Efficiency of National Oil Companies (NOCs) and some implications for GOM exploration

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A Model of the Operation of a National Oil Company

Model precepts

- Intertemporal optimizing model of the operation and development of an NOC
- Contrast an NOC's behavior with that of a shareholder-owned IOC with identical operating parameters such as
  - The total technically recoverable resource,
  - The effect of geology on feasible production rates, and
  - The effect of supply on price or marginal revenues in end-use markets
- Aims:
  - What are the systematic effects of being an NOC?
  - Are the systematic effects observable?
  - What are the consequences of national ownership?

Shareholder-owned corporations

- Many institutional features of shareholder-owned corporations encourage managers to maximize shareholder wealth
- Traded ownership claims (shares) serve a number of purposes:
  - They allow for effective risk diversification and long-lived projects
  - Their prices, reflecting diverse assessments based on dispersed information, provide a readily accessible measure of managerial performance
  - They thus facilitate performance-related compensation for managers
  - Poor decisions reduce their prices, encouraging takeovers and new management
- Increased firm leverage increases the threat of bankruptcy or takeovers
  - Pressures managers if they have substantial firm-specific human capital
- Specific monitoring practices such as standard accounts and financial reports have evolved to limit managerial discretion

Principal-agent issues in NOCs

- Residual ownership claims are not traded and cannot be transferred, resulting in
  - Reduced information about manager performance,
  - Absence of a takeover threat, which reduces pressure on managers to perform, and
  - Reduced ability to compensate managers with performance related pay
- Firm debt guaranteed by government cannot bankrupt the firm
- Audited accounts or formal monitoring and control systems analogous to those in private corporations may not accurately reflect firm performance
- Politicians also may be interested in more than financial performance
- Managers of government-owned firms can be dismissed for poor performance
  - However, they may be given less credit if the firm does well
  - This asymmetry may make managers more risk averse

Modeling the objectives of an NOC

- Politicians likely will use an NOC to pursue goals other than economic efficiency:
  - Benefiting domestic consumers via subsidized prices
  - Enhancing political support by favoring domestic input suppliers (including employees)
  - Constraining investment to increase current revenue flowing to the Treasury
- If managers of government-owned firms are less constrained, they may also pursue objectives such as increased size (and budget) of the firm
  - Excessive expansion may also happen if operations are poorly supervised

Technical environment

- The economic and geological environment of the (NOC or private) firm includes:
  - The technically recoverable resource;
  - The fixed and operating costs of exploitation and how they relate to geology; and
  - The price (or marginal revenues) in end-use markets after transport and marketing costs
- We assume that the environments of an NOC and private firm are identical, thus focusing on allocative inefficiency
  - Technical inefficiency (producing less with the same inputs) would have additional effects

Summary of the results

- Many potential political influences on an NOC tend to push it in the same direction
- An increase in the political pressure to provide immediate funds to Treasury
  - Encourages employment, output and cash flow in the short run, but reduces them in the long run
  - Generally reduces proved reserves, except possibly in the first few years
- Any political or bureaucratic imperative to raise employment will lead to
  - Higher employment throughout the time horizon
  - Higher output, cash flow and reserves in the short run, but these are all lower in the longer term
- Forcing the NOC to subsidize domestic consumers
  - Shifts production from the future toward the present
  - Leads to greater employment in the initial time periods
  - While the firm is exporting, increased employment and output provide additional revenue to offset the losses associated with domestic sales
- The predictions of the model are consistent with NOCs being more focused on current output and cash flow and less focused on developing resources than private firms

Empirical Analysis

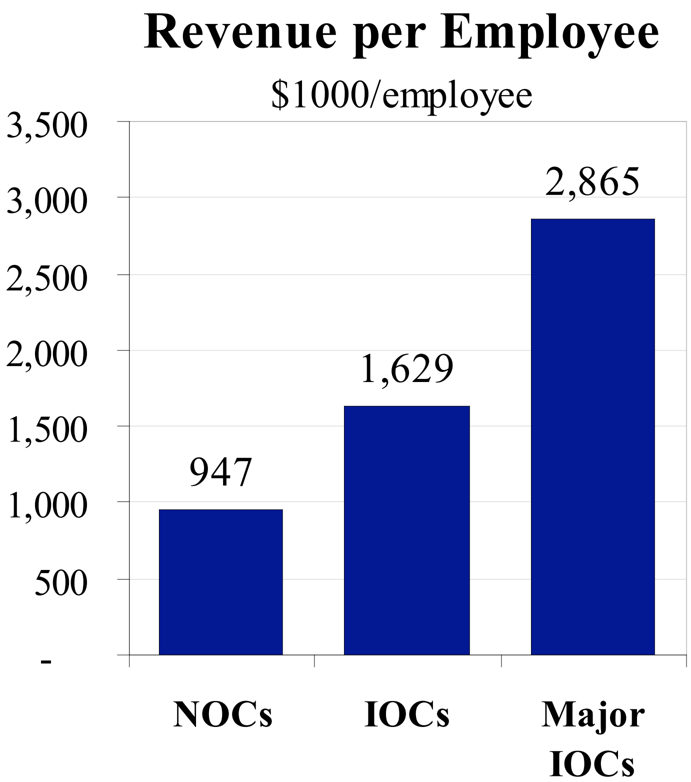
Data

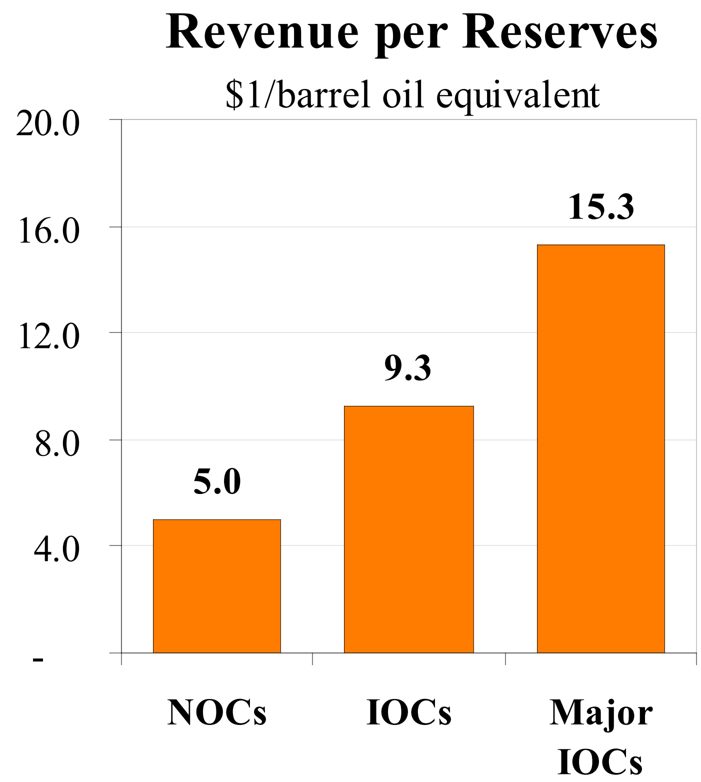
- 78 firms over 2002-2004 (*Energy Intelligence* “Ranking the World’s Oil Companies”):
  - revenue,
  - reserves of natural gas and crude oil,
  - employment,
  - production of natural gas and crude oil and crude oil products, and
  - government ownership share
- We examine relative efficiencies at producing *revenue*
- We allow for three inputs into the production of revenue:
  - employees
  - oil reserves and
  - natural gas reserves
- We do not include total assets as an input
  - Data on total assets is unavailable for many NOCs, especially OPEC members
  - Reserves capture most of the value of assets for these firms
  - Reserves are also likely to be measured more accurately than other assets
  - But, ignoring other assets makes vertically integrated firms look more efficient

Company	Revenue per Employee $1,000/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	200	1.27	100%	Kazakhstan
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
Norsk Hydro	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	1.51	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
Saudi Aramco	2,261	0.40	100%	Saudi Arabia
Sinopec	192	19.76	57%	China
Sonangol	755	1.37	100%	Angola
Sonatrach	688	0.93	100%	Algeria
Statoil	1,910	10.85	71%	Norway
TPAO	154	1.53	100%	Turkey
Average	***994.61***	***5.22***		
Major IOCs				
BP	2,788	15.68	0%	UK
Chevron	2,606	12.78	0%	US
ConocoPhillips	3,368	14.03	0%	US
Exxon Mobil	3,148	12.26	0%	US
Shell	2,418	21.67	0%	Netherlands
Average	***2,865.48***	***15.28***		

Company	Revenue per Employee $1,000/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
Forest Oil	1,841	4.02	0%	US
Husky Energy	2,149	9.53	0%	Canada
Imperial	2,838	17.91	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
Nippon Oil	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
Repsol YPF	1,561	10.79	0%	Spain
Santos	789	1.92	0%	Australia
Sibneft	189	1.81	0%	Russia
Suncor	1,447	13.41	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***	***9.26***		

Summary statistics 2004





Methods used to analyze relative efficiencies

- We used non-parametric Data Envelopment Analysis (DEA), parametric Stochastic Frontier Approach (SFA) and a semi-parametric kernel method
  - DEA calculates maximum output for given inputs using linear programming to construct a piecewise-linear frontier of input-output bundles
  - SFA proposes a functional form for the frontier and identifies inefficiency as part of a two-component error, one being statistical noise while the other captures inefficiency
  - The kernel method, like SFA, uses a functional form for the frontier but allows a very general non-parametric error structure
- The methods have different strengths and weaknesses:
  - SFA more directly reveals how different variables affect efficiency, allows for statistical noise including measurement error and provides a statistical measure of fit
  - <u>But</u> the assumed structural relationships or error distributions in SFA could be wrong
  - DEA requires no assumptions about functional form or error distributions

