Oil and Macroeconomics
Dutch Disease, OPEC, Oil Prices

Mohammad H. Rahmati

Sharif University Of Technology

August 8, 2018

Table of Content

Matsen, Torvik "Optimal Dutch Disease" J. Econ. Dev. (2005), Allcott, Keniston "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America" ReStud (2017)

Asker, Collard-Wexler, De Loecker "(Mis) Allocation, Market Power and Global Oil Extraction" (2018). Smith "Inscrutable OPEC? Behavioral tests of the cartel hypothesis." Energy Journal, (2005)

Baumeister,Kilian. "Forty years of oil price fluctuations: Why the price of oil may still surprise us." Journal of Economic Perspectives, (2016), Kilian "Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market." AER,(2006), Baumeister, Kilian. Forecasting the real price of oil in a changing world: A forecast combination approach. 2013

Introduction

- Resource abundance lowers growth
- How? shifts factors of production away from sectors generating learning by doing (LBD). (van Wijnbergen (1984), Krugman (1987), Matsuyama (1992))
- This paper: how resources should be managed? normative!
- Related normative literature: intergenerational allocation of exhaustible resources by Solow (1974, 1986) Hartwick (1977).

Results

- LBD mechanism $\Rightarrow$ optimal share of national wealth consumed in each period needs to be adjusted downward.
- A positive fraction of the resource wealth should be consumed in each period.
- $\Rightarrow$ lower growth in resource abundant countries is part of an optimal growth path
- Some Dutch disease is always optimal

Results

- The spending path of the resource wealth may be increasing or decreasing over time.
- LBD pulls for large transfers to early generations
- While a negative effect on productivity growth pulls in the other direction
- The higher the share of non-traded, the weaker is the first effect and the stronger is the second
- More non-traded $\Rightarrow$ more likely increasing spending path

Model

- Small open economy, Traded (T), Non-traded (N) goods
- Productivity growth from learning-by-doing in traded sector
  - only affect traded sector ⇒ unbalanced growth (van Wijnbergen (1984), Krugman (1987), Matsuyama (1992) and Gylfason et al. (1999))
  - affect both sectors + balanced growth (Sachs and Warner (1995))
- Dynamics of productivity H are:

$$\frac{H_{t+1} - H_t}{H_t} = \alpha\eta_t$$

fraction of the total labor force employed in traded sector in period t is η_t

α strength of the LBD effect

Model

- Production function (constant return to scale) in two sectors:

$$X_{Nt} = H_t(1 - \eta_t) \qquad X_{Tt} = H_t\eta_t$$

- Real exchange rate (relative price of non-tradables in terms of tradables)=1
- Total GDP: $X_t = X_{Nt} + X_{Tt} = H_t$
- Consumers live for one period (a generation)
- Demand for non-traded goods: $C_{Nt} = (1-\gamma)Y_t = X_{Nt}$ (Y_t disposable income)
- Notice $C_{Tt} = \gamma Y_t$ & no-saving, no-bequest $\Rightarrow Y_t = H_t \Rightarrow \eta_t = \gamma \Rightarrow$ output growth rate is $\alpha\gamma$ (notice no resource here)

The social planner's problem

- Horizon is M periods
  - Inefficiencies: too short planning horizon $\Rightarrow$ ignore LBD
- A role for the government in the model, even in the absence of resource wealth
- Resource wealth in the form of a foreign exchange gift W_1 in $t = 1$
- Planner then decides (in period 1) how to allocate this gift over time
- R_t net lump-sum transfers to generation t

The social planner's problem

- Objective

$$U = \sum_{t=1}^{M} \left(\frac{1}{1+\delta}\right)^{t-1} [\gamma log(C_{Tt}) + (1-\gamma) log(C_{Nt})]$$

- Aggregate consumption

$$C_t = C_{Tt} + C_{Nt} = \gamma Y_t + (1-\gamma) Y_t = R_t + H_t$$

- Rewrite inside social planner

$$\gamma log(C_{Tt}) + (1-\gamma) log(C_{Nt}) = log(C_t) + \gamma log \gamma + (1-\gamma) log(1-\gamma)$$

- So, the objective:

$$U = \sum_{t=1}^{M} \left(\frac{1}{1+\delta}\right)^{t-1} log(C_t)$$

The social planner's problem

- Notice
  $C_{Nt} = (1-\gamma)Y_t = (1-\gamma)(H_t + R_t) = X_{Nt} = H_t(1-\eta_t)$
- Thus:$\eta_t = \gamma - (1-\gamma)\frac{R_t}{H_t}$
- Dutch disease: windfall then decrease resources to tradable.
- This results from high demand because of windfall then all non-tradable should be from domestic products.
- Stronger when the more important nontradables are in consumption, and the larger transfers are relative to production.

The social planner's problem

- Notice $-1 < \frac{R_t}{H_t} < \frac{\gamma}{1-\gamma}$
- First inequality: negative transfers (i.e. taxes) cannot be higher than 100 % of GDP,
- Second inequality: transfer-GDP ratio must be lower than the ratio of tradables to non-tradables in aggregate consumption. (to have $\eta_t < 1$)
- Then: $H_{t+1} = H_t(1 + \alpha\gamma) - \alpha(1 - \gamma)R_t$
- Negative effect of R on future productivity
- So far similar to: Krugman (1987), Sachs and Warner (1995), Gylfason et al. (1999) and Torvik (2001),

The social planner's problem

- Early literature: exogenous R and current account
- This paper: optimal intertemporal use of resource income and the implied optimal current account and growth dynamics.
- Stock of foreign asset W_t (foreign exchange gift is the only initial foreign)
- Constant exogenous real interest rate r, current account is:

$$
\begin{aligned}
CA_t &= W_{t+1} - W_t = X_{Tt} - C_{Tt} + X_{Nt} - C_{Nt} + rW_t \\
&= \eta_t H_t - \gamma(H_t + R_t) + rW_t \\
&= (\gamma - (1-\gamma)\frac{R_t}{H_t})H_t - \gamma(H_t + R_t) + rW_t \\
&= rW_t - R_t
\end{aligned}
$$

The social planner's problem

- Intertemporal budget constraint using $W_{M+1} = 0$:

$$\sum_{t=1}^{M} \left(\frac{1}{1+r}\right)^{t-1} R_t = (1+r)W_1$$

- Social planner problem:

$$\begin{aligned}
max_{\{R_t\}_{t=1}^{M}} & \quad \sum_{t=1}^{M} \left(\frac{1}{1+\delta}\right)^{t-1} log(C_t) \\
H_{t+1} &= H_t(1+\alpha\gamma) - \alpha(1-\gamma)R_t \\
C_t &= H_t + R_t \quad given \quad W_1 \& H_1 \\
\textstyle\sum_{t=1}^{M} & \left(\frac{1}{1+r}\right)^{t-1} R_t = (1+r)W_1
\end{aligned}$$

National wealth

- Planner's measure of national wealth

$$NW_{t+1} = (1+r)W_{t+1} + \sum_{s=t+1}^{M} \left(\frac{1}{1+r}\right)^{s-(t+1)} H_s$$

- =wealth W accumulated through period t plus present value of current and future income

$$\begin{aligned} NW_{t+1} &= (1+r)[(1+r)W_t - R_t] + (1+r)\sum_{s=t}^{M}\left(\frac{1}{1+r}\right)^{s-t} H_s \\ &\quad -(1+r)H_t \\ &= (1+r)\left[(1+r)W_t + \sum_{s=t}^{M}\left(\frac{1}{1+r}\right)^{s-t} H_s - C_t\right] \\ &= (1+r)(NW_t - C_t) \end{aligned}$$

National wealth

- Repeated iteration for $s > t$

$$H_s = (1+\alpha\gamma)^{s-t} H_t - \alpha(1-\gamma) \sum_{i=t}^{s-1} (1+\alpha\gamma)^{s-1-i} R_i$$

- If we substitute:

$$\begin{aligned} NW_{t+1} \quad = \quad & (1+r)[(1+r)W_t - R_t] + \\ & (1+r) \sum_{s=t+1}^{M} \left(\frac{1+\alpha\gamma}{1+r}\right)^{s-t} H_t \\ & -\alpha(1-\gamma) \sum_{s=t+1}^{M} \left(\frac{1}{1+r}\right)^{s-(t+1)} [(1+\alpha\gamma)^{s-(t+1)} R_t \\ & + \sum_{i=t+1}^{M} (1+\alpha\gamma)^{s-1-i} R_i] \end{aligned} \qquad (1)$$

National wealth

- Single dynamic constraint
- Get terminal value $NW_{M+1} = 0$
- A non-growing economy if no LBD, i.e. when $\alpha = 0$.
- Exogenous growth when $\gamma = 1$
  - produce and consume tradables only, in effect giving us a one-sector model with an exogenous output growth rate $= \alpha$
  - planner chooses $\{R_t\}$ to maximize utility subject to (1) and terminal condition.
- Assumption $r > \alpha\gamma$
  - interest rate is higher than the economy's output growth in the absence of government intervention.

Optimal aggregate consumption

- Proposition 1: let

$$J(NW_t) = max_{R_t} \sum_{t=1}^{M} \left(\frac{1}{1+\delta} \right)^{t-1} log(R_t + H_t)$$

subject to (1) and the terminal condition, then

$$J(NW_t) = \Phi_t + \Theta_t log(NW_t)$$

where $\Theta_t = \frac{1+\delta}{\delta} \left[1 - \left(\frac{1}{1+\delta} \right)^{M-t} \right]$ an Φ_t is an inessential function of time only. Optimal consumption is:

$$C_t = h_t NW_t$$

$$h_t = \frac{1}{1 + \left[\frac{1+\delta}{\delta} \left(1 - \left(\frac{1}{1+\delta} \right)^{M-t+1} \right) - 1 \right] \left[1 + \frac{\alpha(1-\gamma)}{r-\alpha\gamma} \left(1 - \left(\frac{1+\alpha\gamma}{1+r} \right) \right. \right.}$$

Optimal aggregate consumption

- Aggregate consumption grows according to

$$\frac{C_{t+1}}{C_t} = (1+r)\frac{h_{t+1}}{h_t}(1-h_t)$$

- Corollary 1 Compared to non-growing economies or economies with exogenous growth, learning by doing implies that it is optimal to consume a lower fraction of national wealth in any period, except for the last period $t = M$
- Consumption is more costly in this endogenous growth model.
- Increased consumption in one period not only lowers future financial wealth, it also lowers future productivity growth
- Consumption-wealth ratio increases faster with LBD

Optimal aggregate consumption

- When $M \to \infty$

$$\lim_{M\to\infty} h_t = \frac{\delta}{1+\delta+\frac{\alpha(1-\gamma)}{r-\alpha\gamma}}$$

- Which is a constant
- zero growth $(\alpha = 0)$ or exogenous growth $(\gamma = 1)$ then
    - a constant share $\frac{\delta}{1+\delta}$ of national wealth should be consumed in each period.

