*Oil*gopoly: a general equilibrium model of the oil-macroeconomy nexus

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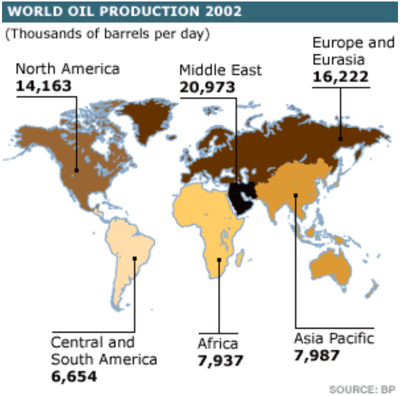
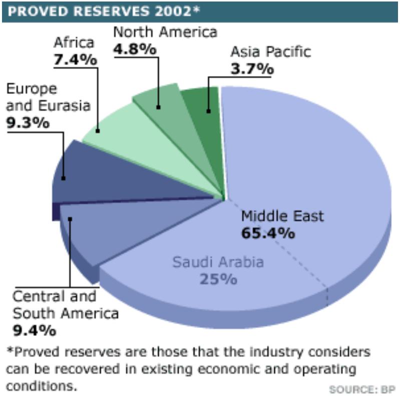
Where is the oil?

Saudi Arabia is the world's largest oil producer



Where is the oil?

Saudi Arabia owns the largest known oil fields



Other oil producers are smaller

Top ten oil companies, ranked by production, 2007

Company	Country	State-owned (%)	Output (mbpd)	Reserves (bil. barrels)
Aramco	Saudi Arabia	100	10.4	264.2
NIOC	Iran	100	4.4	138.4
Pemex	Mexico	100	3.5	12.2
CNPC	China	100	2.8	22.4
Exxon Mobil	US		2.6	11.1
KPC	Kuwait	100	2.6	101.5
PDV	Venezuela	100	2.6	99.4
BP	UK		2.4	10.1
INOC	Iraq	100	2.1	115.0
Rosneft	Russia	75	2.0	17.5

Source: Smith (2009) and Petroleum Intelligence Weekly, December 4, 2008

Saudi Aramco as a dominant firm

"OPEC is Saudi Arabia"

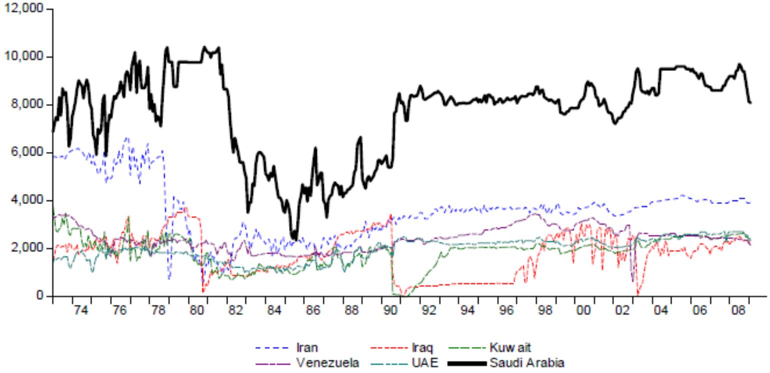
– Mabro (1975)

"The Saudis have acted as what they are:
the leading firm in the world oil market"

– Adelman (1995)

Saudi Arabia's oil output has been highly volatile ...

Output of the largest OPEC producers (tbd)



… even if the Kingdom has been an "island of stability"

Instances when Saudi production was directly affected by exogenous events

- 1977 fire at the Abqaiq facilities
- 1984 several Saudi tankers destroyed during the Iran-Iraq war
- 1991 attacks by Iraqi missiles during the Gulf war

> *"Official Oil Market Chronology"*
> – *U.S. Energy Information Administration*

Apart from these episodes, changes in Saudi oil output were the result of production decisions; not the consequence of disruptions in its production capabilities

Underinvestment and shutting-in existing capacity

- Saudi Arabia is the only producer which "shuts in" significant spare capacity
  - It could add 4% to world oil supply in 2009 just by tapping existing wells (IEA) (equivalent to the entire production of Kuwait, Venezuela, or Norway)
- It restricts the growth of new capacity (Smith, 2009)

Historical episodes

- **Iranian revolution:** Iran's production collapsed from 6 mbd in 9/1978 to 0.7 mbd in 1/1979. Saudi Arabia raised its output from 8.3 mbd to 10.4 mbd (25% in 3 months)
- **The Gulf war:** Iraqi + Kuwaiti output collapsed from 5.3 mbd in 7/1990 to zero in 2/1991. Saudi Arabia's output jumped from 5.4 mbd to 8.4 mbd (56% in 5 months)
- **2001 recession:** From 1/2001 to 12/2001 OPEC cut supply by 2.5 mbd; of this, 1.1 mbd was due to Saudi Arabia
- **Subprime crisis:** Between 7/2008 and 1/2009, world oil supply fell by 3.2 mbd; 1.6 mbd was due to Saudi Arabia.

