(Mis)Allocation, Market Power, and Global Oil Extraction

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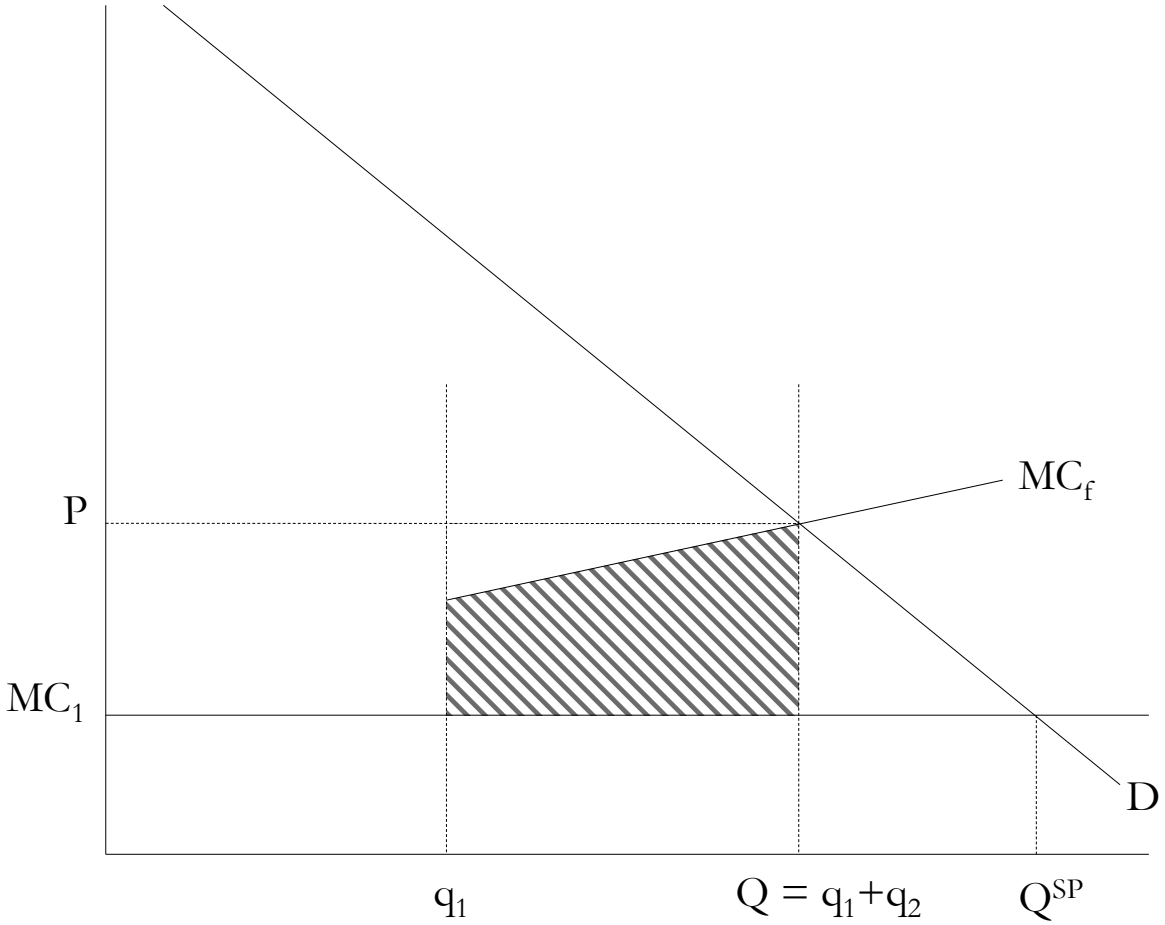
Motivation

- 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 IO: comparatively little focus on resource misallocation resulting from market power (esp. from cartels).
  - Revisit aggregate implications of market power in context of misallocation literature.
    - Harberger 1954: "When we are interested in the big picture of our manufacturing economy, we need not apologize for treating it as competitive, for in fact it is awfully close to being so. On the other hand, when we are interested in the doings of particular industries, it may often be wise to take monopoly elements into account.?
  - The influence of OPEC on the world market for oil.

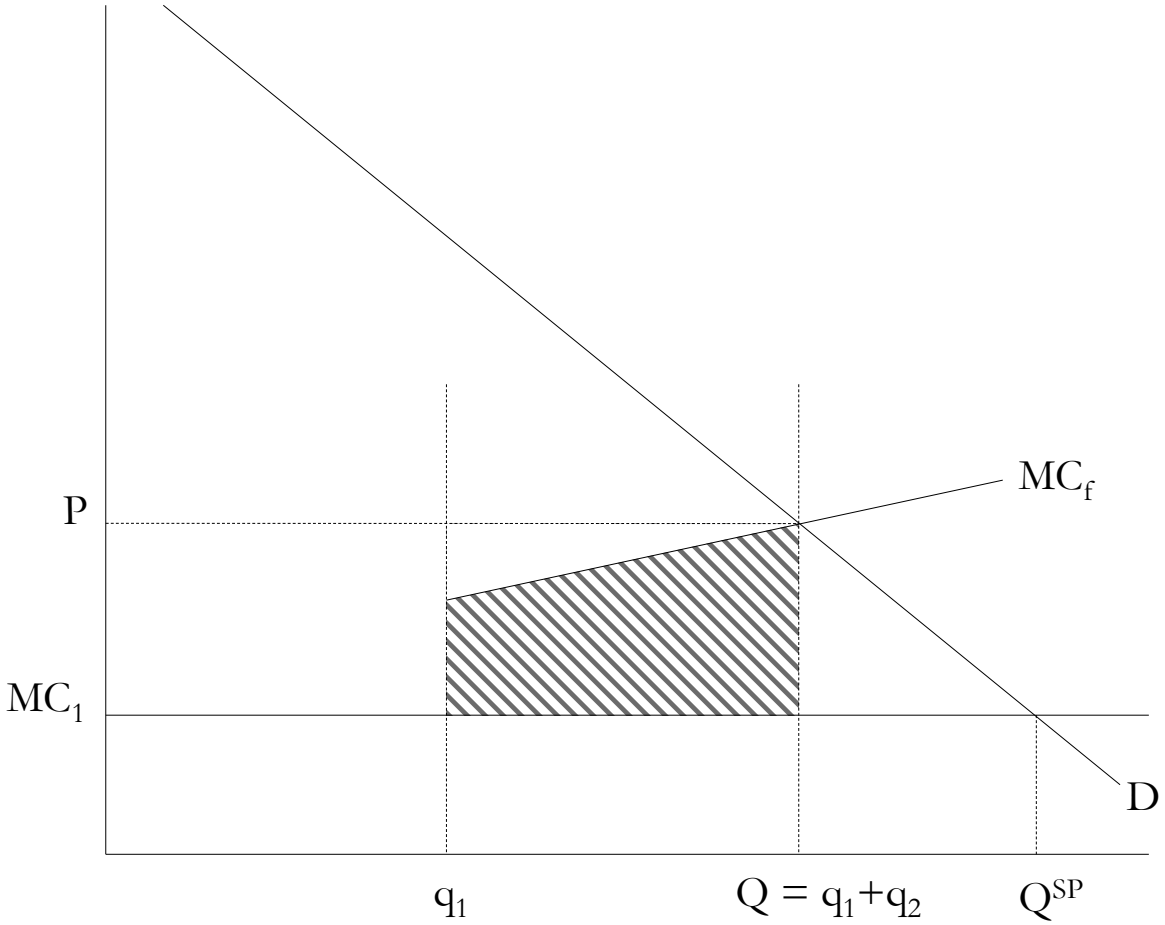
Production Distortion: main approach



Literature

- Borenstein, Bushnell and Wolak 1999 AER.
- Misallocation (Harberger 1954, Harberger 1959, Hsieh and Klenow, 2009 QJE, Asker, Collard-Wexler and De Loecker, JPE 2014, + many others).
- Oil Markets
  - Micro: Kellogg 2014 AER, Covert 2017 WP, Anderson, Kellogg, Salant, 2017 JPE.
  - Macro: Lutz 2009 AER
- OPEC: Cremer and Weitzman 1976 EER, Cremer, Salehi-Isfahani 1991.
- Cartels: Marshall and Marx 2012, Asker AER 2010, Schmitz 2015 WP.

Production Distortion: main approach



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*.

Main Findings

- Costs of oil production are 10 percent higher due to the OPEC cartel: a 163 billion dollar welfare loss over a 45 year period.

Map of Talk

- **Oil and OPEC**
- Data
- Model
- Empirical Analysis
- Conclusion

Background on Oil

- Geology and location have a big impact on costs of extraction
- Exogenous cost variation across production units unrelated to management skill:
  - Technology: onshore, offshore, shale, etc.
  - Location (geology): bedrock structure, climate, etc.
- A little clearer than in most markets what productivity (equiv. cost) is...
- Examples:

West Texas

Aasgard Norway

OPEC Cartel

- OPEC is Algeria, Angola, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, UAE, and Venezuela.
- OPEC is an imperfect cartel

Main Oil Producers

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%

Notes: Global production from 1970-2014 was 1,156 billion barrels. Collectively these 14 countries account for 85.4% of global production.

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Data

- Rich Data on oil from Rystad Energy, a Norwegian Energy Consultancy. One of the main data suppliers in the industry (IHS, Wood Gundy).
- Field Level Information: Gulfaks South versus Ghawar Uthmamiyah.
- Data on 66K oil fields, of which 19K produce crude oil, of which 13K have reserve data.
- Information on production, costs, reserves, technology, location.