- With LBD, a lower constant share of national wealth should be consumed in each period

$$\lim_{M\to\infty} \frac{C_{t+1}-C_t}{C_t} = \frac{r\left(1+\frac{\alpha(1-\gamma)}{r-\alpha\gamma}\right)-\delta}{1+\delta+\frac{\alpha(1-\gamma)}{r-\alpha\gamma}}$$

Optimal transfers and output growth

- $M = 2$
- Then $C_2 = NW_2$ & $C_1 = \frac{1+\delta}{2+\delta+\frac{\alpha(1-\gamma)}{1+r}} NW_1$
- By $C_t = H_t + R_t$ and $\frac{C_2}{C_1} = \frac{1+r}{1+\delta}\left(1 + \frac{\alpha(1-\gamma)}{1+r}\right)$

$$R_2 + H_2 = (R_1 + H_1)\left[\frac{1+r}{1+\delta}\left(1 + \frac{\alpha(1-\gamma)}{1+r}\right)\right]$$

- Then

$$\begin{aligned} R_2 &= \left[\frac{1+r}{1+\delta}\left(1 + \frac{\alpha(1-\gamma)}{1+r}\right) + \alpha(1-\gamma)\right] R_1 \\ & \left[\frac{1+r}{1+\delta}\left(1 + \frac{\alpha(1-\gamma)}{1+r}\right) - (1+\alpha\gamma)\right] H_1 \end{aligned} \quad (2)$$

- From interremporal budget constraint, find R_1, R_2

Optimal transfers and output growth

- Without LBD ($\alpha = 0$) (assume $r = \delta$)
  - $R_2 = R_1$
  - Intertemporal budget: $R_1 = \frac{(1+r)^2}{2+r} W_1$
- Exogenous growth $\gamma = 1$(assume $r = \delta$)
  - $R_2 = R_1 - \alpha H_1$
  - Intertemporal budget: $R_1 = \frac{(1+r)^2}{2+r} W_1 + \frac{1}{2+r} \alpha H_1$
  - Increase transfer to generation 1

Optimal transfers and output growth

- The two-sector, LBD framework (assume $r = \delta$)

$$R_1 = \frac{(1+r)^2}{2+r+\frac{2+r}{1+r}\alpha(1-\gamma)} W_1 + \frac{\alpha\gamma - \frac{\alpha(1-\gamma)}{1+r}}{2+r+\frac{2+r}{1+r}\alpha(1-\gamma)} H_1$$

- Higher $W_1 \Rightarrow$ higher R_1.
- With LBD, lower R_1 than otherwise
- If $W_1 = 0$ then $R_1 > 0$ if $\gamma - \frac{1-\gamma}{1+r} > 0$
- Two effects with opposite directions:
  - positive growth potential ($\alpha > 0$) $\Rightarrow$ higher R_1 to share gain
  - transferring to generation 1 is costly in terms of lower growth
  - if transfer push down more learning $Rightarrow$ cost is higher
  - larger share non-traded $1-\gamma$ in consumption then more costly

Optimal transfers and output growth

- General case

$$R_1 = \frac{(1+r)^2}{1+r+\frac{1+r}{1+\delta}+\frac{2+\delta}{1+\delta}\alpha(1-\gamma)}W_1 + \frac{1+\alpha\gamma-\frac{\alpha(1-\gamma)}{1+r}-\frac{1+r}{1+\delta}}{1+r+\frac{1+r}{1+\delta}++\frac{2+\delta}{1+\delta}\alpha(1-\gamma)}$$

- If W_1 then R_1 is negative if the last numerator is negative.
- Optimal output growth rate is higher than the "market solution" implies, vice versa
- R_1 is increasing in W_1
- Optimal output growth path decreases when the country receives a foreign exchange gift
- This is in fact an optimal response.
- Sign for current account is ambiguous

General case

- For $M > 2$

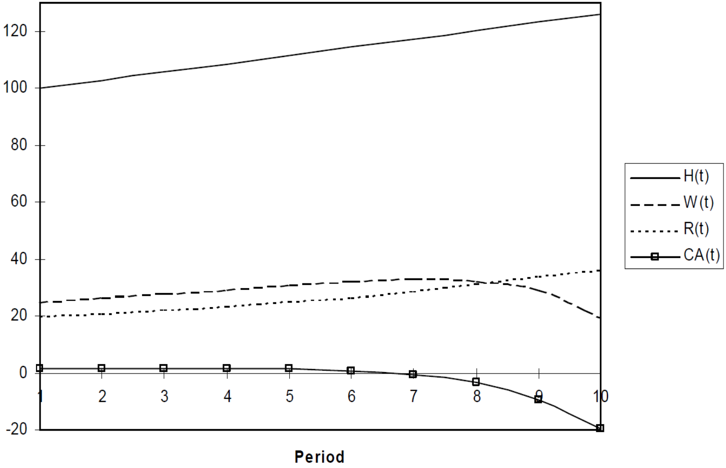
$$R_{t+1} + H_{t+1} = \left[(1+r)\frac{h_{t+1}}{h_t}(1-h_t)\right](R_t + H_t)$$

- With substitution $H_{t+1} = H_t(1+\alpha\gamma) - \alpha(1-\gamma)R_t$

$$\begin{aligned} R_{t+1} &= \left[(1+r)\frac{h_{t+1}}{h_t}(1-h_t) + \alpha(1-\gamma)\right] R_t \\ &- \left[1 + \alpha\gamma - (1+r)\frac{h_{t+1}}{h_t}(1-h_t)\right] H_t \end{aligned}$$

- Parameters:
  - Each time 25 years, 250 years ($M = 10$)
  - $r = \delta = 85.4\%$ (correspond to annual discount 2.5%)
  - $\gamma = 0.4$ & $\alpha = 0.1$
  - $H_1 = 100$ & $W_1 = 25$

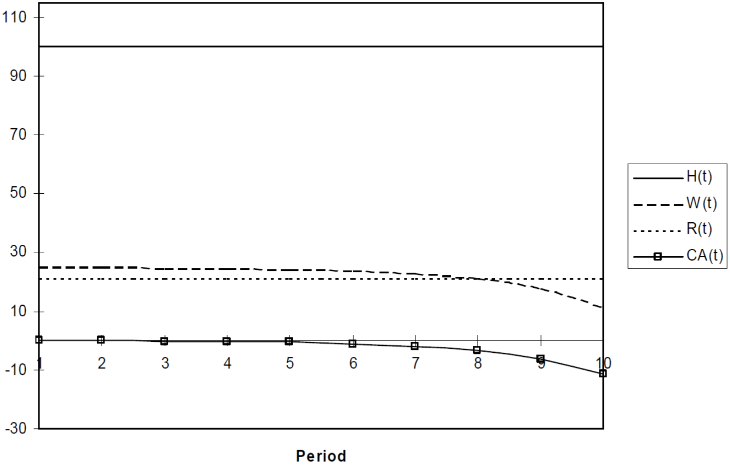
Benchmark results-Optimal Path



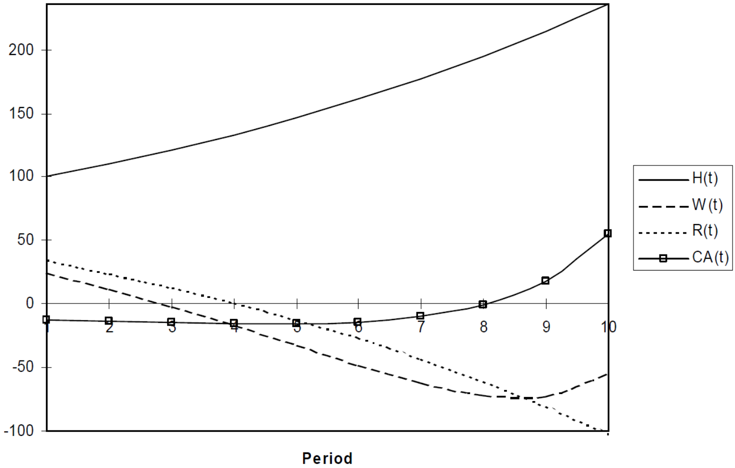
Benchmark results-Optimal Path

- H, R grow over time
- Output growth decreases through time $Y_t = H_t + R_t$
- Growth in R increases
- Optimal to spend little of foreign exchange gift in the first periods
- Country initially builds up its foreign assets
- Period 7 start to run current account deficits
- Because R grows faster than output

Optimal Path No growth- $\alpha = 0$



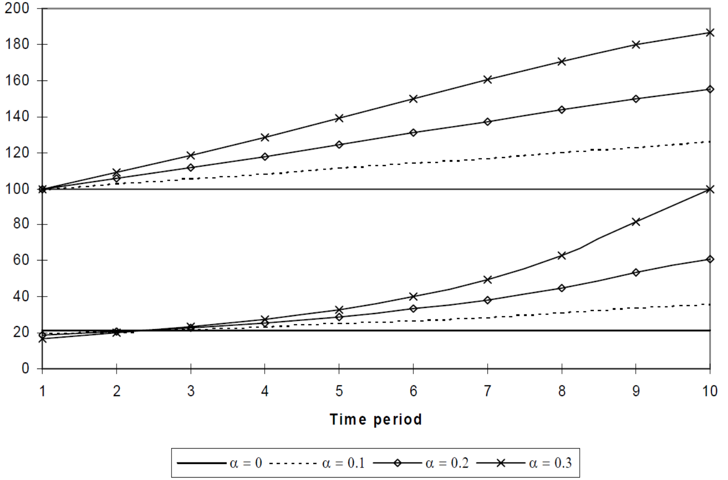
Optimal Path Exogenous Growth- $\gamma = 1$



Optimal Path Comparison

- Without growth:
  - All generations receive same share of foreign exchange gift
  - As a result, current account deficit in each period
  - Constant ratio between R and H
  - Employment in the two sectors in this case is constant.
- With exogenous growth:
  - Spending of gift should decrease over time.
  - CA is negative until period 8 and then positive
  - Equal consumption for each generation
- Endogenous growth :
  - increasing consumption over time
  - Because optimal real interest rate for consumption is larger with LBD

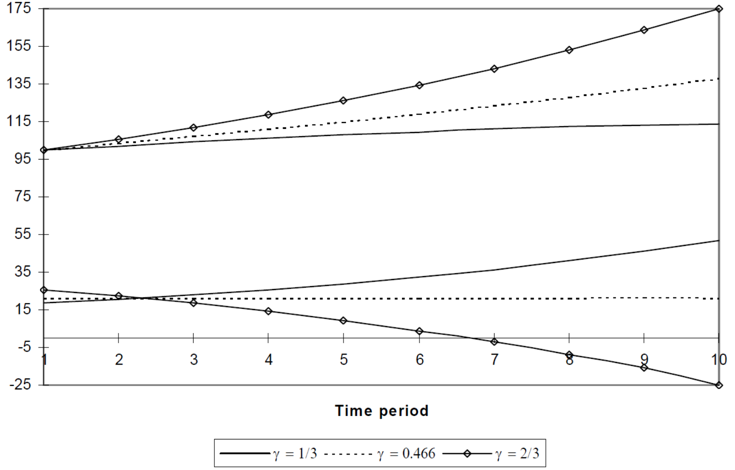
The slope of the spending path- Graph H (upper), R



The slope of the spending path

- Growth rate α
  - Higher α, more concave output path, more convex R.
  - Higher α, R starts lower then increase faster
- Traded goods expenditure share γ
  - Lowe γ increasing spending path
  - A trade-off
    - if higher growth $\Rightarrow$ more transfer early to smooth
    - but transfer early slow down growth
  - high $\gamma \Rightarrow$ large expenditure on traded $\Rightarrow$ large traded sector $\Rightarrow$ high growth potential
  - $\Rightarrow$ higher γ trade-off to transfer early is stronger
  - Moreover, it increase more demand in traded, so boost growth
  - at $\gamma = 0.466$ two effect cancel out and constant optimal spending path

The slope of the spending path- Graph H (upper), R



Descriptive implications

- Literature assume exogenous flow of resource income in each period, all used in the same period
  - then more natural resources, worse the growth outcome
- Venezuela and Zambia vs. Botswana and Norway
- Iimportance of savings out of the resource income
- Optimal saving needs to be adjusted up as the effective interest rate is higher than the market interest rate
- What data say?
  - savings from the national accounts can be very misleading for resource abundant countries
  - savings in the national accounts do not take into account that selling non-renewable natural resources is a reduction in a countrys' wealth,
  - not income in the traditional sense
  - correct for this