Model

- The theoretical model assumed that output

$$Q = F(L) \cdot Rsv \cdot G(E)$$

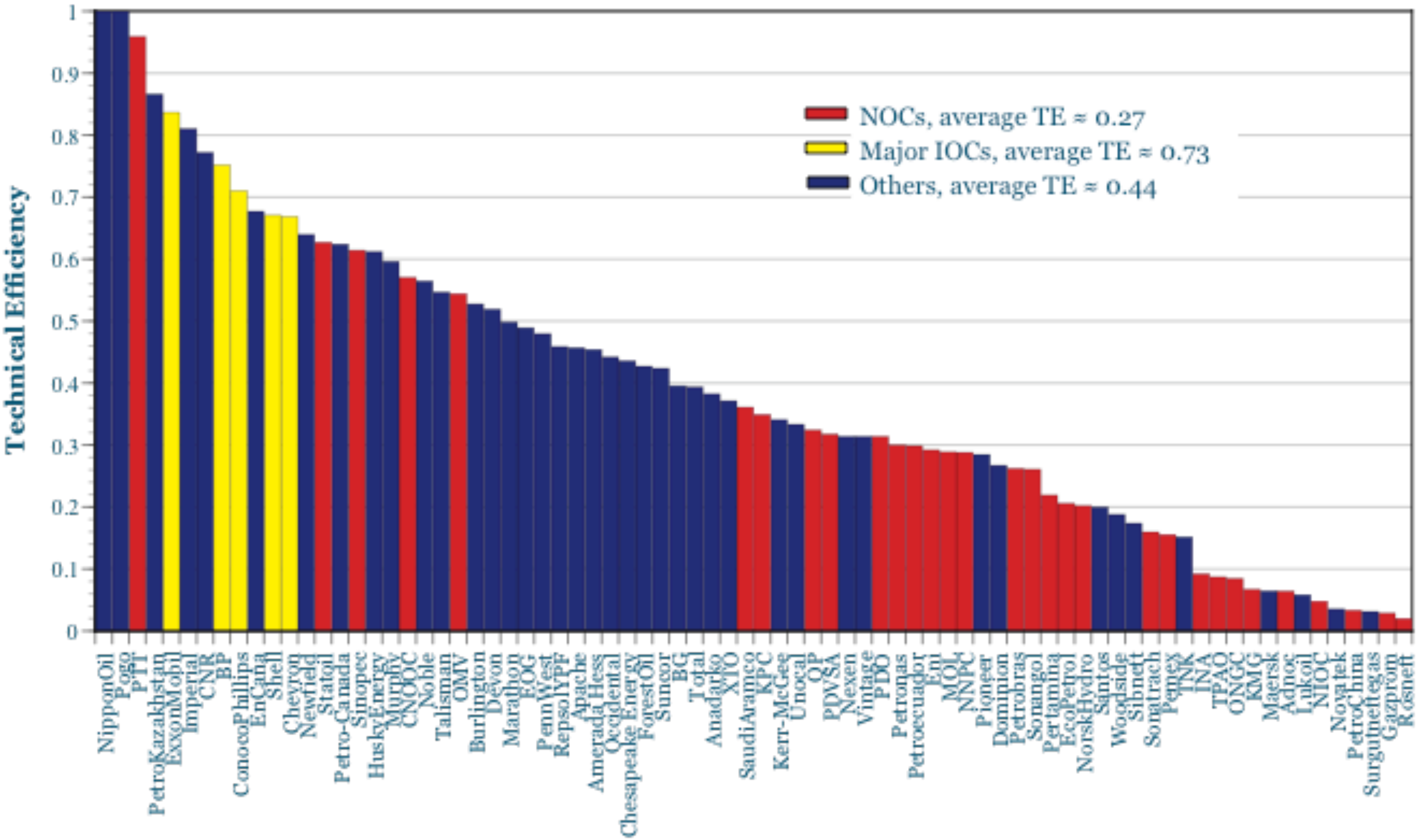
- If p_t is the price of output in year t, the log of revenue for firm n in year t could then be approximated by

$$\ln Rev_{n,t} = \beta_0 + \beta_1 \ln p_t + \beta_2 \ln L_{n,t} + \beta_3 \ln Rsv_{n,t} + \varepsilon_{n,t}$$

where we would expect unmeasured geologic characteristics specific to each firm's reservoirs to be a significant component of $\varepsilon_{n,t}$

- To begin the efficiency analysis, we used output-oriented DEA assuming CRS to calculate the firm-specific revenue efficiency measures using the observed input-revenue bundles for each year

