mean of $u_{n,t}$. Despite the low t -statistic for the coefficient on this variable in Model 3, dropping it leads to a large change in the log likelihood function ($\chi^2_1 = 3.39$), which is statistically significant at the 10% level but not at the 5% level (p -value = 0.0656). In addition, dropping this variable now changes most of the remaining coefficient estimates by a noticeable amount. We therefore conclude that it is more prudent to base the conclusions on Model 3, which includes this variable.

Using the coefficient estimates in Model 3, we can calculate the efficiency rankings of Pemex as in Table 1 presented earlier, but now *after* correcting for the systematic penalties associated with its status as a government-owned firm, its excess employment and the effects of product subsidies. The result is presented in Table 5.

In general, after correcting for Pemex's various disadvantages from being an NOC, its ranks were in the low to mid-teens. The major exception is 2008, when its rank fell to 21 out of 62. It is interesting that the Malmquist analysis summarized in Figure 3 (which was based on the DEA analysis) revealed the period 2007-2008 to be the worst year for Pemex productivity change relative to the other firms in the sample. Indeed, this was the only year in which the Malmquist net productivity change for Pemex was of the opposite sign to the average for the sample, with Pemex showing a decline in productivity while the average of the firms in the sample showed an increase.

The other conclusion one can draw from the rankings in Table 5 versus those in Table 2 is that a substantial part of Pemex's lower productivity, but not all of it, can be explained by the disadvantages associated with being a fully government-owned firm.

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Table 5. SFA Model 3-derived Pemex Ranking by Year after Adjusting for Disadvantages of NOC status, Excessive Employment, and Product Subsidies

	SFA Model 3 Pemex ranking (out of 62 firms)
2001	12
2002	8
2003	14
2004	15
2005	13
2006	11
2007	13
2008	21
2009	16

IV. Conclusion

The first decade of the 21st century has been a difficult one for Pemex. Output from its key Cantarell Field has begun to decline steeply and to replace it will require substantial investments, including in technologies and exploration frontiers in which Pemex currently has no expertise. Our analysis reveals that the productivity improvements in Pemex generally lagged those of the rest of the industry throughout the decade. We found that if Pemex had performed as well as the most efficient firms in our sample, it could have earned on average 48% more revenue in each year from 2001-2009 using only its existing resources.

The comparisons with other firms in our sample also implied that there was substantial excess employment in Pemex. We further showed that the inefficiencies in Pemex operations, including its excess employment, were shared with other NOCs. However, even after correcting for the average disadvantages of being an NOC rather than a private firm, Pemex was still found to be less efficient than the best firms in the sample, which may indicate room for improvement in other ways.

It is also important to emphasize that we used two very different techniques to measure the relative efficiency of Pemex. Nevertheless, the results were similar. This should provide some comfort that the results are not simply an artifact of the mode of statistical analysis.

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