Resource Wealth Adjusted Saving Rates, 1972-2000

Escapers		Non-escapers	
Australia	18.0 %	Algeria	6.11 %
Botswana	33.0 %	Congo	-11.9 %
Canada	15.7 %	Ecuador	n.a.
Chile	7.4 %	Mexico	10.8 %
Ireland	22.0 %	Nigeria	-22.0 %
Malaysia	19.9 %	Saudi Arabia	-21.5 %
New Zealand	18.4 %	Sierra Leone	-1.8 %
Norway	17.0 %	Trinidad & Tobago	-3.9 %
Oman	-26.6 %	Venezuela	-1.8 %
Thailand	20.0 %	Zambia	-5.8 %
USA	15.1 %		

Saving and Curse

- Countries that have escaped the resource curse have higher resource wealth adjusted savings rates
- What uncertainty and curse?
- In the model should allow planner to invest in risky-high yields, & contingent assets
- Planner do precautionary saving.
- The result is ambiguous

Empirical Test of Dutch Disease

- Allcott, Hunt, and Daniel Keniston. "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America." The Review of Economic Studies 85.2 (2018): 695-731.
- Manufacturing positive productivity spillovers on other nearby firms ⇒ reducing transport costs for goods, workers, and ideas
- If natural resource sector growth crowds out manufacturing ⇒ reduces productivity spillovers, which could reduce long run growth (Matsuyama (1992))
- Test the impact of oil boom by a county in the US.
- Restrictions: labor is perfectly mobile, no exchange rate differences,

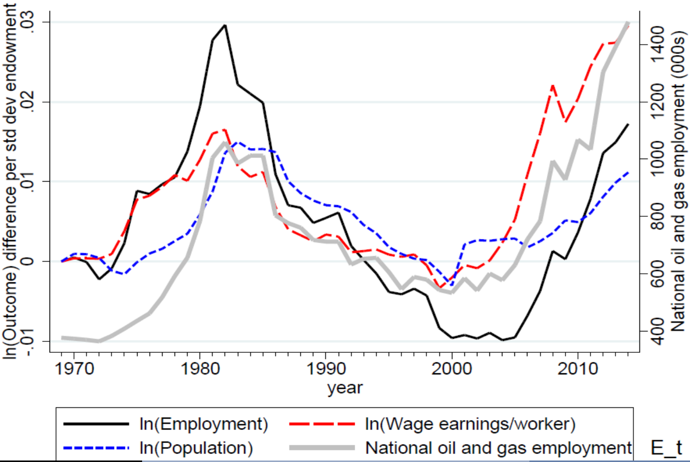
Model

- Compare higher vs. lower endowment on economic outcomes through boom and bust cycles
- τ^r relative effects: effect of resource boom on difference: General equilibrium effects and other types of geographic spillovers
- τ^a absolute effects: average treatment effect on the treated
- County c, year t, ϕ_{dt} census division by year dummy

$$ln(Y_{ct}) = \tau_t^r R_{ct} + \lambda R_{ct} + \mu_t ln(Y_{0c}) + \phi_{dt} + \varepsilon_{ct}$$

- Y_{oc} outcome in baseline year (1960) with time varying coefficient μ_t
- R_{ct} oil endowments, omit τ_t^r for 1969, so λ measures association between endowments and outcome in 1969, $\Rightarrow \tau_r^t$ measure difference between associations in t and 1969.

County-Level Aggregates Over Time in Resource-Abundant Counties, τ_r^t



E_t

Model Specification

- "Shift-share" regression, use difference b/c serially corr. ε_{ct}

$$\Delta ln(Y_{ct}) = \tau^r R_{ct} \Delta ln(E_t) + \lambda R_{ct} + \mu_t ln(Y_{0c}) + \phi_{dt} + \varepsilon_{ct}$$

- Cluster by state, τ: differential elasticity w.r.t E_t for counties with one standard deviation additional endowment

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	Population	Employment	Housing rent	Earnings/ worker	Mfg. earnings/ worker	Mfg. employment
Δln(National oil&gas emp)	0.0119***	0.0282***	0.0270***	0.0179***	0.0108***	0.0293***
×endowment	(0.00201)	(0.00607)	(0.00754)	(0.00510)	(0.00376)	(0.00724)
Observations	135,274	138,349	15,371	138,349	111,709	111,754

- Outcomes in higher-endowment counties are significantly more procyclical with oil employment than in lower-endowment counties. A boom significantly increases relative growth, and a bust significantly decreases relative growth.

Model of Absolute Effect

- Need assumption about structure of spillover
  - People likely to move across state for a job than across the country
  - Spillovers from other counties scale with distance from county c, and that counties outside a maximum radius of 400 miles are unaffected.
  - Total oil endowment for all counties with centroids within eight different doughnuts around county c: 0-50, 50-100, $\cdots$, 350-400 miles as R_{ctd}

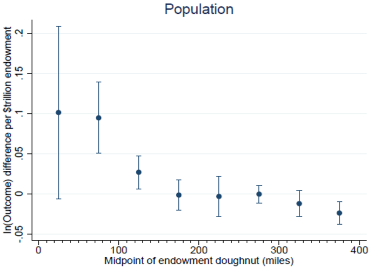
$$\Delta ln(Y_{ct}) = \tau^{a} R_{ct} \Delta ln(E_t) + \sum_{d=1}^{8} [\nu_d R_{ctd} \Delta ln(E_t) + \vartheta R_{ctd}] + \lambda R_{ct} + \mu_t ln(Y_{0c}) + \phi_{dt}$$

- ν_d represents the effect of additional endowment in doughnut d on a county's economic outcomes. (nice spillover effect by Miguel and Kremer (2004), Clarke (2015))

Absolute Effects

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	Population	Employment	Housing rent	Earnings/ worker	Mfg. earnings/ worker	Mfg. employment
Δln(National oil&gas emp)	0.00692***	0.0162***	0.0120*	0.0102***	0.00176	0.0166**
×endowment	(0.00155)	(0.00579)	(0.00702)	(0.00304)	(0.00212)	(0.00626)
Observations	135,274	138,349	15,371	138,349	111,709	111,754

Figure 8: **Geographic Spillovers**



Geographic Spillover

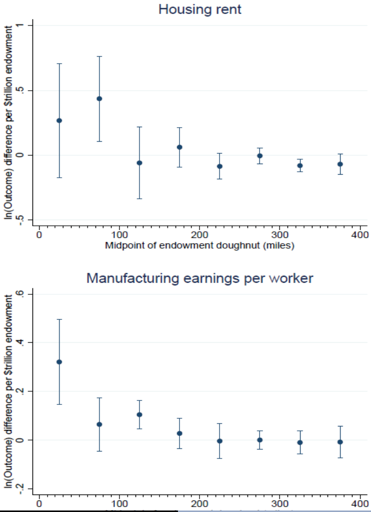


Table of Content

Matsen, Torvik "Optimal Dutch Disease" J. Econ. Dev. (2005), Allcott, Keniston "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America" ReStud (2017)

Asker, Collard-Wexler, De Loecker "(Mis) Allocation, Market Power and Global Oil Extraction" (2018). Smith "Inscrutable OPEC? Behavioral tests of the cartel hypothesis." Energy Journal, (2005)

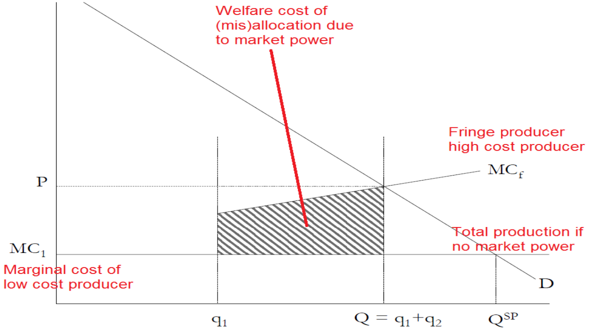
Baumeister,Kilian. "Forty years of oil price fluctuations: Why the price of oil may still surprise us." Journal of Economic Perspectives, (2016), Kilian "Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market." AER,(2006), Baumeister, Kilian. Forecasting the real price of oil in a changing world: A forecast combination approach. 2013

Motivation

- Research Question: Impact market power on the misallocation of production?
- Approach: Data driven examination of upstream oil industry (Extraction and pre-refinery production)
- Why is this interesting?
  - Effect of market power is central to Energy Economics (we will see Wolak paper on the effect of market power in power market).
  - Both cartel activity and unilateral market power.
  - Case of aggregate implications of market power in context of misallocation literature.
  - The influence of OPEC on the world market for oil.

Production Distortion: main approach

- Welfare loss: comparing realized resource cost of production (area under actual marginal cost curve) to the efficient resource cost of production
- Market power is a distortion



Extending the static (graphical) analysis

- Oil is an exhaustible resource: we need to take the dynamics of production seriously.
  - Depletion of Reserves.
  - Constraints on extraction speed.
  - When a field gets extracted, not if.

Literature

- Borenstein, Bushnell and Wolak 1999 AER.
- Oil Markets
  - Micro: Kellogg 2014 AER, Covert 2017, Anderson, Kellogg, Salant, 2017 JPE.
  - Macro: Lutz 2009 AER
- Cartels: Marshall, Marx 2012, Asker AER 2010, Schmitz 2015.
- OPEC: Cremer and Weitzman 1976 EER, Cremer, Salehi-Isfahani 1991.
- Misallocation (Hsieh and Klenow, 2009 QJE, Asker, Collard-Wexler and De Loecker, JPE 2014)
- Main Findings: Costs of oil production are 10 percent higher due to the OPEC cartel: about a 163 billion dollar welfare loss over a 35 year period.

Background on Oil

- Geology and location have a big impact on costs of extraction
- Exogenous cost variation across production units unrelated to management skill rather:
  - Model (technology): onshore, offshore, shale, etc.
  - Location (geology): bedrock structure, climate, etc.
- Examples:

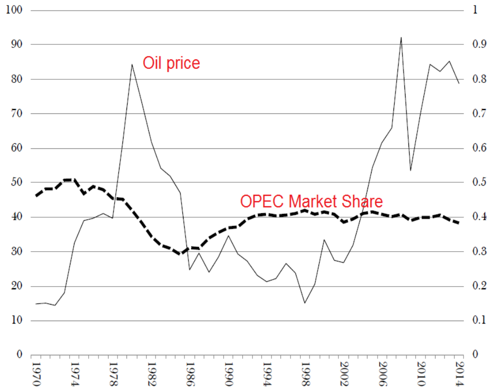
OPEC Cartel

- OPEC is Algeria, Angola, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi , UAE, Venezuela.
- OPEC is an imperfect cartel
  - Production Quota Mechanism: No monetary transfers
  - Frequent instances of cheating on quotas.
  - Saudi Arabia, Kuwait, UAE usually enforce cartel by raising production

Table: Largest crude producers, % of global production 1970-2014

OPEC		Non-OPEC	
Saudi Arabia	11.8%	United States	14.4%
Iran	5.4%	Russia	13.0%
Venezuala	3.8%	China	4.1%
UAE	3.1%	Mexico	3.7%
Nigeria	2.8%	Canada	3.3%
Iraq	2.7%	UK	2.4%
Kuwait	2.6%	Norway	2.4%

Price and OPEC



Data

- Rich Data on oil from Rystad Energy. One of the main data suppliers in the industry.
- Field Level Information: Gulfaks South versus Ghawar.
- Data from 13,000 fields.
- Information on production, costs, reserves, technology

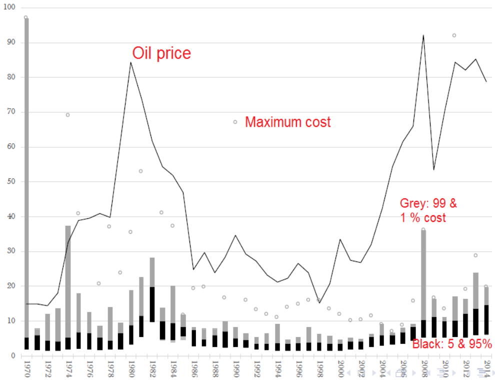
Variable	mean	median	5%	95%
Field-year characteristics:				
Production (mB/year)	3.43	0.22	0.00	10.92
Reserves (mB)	99.49	3.71	0.03	239.78
Discovery Year	1965	1967	1911	1999
Startup Year	1971	1974	1916	2005
Off-shore	0.19			
Costs: ($m)				
Exploration Capital Expenditures	0.61	0.00	0.00	0.41
Well Capital Expenditures	9.10	0.49	0.00	35.32
Facility Capital Expenditures	5.14	0.21	0.00	16.85
Production Operating Expenditures	10.41	0.46	0.00	38.47
Transportation Operating Expenditures	2.27	0.13	0.00	7.01
SGA Operating Expenditures	2.65	0.22	0.00	8.85

Reserves, 2014

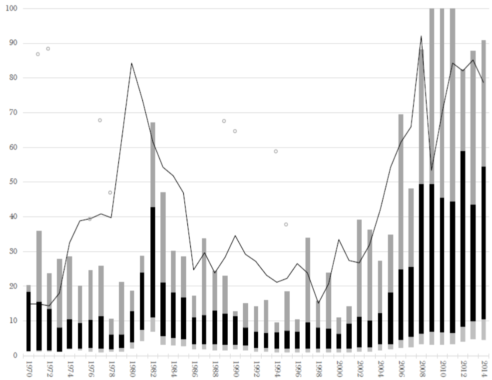
- Reserves are measured as the unextracted, but recoverable, quantity of oil remaining in the ground in a field.
    1. Descriptive stats: P50 value at an oil price of $70
    2. Counterfactual (1970 onward) sum of: i) the actual production history from 1970 to 2014, and ii) the P50 value at an oil price of $70 a barrel in 2014.