Questions

- How can one rationalize the behavior of Saudi Arabia?
  - Stagnant investment in new capacity
  - Low utilization rate of installed capacity
  - Highly volatile output despite internal stability
  - Offsetting output collapses of other producers
- What impact does it have on the oil market as a whole?
- What are the (GE) effects of a tax on oil consumption / production?

Our take

- A competitive model cannot account for these facts
- Instead, we model Saudi Arabia as a dominant firm, with the rest of oil producers as a competitive fringe
- The behavior of the dominant firm can be seen as a profit maximizing response
  - Underinvestment in new capacity raises the average oil price
  - Spare capacity allows fast adjustment of output as necessary in response to demand and supply shocks
- Bonus:
  - A quantitative DSGE model with endogenous oil price *and* oil supply decisions
  - Can study the effects of *different* oil shocks ("*not all oil shocks are alike*")
  - Derive long run implications and perform comparative statics
  - Study the effects of oil taxes in general equilibrium

Related literature

- Transmission of exogenous oil price shocks
  Kim and Loungani (1992), Leduc and Sill (2004), ...
- Overwhelming evidence against exogenous oil prices
  Barsky and Kilian (2004); Kilian (2008)
- Despite this evidence, few general equilibrium models treat the oil price as endogenous
  Leduc and Sill (2007), Bodenstein et. al. (2008), Campolmi (2008)
- Even fewer determine endogenously the oil price *and* quantity
  Backus and Crucini (2000)
- We model oil supply as a dominant firm with comp. fringe
  Nakov and Pescatori (*JMCB*, 2010)

Model

- Three regions: one oil-importing and two oil-exporting ones
- The oil-importer uses oil in consumption, and uses labor to produce final goods, part of which are consumed domestically, with the rest exported to the oil-producers
- Oil is a homogeneous commodity supplied by two types of producers: a dominant firm and a "competitive fringe"
- The fringe takes the oil price as given
- The dominant producer faces a downward sloping "residual demand" curve, picking profit-maximizing points
- Oil exporters produce oil only, and their revenues are recirculated to the oil importer as demand for final goods
- We allow no borrowing across regions and abstract from monetary and exchange rate factors

Model

Oil importer

A representative household maximizes utility

$$\max_{C_t, O_t, L_t, B_t} E_o \sum_{t=0}^{\infty} \beta^t \left[\log(C_t) + \nu_t \frac{O_t^{1-\eta}}{1-\eta} - \frac{L_t^{1+\psi}}{1+\psi} \right] \qquad (1)$$

subject to the budget constraint

$$C_t + s_t O_t + B_t = w_t L_t + (1 + r_{t-1}) B_{t-1} + D_t \qquad (2)$$

A representative firm produces final goods under perfect competition

$$Y_t = Z_t L_t^{\alpha} \qquad (3)$$

where $\Delta \log(Z_t) = \rho_z \Delta \log(Z_{t-1}) + \varepsilon_t^z$.
The firm chooses its labor input to maximize profits.

Model

Fringe producers

A representative household maximizes

$$\max_{\tilde{C}_t, \tilde{I}_t} E_o \sum_{t=0}^{\infty} \beta^t \log(\tilde{C}_t) \tag{4}$$

$$s.t.: \; \tilde{C}_t + \tilde{I}_t = \tilde{r}_t^k \tilde{K}_{t-1} + \tilde{\Pi}_t \tag{5}$$

$$\tilde{K}_t = (1-\delta)\,\tilde{K}_{t-1} + \left[1 - \chi\left(\tilde{I}_t / \tilde{I}_{t-1} - G^z\right)^2\right] \tilde{I}_t \tag{6}$$

A representative competitive firm maximizes period profits $\tilde{\Pi}_t$,

$$\max_{\tilde{X}_t, \tilde{K}_{t-1}} \left[s_t \tilde{O}_t - \tilde{X}_t - \tilde{r}_t^k \tilde{K}_{t-1} \right], \tag{7}$$

taking the oil price as given, and subject to $\tilde{O}_t = \tilde{Z}_t \tilde{X}_t^{\tilde{\gamma}} \tilde{K}_{t-1}^{1-\tilde{\gamma}}$, where $\tilde{Z}_t = \tilde{A}_t \tilde{Z} \exp(g^{\tilde{z}} t)$, with $\tilde{Z} \exp(g^{\tilde{z}} t)$ a deterministic trend, and $\tilde{A}_t$ a stationary AR(1) process.