Average DEA scores over 2002-04



Model 1 Revenue TE, Inputs: Employees, Oil & Gas Reserves

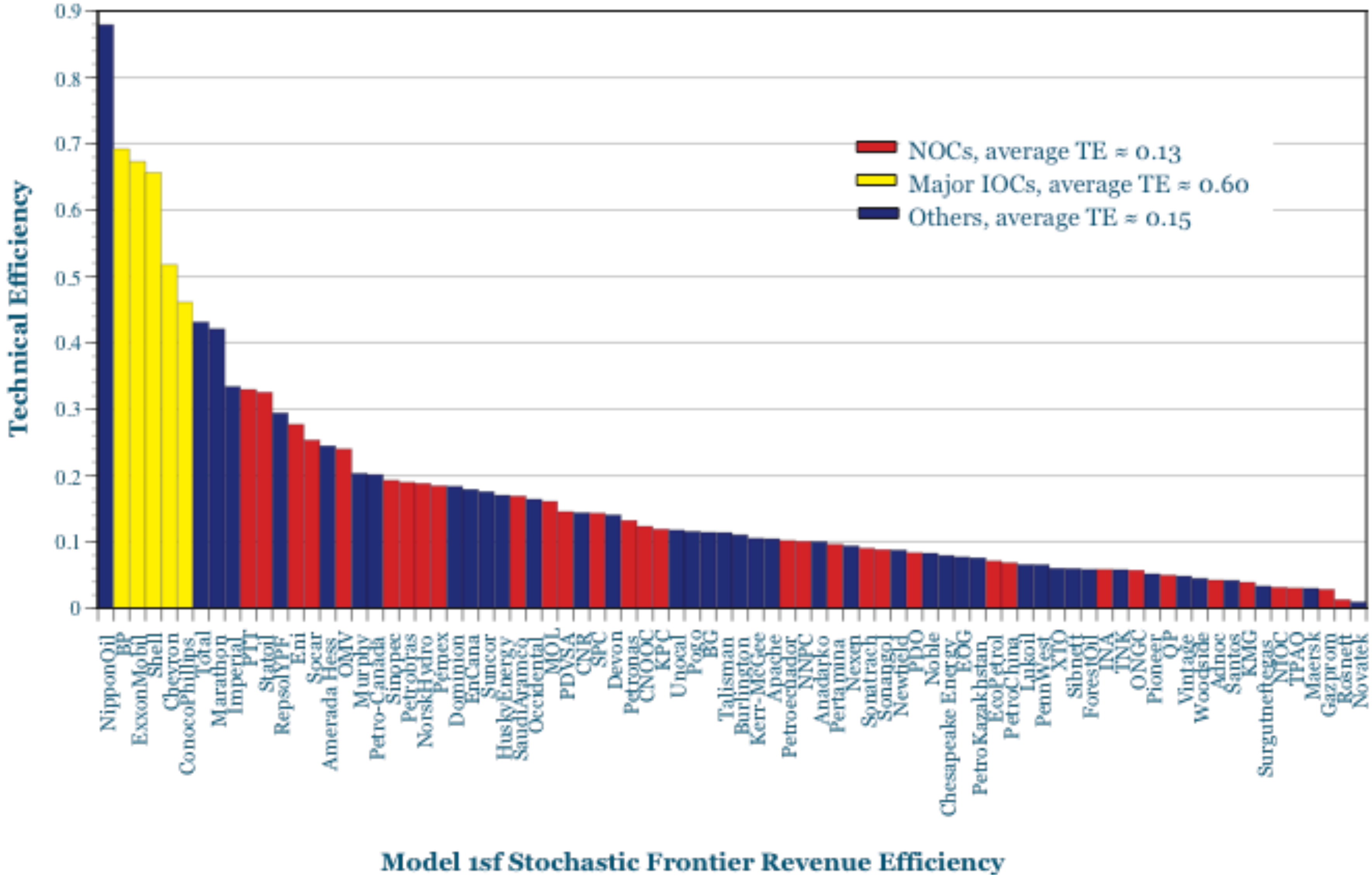
Stochastic frontier analysis

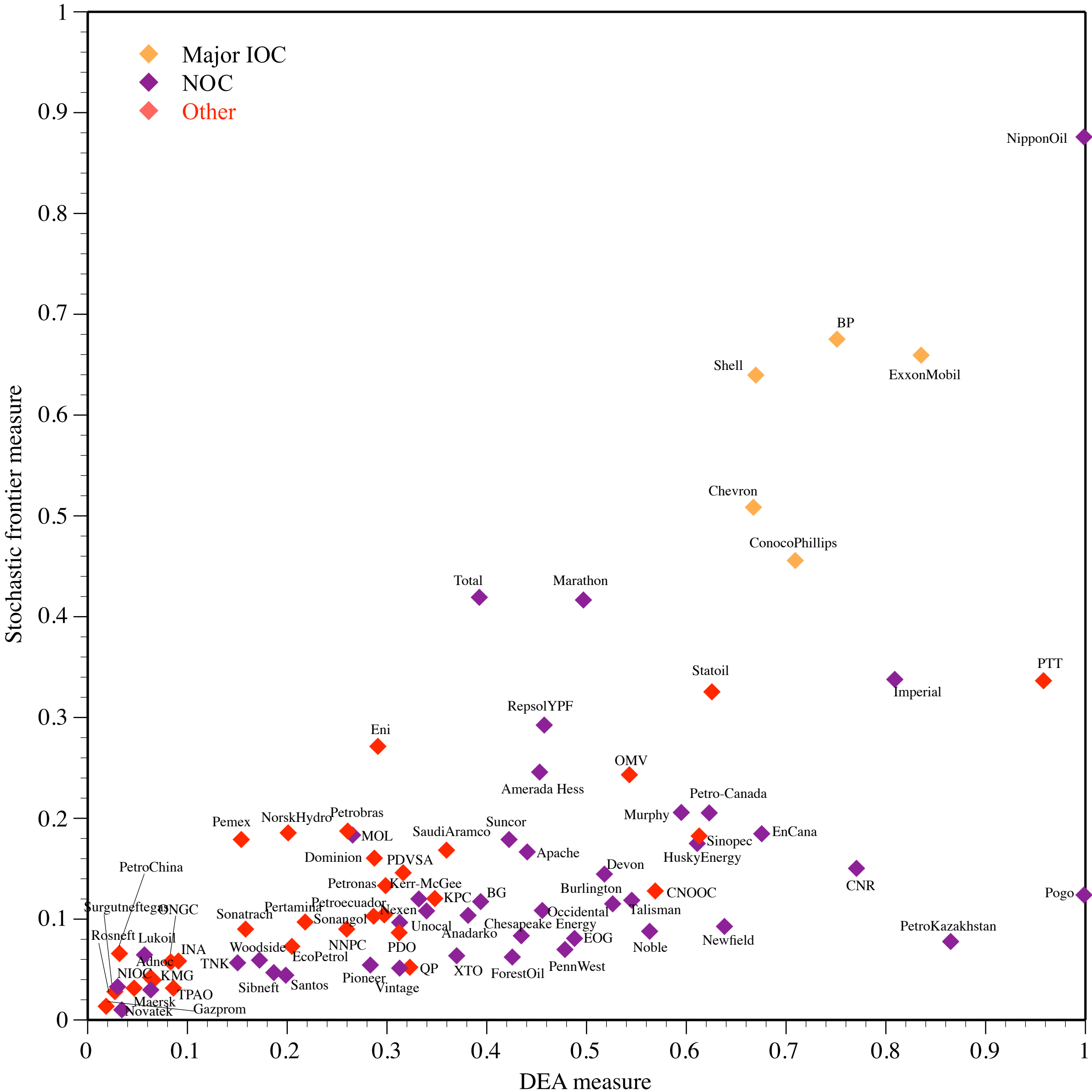
- The equation estimated using SFA is given as (standard errors in parentheses):

$$\ln Rev_{n,t} = \underset{(0.5928)}{4.8036} + \underset{(0.0636)}{0.3961^*} \ln L_{n,t} + \underset{(0.0608)}{0.1196^*} \ln OilRsv_{n,t} + \underset{(0.0547)}{0.1855^*} \ln NGRsv_{n,t}$$
$$+ \underset{(0.0249)}{0.2702^*} t_{2003} + \underset{(0.0251)}{0.4423^*} t_{2004} + v_{n,t} - u_n$$

- Estimated TE is assumed constant over the three year period
  - Include yearly effects to allow especially for varying oil and gas prices by year
  - Year effects are unnecessary in DEA since TE is calculated separately for each year
- Each coefficient has the expected sign, but the relative magnitudes of the coefficients on oil and gas reserves are unexpected
- $\gamma = \sigma_u/(\sigma_u+\sigma_v) = 0.9717$ with an estimated standard error of 0.0062

Stochastic frontier efficiency measures





Spearman rank order correlation = 0.6974

$$RevEff_{DEA,n} = \underset{(0.0327)}{0.2247} + \underset{(0.1450)}{1.0523} * RevEff_{SFA,n}$$

Explaining DEA measured inefficiencies

- *VertInt* = petroleum product sales divided by total liquids production
- *GovShare* = Government ownership share
- Using the basic DEA measured inefficiencies, we obtained the following Tobit panel regression results

$$RevEff_{DEA,n} = \underset{(0.0318)}{0.4183} + \underset{(0.0110)}{0.0519^*}\, VertInt - \underset{(0.0540)}{0.2429^*}\, GovShare$$

Explaining SFA measured inefficiencies

- For SFA, following Battese and Coelli we allowed the one-sided error to satisfy

$$u_{nt} = z_{nt}\delta + w_{nt}$$

for explanatory factors z_{nt} and where the random variable $w_{nt} \geq -z_{nt}\delta$ is a truncated normal distribution with zero mean and v is zero mean and independently distributed from the u_{nt}

- The resulting estimated model was

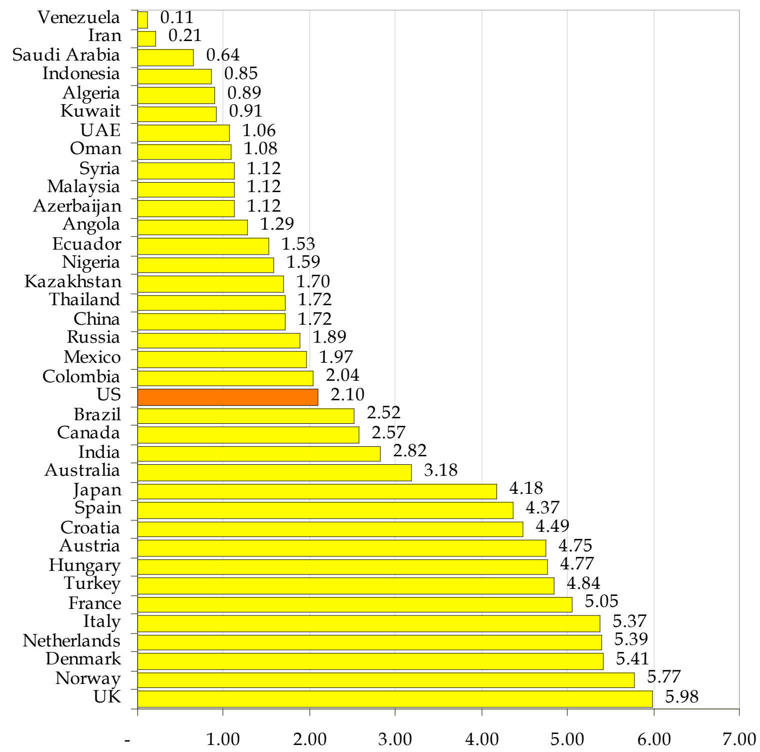
$$\begin{aligned}\ln Rev_{n,t} &= \underset{(0.6052)}{4.8297} + \underset{(0.0427)}{0.2872^*}\ln L_{n,t} + \underset{(0.0552)}{0.3976^*}\ln OilRsv_{n,t} + \underset{(0.0342)}{0.1176^*}\ln NGRsv_{n,t} \\ &\quad + \underset{(0.1125)}{0.2630^*}t_{2003} + \underset{(0.1447)}{0.4248^*}t_{2004} + v_{n,t} - u_{n,t} \\ u_{n,t} &= \underset{(0.5338)}{2.6681} - \underset{(0.0299)}{0.3279^*}VertInt_{n,t} + \underset{(0.1245)}{0.8648^*}GovShare_{n,t}\end{aligned}$$

- The estimated variance ratio γ is now 0.7120 (standard error of 0.1998)

Price subsidies and over-employment

- The theoretical model assumed that politicians would likely use the NOC to subsidize domestic consumers and domestic employment
- *TierP* = two-tier pricing, defined based on average retail prices relative to US

Average pump prices 2004



SFA frontier allowing for subsidies

- Looking specifically at the factors suggested by the theoretical model

$$\ln Rev_{n,t} = \underset{(0.4175)}{3.5792} + \underset{(0.0344)}{0.4177^{*}} \ln L_{n,t} - \underset{(0.0357)}{0.2849^{*}} \left(\ln L_{n,t} * GovShare_{n,t} \right) + \underset{(0.0367)}{0.4240^{*}} \ln OilRsv_{n,t}$$

$$+ \underset{(0.0280)}{0.1365^{*}} \ln NGRsv_{n,t} - \underset{(0.1064)}{1.1436^{*}} TierP_{n,t} + \underset{(0.0887)}{0.2608^{*}} t_{2003} + \underset{(0.0888)}{0.4062^{*}} t_{2004} + v_{n,t} - u_{n,t}$$

- $u_{n,t} = \underset{(0.3435)}{2.6501} - \underset{(0.0287)}{0.1897^{*}} VertInt_{n,t} - \underset{(0.4193)}{3.0571^{*}} GovShare_{n,t}$

- The estimated variance ratio γ is now 0.1192 (with a standard error of 0.0365)

Semi-parametric SFA model

- Tran and Tsionas (2009) assume that υ and u are mutually independent and

$$E\left(u_{n,t}|x_{n,t},z_{n,t}\right)=E\left(u_{n,t}|z_{n,t}\right)=f\left(z_{n,t}\right)>0$$

with f an unknown smooth function of the k covariates z

- Defining $f^{*}\left(z_{n,t}\right)=\ln\left(f\left(z_{n,t}\right)\right)$, $u_{n,t}^{*}=u_{n,t}-f^{*}\left(z_{n,t}\right)$ and $\varepsilon_{n,t}=\upsilon_{n,t}-u_{n,t}^{*}$ the stochastic frontier is

$$\ln y_{n,t}=\ln x_{n,t}'\beta-f^{*}\left(z_{n,t}\right)+\varepsilon_{n,t}$$

and hence

$$Y_{n,t}=\ln y_{n,t}-E\left(\ln y_{n,t}|z_{n,t}\right)=\left[\ln x_{n,t}'-E\left(\ln x_{n,t}|z_{n,t}\right)'\right]\beta+\varepsilon_{n,t}=X_{n,t}'\beta+\varepsilon_{n,t}$$

- Tran and Tsionas then propose using a kernel method to estimate the conditional expectations
- Writing these estimates as $\hat{Y}$ and $\hat{X}$ and defining $\tilde{Y}=Y-\hat{Y}$ and $\tilde{X}=X-\hat{X}$ a consistent estimate of β can then be obtained as $\tilde{\beta}=(\tilde{X}'\tilde{X})^{-1}\tilde{X}'\tilde{Y}$

Estimating the unknown function $f^*(z)$

- Using the estimated $\tilde{\beta}$ we can write

$$\ln y_{n,t} - \ln x'_{n,t}\tilde{\beta} = -f^*\left(z_{n,t}\right) + \ln x'_{n,t}\left(\beta - \tilde{\beta}\right) + \varepsilon_{n,t} = -f^*\left(z_{n,t}\right) + \xi_{n,t}$$