	Reserves (mB)	reserves (%)	Reserves/(Annual production) (%)
Non-OPEC	218,054	50	10
OPEC	220,561	50	19
Saudi Arabia	74,194	17	18

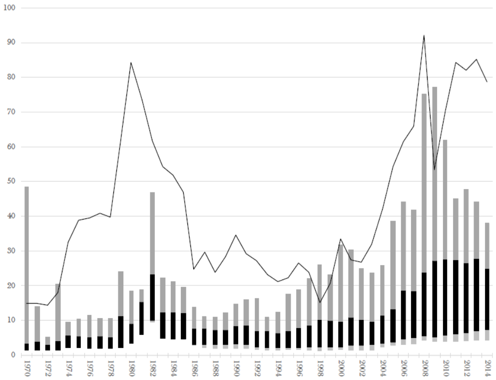
Cost Changes over time: Saudi Arabia



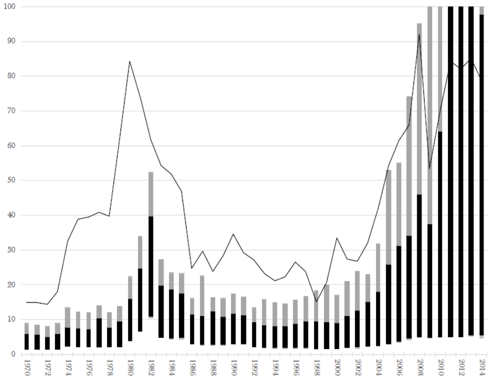
Cost Changes over time: Nigeria



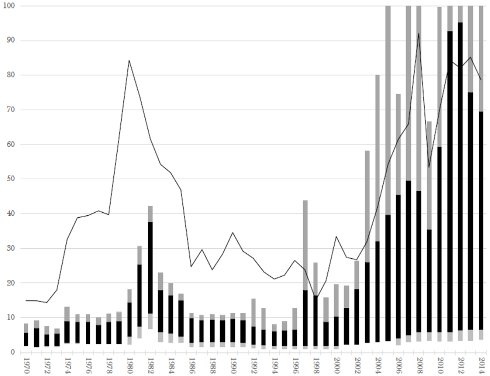
Cost Changes over time: Russia



Cost Changes over time: United States



Cost Changes over time: Canada



Competitive Equilibrium

- Productive Inefficiency Definition

  Productive inefficiency is the net present value of the difference between the realized costs of production, and the cost of production had the realized production path been produced by firms taking prices as exogenous.
- In an exhaustible resource industry, the welfare losses come from the welfare effects of when to extract oil given discounting.

Quantifying the extent of misallocation

- **Cost:** They take a relatively long run perspective on costs: what if OPEC had not operated over the last 20 years: mush together startup, fixed, and marginal costs.
- In the paper they build this up from a production function with input costs that vary by year.
- Marginal cost: $c_{ft} = c_f \mu_{st}$
- μ_{st} is a martingale $E(\mu_{st+k}|\mu_{st}) = \mu_{st}$

Characterization of Equilibrium

- Homogenous product market
- Producer Solves:

$$E max_{q_{ft}} \sum_{t=1}^{T} \delta^{t-1}(p_t - c_{ft})q_{ft}$$

subject to

$$R_f \geq \sum_{t=1}^{T} q_{ft},\ and\, q_{ft} > 0\, \forall t \in \{1, \cdots, T\}$$

- **Sorting Theorem** Proposition 1 and corollary 1: lowest cost fields are extracted first in any competitive equilibrium

Structural Model

- Use the sorting algorithm to compute counterfactual paths for the industry - the competitive path.
- Notice that, as in the figure, we are looking at changes in costs holding total quantity fixed.
- We will first present two types of counterfactuals:
  1. Static Counterfactual: one period effects of moving to a competitive equilibrium.
  2. Dynamic Counterfactuals: long run effects - all about when a barrel will be extracted, not if.

Inputs into the Dynamic Structural Model

- Discount rate $\beta = 0.95$
- Limits on how much oil can be extracted at once (Anderson, Kellogg, and Salant 2017). We cap the extraction rate at 10 percent of reserves.
- Fields can only be extracted after their discovery date: take the path of new discoveries as exogenous.
- We do not consider the contribution of fields that do not produce in 1970-2015, likely to understate welfare losses.
- Simulate out to 2050 - until all reserves have been depleted.
    - Demand growth set at 1.3 percent (geometric average over 1970-2015).
    - Forecasted production is optimal after 2015 (end of the data) - lower bound on welfare losses.
- Need to estimate counterfactual costs: what a field would have cost to extract in 1990 using data on costs in 2010.

Dynamic counterfactual results

NPV of costs in billions of 2014 dollars

	Timespan 1970-2014		1970-2100	
Actual (A)	2184	(125)	2499	(130)
Counterfactual (C)	1268	(76)	1756	(79)
Total distortion (A - C)	916	(124)	744	(112)
Decomposition of total distortion				
Within country (non-OPEC)	329	(80)	284	(41)
Within country (OPEC)	192	(46)	157	(72)
Across country (within non-OPEC)	163	(18)	139	(17)
Across country (within OPEC) (X)	85	(22)	58	(21)
Between OPEC and non-OPEC (Y)	148	(29)	105	(25)
Production distortion due to OPEC market power				
Upper bound (X+Y)	233	(42)	163	(38)
Lower bound (Y only)	148	(29)	105	(25)

Static Distortion: as of 2014 OPEC

Country	Actual output share	Counterfactual output share	Δ Share
Persian Gulf OPEC	0.258	0.744	0.486
Iran	0.057	0.091	0.034
Iraq	0.029	0.069	0.040
Kuwait	0.030	0.155	0.125
Qatar	0.009	0.015	0.006
Saudi Arabia	0.133	0.414	0.281
United Arab Emirates	0.031	0.075	0.044
Other OPEC	0.135	0.044	-0.091
Algeria	0.021	0.015	-0.006
Indonesia	0.020	0.002	-0.018
Libya	0.025	0.012	-0.013
Nigeria	0.028	0.006	-0.022
Venezuela	0.041	0.009	-0.032

Static Distortion: as of 2014 Not-OPEC

Country	Actual output share	Counterfactual output share	Δ Share
Non-OPEC	0.607	0.212	-0.395
Brazil	0.014	0.001	-0.013
Canada	0.023	0.006	-0.017
China	0.045	0.002	-0.043
Kazakhstan	0.010	0.000	-0.01
Mexico	0.023	0.013	-0.01
Norway	0.027	0.009	-0.018
Russia	0.144	0.047	-0.097
United Kingdom	0.022	0.001	-0.021
United States	0.132	0.013	-0.119
Rest of the World	0.136	0.044	-0.092

Welfare accounting: implementation

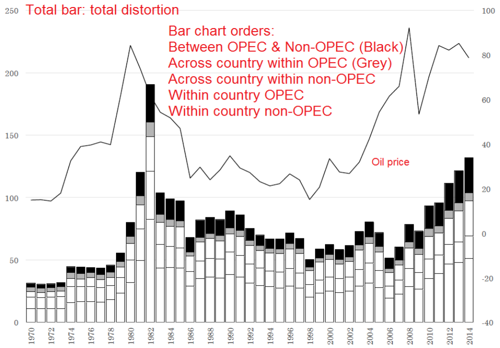
- Nested Set of Constraints:
  - Hold production in each field fixed (actual).
  - Hold production in each country fixed.
  - Hold production inside and outside of OPEC constant

Table: Static Distortion: Production Cost in 2014 in Billions of Dollars

Actual	240
Optimal Country	203
Optimal OPEC	154
Optimal	121

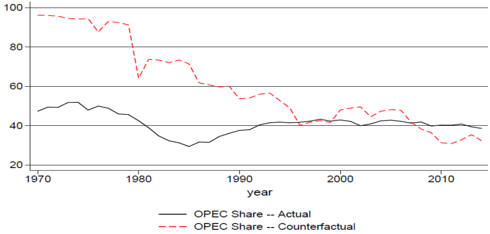
- Also, can look at cartel inefficiency at intensive and extensive margin

Static Distortion over Time



Dynamic Counterfactual

- Simulate from 1970 to 2015: NPV starting in 1970.



- Almost all the production in the 1970s is accounted for by a couple of fields: Ghawar Uthmaniyah, Greater Burgan, Ghawar Shedgum.

Conclusions

- Significant misallocation aligned with known OPEC mechanism.
    - Countries with clear market power: Gulf OPEC members.
    - Most of impact comes from timing of Ghawar (SA), Burgan (KW) and Kirkuk (IQ) extractions.
    - Misallocation rises when OPEC is known to be holding down productions and prices spike.
- Very large welfare loss , due to productive inefficiency: 160 billion USD.
- No discussion of the role of distortionary taxes or carbon externalities in this market.

Introduction-OPEC Test Market Power

- Smith, J. L. "Inscrutable OPEC? Behavioral tests of the cartel hypothesis." Energy Journal 26.1 (2005): 51-82.
- Gately (1984)-survey paper and conclude no consensus.
- Griffin (1985, p. 954)
  - The standard practice to date has been to reach onto the shelf of economic models, to select one, to validate its choice by pointing to selected events not inconsistent with the model's predictions, and then to proceed with some normative exercise
- Need a model, check its predictions with reality

Literature-OPEC Test Market Power

- Empirical literature are inconclusive about OPEC
- Few hypotheses have been rejected
- Gulen (1996), Griffin (1985) if cooperation $\Rightarrow$
  - H_0 : output of OPEC members move in parallel
- But, parallel movement
  - not inconsistent with cartel hypothesis
  - neither is it inconsistent with competitive hypothesis
  - if demand shock, competitive output move together
- How to distinguish the two empirically?