Model

Dominant oil producer

The dominant oil producer maximizes the household's utility of consumption

$$\max E_o \sum_{t=0}^{\infty} \beta^t \log(s_t \hat{Z}_t \hat{X}_t^{\hat{\gamma}} \hat{K}_{t-1}^{1-\hat{\gamma}} - \hat{I}_t - \hat{X}_t). \tag{8}$$

Oil is produced according to

$$\hat{O}_t = \hat{Z}_t \hat{X}_t^{\hat{\gamma}} \hat{K}_{t-1}^{1-\hat{\gamma}}, \tag{9}$$

where technology evolves deterministically $\hat{Z}_t = \hat{Z} \exp(g^{\hat{z}} t)$. The firm accumulates capital according to

$$\hat{K}_t = (1-\delta)\,\hat{K}_{t-1} + \left[1 - \chi\left(\hat{I}_t / \hat{I}_{t-1} - G^z\right)^2\right] \hat{I}_t. \tag{10}$$

Model

Dominant oil producer decision problem

$$\max_{\hat{C}_t,\hat{K}_t,\hat{I}_t,\hat{X}_t,\tilde{X}_t,s_t,O_t,L_t} E_o \sum_{t=0}^{\infty} \beta^t \log\left(s_t \hat{Z}_t \hat{X}_t^{\hat{\gamma}} \hat{K}_{t-1}^{1-\hat{\gamma}} - \hat{I}_t - \hat{X}_t\right) \quad (11)$$

subject to

$$\begin{aligned}
s_t O_t^{\eta} &= \nu_t \alpha Z_t L_t^{\alpha-1-\psi} && (12)\\
\tilde{X}_t &= \tilde{\gamma} s_t \tilde{Z}_t \tilde{X}_t^{\tilde{\gamma}} \tilde{K}_{t-1}^{1-\tilde{\gamma}} && (13)\\
O_t &= \hat{Z}_t \hat{X}_t^{\hat{\gamma}} \hat{K}_{t-1}^{1-\hat{\gamma}} + \tilde{Z}_t \tilde{X}_t^{\tilde{\gamma}} \tilde{K}_{t-1}^{1-\tilde{\gamma}} && (14)\\
s_t O_t^{\eta} &= \nu_t Z_t L_t^{\alpha} - \nu_t s_t O_t && (15)\\
\hat{K}_t &= (1-\delta)\hat{K}_{t-1} + \left[1 - \chi\left(\hat{I}_t/\hat{I}_{t-1} - G^z\right)^2\right]\hat{I}_t && (16)
\end{aligned}$$

Calibration

Steady state

Table 3. Data and model-implied averages

%	Saudi share	Oil output growth	Oil price growth	Oil/ GDP	Final output growth
Data	12.3	0.78	2.21	5.0	2.98
Model	12.7	0.77	2.21	5.7	3.00

Lemma

The real price of oil grows at rate $-g^{\tilde{z}}$.

Proof.

Since O_t grows at rate $g^z + g^{\tilde{z}}$, while Y_t grows at rate g^z, for the ratio $s_t O_t / Y_t$ to remain stable, s_t should grow at a rate $-g^{\tilde{z}}$. □

Lemma

Oil efficiency ν_t *grows at rate* $(\eta - 1)\left(g^z + g^{\tilde{z}}\right)$.

Proof.

Along the balanced growth path C_t grows at rate g^z while $s_t O_t^{\eta}$ grows at rate $\eta\left(g^z + g^{\tilde{z}}\right) - g^{\tilde{z}}$. Hence, along the balanced growth path ν_t must grow at rate $(\eta - 1)\left(g^z + g^{\tilde{z}}\right)$. □

Secular Features of the Oil Market

Oil price markup

Lemma

The price mark-up of the dominant oil producer is given by

$$\mu = \frac{\hat{Z}}{\tilde{Z}} \frac{\hat{\gamma}^{\hat{\gamma}}(1-\hat{\gamma})^{1-\hat{\gamma}}}{\tilde{\gamma}^{\tilde{\gamma}}(1-\tilde{\gamma})^{1-\tilde{\gamma}}} r_k^{\hat{\gamma}-\tilde{\gamma}}, \tag{17}$$

where $r_k = g_z/\beta + \delta - 1$ *is the rental rate of capital in oil production.*

Proof.