Summary Statistics

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

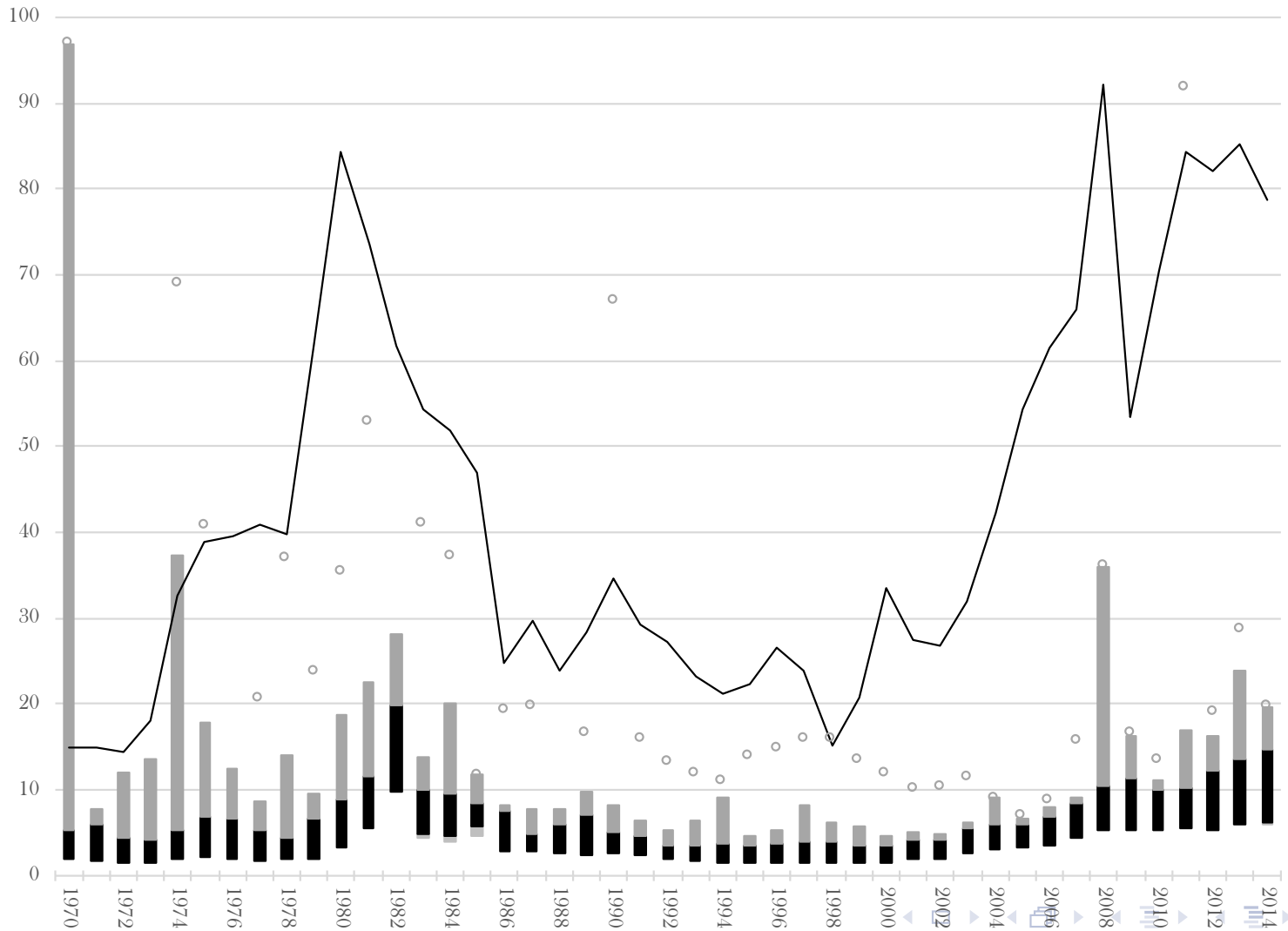
Reserves, 2014

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

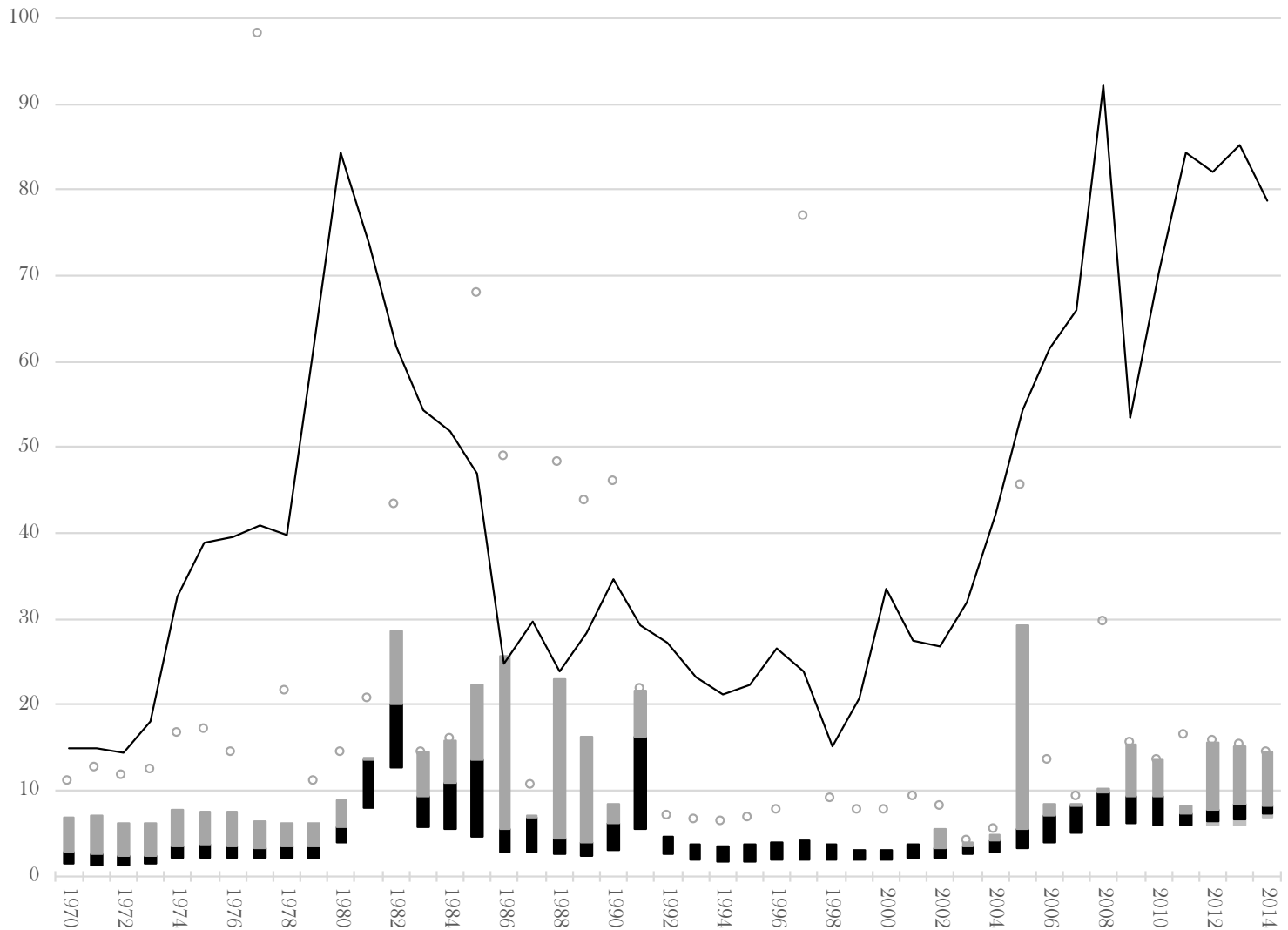
- Reserves are measured as the unextracted, but recoverable, quantity of oil remaining in the ground in a field.
  1. Descriptive stats: P50 value at an oil price of $70
  2. Counterfactual (1970 onward) sum of: i) the actual production history from 1970 to 2014, and ii) the P50 value at an oil price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