Literature-OPEC Test Market Power

- Aihajji and Huettner (2000b)
  - estimate price elasticity of demand for OPEC oil
  - monopolist would not choose to operate on the inelastic portion of its demand curve
  - $\Rightarrow$ demand elasticities < -1 not inconsistent with cartel hypothesis
  - neither inconsistent with perfectly competitive hypothesis
- Libecap (1989) Dahl, Yucel (1991)
  - H_0 : "swing" producers larger changes in production than core
  - note: individual swing producer is vulnerable to small fluctuations in aggregate output
  - so, non conclusive results for monopoly
  - if output variations random
  - then, variation for individual producers exceeds variation of total

Literature-OPEC Test Market Power

- Dahl and Yiicel (1991)
  - low-cost producers in cartel, produce more than high-cost producers
  - ⇒ marginal cost significant & negative into production equation
  - they find this result
  - but the hypothesis hold among perfectly competitive producers
  - Results are inconclusive.
- Gault, et. al. (1999)
  - study determination of individual OPEC quotas
  - find a preference for certain models over others
  - but they find that none of the four tested models of quota assignments was statistically inconsistent with data.

Literature-OPEC Test Market Power

- Griffin (1985)
  - reject the "constant market sharing"
  - $\Rightarrow$ production shares of a profit-maximizing cartel only by coincidence

  - reject "strict" version of target revenue hypothesis
  - H_0 producers vary production inversely with price to maintain a constant level of revenue
  - "partial": investment requirements to drive production
  - "partial" version not rejected

Literature-OPEC Test Market Power

- Loderer's (1985)
  - H_0: OPEC policies had no impact on market prices
  - a rejection establishes market impact
  - however could be "consistent with either effective cartel or non-cooperative oligopolists."
  - price impact is a necessary but not sufficient condition for cartel identification
  - unable to reject H_0 for 1974-80 (period w/ increase in price)
  - reject in 1981-83 (during decline)

Literature-OPEC Test Market Power

- Geroski. Ulph, and Ulph (1987)
  - OPEC's behavior varies over time (cartel to oligopoly)
  - no simple hypothesis
  - model: partially altruistic objective function: incorporates its own profits & other members.
  - authors reject "constant-behavior" hypothesis
  - evidence for "tit-for-tat" game strategy
  - first cooperate, then subsequently replicate an opponent's previous action
- Griffin and Neilson (1994)
  - subsequent to the oil price crash of 1985-1986
  - Saudi Arabia adopted a tit-for-tat production strategy
  - so, alternately disciplines and rewards other cartel members

Some Misreported Results

- Incorrect studies.
- Spilimbergo (2001)
  - "conclude that failure to reject his null hypothesis constitutes a rejection of the alternative"
  - correct interpretation: results are not strong enough to distinguish between $H_0 \& H_1$
- Dabl and Yucel (1991)
  - same error
  - null hypothesis of non-dynamic behavior (short-term planning horizon) can not be rejected.
  - incorrectly conclude dynamic behavior among OPEC producers is "strongly rejected"

Some Misreported Results

- Alhajji and Huettner's (2000b)
  - test of whether OPEC producers exploited their market power by limiting output to the point where marginal cost equals marginal revenue.
  - problem 1: flawed cost estimates
  - problem 2: failure to account for the uncertainty
  - problem 3: demand elasticities are inconsistent with their estimated demand equations

Some Misreported Results

- Dahl and Yucel (1991) and Glilen (1996)
  - H_0: production levels of OPEC members are not cointegrated
  - cointegration tests presume that production series from the respective regions are nonstationary
  - so unbounded
  - approach seems inconsistent with physical facts
  - The statistical power of cointegration tests is also known to be low
  - if two producers,
    - firm random
    - second periodic production adjustments that exactly offset the first (swing producer)
  - cointegration approach would not detect it since neither production series is nonstationary

Some Misreported Results

- Griffin's (1985)
  - reject "competitive" hypothesis in 5 of 11 OPEC members.
  - due to data limitations, competitive model is limited to a simple bivariate linear equation that relates a country's output to the prevailing price level
  - "rejection" of the competitive hypothesis: finding a significant negative relationship between a output & market price
  - problem: abstract of cost.significant cost escalation because of rush of drilling
  - may be omitted variables
- extension of Griffin, consider supply too
  - Jones (1990): reject competitive hypothesis for 2 of 11 OPEC members
  - Ramcharran (2002) reject for only two OPEC members
  - Watkins and Streifel (1998) obtained similar

Distinguish Monopoly from Competition

- Is there any empirical test to distinguish?
- Study price
  - Needs a model for pricing behavior of major deviation from marginal cost
  - Challenge: our empirical knowledge of cost functions & demand curves is imprecise Phlips (1996)
- Study production decisions
  - Test comparative static production responses to exogenous shocks
  - Could be conclusive.

Price Analysis

- Producers G (may collude)
- "Competitive fringe" of price-taking producers

$$
\begin{aligned}
H_0: &\quad MC_i = p, \forall i \in G \\
H_a: &\quad MC_i = p(1 + \tfrac{1}{\epsilon_G}), \forall i \in G \\
&\quad Q_G(P) = Q_d - Q_f(P) \\
&\quad \epsilon_G = \epsilon_d/s - \epsilon_f(1-s)/s \\
&\quad 1 - s = Q_f/Q_d
\end{aligned}
$$

- H_0 perfect competition assumption
- H_1 perfect cartel-multi-plant monopoly
- $Q_G(P)$ total demand less fringe supply
- ϵ_G elasticity of residual demand
- $1 - s$ fringe market share

Price Analysis

- Even if the alternative hypothesis is true, the ability to reject the null depends on having good estimates of
  - marginal cost
  - elasticity of residual demand
- Reject H_0 if $\frac{P-\overline{MC}}{\sigma_{\overline{MC}}} > z_\alpha$
- Otherwise: Do not reject H_0
- $\overline{MC}$=unbiased estimate of marginal cost
- σ_{MC}=standard deviation of $\overline{MC}$
- if mc is expected value of MC

Power of Test

$$Power = Pr\left[\frac{P-\overline{MC}}{\sigma_{\overline{MC}}} > z_\alpha | mc = P\left(1+\frac{1}{\epsilon_G}\right)\right]$$

$$Pr\left[\overline{MC} < P - z_\alpha \sigma_{\overline{MC}} | mc = P\left(1+\frac{1}{\epsilon_G}\right)\right]$$

$$Pr\left[\frac{\overline{MC}-P(1+\frac{1}{\epsilon_G})}{\sigma_{\overline{MC}}} < \frac{P-z_\alpha\sigma_{\overline{MC}}-P(1+\frac{1}{\epsilon_G})}{\sigma_{\overline{MC}}}\right]$$

$$Pr\left[z < -z_\alpha - \frac{P}{\epsilon_G \sigma_{MC}}\right]$$

- last step depend on cost estimate $\sim N(mc, .)$, and z standard normal

Power of Test

- Phlips: power depend on precision of mc or $\lambda = \frac{\sigma_{\overline{MC}}}{mc}$

$$Power = Pr\left[z < -z_\alpha - \frac{P}{\epsilon_G \lambda P(1+\frac{1}{\epsilon_G})}\right]$$
$$Pr\left[z < -z_\alpha - \frac{1}{\lambda(1+\epsilon_G)}\right]$$

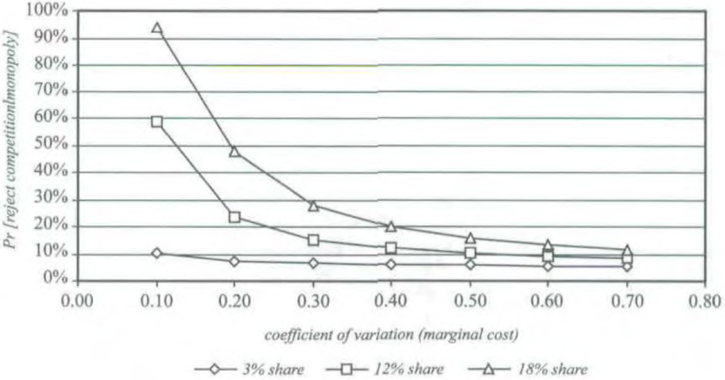
- Note that $(1+\epsilon_G) < 0$ under the alternative hypothesis
- $Pr\left[z < -z_\alpha\right] = \alpha \Rightarrow$ power of the test can not drop below α

Power of Test

- The power to distinguish competition from collusion:
  - a increases as precision of the marginal cost estimate improves $(\lambda \to 0)$
  - b increases as the elasticity of residual demand decreases in absolute value ($\epsilon_G \to -1$ from below)
  - c is even lower than reported above if collusive producers occasionally commit random pricing errors
    - then alternative hypothesis must be restated as $MC_i = P(l + \frac{l}{\epsilon_G}) + e_i$
    - e_i represents random error in attaining the first order conditions of profit maximization
- The power to reject the competitive hypothesis is extremely low

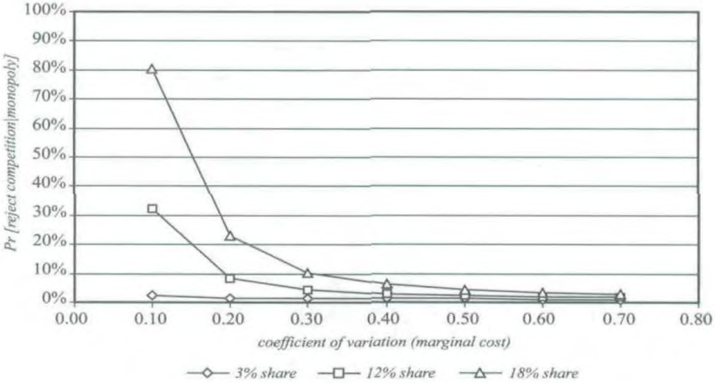
Power Function, 5% significance level

- Saudi Arabia is assumed to constitute the "cartel core" with others competitive fringe.



Power Function, 1% significance level

- Saudi Arabia is assumed to constitute the "cartel core" with others competitive fringe.



Power of Test

- Elasticity of world demand is -0.5
- Elasticity of supply from the rest of the world is +0.3
- Saudi market share vary between 3% and 18%
- Estimate of Saudi marginal cost vary between 0.1 and 0.7
- Random sample is very unlikely to reject the null hypothesis of competitive pricing unless marginal cost is estimated with high precision ($\alpha < 0.3$)
- Possibility of rejecting at 1% significance is remote
  - Saudi's average share: 12
  - Marginal cost estimate precision: coefficient of variation near 0.50
  - $\Rightarrow$ ability to reject the competitive hypothesis, even if it were false, is extremely low—hardly greater than the probability of committing a Type-I error

Output Analysis

- Offsetting or “compensating” production changes among potential rivals
- Could be for many reason.
- In Cournot oligopoly: reaction functions
- Within a perfect managed cartel: constantly shifting output among producers to ensure that least-cost operation is maintained
- Cost shocks by other members
  - cartel shifts perfectly the output plans
  - perfect competitive: no reaction by one producer to fluctuations in the output of another.

Output Analysis

- N firms, a homogeneous product,

$$mc_i(q_i) = a_i + b_i q_i$$

- a_i vary randomly from period to period, $a_i > 0 \quad b_i > 0$
- Δa_i zero mean and finite variance, $E[\Delta a_i \Delta a_j] = 0$ for all $i \neq j$
- Demand $Q_d(p) = D - p$
- F.o.c. $q_i(p) = (p - a_i)/b_i$, for now assume $b_i = b$

$$Q_s(p) = \sum_{i=1}^{N} q_i(p) = \frac{Np}{b} - \frac{1}{b}\sum_{i=1}^{N} a_i$$

Output Analysis

- Demand meet supply: $p^* = \frac{bD + \sum_{i=1}^{N} a_i}{b+N}$ and
$$q_i = \frac{bD - (b+N-1)a_i + \sum_{j \neq i} a_j}{b(b+N)}$$
- cost shock
$$\Delta q_i = \frac{b+N-1}{b(b+N)} \Delta a_i + \frac{1}{b(b+N)} \sum_{i \neq j} \Delta a_j$$
- Because $E[\Delta q_i] = 0$ then,
$$E[\Delta q_i \Delta q_j] = -\sigma^2 \frac{2b+N}{b^2(b+N)^2}$$

Output Analysis

- So, the variance of each producer:

$$E[\Delta q_i^2] = \sigma^2 \frac{(b+N-1)^2 + (N-1)}{b^2(b+N)^2}$$

- Correlation between output adjustments of perfectly competitive producers

$$\rho_{perfectcomp} = \frac{E[\Delta q_i \Delta q_j]}{\sqrt{E[\Delta q_i^2]E[\Delta q_j^2]}} = -\frac{2b+N}{(b+N-1)^2 + (N-1)}$$

- $\rightarrow$ zero as N grows.