No barriers to entry in the competitive fringe $\Rightarrow$ fringe producers make zero profits. The real price of oil equals the marginal cost of the fringe

$$s = \widetilde{MC} = \frac{r_k^{1-\tilde{\gamma}}}{\tilde{Z}\tilde{\gamma}^{\tilde{\gamma}}(1-\tilde{\gamma})^{1-\tilde{\gamma}}}. \tag{18}$$

□

Proof.

[Proof (cont'd)] A similar formula gives the marginal cost of the dominant producer,

$$\widehat{MC} = \frac{r_k^{1-\hat{\gamma}}}{\hat{Z}\hat{\gamma}^{\hat{\gamma}}(1-\hat{\gamma})^{1-\hat{\gamma}}}. \tag{19}$$

The oil price markup is the ratio of price s to marginal cost $\widehat{MC}$ of the dominant firm. □

Corollary

Special case $\tilde{\gamma} = \hat{\gamma}$ (symmetric technologies). A dominant producer persists as long as it has a cost advantage, $\hat{Z} > \tilde{Z}$.

Secular Features of the Oil Market

Capacity utilization

Can write the production function for oil as $O = Zu(X, K)K$

Definition

The capacity utilization rate of installed capital is defined as $u(X, K)$, with $u(0, K) = 0$, $\partial u / \partial X > 0$, and $\partial^2 u / \partial X^2 < 0$.

In the Cobb-Douglas case, $u(X, K) = (X/K)^{\gamma}$.

Capacity utilization of the dominant oil producer *relative* to that of the competitive fringe

$$\frac{u(\hat{X}, \hat{K})}{u(\tilde{X}, \tilde{K})} = \frac{\left(\hat{X}/\hat{K}\right)^{\hat{\gamma}}}{\left(\tilde{X}/\tilde{K}\right)^{\tilde{\gamma}}} = \frac{\left(\hat{\gamma}\widehat{MC}\right)^{\frac{\hat{\gamma}}{1-\hat{\gamma}}}}{\left(\tilde{\gamma}\widetilde{MC}\right)^{\frac{\tilde{\gamma}}{(1-\tilde{\gamma})}}}. \tag{20}$$

Oil Market Dynamics

Matching the historical volatilities

Shock and elasticity parameters					
ρ_Z	$\rho_{\tilde{A}}$	σ_Z	$\sigma_{\tilde{A}}$	$1/\eta$	$\hat{\gamma}$
0.944	0.944	0.004	0.04	0.05	0.5

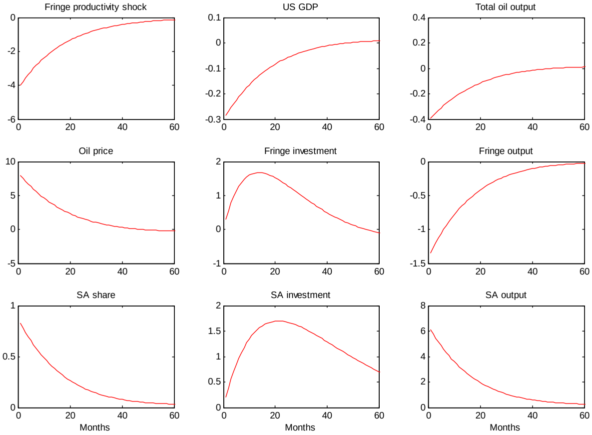
Table 4. Data and model-implied standard deviations

	Oil price	Oil output	Fringe output	Saudi output	Saudi share	Final output
Data	8.5	1.7	1.5	6.9	2.6	0.7
Model	8.3	1.2	1.8	6.4	2.7	1.2

Standard deviations (in pp) of first log differences (except "Saudi share")