Cost Changes over time: Saudi Arabia

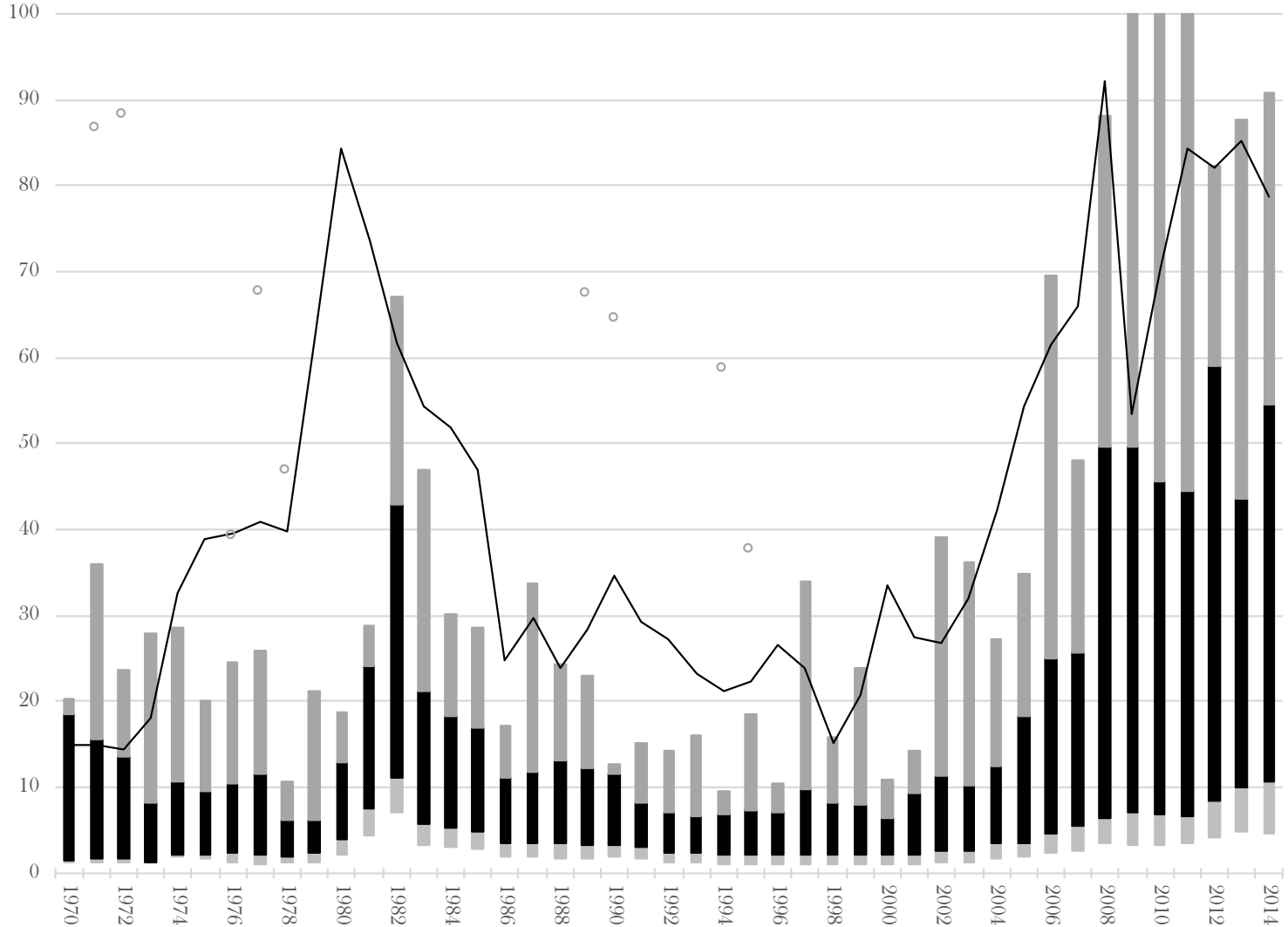
black: 95%, grey: 99% and circle: max.