- For each point $z_j = (z_{j1}, z_{j2}, \ldots, z_{jk})$ in a grid of z values, locally approximate $f^*(z)$

$$f^*(z) \cong \tilde{f}(z_j) + \sum_{i=1}^{k} \frac{\partial \tilde{f}(z_j)}{\partial z_i} \cdot \left(z_i - z_{ji}\right)$$

  and estimate the constant and slope terms at each grid point using a weighted least squares regression with kernel functions as weights

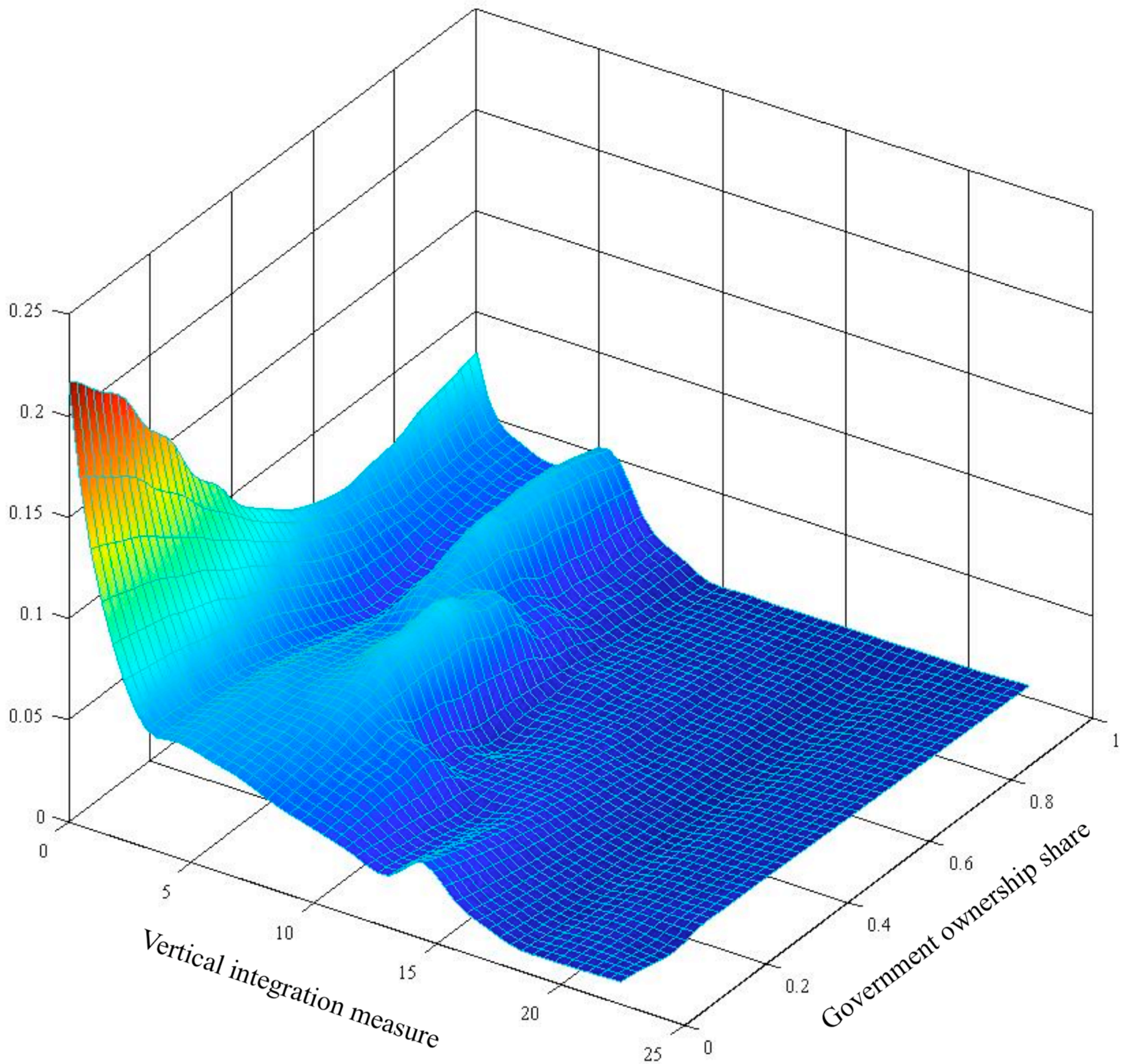
- Mean technical inefficiency at z_j is then given by $\exp(\tilde{f}(z_j))$ while the marginal effects on technical inefficiency from changes in the ith covariate at z_j are given by $\exp\left(\tilde{f}(z_j)\right)\partial\tilde{f}(z_j)/\partial z_i$
- A tensor cubic spline interpolation can then be fit to these estimates of the function values and partial derivatives at each grid point

Results from the semi-parametric method

- Using Gaussian product kernels with bandwidths given by the sample standard deviations of *VertInt* and *GovShare* times $(NT)^{-1/6}$ we obtained

$$\begin{aligned}\ln Rev_{n,t} &= \underset{(0.0379)}{0.3498^*}\ln L_{n,t} - \underset{(0.0544)}{0.1381^*}\left(\ln L_{n,t} * GovShare_{n,t}\right) + \underset{(0.0413)}{0.4139^*}\ln OilRsv_{n,t} \\ &+ \underset{(0.0284)}{0.1206^*}\ln NGRsv_{n,t} - \underset{(0.1106)}{1.0458^*}TierP_{n,t} + \underset{(0.0862)}{0.2605^*}t_{2003} + \underset{(0.0861)}{0.4104^*}t_{2004} - f^*\left(z_{n,t}\right) + \varepsilon_{n,t}\end{aligned}$$

- The spline approximation to the residual function f^* is on the next slide


0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
Vertical integration measure
0
0.2
0.4
0.6
0.8
1
Government ownership share

Interpreting the *residual* inefficiencies

- Consistent with the Battese and Coelli results, privately owned firms that are not vertically integrated have relatively high *residual* inefficiency
  - Perhaps the coefficient on *TierP* over-estimates the revenue penalty for a firm headquartered in a country with subsidized product prices if that firm focuses primarily on upstream activity
  - Alternatively, opportunities for over-employment are greater in firms that are more concentrated in refining, transport and retailing operations than in firms specialized in upstream production
  - It also is possible that the average geological characteristics of reservoirs differ systematically between NOC's and privately owned firms, with NOC's focused on upstream activities having better reservoirs

Summary remarks

- The empirical analyses confirm that higher government ownership makes a firm less effective at producing revenue from employees and reserves
- We further found specific evidence that:
  - Over-employment was a strong common feature of NOCs
  - Domestic price subsidies negatively affect a NOC's ability to generate revenue
- Relative inefficiency of NOC's thus appears to result from government attempts to redistribute rents to domestic consumers and employees
- The forgone revenue will, however, reduce government spending on other items or require higher taxes
  - Product subsidies or over-employment in a NOC are generally inefficient compared to taxes and transfers as a way of redistributing income
  - They are poorly targeted as transfers, and more inefficient than a broadly-based tax as a means of raising revenue

Some Implications

Why might NOCs exist?

- A private firm may exploit domestic consumers if it is a domestic monopoly
- Resource development may be associated with wider economic development and a private firm might neglect these wider social benefits
- Government wants to redistribute rent from resource exploitation
  - Other mechanisms (other than nationalization) may be unavailable
    - The tax collection system may be weak
    - There may not be a royalty or lease auction system, or it may not be effective
    - The government may have a history of not adhering to prior agreements
  - The government wants to use rents to favor particular political constituencies and needs more control to do so
- According to the “paradox of plenty,” resource rents may invite more intervention
  - Petroleum revenue may
    - weaken government fiscal discipline,
    - postpone needed structural change,
    - lead to a tendency to rely on the state for resolution of problems

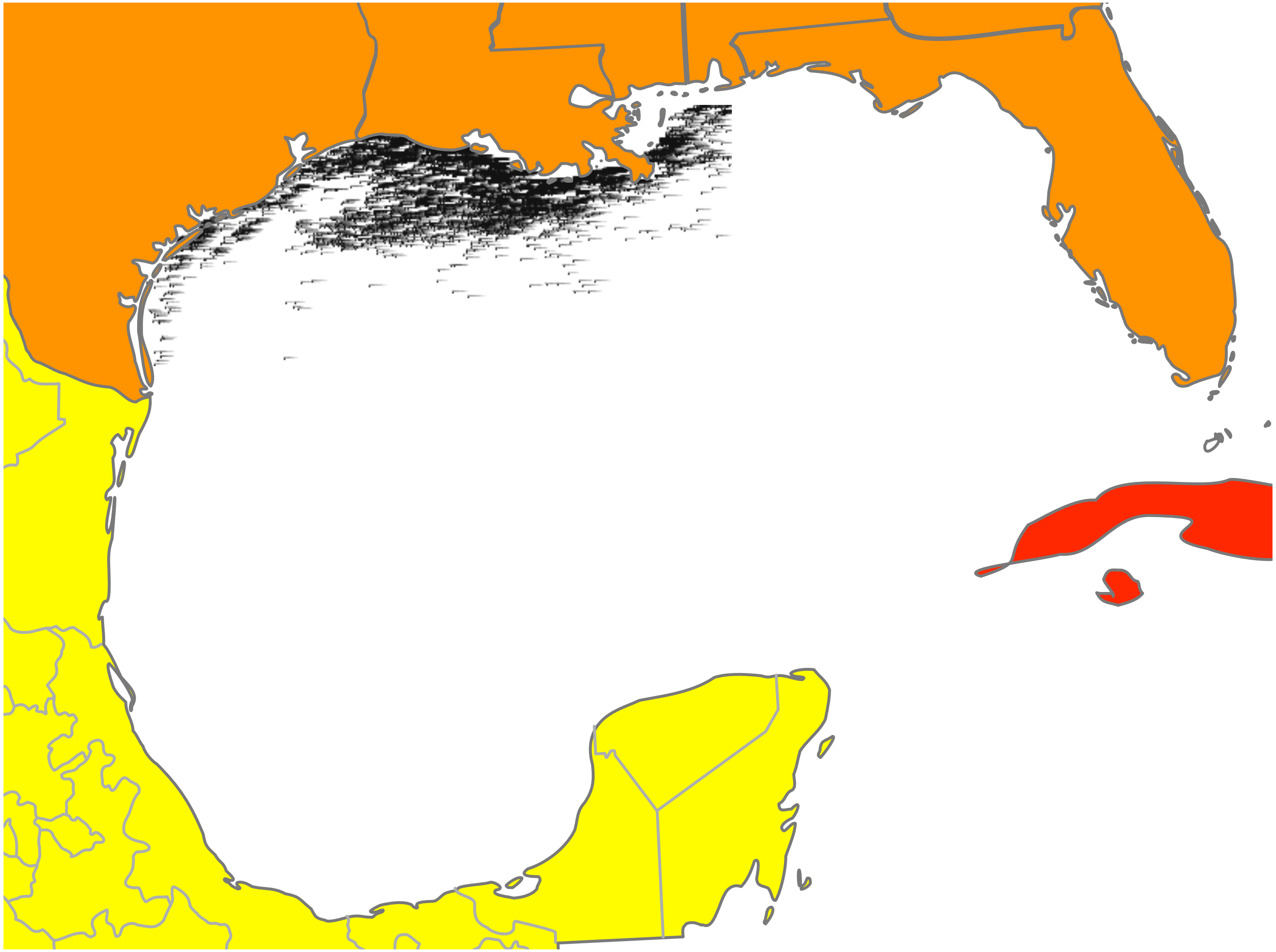
Can the NOCs meet future demand?