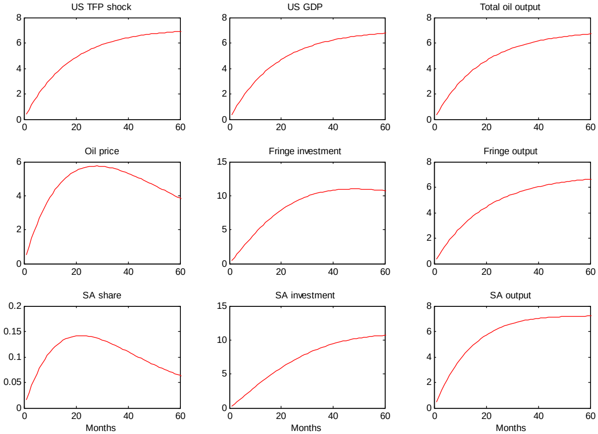
Oil Market Dynamics: Impulse-responses

Oil “supply” shock: 4% drop in competitive fringe productivity



Oil Market Dynamics: Impulse-responses

Oil "demand" shock: 0.4% increase in the growth rate of importer's TFP



Scenario Analysis

- Competitive oil market
- Fringe oil peaks
- All oil peaks

Table 5. Comparative statics

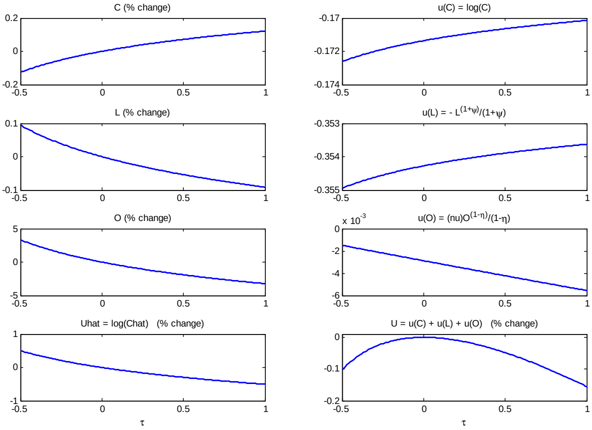
Scenario	Mark-up %	SA share %	Oil/ GDP %	Cap. Util. %	GDP %Δ	Oil output %Δ	Oil price %Δ
Baseline	20	12.7	5.7	75			
Compet.	0	0	4.6	100	+0.7	+1.1	–20
Fr. costs ↑	60	30.8	11.5	75	–3.5	–3.5	+100
Oil costs ↑	20	12.7	11.5	75	–3.5	–3.5	+100

Note: last three columns are % changes from the baseline steady state

Tax Analysis

Proportional tax on oil consumption rebated lump-sum

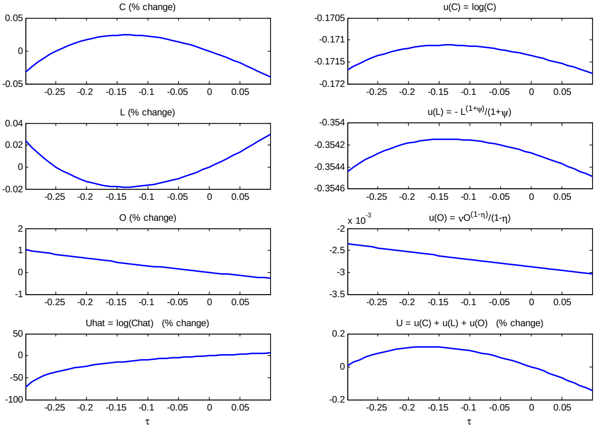
$$C_t + (1+\tau)\, s_t O_t = w_t L_t + T_t \qquad (21)$$



Tax Analysis

Proportional subsidy to fringe oil production collected lump-sum

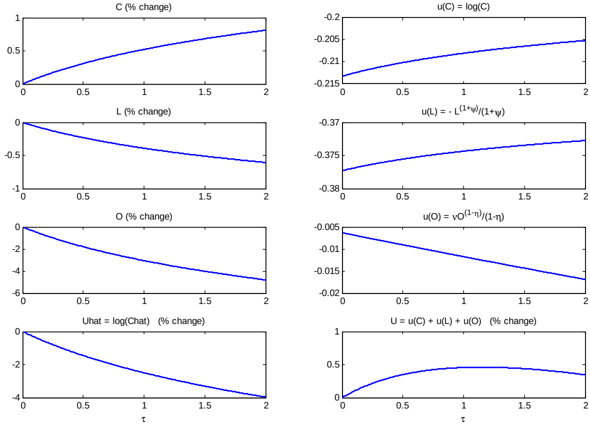
$$C_t + s_t O_t = Y_t + \phi \tilde{I}_t \tag{22}$$



Tax Analysis

Proportional tax on oil consumption with decreasing returns to scale

$$\hat{O}_t = \hat{Z}_t \hat{X}_t^{\hat{\gamma}}, \qquad \hat{K}_t = 1 \tag{23}$$



Conclusions and future research

- The stylized facts of the oil market (oil production and price volatilities, spare capacity, etc) can be accounted for well *quantitatively* by a model of a dominant firm with competitive fringe
- The dominant oil producer represents a distortion which results in a loss of output and utility for oil-importing countries
- A simple proportional tax on oil consumption may not necessarily mitigate the distortion (depends on returns to scale)
- A proportional subsidy to fringe oil production may be welfare improving for oil importers