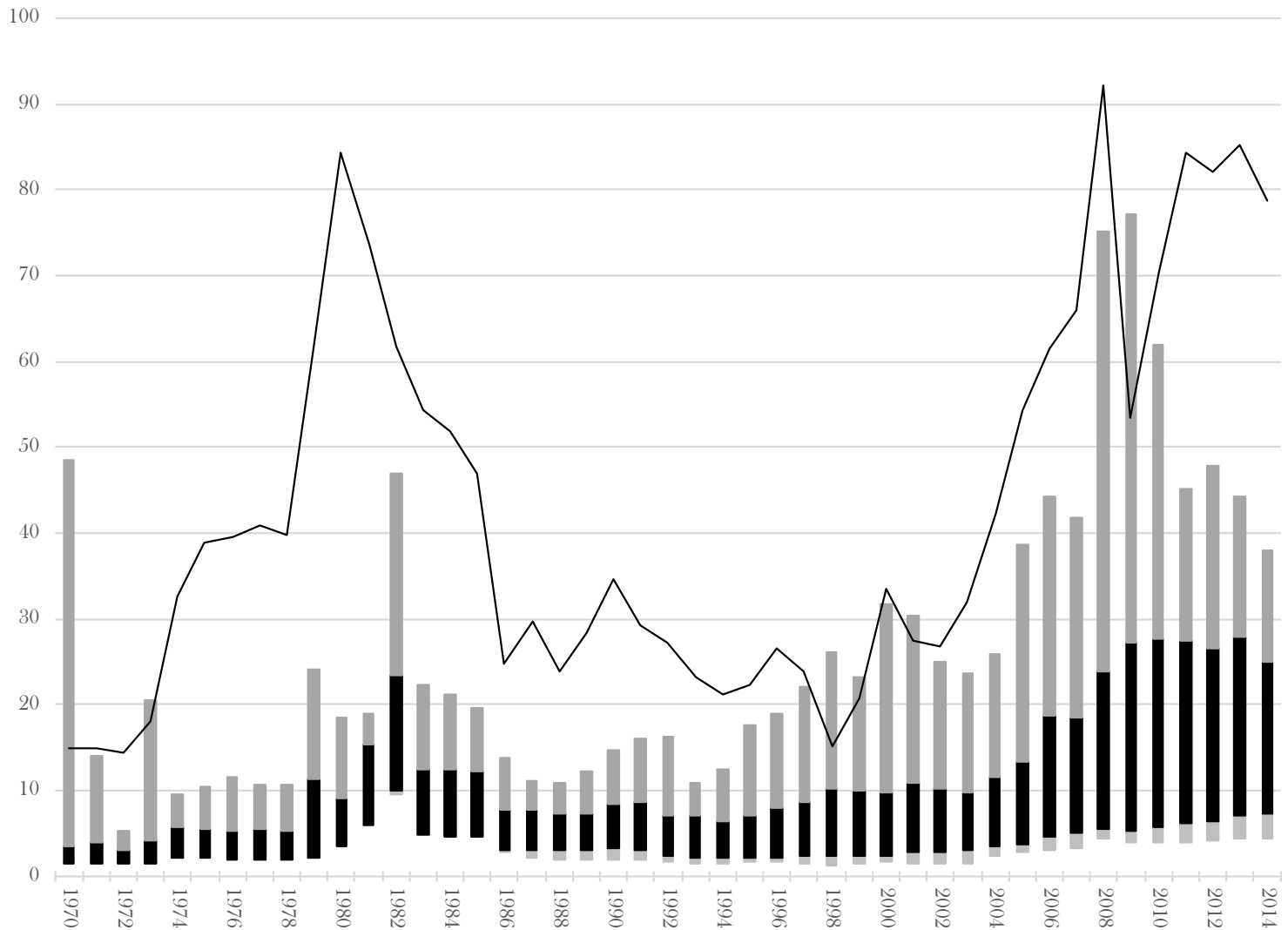
Cost Changes over time: Kuwait



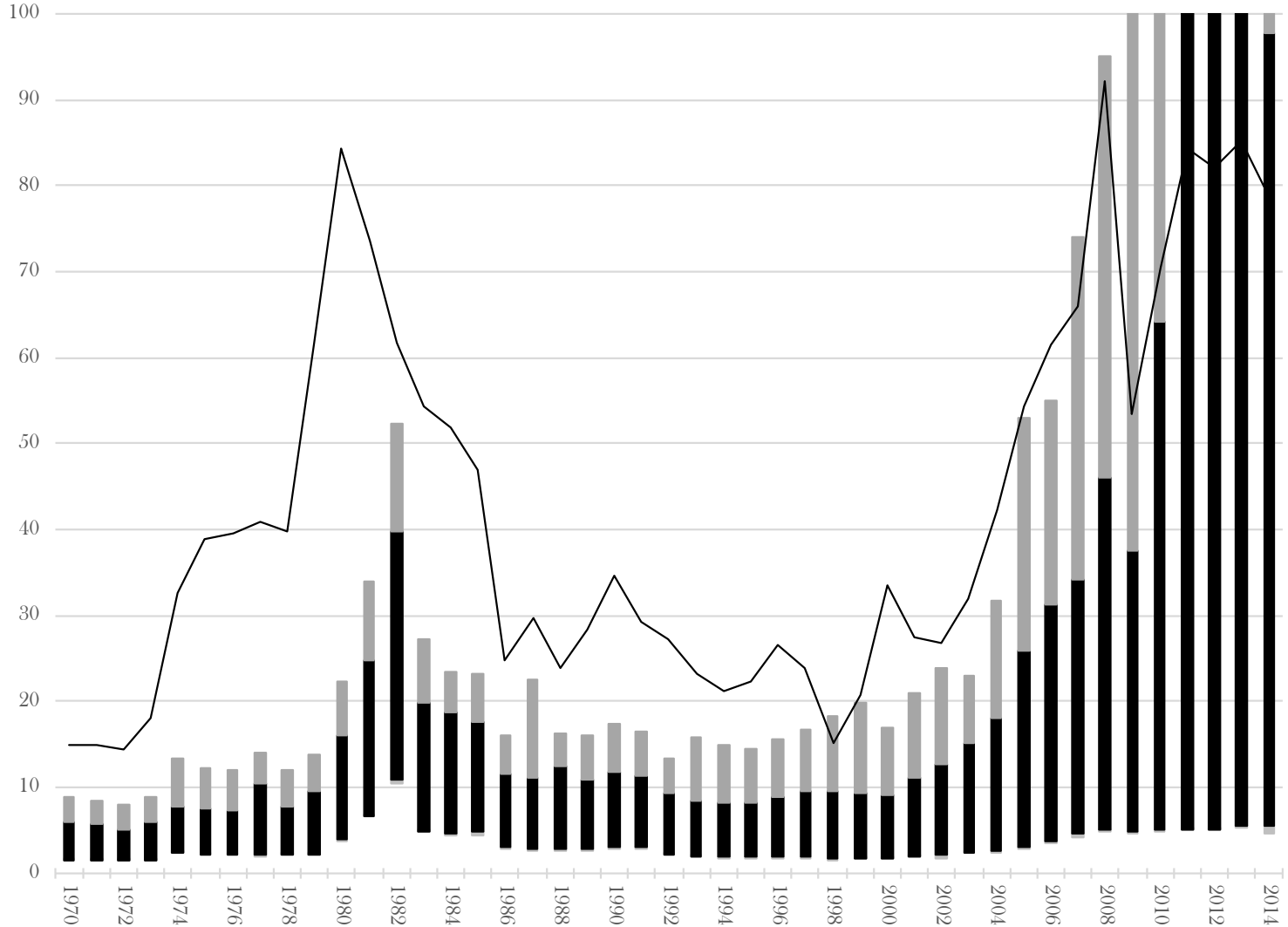
Cost Changes over time: Nigeria



Cost Changes over time: Russia



Cost Changes over time: United States



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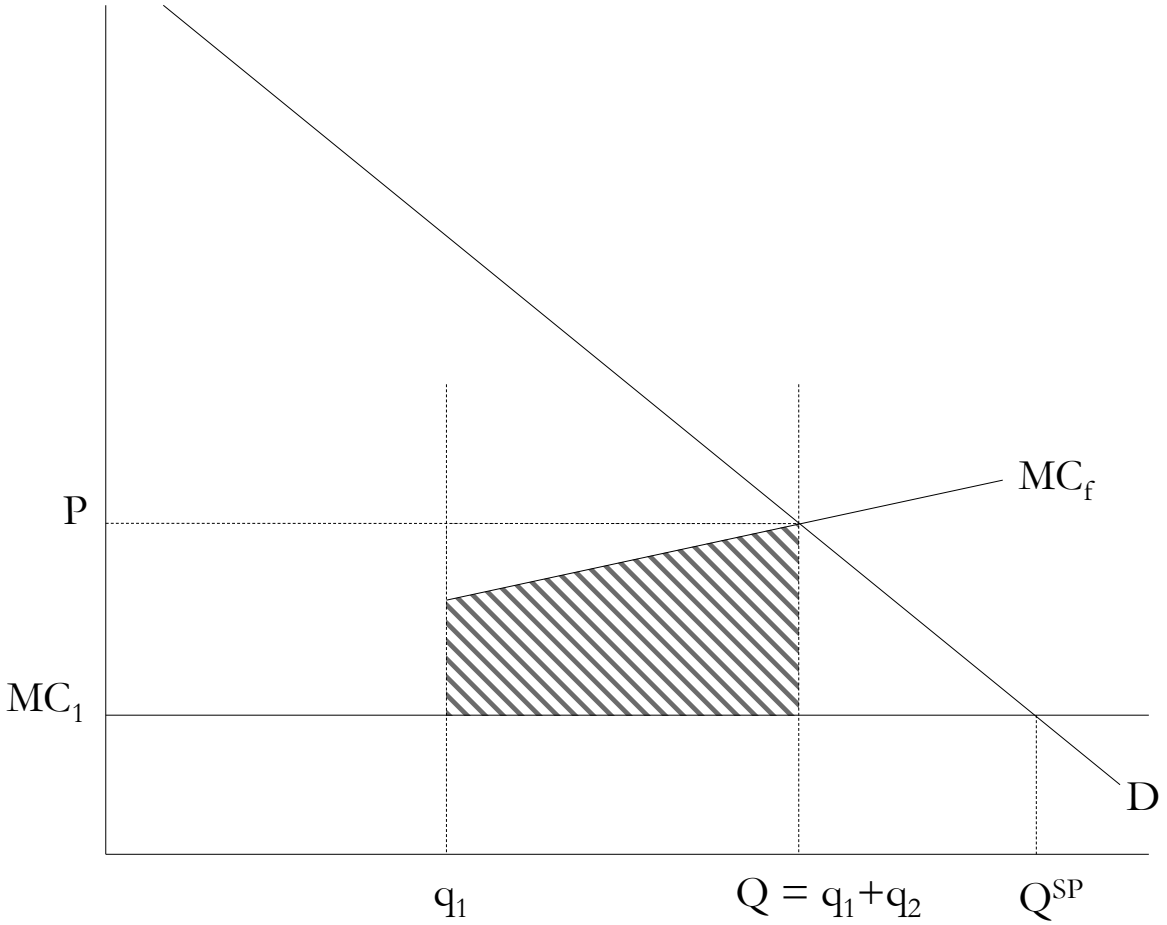
Production Distortion



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.

Assumptions on costs

- Leontief Production Function:

$$q_{ft} = \min\left\{\gamma_{ft} L_{ft}, \alpha_{ft} K_{ft}\right\} \tag{1}$$

- Input Prices (w_{ft}, r_{ft}) evolve over time: $r_{ft} = \mu_{st} r$ and $w_{ft} = \mu_{st} w$.

- This yields the cost function

$$\begin{aligned} C\left(q_{ft}\right) &= \left(\frac{w_{ft}}{\gamma_f} + \frac{r_{ft}}{\alpha_f}\right) q_{ft} \\ &= \underbrace{\left(\frac{w}{\gamma_f} + \frac{r}{\alpha_f}\right)}_{c_f} \mu_{st} q_{ft} \\ &= c_f \mu_{st} q_{ft} \end{aligned} \tag{2}$$

Characterization of Equilibrium

Assumptions:

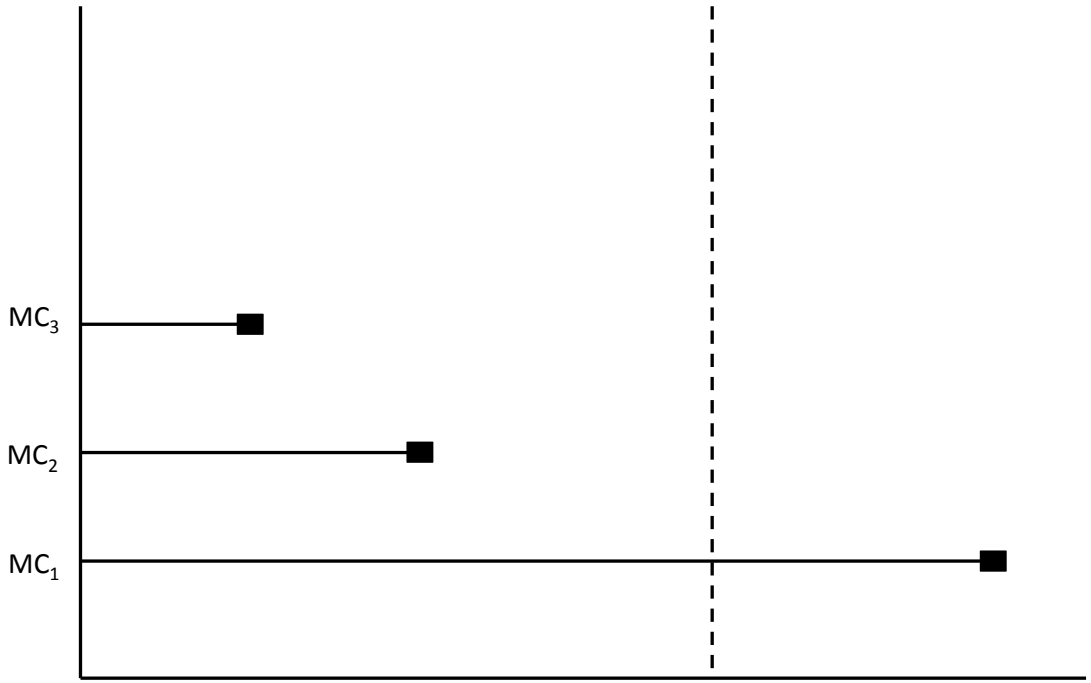
- Homogenous product market
- Common discount factor δ
- Constant marginal cost $= c_f \mu_{st}$ (equiv. Leontief production function)
- Martingale Assumption on expectation of μ:

$$E\left(\mu_{st+k} \,|\mu_{st}\right) = \mu_{st}$$

Implication:

Sorting Algorithm: lowest cost fields are extracted first in any competitive equilibrium.

Sorting Algorithm for Optimal Extraction Decisions



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Structural Model

- Use the sorting algorithm to compute counterfactual paths for the industry — the competitive path.

Inputs into the Dynamic Structural Model

- Discount rate $\beta = 0.95$.
- Physical limits on how much oil can be extracted at once. We cap the extraction rate at max{10 percent of reserves, max for feild}.
- 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 1970-2014, 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.