- Can the NOC's develop the vast resources under their control in a timely manner given the constraints imposed by political influences?
  - Many NOC's have falling oil exports due to domestic subsidies, and stagnant production resulting from government interference, corruption, inefficiency, and diversion of capital to social spending
- In response importing nations may be more compelled to reduce their vulnerability to NOC's
- Importing nations can promote free trade and utilize multilateral frameworks to press NOC's to adopt institutional structures to:
  - Enhance their efficiency,
  - Promote market competition, and
  - Curb interference in commercial investment decisions by their national government
- A potential lever: NOC's have been seeking security of demand and other benefits of vertical integration by buying into downstream markets

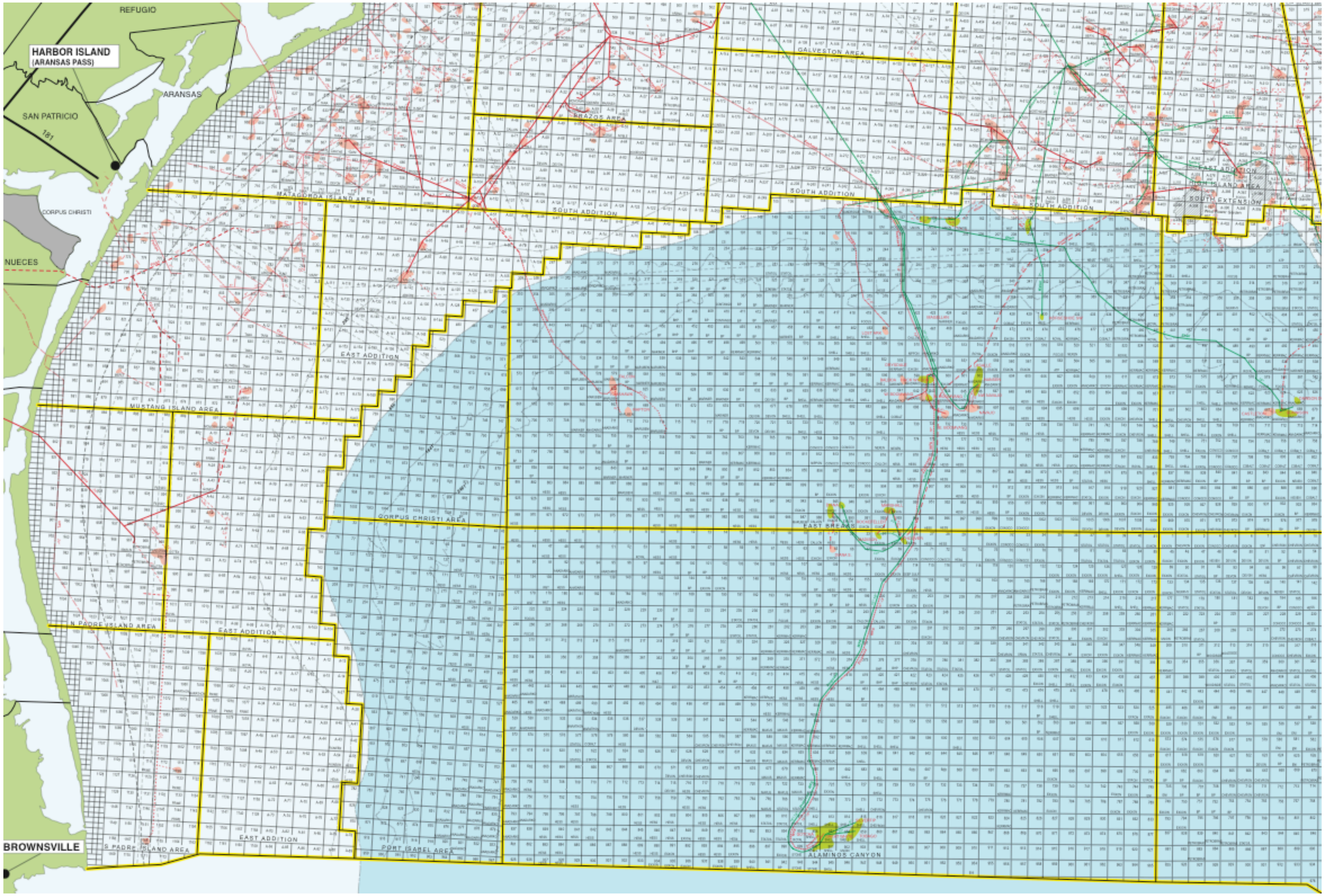
Some implications for Gulf of Mexico

- Doubts about NOC capability increase the importance of resources, such as in the Gulf of Mexico, that are still accessible to private development
- Of the NOCs active in the Gulf of Mexico – Eni, Statoil, Petrobras, Repsol and Ecopetrol – only Ecopetrol is fully government owned
- As the map on the next page shows, further hydrocarbon resources are likely to be found on the Mexican side of the Gulf, but Mexican law currently does not allow anyone but Pemex to exploit these
  - However, it would appear that Pemex would not be capable of effective E&P in deep Gulf waters for some time
- Cuba has also begun looking for oil in the Gulf of Mexico, working with Peberco and Sherrit of Canada and NOCs Repsol (partnering with Statoil and ONGC of India), Eni, Petrobras, Petronas, PDVSA and PetroVietnam (see map)
- Both Mexico and Cuba might prefer at least part state-owned companies if they are to allow exploration and production from their sectors of the Gulf

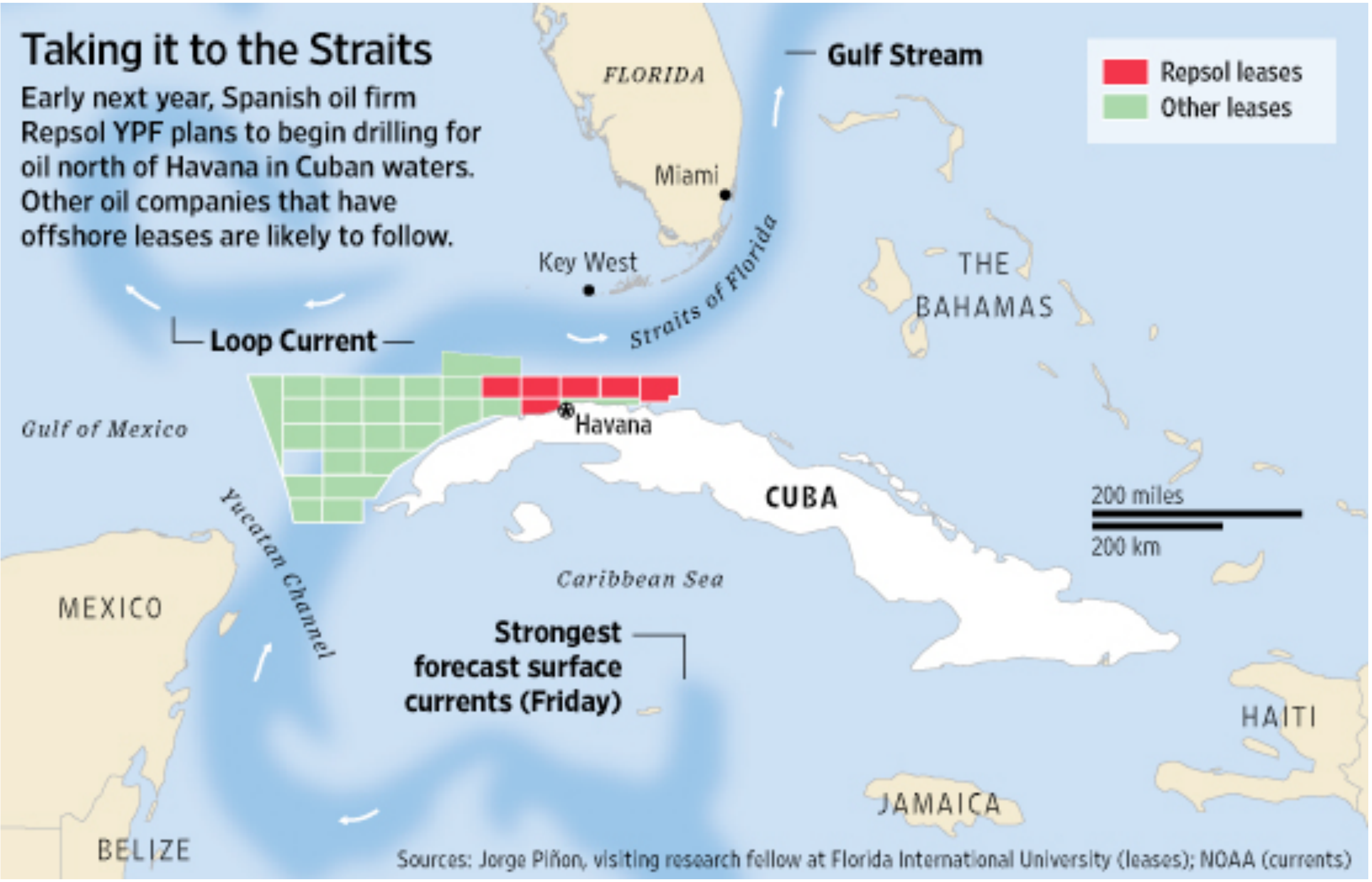
Existing platforms in the Gulf of Mexico