Output Analysis

- If cost shocks are normally distributed
- define: θ probability of "compensating" output adjustments
- In perfectly competitive case
- compensating output changes would occur only by chance and with a frequency of 50%

$$\begin{aligned}\theta &= Pr[\Delta q_i \Delta q_j < 0] \\ & Pr[(\Delta q_i < 0 \cap \Delta q_j > 0)] + Pr[(\Delta q_i > 0 \cap \Delta q_j < 0)] \\ & Pr[(\Delta q_i < 0)]Pr[(\Delta q_j > 0)] + Pr[(\Delta q_i > 0)]Pr[(\Delta q_j < 0)] \\ & = 1/2 \times 1/2 + 1/2 \times 1/2 = 1/2\end{aligned}$$

- No correlation among the individual reactions of perfectly competitive firms to idiosyncratic cost shocks
- If distributed normally, compensating output changes among perfectly competitive producers occurs 50%

Compensating Output Adjustments: Testable Hypotheses

- Theory:

$$\rho_{cartel} < \rho_{be} < \rho_{stackelberg} < \rho_{cournot} < \rho_{perfcomp} \approx 0\%$$

$$\theta_{cartel} > \theta_{be} > \theta_{stackelberg} > \theta_{cournot} > \theta_{perfcomp} \approx 50\%$$

- ρ_x:output correlation
- θ_x: probability of observing offsetting production changes among producers

- cartel: multi-plant monopoly; allocating output to equalize the marginal cost of each producer with marginal revenue of the cartel
- be: Bertrand-Edgeworth competition, rivals compete via pricing strategies that devolve in equilibrium to pricing at marginal cost

Compensating Output Adjustments: Testable Hypotheses

- stackelberg: dominant-firm variant of the Cournot hypothesis: one firm acts as the "leader" and sets its output in correct anticipation of the reaction of the "fringe"
- cournot: each producer takes the output of rivals as given, then equates its own marginal cost to perceived marginal revenue.
- perfcomp: The perfectly competitive benchmark, no firm is large enough to have a perceptible impact on market price, and all firms act as price takers.

Compensating Output Adjustments: Testable Hypotheses

- Smith (2004): collusive with transactions costs: “bureaucratic production syndicate”
- Difficulty in reaching consensus on proposed output
- $\Rightarrow$ change output allocations infrequently
- So, $\rho_{cartel} < \rho_{bureaucratic}$ and $\theta_{cartel} > \theta_{bureaucratic}$
- Compare to other market, depends on transaction costs
- Possible $\rho_{bureaucratic} > 0$ and $\theta_{bureaucratic} < 50\%$ for high costs
- bureaucratic syndicate is the only form of interdependent behavior reviewed here that could conceivably fall on the “other side” of the perfectly competitive benchmark

Testable Hypotheses

- H_1
  - OPEC members exhibit compensating production changes (measured vs. the rest of OPEC) no less frequently than non-OPEC (measured vs. the rest of non-OPEC output).
  - Rejection of H_1 would be inconsistent with the competitive, Cournot, Bertrand-Edgeworth, Stackelberg, and friction less-cartel hypotheses.
  - It would not be inconsistent with the bureaucratic syndicate hypothesis, but it would be indicative that transactions costs within OPEC are relatively high.

Testable Hypotheses

- H_2
  - OPEC members exhibit compensating production changes (measured vs. the rest of OPEC and vs. non-OPEC output) no less frequently since the formal quota system was adopted than before.
  - Rejection of H_2 would contradict the notion that introduction of the quota system has had no effect on the behavior of OPEC members
  - Rejection would indicate that the quota system has tended to increase transactions costs within the organization

Testable Hypotheses

- H_3
  - OPEC members exhibit compensating production changes measured vs. the rest of OPEC no less frequently than they do vs. the output of non-OPEC producers.
  - Rejection of H_3, would be inconsistent with the competitive hypothesis., but not necessarily inconsistent with the cartel or other, oligopolistic hypotheses.

Testable Hypotheses

- H_4
  - Saudi Arabia exhibits compensating production changes (vs. output from the rest of OPEC and from non-OPEC producers) no more frequently than do other OPEC members.
  - Rejection of H_4 would be inconsistent with the hypothesis that OPEC is an organization of equals always operating on a cooperative basis, and indicative of a special role (e.g., Stackelberg leader) played by the Saudis within OPEC.

Data

- Monthly crude oil production by EIA (January 1973 through December 2001)
- Deviate significantly from self-reported
- Divided into “pre-quota” and “quota” periods.
  - January 1973 through March 1982, OPEC assigned no formal production quotas
  - Instead a system of posted prices by various quality
  - Quota system initiated in April 1982 so on

Empirical Strategy

- Output changes are measured as follows

$$\Delta q_i^t = q_i^t - q_i^{t-1}$$

- Producer i is counted as having exhibited a compensating change vs. reference groups j in any period for which:

$$\Delta q_i^t \times \Delta q_j^t < 0$$

- The relative frequency of compensating production changes over the interval from T_1 to T_2 can then be represented as

$$f_{ij} = \sum_{t=T_1+1}^{T_2} I_{ij}^1 / (T_2 - T_1)$$

- where I_{ij}^1 is an indicator variable that equals 1 if $\Delta q_i^t \times \Delta q_j^t < 0$, and zero otherwise.

Empirical Strategy

- Look for systematic differences for different types of pairings
  - when the frequency of compensating changes among OPEC members is compared to that among non-members
  - when pre-quota OPEC behavior is compared to subsequent behavior.

$$ln\left[\frac{f_{ij}}{1-f_{ij}}\right] = \alpha + X_{ij}\beta + \varepsilon_{ij}$$

- X_{ij} variables that identify the type of pairing (producer, reference group, quota, etc.)
- β are parameters that represent the hypothesized differences

Frequency of Compensating Production Changes

- Indonesia's monthly production changes offset the change in the rest of OPEC 35.5% of the time prior to the implementation of OPEC's quota system, but only 27.0% of the time thereafter.

	*vs. Rest of OPEC**			*vs. non-OPEC**		
Country	*pre-quota*	*quota*	*overall*	*pre-quota*	*quota*	*overall*
Algeria	17.3%	16.0%	16.7%	19.1%	15.6%	17.4%
Indonesia	35.5%	27.0%	31.3%	47.3%	31.2%	39.3%
Iran	33.6%	37.1%	35.4%	39.1%	38.0%	38.6%
Iraq	35.5%	31.6%	33.6%	30.9%	36.7%	33.8%
Kuwait	36.4%	33.3%	34.9%	42.7%	41.4%	42.1%
Libya	40.0%	17.3%	28.7%	49.1%	18.1%	33.6%
Nigeria	41.8%	35.9%	38.9%	49.1%	41.8%	45.5%
Qatar	42.7%	26.6%	34.7%	44.5%	32.5%	38.5%
UAE	44.5%	27.8%	36.2%	50.9%	36.3%	43.6%
Venezuela	46.4%	28.7%	37.6%	50.9%	28.7%	39.8%
Saudi Arabia	33.6%	37.1%	35.4%	36.4%	43.9%	40.2%
OPEC average	37.0%	28.9%	33.0%	41.8%	33.1%	37.5%

Frequency of Compensating Prod. Changes (Quarterly)

	vs. Rest of OPEC*			vs. non-OPEC*		
Country	*pre-quota*	*quota*	*overall*	*pre-quota*	*quota*	*overall*
Algeria	25.0%	21.5%	23.3%	50.0%	30.4%	40.2%
Indonesia	41.7%	38.0%	39.9%	47.2%	48.1%	47.7%
Iran	33.3%	35.4%	34.4%	55.6%	39.2%	47.4%
Iraq	33.3%	34.2%	33.8%	38.9%	22.8%	30.9%
Kuwait	22.2%	35.4%	28.8%	55.6%	40.5%	48.1%
Libya	36.1%	22.8%	29.5%	58.3%	35.4%	46.9%
Nigeria	38.9%	36.7%	37.8%	47.2%	41.8%	44.5%
Qatar	38.9%	32.9%	35.9%	55.6%	34.2%	44.9%
UAE	22.2%	32.9%	27.6%	50.0%	43.0%	46.5%
Venezuela	41.7%	36.7%	39.2%	58.3%	35.4%	46.9%
Saudi Arabia	33.3%	35.4%	34.4%	41.7%	43.0%	42.4%
OPEC average	33.3%	32.9%	33.1%	50.8%	37.6%	44.2%
Canada				63.9%	55.7%	59.8%
Mexico				33.3%	48.1%	40.7%
Norway				47.2%	39.2%	43.2%
Russia				19.4%	39.2%	29.3%
UK				61.1%	38.0%	49.6%

Estimation Results

- For non-OPEC producers: competitive producers exhibit compensating production changes roughly 50% of the time
- Changes occurred by chance.
- To determine whether behavior of OPEC members deviates significantly from that of non-OPEC (i.e., competitive) producers: logistic regressions
- To capture all of the hypothesis $(H_1 - H_4)$ two versions of the model are estimated

Estimation Results

- Explanatory variables
  - OPEC =1 if producer if OPEC member
  - Quota = I if after March 1982 and producer is OPEC member
  - Saudi = 1 if producer is Saudi Arabia,
  - ν NOPEC = 1 if comparison is to non-OPEC production
  - Core = I if producer is Kuwait, Saudi Arabia, or UAE,

Estimated Logistic Equations

				A. Monthly Observations				
Model/Sample	*constant*	*OPEC*	*Quota*	*Saudi*	*Core*[3]	*v NOPEC*	R^2	*N*
Model 1a: Like vs. Like[1]	-0.156	-0.402	-0.041				0.50	34
	(1.80)	(2.75)	(1.96)					
Model 2a: OPEC vs. All[2]	-0.528		-0.364	0.221		0.205	0.31	44
	(4.66)		(3.07)	(1.18)		(1.82)		
Model 3a: OPEC vs. All[2]	-0.571		-0.365		0.227	0.203	0.34	44
	(5.01)		(3.16)		(1.89)	(1.85)		
				B. Quarterly Observations				
Model/Sample	*constant*	*OPEC*	*Quota*	*Saudi*	*Core*[3]	*v NOPEC*	R^2	*N*
Model 1b: Like vs. Like[1]	-0.148	-0.551	0.003				0.35	34
	(1.50)	(3.29)	(0.07)					
Model 2b: OPEC vs. All[2]	-0.498		-0.288	0.049		0.366	0.45	44
	(5.17)		(2.90)	(0.31)		(3.96)		
Model 3b: OPEC vs. All[2]	-0.504		-0.289		0.042	0.365	0.45	44
	(5.11)		(2.91)		(0.41)	(3.95)		

Results

- OPEC members exhibit compensating behavior vs. the rest of OPEC 33.0% of the time
- non-OPEC members exhibit compensating behavior vs. non-OPEC output more frequently, 45.8% of the time.
- $\Rightarrow$ OPEC members have exhibited significantly less compensating behavior than their non-OPEC counterparts have.
- $\Rightarrow$ a strong rejection of H_1
- which implies also a strong rejection of the competitive, Cournot, Stackelberg, Bertrand-Edgeworth, and frictionless cartel models of OPEC behavior in favor of the bureaucratic-syndicate hypothesis.