Cost Estimate

- Marginal Costs are given by:

$$c_{fts} = c_f \mu_{st} \exp\left(\epsilon_{f,t,s}\right) \tag{3}$$

1. First estimate μ_{st}: Compute the average unit cost of production by year t and technology s:

$$\ln \hat{\mu}_{st} = \sum_{f \in s} \kappa_{fts} \ln c_{f,t,s}, \tag{4}$$

   where κ_{fts} is the quantity weight of a field in a given year's total output, $\kappa_{fts} = \frac{q_{ft}}{\sum_{f \in s,t} q_{ft}}$.
2. Next: Recover an estimate of field-specific marginal cost shifter c_f, allowing for measurement error, using the following regression:

$$(\ln c_{fts} - \ln \hat{\mu}_{st}) = \ln c_f + \epsilon_{f,t,s} \tag{5}$$

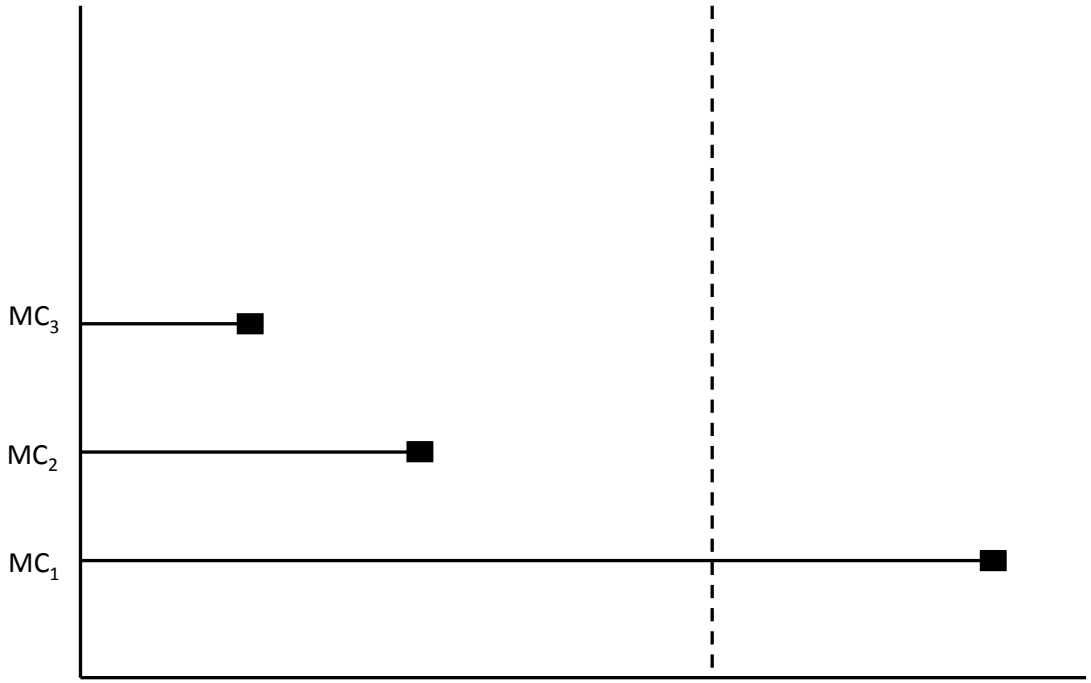
Static Distortion: as of 2014

Country	Actual output share	Counterfactual output share	Δ Share
Persian Gulf OPEC	0.258	0.744	0.486
Saudi Arabia	0.133	0.414	0.281
Other OPEC	0.135	0.044	-0.091
Venezuela	0.041	0.009	-0.032
Non-OPEC	0.607	0.212	-0.395
Russia	0.144	0.047	-0.097

1. Take 2014 as an initial condition
2. Compute the counterfactual extraction path according to the sorting algorithm
3. Compare what actually happened in 2014 to what the counterfactual says happens in 2014...

Doing the welfare accounting

- Comparing the sorting algorithm to the data is too strong: encapsulates any distortion, and also measurement error, model misspecification and such.



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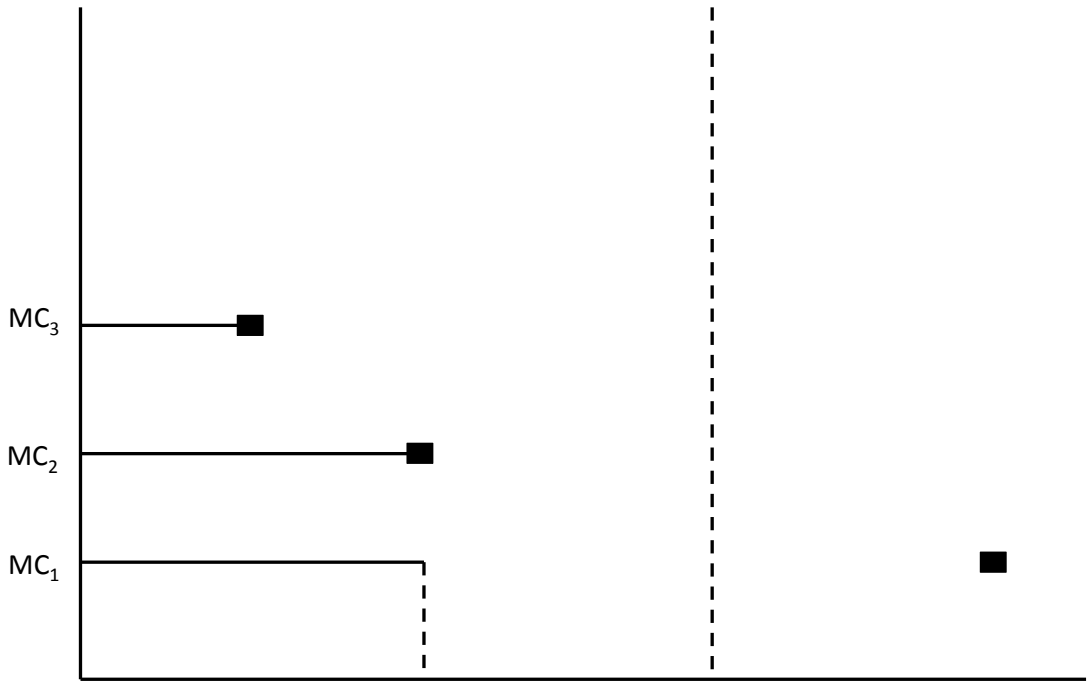

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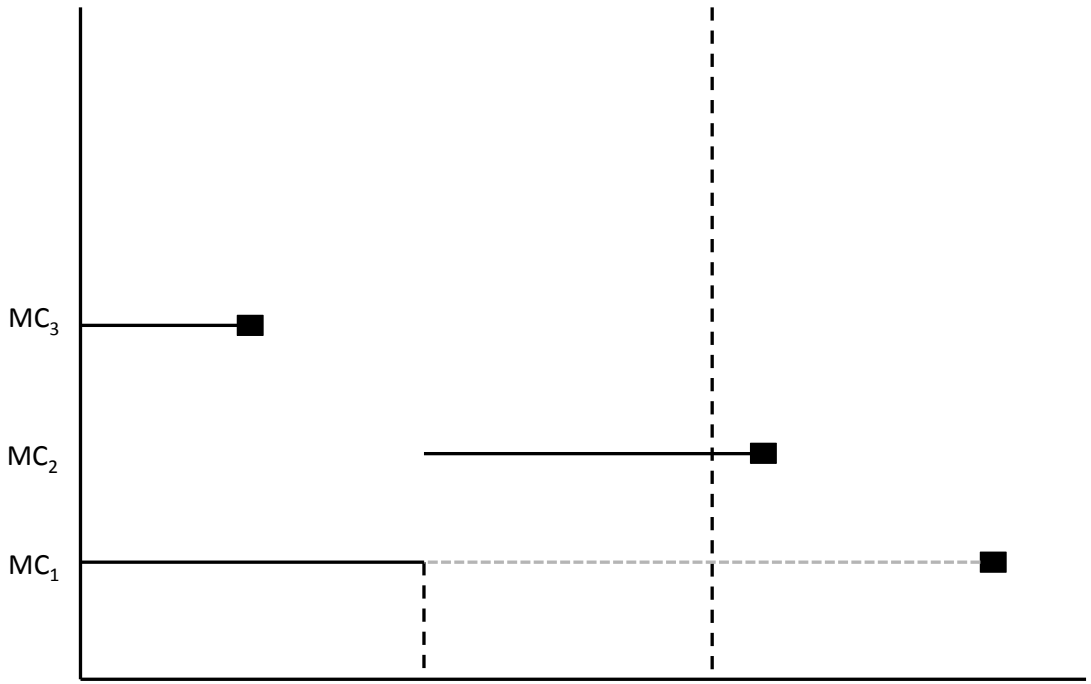