Detail on the US/Mexico border



Cuba petroleum exploration leases



Appendix: Supporting slides

Model detail

Objective function

$$\int e^{-\rho t}\left\{\underbrace{Xp(X)+p_d d(p_d)-p_m M-wL-\psi(I)H(S)}_{\text{Fiscal profits}}+\underbrace{\nu_c}_{\text{Weight of consumer surplus}}\underbrace{\int_{p}^{\bar{p}} d(z)dz}_{\text{Consumer surplus}}+\underbrace{\nu_L}_{\text{Weight of employment}}L\right\}dt$$

- where:
- $X \geq 0$ is exports and $p(X)$, with $p'(X) < 0$, is the price of exports
- p_d is the domestic price and $d(p_d)$ domestic demand
- Domestic consumer surplus represents domestic consumer interests with domestic consumers neither taxed nor subsidized relative to other claimants on fiscal profits when $\nu_c = 1$,
- $M \geq 0$ is imports and p_m the price of imports, while production $Q = X + d(p_d) - M$
- L is variable input to production with cost w, but implicit subsidies to L reflecting employee interests make the cost look like $w - \nu_L$ not w
- I is investment needed to prove up and ready reserves for production, S the cumulative proved and connected resource to date, and $\psi(I)H(S)$ the investment cost with $\psi(0)=0$, $\psi'>0$, $\psi''>0$, $H(0)=1$, $H'>0$, $H''>0$, $H(S)\to\infty$ as $S\to S_0$
- Political pressure to increase current relative to future revenue (or manager risk aversion) is reflected in a discount rate $\rho = r + \nu_r$ above the commercial rate r

State variables and constraints

- Since it is often alleged that NOCs are under-investing in reserves we wanted to explicitly model the investment process producing reserves out of resources
- This leads to two state variables – the cumulative proved and connected resource S and the cumulative extraction E, with proved reserves $R = S - E$
- Production depends on cumulative extraction and proved reserves as well as L,
  - $Q = RF(L)G(E)$
- where $0 < G \leq \gamma$, $G' < 0$, $G'' < 0$, $0 < F < 1$, $F' > 0$, $F'' < 0$ and $F \to 1$ as $L \to \infty$
- By definition, E will satisfy a differential equation

$$\dot{E} = \left(S - E\right) F(L)G(E)$$

with initial E=0

- Similarly, the definition of S implies it will satisfy the differential equation

$$\dot{S} = I$$

with initial S =0

Summary of the critical assumptions

1. Although the NOC can affect the world oil price if it is an exporter, we assume that the importing NOC is a price taker in the international oil market, and hence cannot exercise monopsony power
2. Since we ignore transportation costs, the price of oil imports equals export prices when exports are zero and exceeds marginal revenue when exports are strictly positive
3. Short run constraints on capital availability raise marginal investment costs as investment increases
4. There is a physical upper limit, S_0, to the total technically recoverable resources, but exploration and development costs become prohibitive as cumulative proved and connected resource $S \rightarrow S_0$
5. Geology places an instantaneous limit on the ratio of production to reserves that becomes more stringent as past exploitation E rises
6. The productivity of variable input L falls as E rises, for example because more water injections may be required or reservoirs that are easier to exploit are mined first
7. Short run marginal costs of production (varying L while holding R and E fixed) are given by $(w - \nu_L)/[(S-E)G(E)F'(L)]$ and rise with output
8. As ν_r, ν_c and $\nu_L \rightarrow 0$, the NOC behaves like a private domestic monopoly

Optimization problem

- The current value Hamiltonian for the unconstrained optimization problem is
- $$H = Xp(X) - p_m M + p_d d(p_d) - (w - v_L)L - \psi(I)H(S) + v_c \int_{p_d}^{\bar{p}} d(x)dx$$
  $$+q(S-E)F(L)G(E) + \mu I$$

- Incorporating production constraint and the non-negativity constraints on *X*, *M*, *L* and *I* yields the Lagrangian

$$L = H + \varphi\left[(S-E)F(L)G(E)\right] + M - X - d(p_d) + \lambda_X X + \lambda_M M + \lambda_L L + \lambda_I I$$

First order conditions

$$p(X)+Xp'(X)-\varphi+\lambda_X=0,\quad \lambda_X X=0,\quad \lambda_X\ge 0,\quad X\ge 0$$

$$-p_m+\varphi+\lambda_M=0,\quad \lambda_M M=0,\quad \lambda_M\ge 0,\quad M\ge 0$$

$$d(p_d)+p_d d'(p_d)-v_c d(p_d)-\varphi d'(p_d)=0$$

$$-w+v_L+\lambda_L+(q+\varphi)(S-E)G(E)F'(L)=0,\quad \lambda_L L=0,\quad \lambda_L\ge 0,\quad L\ge 0$$

$$-\psi'(I)H(S)+\mu+\lambda_I=0,\quad \lambda_I I=0,\quad \lambda_I\ge 0,\quad I\ge 0$$

$$\dot{q}=\rho q+(q+\varphi)F(L)\left[G(E)-(S-E)G'(E)\right]$$

$$\dot{\mu}=\rho\mu+\psi(I)H'(S)-(q+\varphi)F(L)G(E)$$

Some qualitative implications

- The firm will not both import and export at the same time
- Since minimum marginal cost depends on $1/R$, minimum R is needed for production
- The firm passes through a life cycle:
  - Import until domestic production is sufficient to meet domestic demand
  - Export until the increase S makes further investment too expensive
  - Cease investing in reserves, but production and exports continue with reserves declining
  - Production declines until the NOC again imports to satisfy domestic demand
  - Domestic production eventually ceases and imports satisfy all domestic demand
- If $\nu_c = 1$, $p_d = p_m$ (in import regimes) or export marginal revenue (in export regimes)
  - If $\nu_c \neq 1$, the domestic tax or subsidy varies inversely with demand elasticity
- Although the true opportunity cost of L is w, the marginal product of labor is equated to $w-\nu_L$ so there is over-employment
- Marginal revenue (or the import price) φ is equated to short run marginal cost (using $w-\nu_L$ as the cost of L) plus a measure of rents or user cost of mining the resource
- Rent (or marginal user cost) q shrinks to zero (when production ends) at a rate equal to the effective discount rate minus the effect of cumulative extraction E on costs

Numerical solution

Solution outline

- Noting that φ represents either p_m or the marginal revenue from exports, employment and investment (when positive) are determined from

$$(q+\varphi)(S-E)G(E)F'(L) = w - \nu_L$$

$$\psi'(I)H(S) = \mu$$

- We get a system of 4 simultaneous differential equations involving four endogenous functions of time:

$$\begin{aligned}
\dot{E} &= (S-E)G(E)F\left[L(E,S,\varphi,q;w)\right] \\
\dot{S} &= I(\mu,S) \\
\dot{q} &= \rho q + (q+\varphi)F\left[L(E,S,\varphi,q;w)\right]\left[G(E)-(S-E)G'(E)\right] \\
\dot{\mu} &= \rho\mu + \psi\left[I(\mu,S)\right]H'(S) - (q+\varphi)F\left[L(E,S,\varphi,q;w)\right]G(E)
\end{aligned}$$

- To find a unique solution, we need 4 initial or terminal conditions
  - We assume that initially $R = S = 0$
  - Also, when production ceases at time T the transversality conditions require $\mu(T) = q(T) = 0$

Solutions for specific functional forms

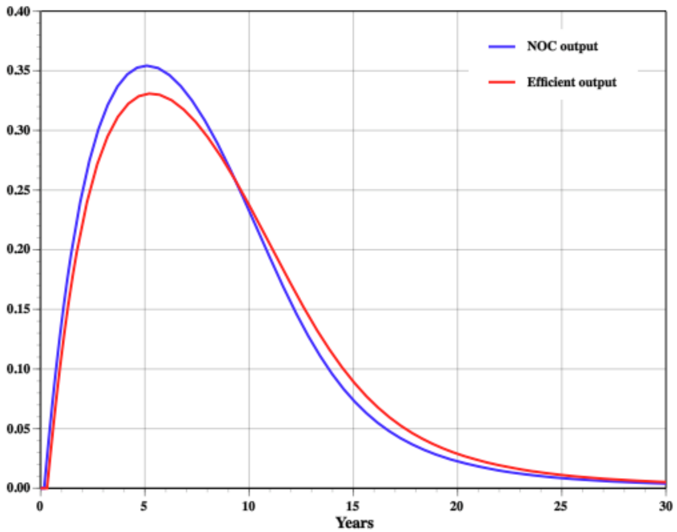
	Functional form	Notes
Production		
$F(L)$	$1 - e^{-\alpha L}$	Larger α implies a small increase in L will quickly raise output to the maximum level given by $G(E)$
$G(E)$	$\dfrac{\gamma\left[1 - e^{-\beta(S_0 - E)}\right]}{1 - e^{-\beta S_0}}$	$\gamma/(1-e^{-\beta S})$ determines deliverability for given R, E β determines productivity decline with E S_0 is a physical limit to identifiable resource size
Investment		
$\psi(I)H(S)$	$\left(\psi_1 I + \psi_2 I^2\right)\left(1 + \dfrac{\psi_3 S}{S_0 - S}\right)$	ψ_1 measures exploration MC for $I = S = 0$ ψ_2 measures how cost escalates with I ψ_3 measures how depletion raises costs
Demand		
$p(X)$	$p_m - \xi X^2$ for $X \geq 0$, p_m otherwise	ξ determines how X reduces export prices, while as $X \to 0$ $p(X) \to p_m$ and demand elasticity $\to \infty$
$d(p_d)$	$A\left(\bar{p} - p_d\right)^{\varepsilon}$ for $p_d \leq \bar{p}$, 0 otherwise	$\bar{p}$ is maximum domestic price (where domestic demand is 0), ε determines demand elasticity and A determines demand at $p_d = 0$