Results

- Also test of the impact of the quota system (hypothesis H_2).
- Because the quotas do not bind output of non-OPEC producers, the “Quota” variable is introduced as an interaction effect that applies only to OPEC members and only after the quota was introduced.
- Estimated coefficient is significantly less than zero
- meaning that compensating behavior among OPEC producers occurred less frequently after March 1982.
- In contrast, compensating behavior among the control group of non-OPEC producers hardly varies between periods
- So, quota system rather than changes in the broader market that tended to suppress compensating production changes within OPEC
- H_2 would be rejected.

Results

- The quarterly data different results about the quota.
- Quota system no effect on the frequency with which OPEC members offset variations from the rest of OPEC.
- How to resolve the conflict between monthly and quarterly results?
- It may be that the quarterly data are freer of reporting errors and provide a more accurate picture
- May be not

Results

- Second model for a test of H_3
- Hypothesis: OPEC producers offset (internal) changes in the output of the rest of OPEC no less frequently than they offset (external) changes in non-OPEC production.
- Significant positive coefficients associated with the variable "ν NOPEC" in Models 2
- H_3 is strongly rejected
- OPEC producers are much more likely to offset output changes that originate outside the group than those that come from within
- Inconsistent with competitive hypothesis, but consistent with cartel that incurs relatively high transaction costs whenever market shares shift.

Results

- Second model AND impact of quota system
- OPEC producers became significantly less likely to offset production changes (whether emanating from within or without) after quotas were introduced.
- highly significant negative coefficients on the “Quota”
- Note: Iraq, which has been exempt from the quota system since July 1998.
- Before becoming exempt, Iraq exhibited compensating changes relative to the rest of OPEC 30.8% of the time,
- Since exemption this has risen to 50% (like non-OPEC producers)

Results

- Results: quota system increased transaction costs
- Raw data: Saudi Arabia played a special role within OPEC, contrary to hypothesis H_4
- Unlike the rest of OPEC, Saudis actually increased frequency of compensating production changes after quotas
- In model: coefficient not significantly different from zero
- Data are inconclusive on Saudi leadership

Table of Content

Matsen, Torvik "Optimal Dutch Disease" J. Econ. Dev. (2005), Allcott, Keniston "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America" ReStud (2017)

Asker, Collard-Wexler, De Loecker "(Mis) Allocation, Market Power and Global Oil Extraction" (2018). Smith "Inscrutable OPEC? Behavioral tests of the cartel hypothesis." Energy Journal, (2005)

Baumeister,Kilian. "Forty years of oil price fluctuations: Why the price of oil may still surprise us." Journal of Economic Perspectives, (2016), Kilian "Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market." AER,(2006), Baumeister, Kilian. Forecasting the real price of oil in a changing world: A forecast combination approach. 2013

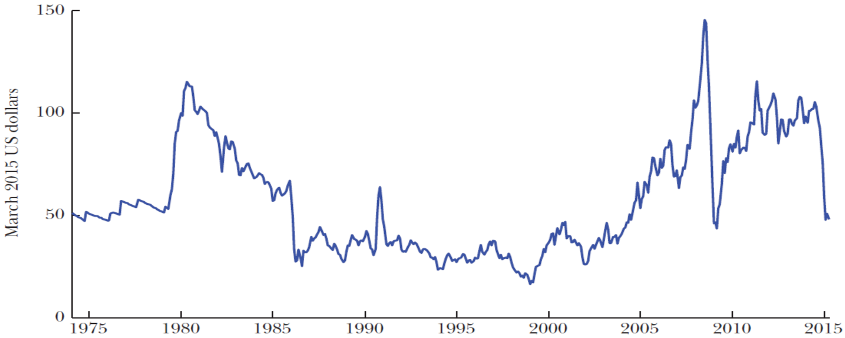
Introduction

- Baumeister,Kilian. "Forty years of oil price fluctuations: Why the price of oil may still surprise us." Journal of Economic Perspectives, (2016),
- Oil crisis in 1973/74 when the price of imported oil nearly quadrupled over the course of a quarter
- Some governments in industrialized countries responded by imposing ceilings on oil and gasoline price
- Causing gasoline shortages and long lines at gas stations
- Many governments introduced speed limits, banned automobile traffic on Sundays, or limited retail gasoline purchases
- Pictures of long lines at gas stations and empty highways

Introduction

- Before 1970s, oil prices were regulated by US and occasionally adjusted
- In crisis rose from $4.31 per barrel in September 1973 to $10.11 in January 1974.
- So, there was a structural break in the time series process
- Potential determinants of oil price fluctuations
    1. shocks to global crude oil production arising from political events in oil-producing countries, the discovery of new fields, and improvements in the technology of extracting crude oil;
    2. shocks to the demand for crude oil associated with unexpected changes in the global business cycle
    3. shocks to the demand for above-ground oil inventories, reflecting shifts in expectations about future shortfalls of supply relative to demand in the global oil market.

Inflation-Adjusted WTI Price of Crude Oil, 1974.1–2015.3



The 1973/74 Oil Crisis

- October 6 and 26, 1973 war between Israel, Egypt, and Syria.
- Arab OPEC countries cut their oil production by 5 % starting on October 16, while raising the posted price of their oil, followed by the announcement of an additional 25 % production cut on November 5, ten days after war ended.
- Last to March 1974. Hamilton (2003): was due to war
- Barsky and Kilian (2002)
  - before 1973, fixed price because of 5-year 1971 Tehran/Tripoli agreements b/w oil companies and oil countries.
  - in exchange oil companies to extract as much oil as they want
  - boom global oil demand in 1972–73, no spare capacity
  - and depreciating US dollar and rising US inflation ⇒ agreement unfair
  - Arab opposition to Tehran/Tripoli agreements
  - Repudiation of agreements on October 10, 1973

The 1979/80 Oil Crises

- Rose from less than \$15 in Sept. 1978 to \$40 in April 1980
- Hamilton (2003): reduction in Iranian oil production
- Barsky, Kilian (2002): timing inconsistent with this.
  - Revolution started gradually in late 1978
  - Biggest Iranian production shortfalls occurred in January & February 1979
  - Iranian oil production started recovering in March.
  - Saudi Arabia substitute production, shortfall of OPEC oil output in January 1979 was 8 % relative to September 1978
  - By April, the shortfall of OPEC output was zero%
  - Price not increase substantially before May 1979
  - Even in April 1979, WTI was under \$16
  - \$40 per barrel in April 1980
- It was anticipation, evidence: rising inventory demand starting in May 1979

The 1980s and 1990s

- Iraq invaded Iran, $36 in Sept. to $38 Jan. 1981
- Paul Volcker's decision to raise US interest rates, global recession, systematic price decline
- High oil price, Mexico, Norway, UK invest on oil production and become exporter
- OPEC share:1973: 53% ,1980: 43%,1985: 28%
- Early 1980s,OPEC agreements to set price:
  - restrict production to prop up price
  - members cheat
  - Saudi Arabia decided to stabilize price by reducing its production
  - did not succeed
  - Saudi losses so large that forced him to reverse its policy in late 1985
  - Sharp fall in the price of oil in 1986

The 1980s and 1990s

- Iraq invade Kuwait and disrupt production in 1990
- demand for oil inventories in anticipation of a possible attack on Saudi oil fields
- when US troops in Saudi, then price of oil dropped sharply
- Asian financial crisis of mid-1997, then Russia, Brazil, Argentina
- in 1990s,very low price, in Dec. 1998: $11
- price recovery in 1999, because of recovery from recession.
- followed by civil unrest in Venezuela
- was in Itaq led by US, but little inventory demand because less treat to Saudi from missile
- price only add $6

Great Surge of 2003-08 to the Global Financial Crisis

- mid-2003: $28 , mid-2008:$134
- by a series of individually small increases in the demand
- strong additional demand for oil from emerging Asia
- no evidence of increased inventory demand
- financial crisis of 2008: June 2008: $134, Feb. 2009:$39
- 2009: global financial system was not imminent: $100
- Libyan uprising in 2011:about $3 to $ 13
- Green movement in Iran 2012: about $0 to $ 9
- 2011: widening of spread b/w WTI and Brent because of Shale oil
- so world index shift to Brent
- again: June 2014: $112, Jan.2015: $ 47
- because of high new production in US, Canada, Russia and weakening economy

Introduction

- Kilian "Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market." AER,(2006)
- Common approach: evaluate aggregate variables to exogenous changes in oil prices.
- Problems invalidate ceteris paribus assumption
  - reverse causality from macro aggregates to oil prices
  - the price of oil is driven by distinct demand and supply shocks.
  - they have distinct effect on economy.
- Solution: structural VAR model
- Structural decomposition of the real price of crude oil
  1. crude oil supply shocks
  2. shocks to the global demand for all industrial commodities
  3. demand shocks that are specific to the global crude oil market (idea:precautionary demand, availability of future oil supplies)

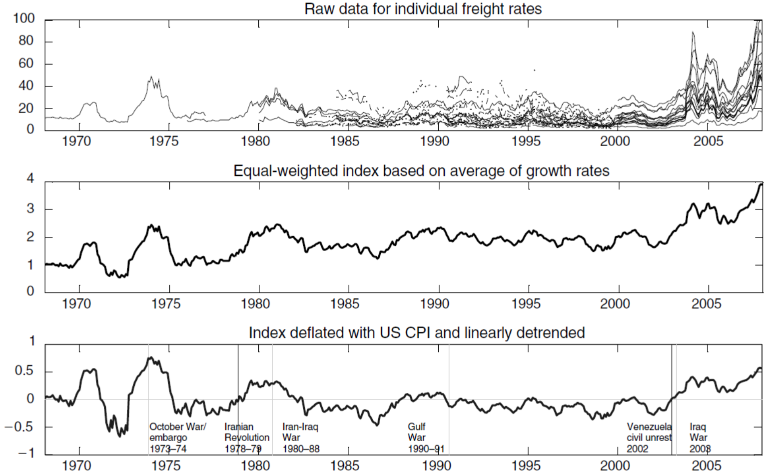
Introduction

- Results: price driven mainly demand and precautionary demand (not supply shocks)
- Difficulty in demand shock: no readily available indices that capture shifts in the demand for industrial commodities driven by the global business cycle
- Unobserved shifts in expectations
- Idea: control for oil supply shocks, then a measure driven demand for all industries
- Let structural method identify the rest, which is shock solely to oil market
-

A Monthly Measure of Global Real Economic Activity

- freight rates as indicators of strong cumulative global demand pressures
- Single-voyage freight rates available in the monthly report on "Shipping Statistics and Economics"
- Two drawback:
  - ship-building and scrapping cycle may weaken the link between real economic activity and the freight rate index
  - dry cargo freight rates may increase during oil price shocks because fuel more expensive
  - In the econometric analysis,feedback from crude oil prices to shipping freight rates is considered

Monthly Index of Dry Cargo Bulk Freight Rates



Decomposing the Real Price of Oil

- Price of oil is endogenous
- Decompose unpredictable changes in the real price of oil into mutually orthogonal components with a structural economic interpretation.
- VAR model, monthly data, $z_t = (\Delta prod_t, rea_t, rpo_t)'$
- $\Delta prod_t$ percent change in global crude oil production, rea_t denotes real economic activity,rpo_t real price of oil (prices in log)

$$A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t$$

- ε_t denotes the vector of serially and mutually uncorrelated structural innovations

Decomposing the Real Price of Oil

- A_0^{-1} has a recursive structure such that the reduced-form errors et can be decomposed according to et $e_t = A_0^{-1}\varepsilon_t$