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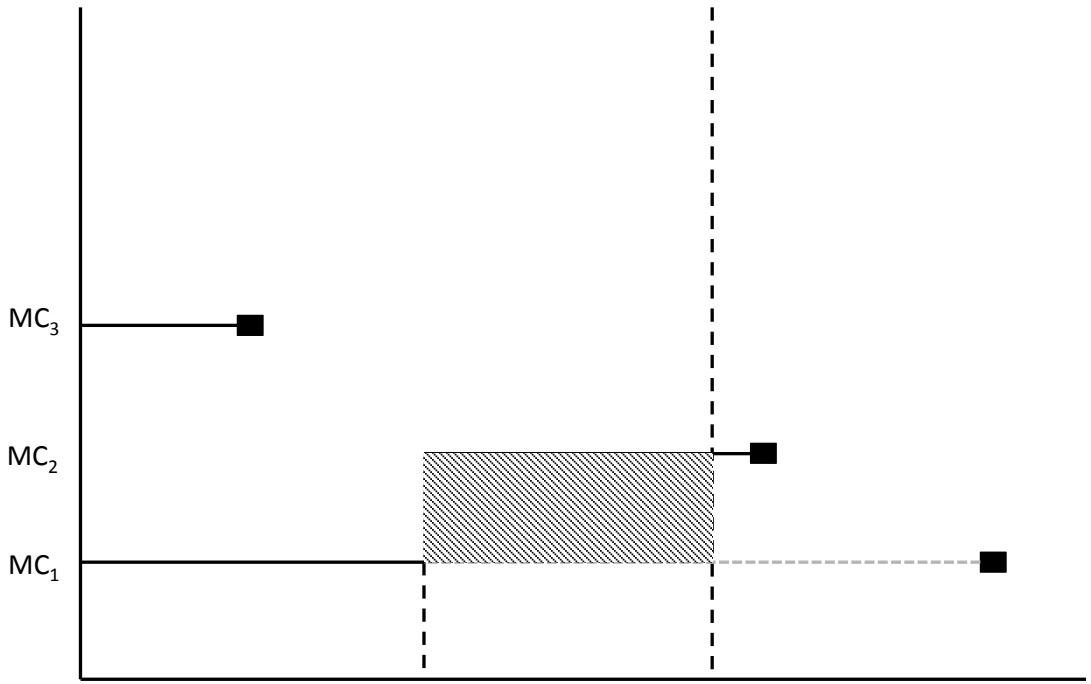

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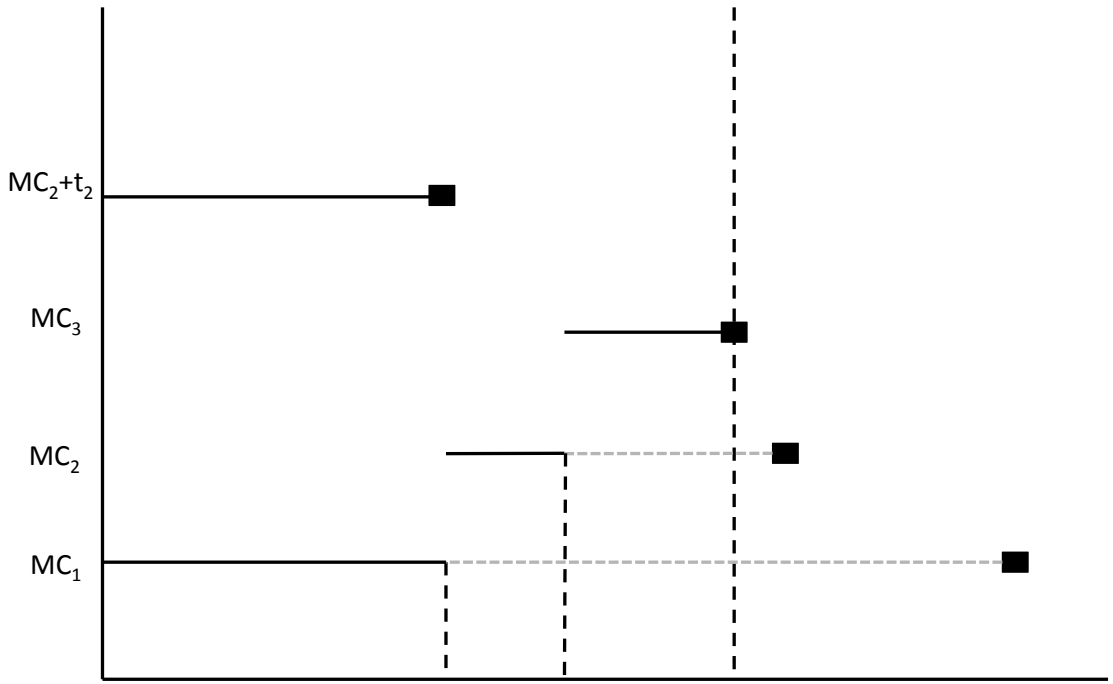

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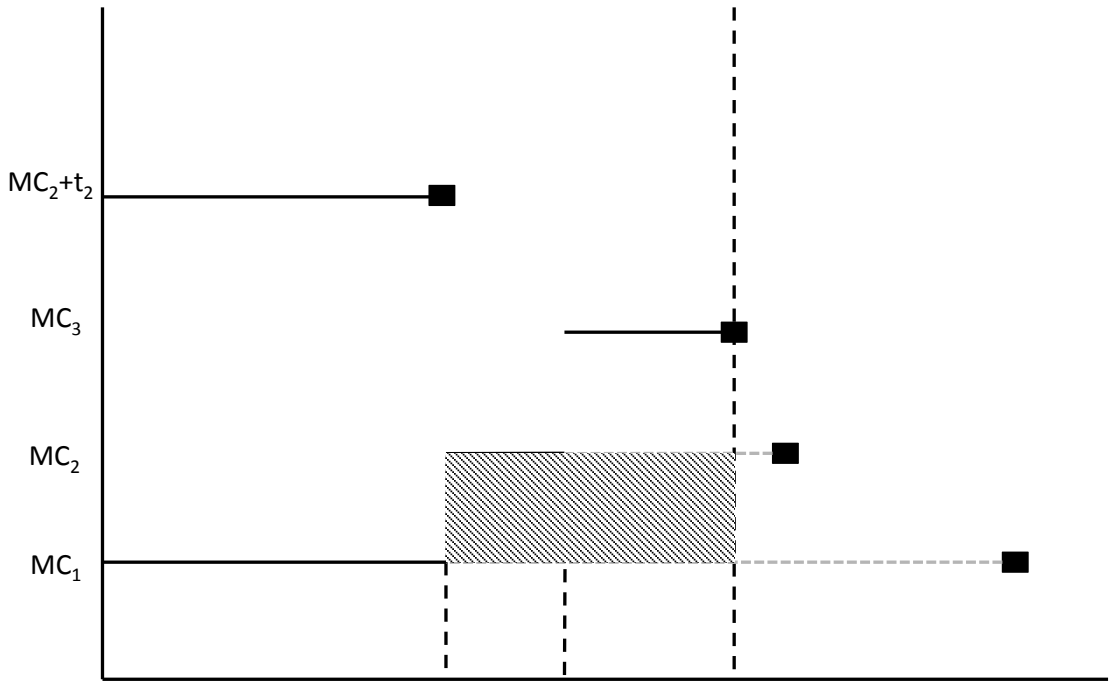

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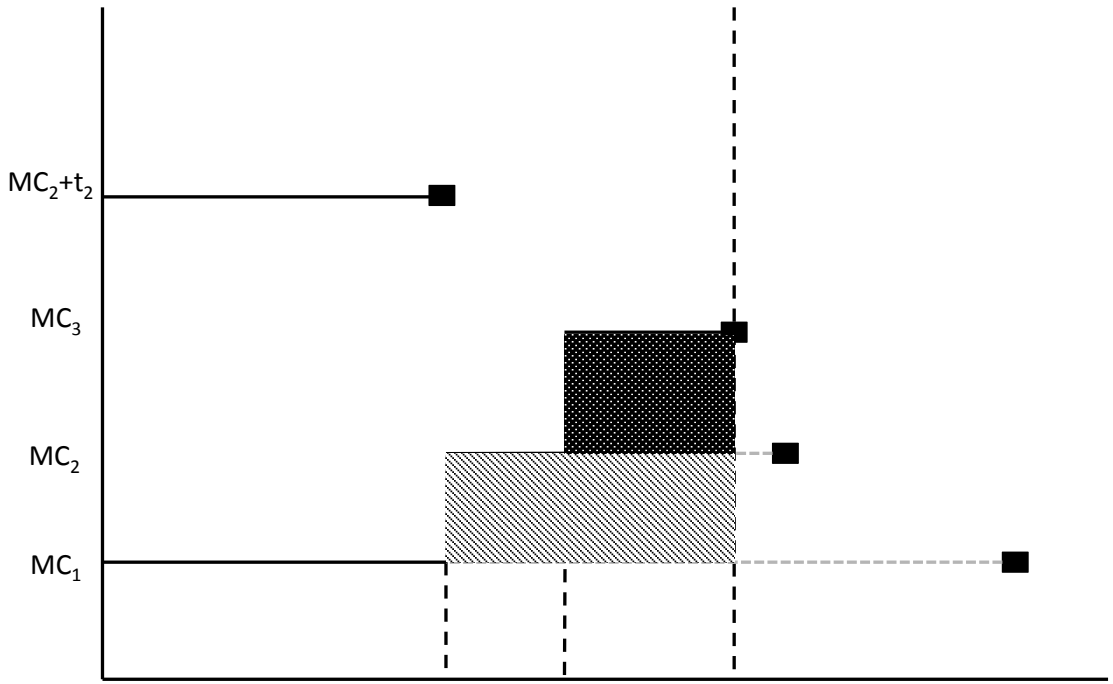