Parameter values for NOC

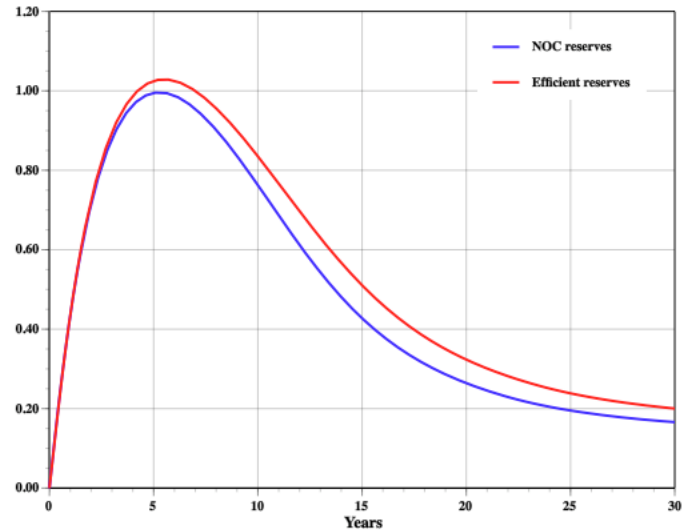
α	β	γ	S_0	w	ψ_1	ψ_2	ψ_3	r	p_m	ξ	A	$\bar{p}$	ε	ν_L	ν_c	ν_r
0.6	1.75	0.4	4.0	0.01	0.01	0.5	0.1	0.1	1.0	0.2	0.0018	10.0	0.8	0.2w	1.05	0.1

NOC versus efficient firm

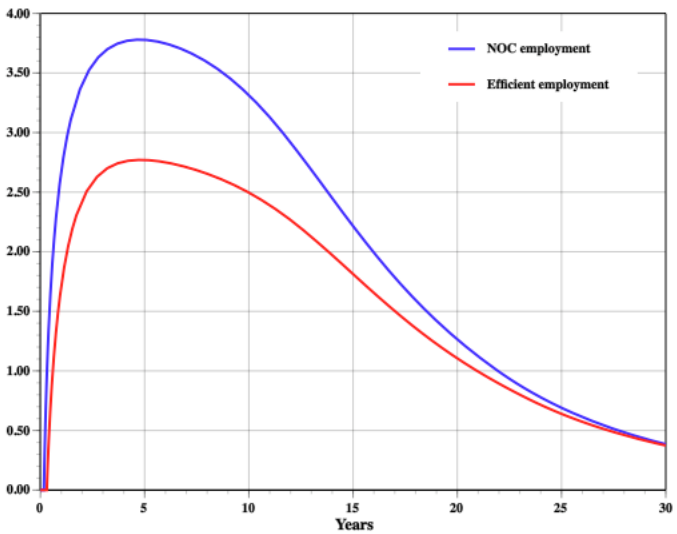
NOC and efficient production



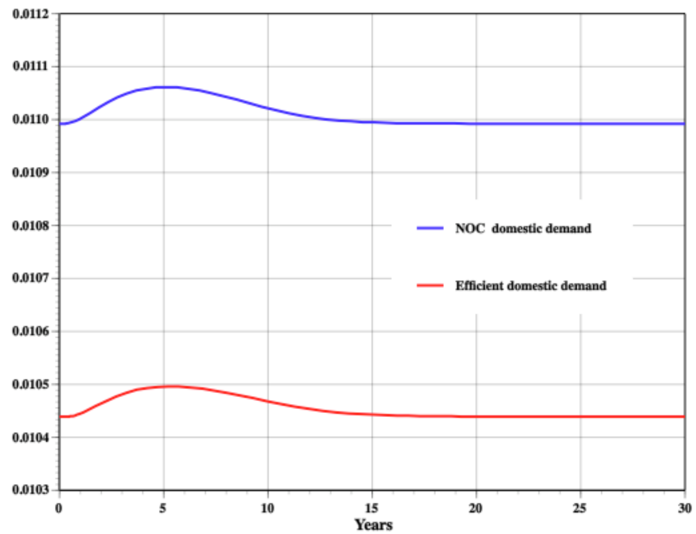
NOC and efficient reserves



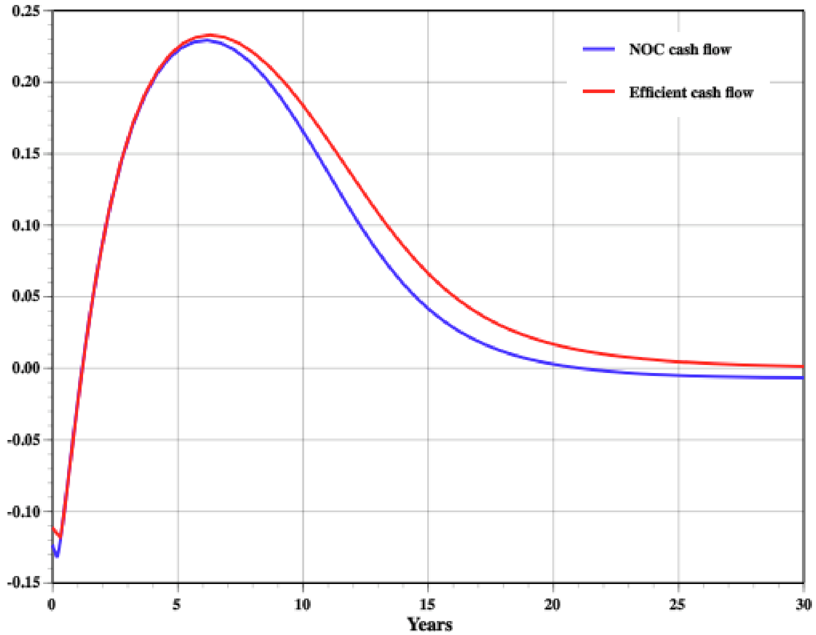
NOC and efficient employment



NOC and efficient domestic demand

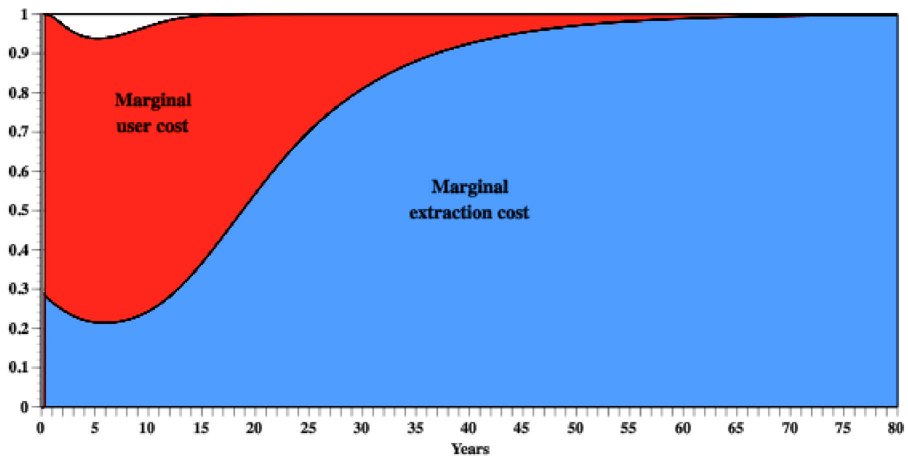


Cash flows

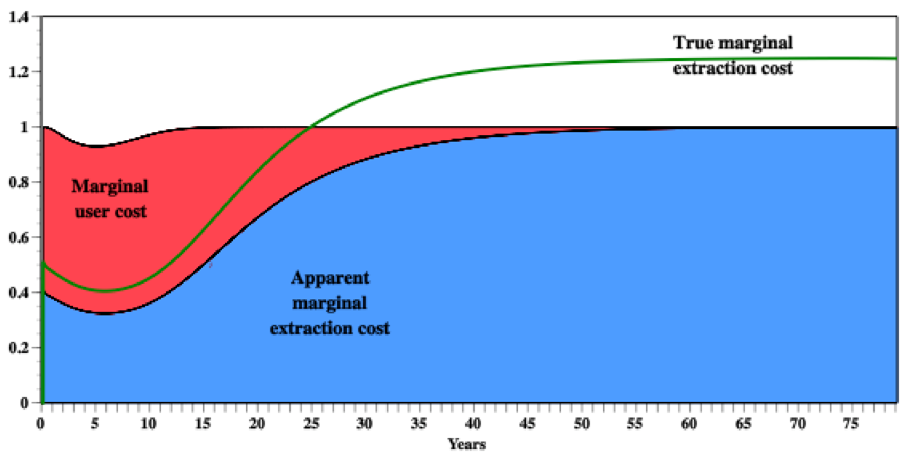

0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0
5
10
15
20
25
30
Years
NOC cash flow
Efficient cash flow