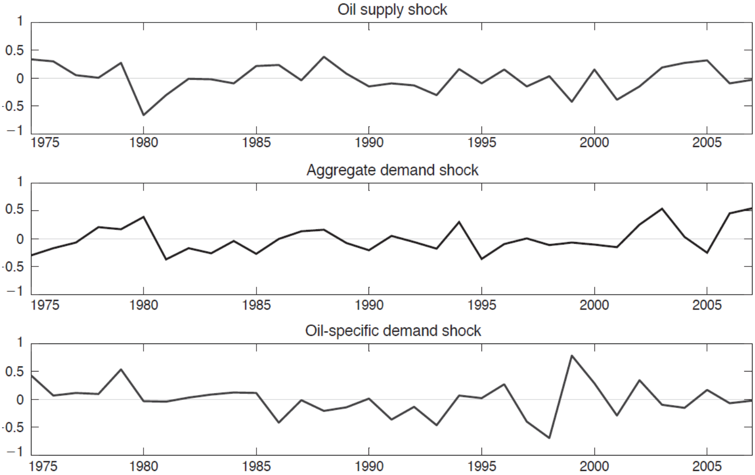
$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \end{pmatrix}$$

- Exclusion restriction: Crude oil supply not to respond to innovations to the demand for oil within the same month.
- Oil-producing countries, slow in response (bureaucratic+adjustment cost)
- The latter structural shock will reflect, in particular, fluctuations in precautionary demand for oil driven by uncertainty about future oil supply shortfalls

Empirical Results

- Steps:
  - Reduced-form VAR model is estimated by OLS
  - Resulting estimates used to construct the structural VAR representation
  - Inference is based on a recursive-design wild bootstrap with 2,000 replications
- Despite Iranian Revolution no disruption in oil supply in 1978-79
- 1980 large supply shock by Iran-Iraq war
- 1980 large unanticipated oil-specific demand: (Iranian Revolution, the Iranian hostage crisis, and the Soviet invasion of Afghanistan)

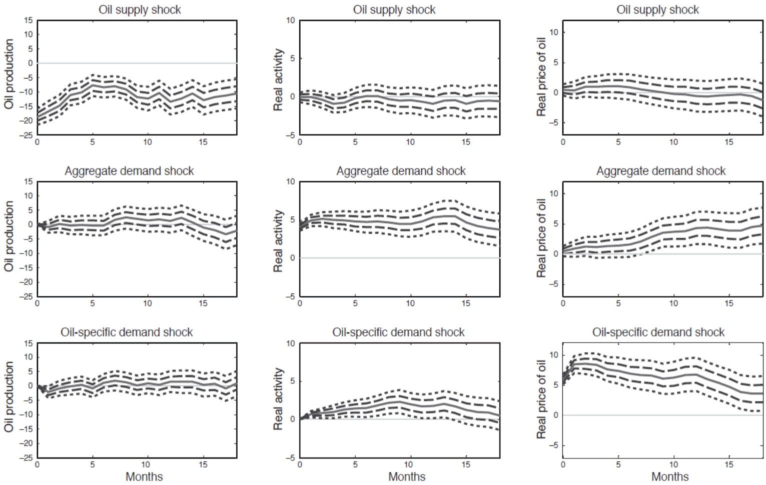
Historical Evolution of the Structural Shocks



Empirical Results

- Response to one-standard deviation structural innovations.
  - oil supply contractions tend to trigger production increases with one year lag.
  - Supply shock: statistically significant, small & transitory increase in real price of oil for about eight months
  - The effect of innovation in global real economic activity is very persistent and highly significant.
  - It increases global oil production with a delay of half a year.
  - It causes a large, persistent, and statistically significant increase in the real price of oil
  - Unanticipated oil market–specific demand increases have an immediate, large, and persistent positive effect on real price of oil
  - Oil market–specific demand increases do not cause an increase in global oil production.

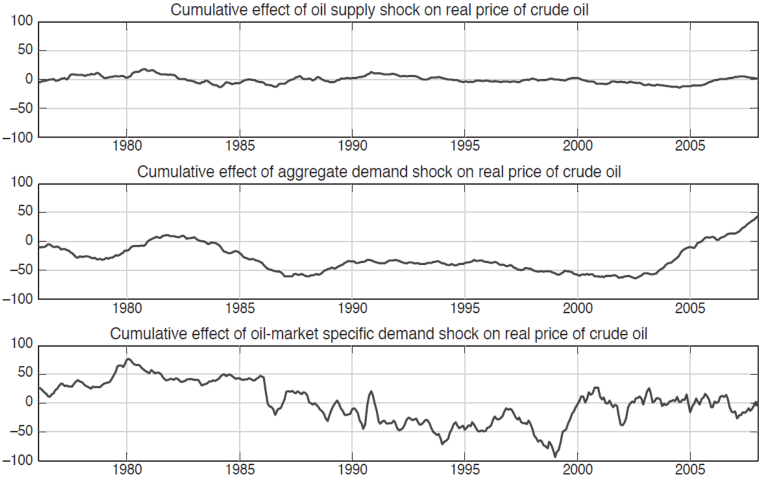
Responses to One-Standard Deviation Structural Shock



Empirical Results

- Simulation based on historical decomposition of the data
- The biggest contributions are due to the aggregate demand shock (cause long swing) and the oil market–specific demand shock (cause sharp changes)
- Oil supply shocks served only to amplify some of the short-run dynamics of the real price of oil, sometimes raising the price of oil and sometimes lowering it.
- For periods:
  - 1797 rise due to expectation, and increase in demand
  - price fall 1985 due to market-specific demand not Saudi increase in production
  - spike in 1991 purely specific-demand due to invasion of Kuwait
  - fall in precautionary demand in 1997
  - increase 2002-07 entirely due to demand

Historical Decomposition of Real Price of Oil



Understanding the Effects of Oil Price Disturbances on the US Economy

- How the structural innovations ε relate to US macroeconomic aggregates such as CPI inflation (π_t) or real GDP growth (y_t)
- This data is monthly, so define $\hat{\zeta}_{jt} = \frac{1}{3}\sum_{i=1}^{3}\hat{\varepsilon}_{j,t,i}\; j = 1,2,3$

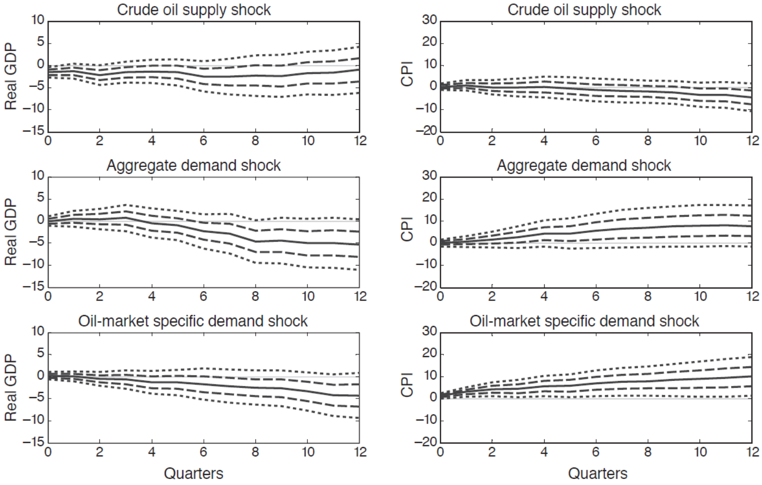
$$
\begin{aligned}
\Delta y_t &= \alpha_j + \sum_{i=0}^{12}\phi_{ji}\hat{\zeta}_{jt-i} + u_{jt}\; j = 1,2,3 \\
\pi_t &= \delta_j + \sum_{i=0}^{12}\psi_{ji}\hat{\zeta}_{jt-i} + \nu_{jt}\; j = 1,2,3
\end{aligned}
$$

- ν_{jt}, u_{jt} serially correlated errors
- This is not necessary causality.
- Just study separately the effect of supply and demand.

Empirical Results

- Impact on US:
  - unanticipated oil supply disruptions significantly lower real GDP.
  - consumer price level is largely flat and mostly statistically insignificant
  - unanticipated aggregate demand expansion causes a statistically insignificant increase in real GDP in the first year, followed by a decline below the initial level in the second year
  - In the third year, the response remains negative and becomes statistically significant.
  - The corresponding effect on the price level shows a sustained increase that reaches its maximum in the third year
  - Unanticipated oil market–specific demand increases result in a gradual reduction in real GDP that reaches its maximum after three years

Historical Decomposition of Real Price of Oil



Introduction

- Baumeister, Kilian. Forecasting the real price of oil in a changing world: A forecast combination approach, 2013
- Long-term oil contracts were abandoned around 1980
- Need to forecast the price of crude oil
- U.S. Energy Information Administration (EIA) forecast judgmentally monthly and quarterly
- Davies 2007, Hamilton 2009: current price of oil as best forecast of future oil prices
    1. vector autoregressive (VAR) models
    2. based on price index of non-oil industrial raw materials
    3. based on West Texas Intermediate (WTI) oil futures prices
    4. no-change forecast
    5. based on spread of U.S. spot price of gasoline relative to WTI
    6. a time-varying parameter forecasting model of gasoline spot spread, heating oil spot spread

VAR Model of the Global Oil Market

- Reduced-form representation of structural global oil market model (Kilian and Murphy (2014))
- Dependent variable $y_t = [\Delta prod_t, rea_t, r_t^{oil}, \Delta inv_t]'$ (last one: change in global crude oil inventories)

$$B(L)y_t = \nu + u_t$$

- Empirical success of VAR forecasting: from measures of global real economic activity
- Capture fluctuations in the demand for industrial commodities
- Level oil price: $\hat{R}^{oil}_{t+h|t} = exp(\hat{r}^{oil,VAR}_{t+h|t})$
- VAR model best during times of persistent and predictable fluctuations in economic fundamentals

Forecast by Price of Non-Oil Industrial Raw Materials

- Predictable shifts in the demand for globally traded commodities:changes in non-oil industrial commodity price indices (Baumeister and Kilian (2012))

$$R^{oil}_{t+h|t} = R^{oil}_{t}(1 + \pi_t^{h,industrial\ raw\ materials} - E_t(\pi^h_{t+h}))$$

- $\pi_t^{h,industrial\ raw\ materials}$ percent change of an index of the spot price of industrial raw materials over the preceding h months.
- $E_t(\pi^h_{t+h})$ expected inflation rate over the next h periods

Forecast based on Oil Futures Prices

- Use future prices to forecast:

$$R^{oil}_{t+h|t} = R^{oil}_t(1 + f^h_t - s_t - E_t(\pi^h_{t+h}))$$

- f^h_t log of current WTI oil futures price for maturity h, s_t is corresponding WTI spot price,
- not significantly more accurate than no-change
- No data/trade of future in long horizon

Spread between Spot Prices of Gasoline and Crude Oil

- Rising spread between price of gasoline (s_t^{gas}) and price of crude oil signals upward pressures on price of crude oil: Baumeister et al. (2013)

$$\hat{R}_{t+h|t}^{oil} = R_t^{oil} exp\{\hat{\beta}[s_t^{gas} - s_t] - E_t(\pi_{t+h}^h)\}$$

- $be\hat{t}a$ from $\Delta S_{t+h|t} = \beta[s_t^{gas} - s_t] + \varepsilon_{t+h}$
- Notice with no intercept improve out-of-sample prediction
- Greatly improves on accuracy of no-change forecast especially at horizons beyond one year

Time-Varying Parameter Model of the Gasoline and Heating Oil Spreads

- Generalization of 5 to overcome unrelated shocks, add heating oil
- Recursively estimate this:

$$\Delta S_{t+h|t} = \beta_{1t}[s_t^{gas} - s_t] + \beta_{2t}[s_t^{heat} - s_t] + \varepsilon_{t+h}$$

- Postulate $\varepsilon_{t+h} \sim NID(0, \sigma^2)$ and $\theta_t = [\beta_{1t} \;\; \beta_{2t}]$ with random walk $\theta_t = \theta_{t-1} + \zeta_t$ and ζ_t independent Gaussian white noise with variance Q

$$\hat{R}^{oil}_{t+h|t} = R_t^{oil} exp\{\hat{\beta}_{1t}[s_t^{gas} - s_t] + \hat{\beta}_{2t}[s_t^{heat} - s_t] - E_t(\pi^h_{t+h})\}$$

- Work better than no-change in long horizon