Welfare accounting: implementation

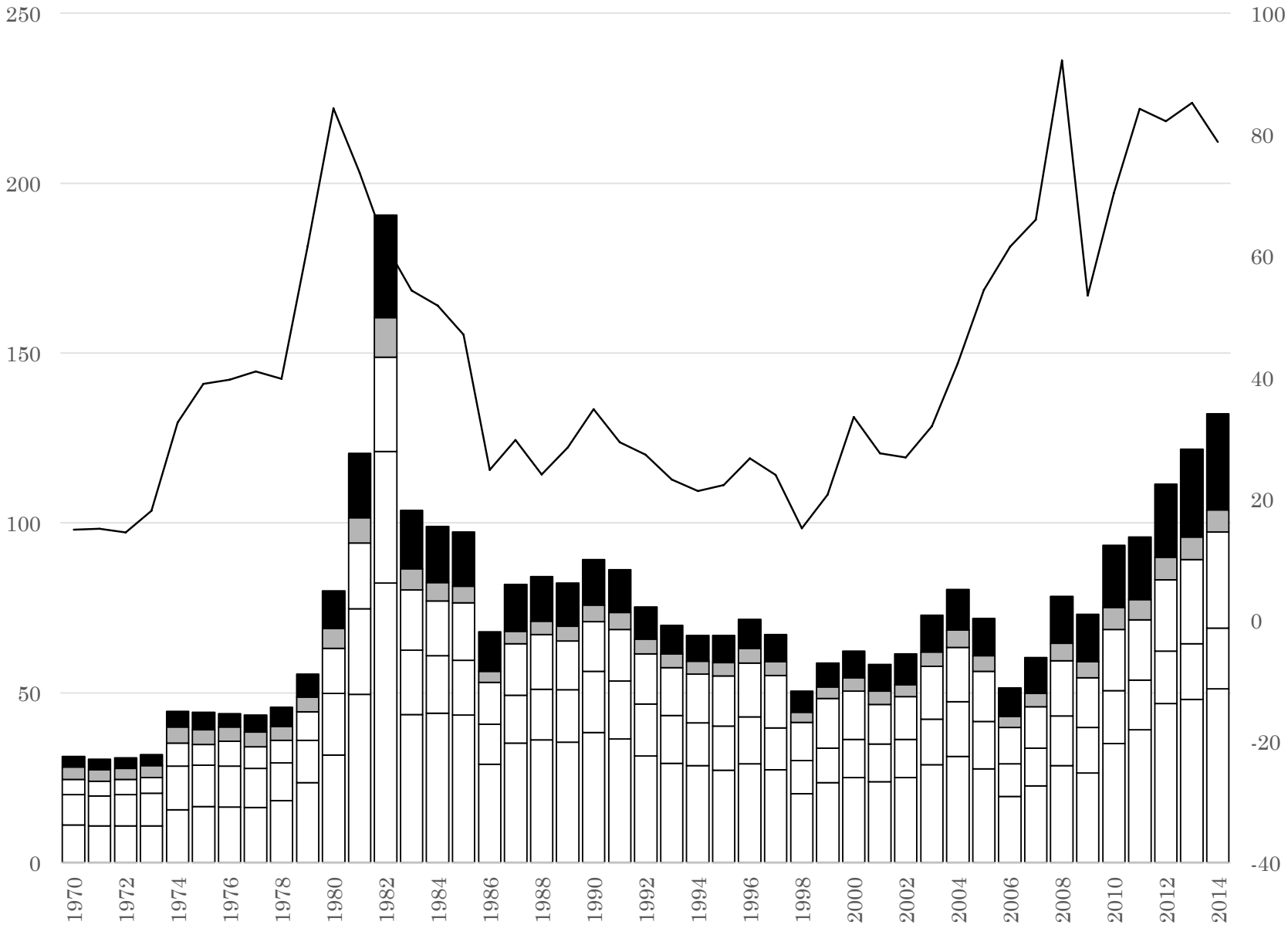
- Nested Set of Constraints:
  1. Hold production in each field fixed (= actual data).
  2. Hold production in each country fixed.
  3. Hold production outside of OPEC constant
  4. Hold production inside OPEC constant (= within cartel inefficiency)
  5. Relax all constraints and get global optimum (= OPEC vs ROW inefficiency)

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

Actual (1)	240
Optimal s.t. (2)	203
Optimal s.t. (3) & (4)	154
Optimal	121

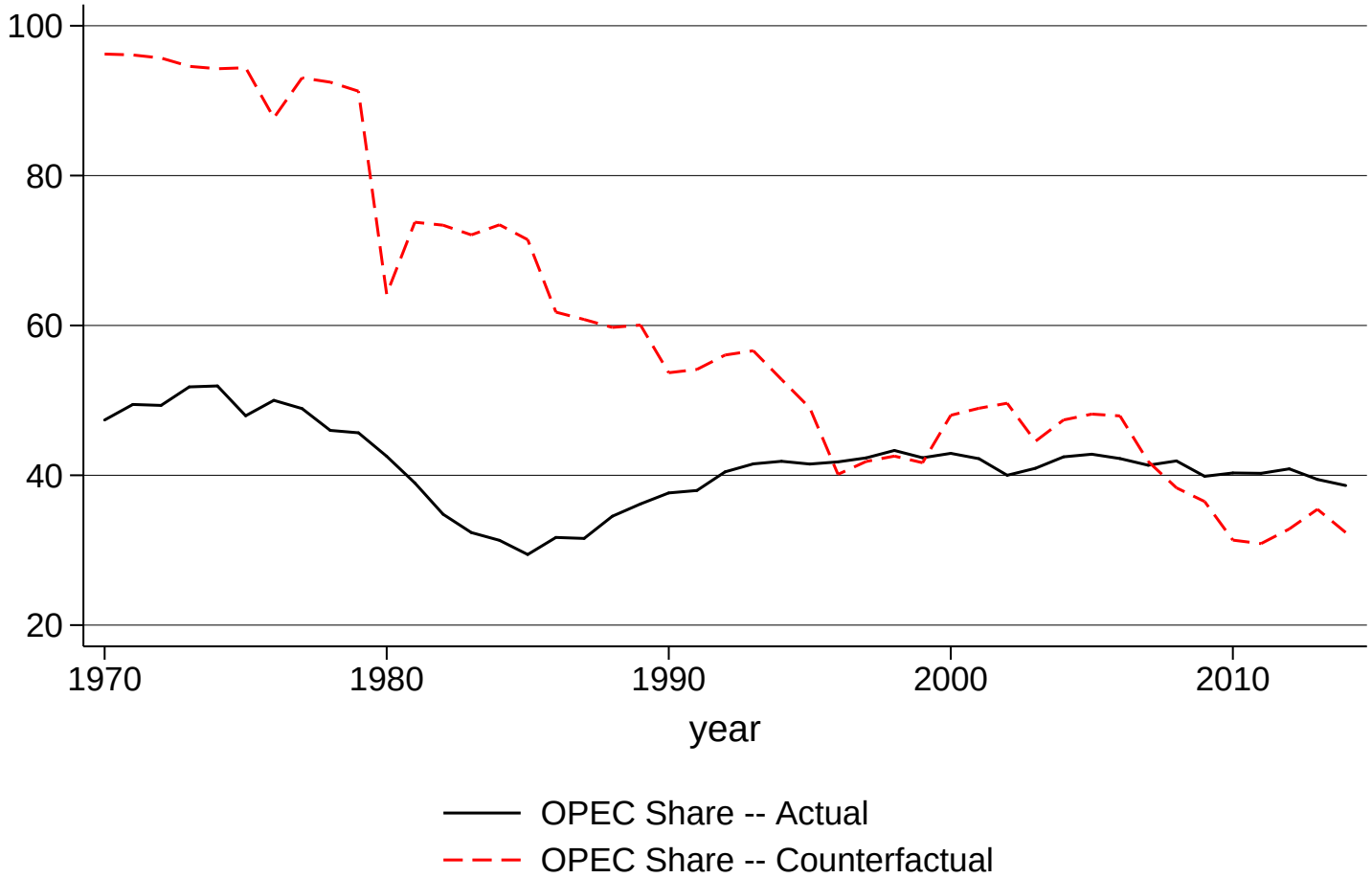
Also, can look at cartel inefficiency at intensive and extensive margin.

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.

Full dynamic model: results

Table 6: 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)