User and extraction costs

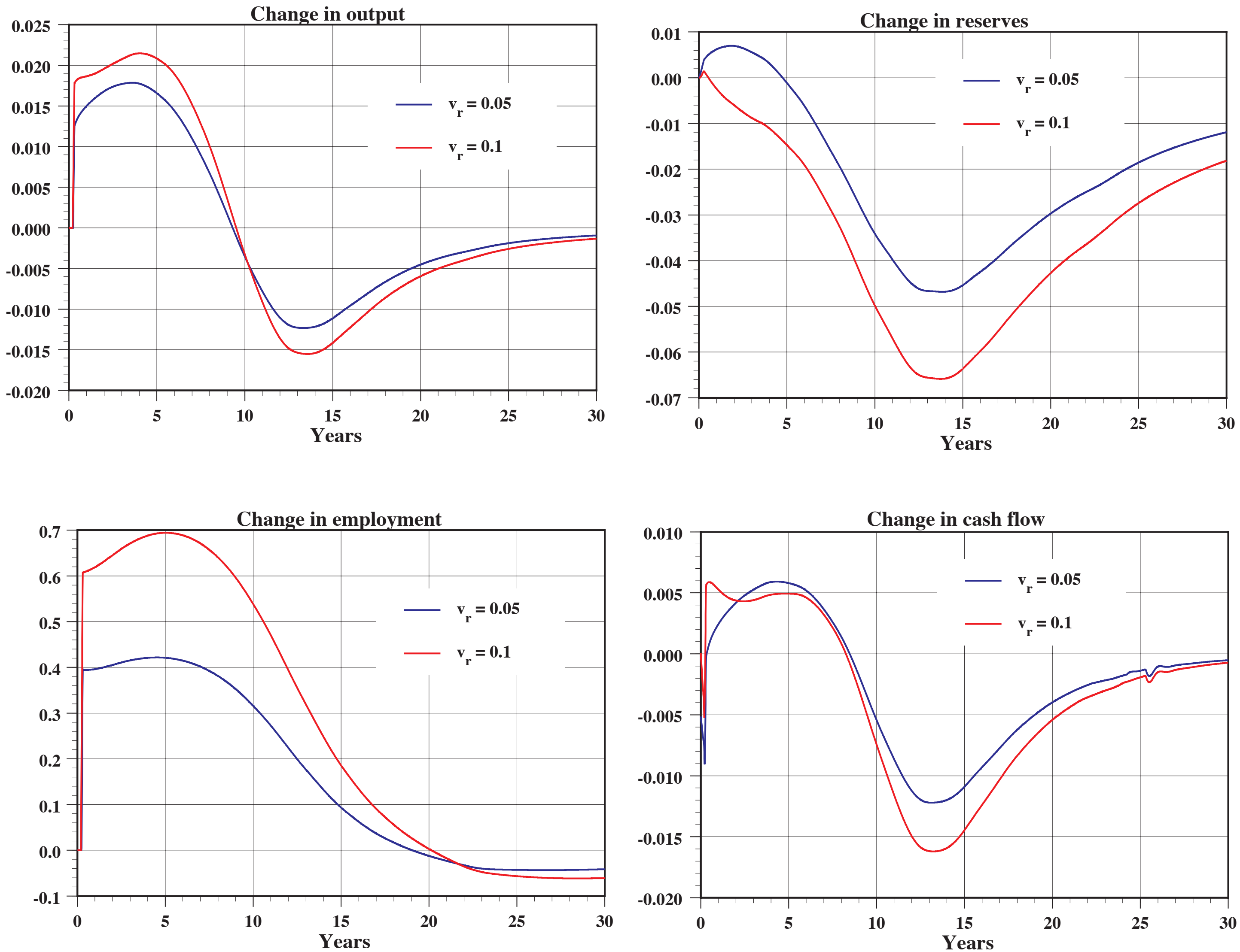
Efficient firm: marginal costs and revenues



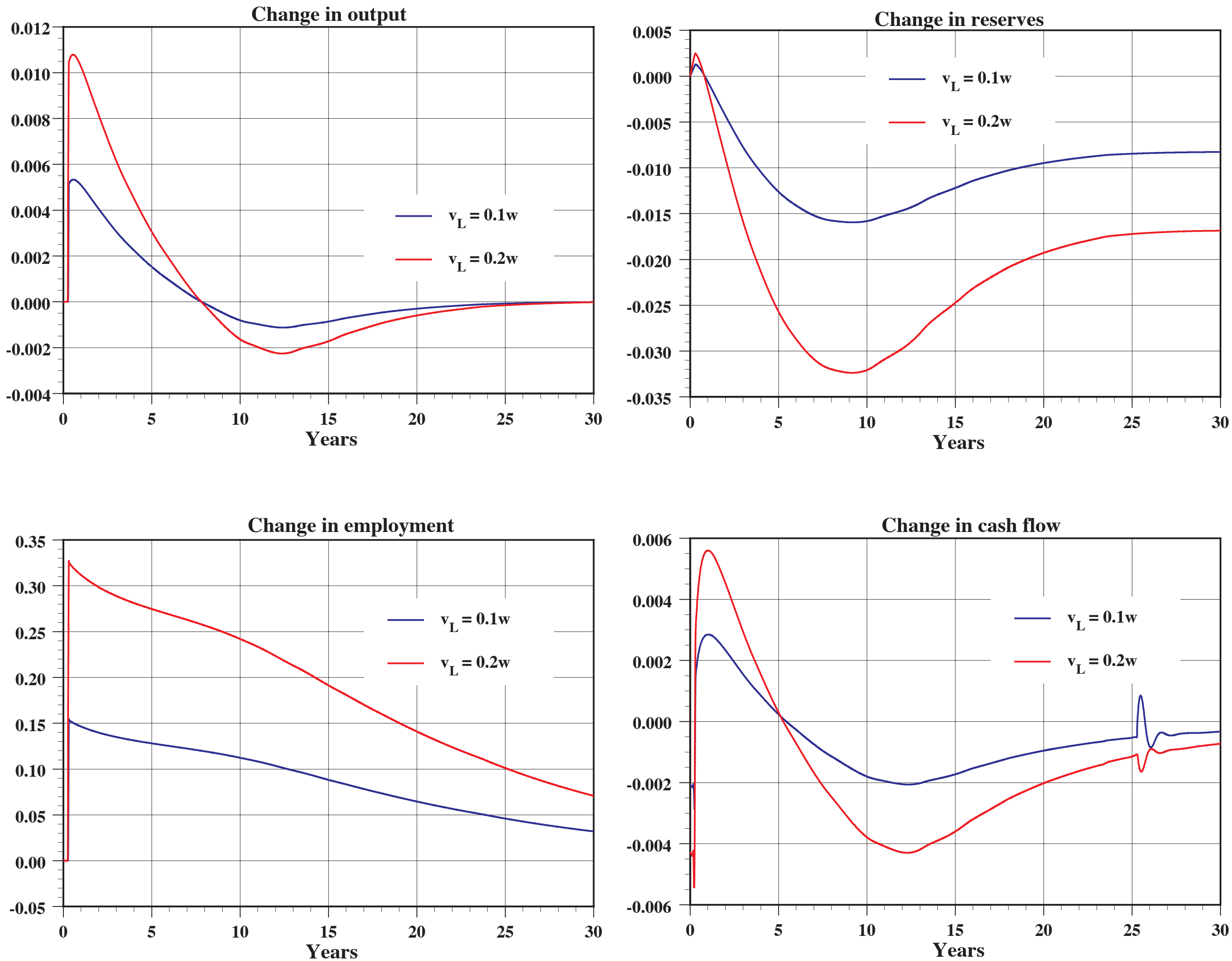
NOC: marginal costs and revenues



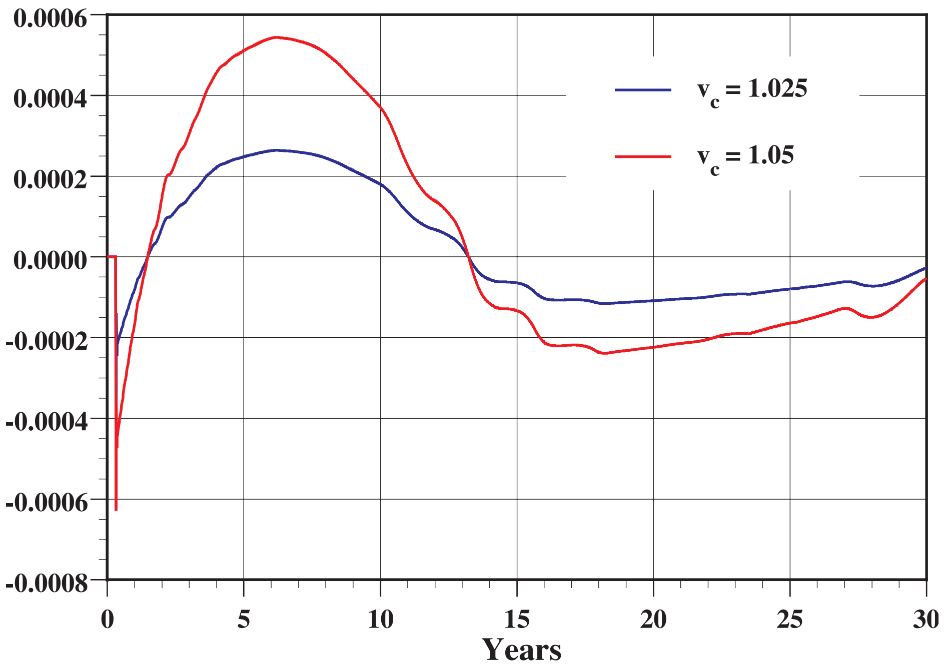
Effect of higher discount rates



Effects of increasing the employment incentive



Employment effects of increased domestic subsidy



Potential paths to NOC reform

- Can social welfare and revenue maximization be better balanced by adopting some institutional elements of private sector firms to enhance NOC performance?
  - These institutional structures include:
    - Competition in the home industry
    - Competition in international exploration and refining
    - More strict monitoring through generally accepted accounting and financial reporting
    - At least partial privatization or bond issues in major international markets
    - Autonomous board of directors and professional management
  - These institutional structures encourage NOC managers to
    - Minimize the commercial impact of pursuit of non-commercial objectives,
    - Focus on core business activities, and
    - Reduce corruption and wasteful spending
- The strategy of vertical integration has multiple benefits for a NOC
  - By entering into the downstream market, a NOC is able to capture the value added from production and sale of finished products
  - It enhances security of demand by providing market access, especially if it is able to invest in downstream assets in key consuming regions
  - It helps the NOC diversify and mitigate risk
  - Upstream/downstream asset swaps are a promising avenue for IOC/NOC partnering and collaboration.