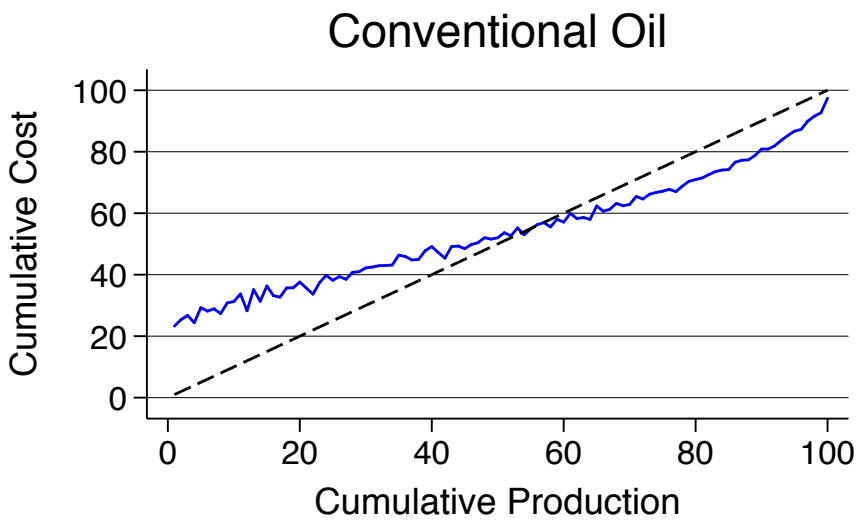
Robustness of Counterfactuals

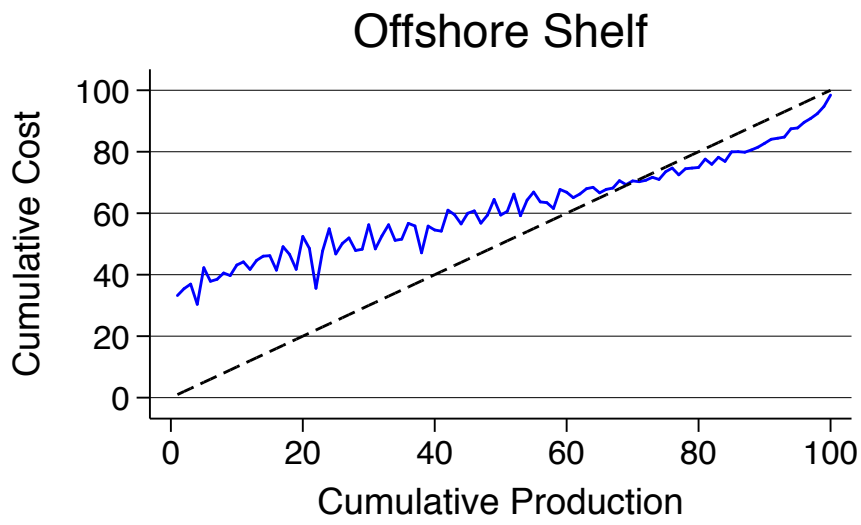
	Specification			
	(1)	(2)	(3)	(4)
Actual (A)	2498	2492	2670	2596
Counterfactual (C_1)	1757	1757	-	-
Counterfactual (C_2)	-	-	1825	2452
Total distortion (A - C_1)	741	735	-	-
Second-Best distortion (A - C_2)	-	-	845	144
Distortion due to OPEC	-	-	845	144
Upper bound	174	158	-	-
Lower bound	117	100	-	-

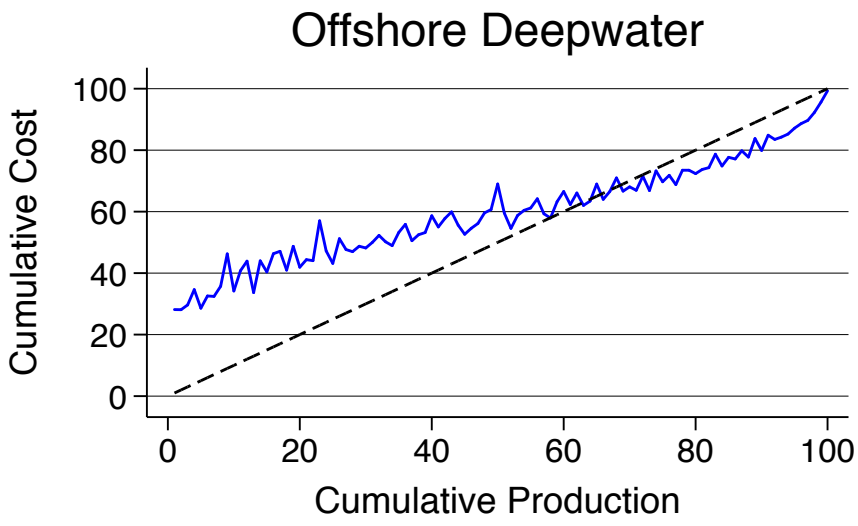
Conclusions

- 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.

Conclusions


Conventional Oil
Cumulative Cost
0
20
40
60
80
100
Cumulative Production


Offshore Shelf
Cumulative Cost
0
20
40
60
80
100
Cumulative Production


Offshore Deepwater
Cumulative Cost
0
20
40
60
80
100
Cumulative Production

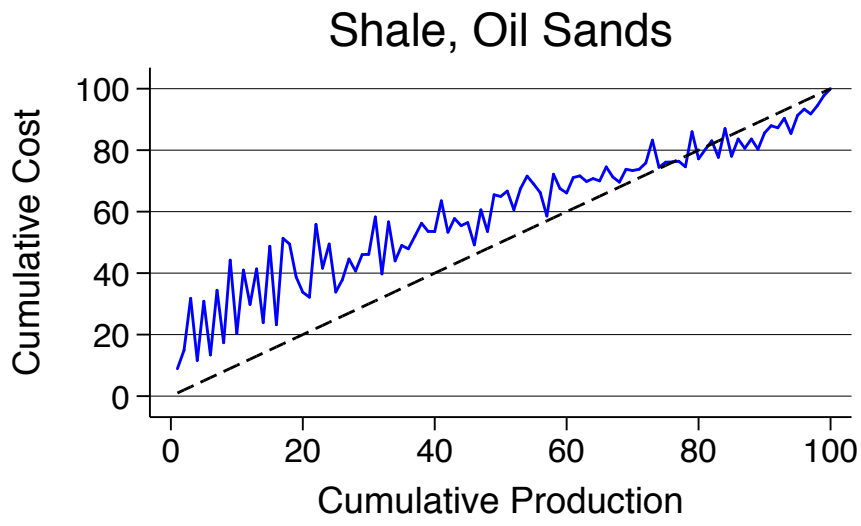
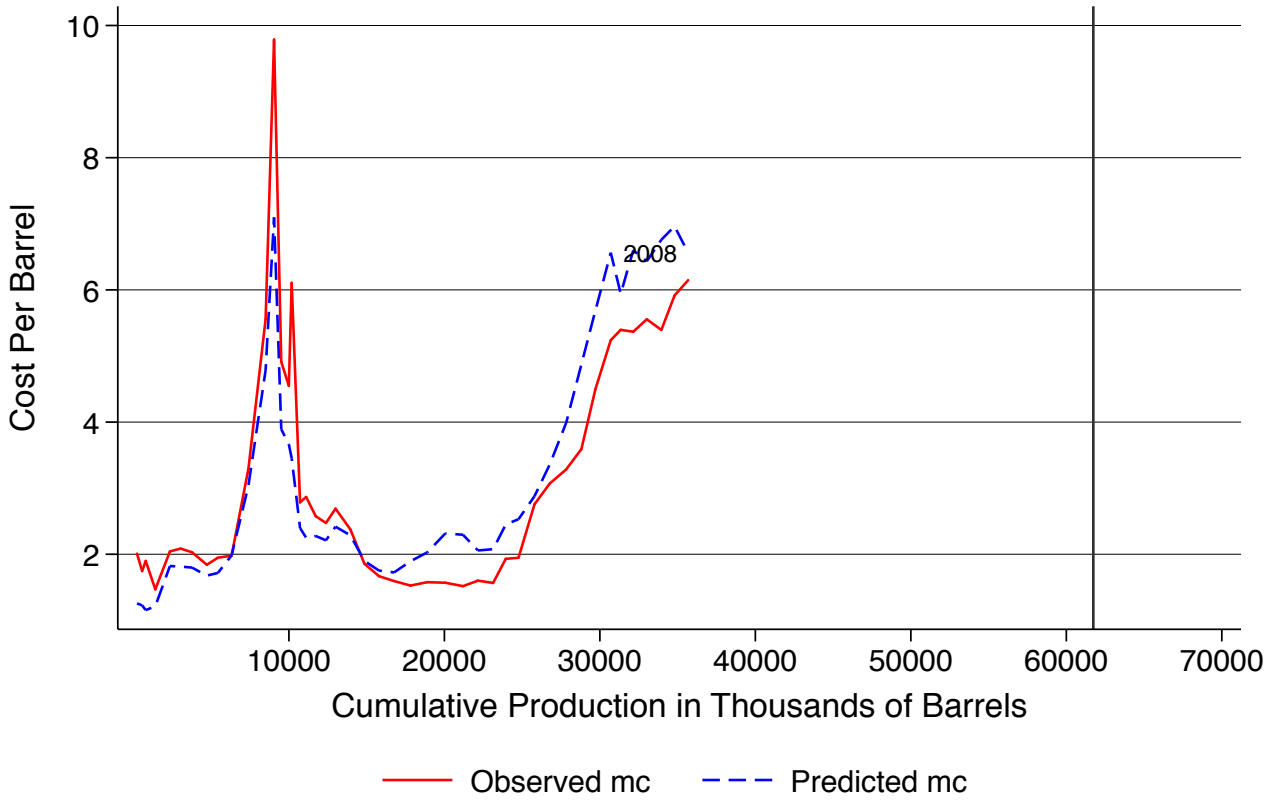

Shale, Oil Sands
Cumulative Cost
0
20
40
60
80
100
Cumulative Production

Figure: Observed and Predicted Marginal Cost
Ghawar Uthmaniyah (SA)



Notes: Observed and predicted marginal cost, using the cost specification in equation **??**, is plotted against cumulative production. The vertical line indicates the proven reserves, and we insert the production year 2008, the year with the highest oil price in the sample period 1970-2014.

Sorting Algorithm

- Proposition 1 and corollary 1: lowest cost fields are extracted first in any competitive equilibrium.
- Sketch: take fields $\underline{F}$ and $\overline{F}$, with c_f equal to $\underline{c}$ and $\overline{c}$. By contradiction suppose that $\overline{F}$ extracted at period 1 and $\underline{F}$ extracted at period t. Then we have:

$$\delta^{t-1}(P_t - \underline{c}) \geq (P_1 - \underline{c}) \tag{6}$$

and

$$\delta^{t-1}(P_t - \overline{c}) \leq (P_1 - \overline{c}) \tag{7}$$

- Martingale means $E(c_t|c) = c$

Price and OPEC