The Global Welfare Implications of Oil Exploration

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Context: Oil Exploration Continues Despite Climate Concerns

- Oil production and use account for about a third of anthropic GHG emissions.

‘Will you stop exploring yours?’: Latin America forges ahead on new oil frontier

The Brazilian president, Luiz Inácio Lula da Silva, at the opening of Platform P50 in Campos, Brazil in 2006. Photograph: Bruno Domingos/Reuters

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- → **Pollution risk or stranded assets**.

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- **Arguments #1 and 2 make sense from a social planner perspective.**
- **Need to be assessed against the risk of over-supply** .

Research Questions

1. Should we continue exploration and development of new oilfields?

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2. What are the social benefits and costs of allowing exploration in

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- a carbon-ignorant World in which GHG emissions are ignored?

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- a climate-wise World in which GHG emissions are internalized?
- a carbon-ignorant World in which GHG emissions are ignored?

Oil-related GHG emissions are currently mispriced... ▸ Carbon Mispricing

3. In a carbon-ignorant World, is it better to ban oil exploration outright?

Motivation

- **Policy initiatives on exploration bans:**
  - A few countries banned oil and gas exploration.
  - NGOs' campaigns: Just Stop Oil, People & Planet's Fossil Free initiative
- **Understanding risks related to oil exploration:**
  - Increased production, higher GHG emissions.
  - Stranded assets; investments could be better directed towards green energy sources.

Key Takeaways: An Exploration Ban is a Good Second-best Policy!

- **Exploration under an optimal carbon tax increases welfare by only 0.04 TUSD.**
- **Without a global carbon tax, exploration decreases welfare by 15 TUSD.**
- **Partial ban:** An exploration ban only in OECD-BRICS yields large welfare gains.

Quantifying Welfare Impacts of Exploration Across Carbon Tax Scenarios

Exploration Regulation

Tax Policy

Carbon Tax Exploration (Optimum)	Carbon Tax No Exploration
No Carbon Tax Exploration (*Laissez-faire*)	No Carbon Tax No Exploration

account for the **social cost of oil**
(Private cost + Life-cycle CI $\times$ SCC)

account only for the **private cost of oil**

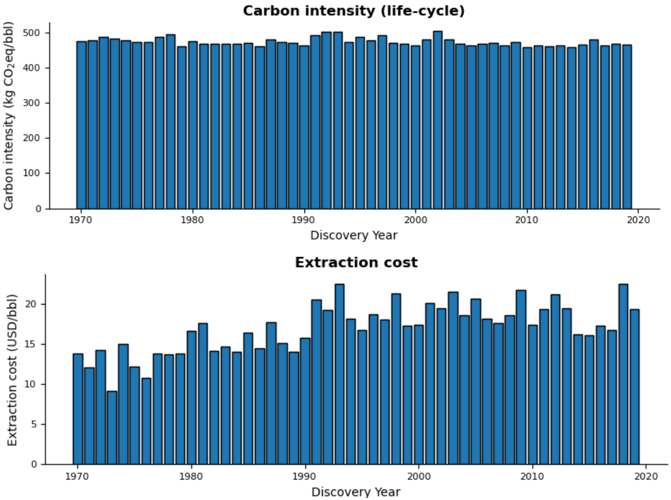
Intuition

Micro-data on Oil Deposits and Carbon Intensities Estimations

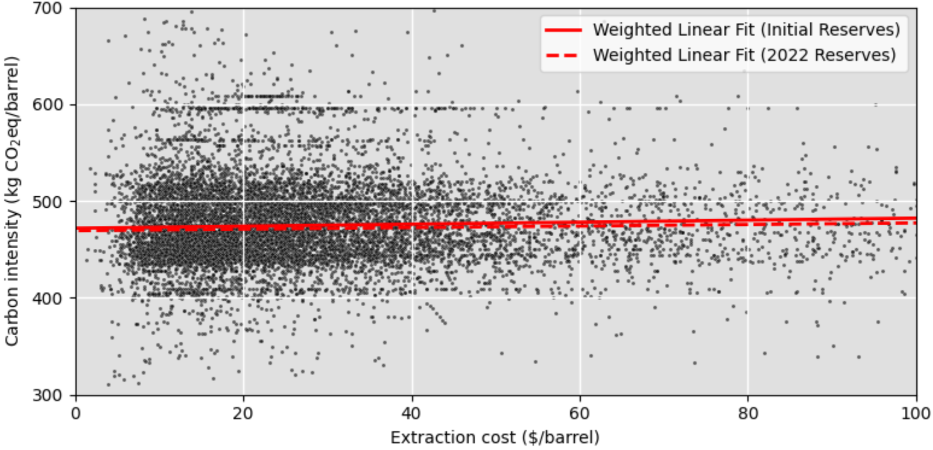
- Rystad proprietary database: field-level data that cover the world production:
  - 14,000 oil assets ; proven reserves as of 2022: 1,235 Gbbl.
  - Productions, costs (operational and capital expenditures), location, ownership.
  - Oil and reservoir characteristics (e.g., API gravity, gas-to-oil ratio).
- Oil-climate Index models that cover life-cycle GHG emissions from exploration to combustion: OPGEE (extraction), PRELIM (refining) and OPEM (combustion)
  - Flaring: NASA/ NOAA /Visible Infrared Imaging Radiometer Suite (VIIRS)

→ Heterogeneity in CI comes from extraction and refining (that account for about 20% of the life-cycle CI) ▸ CI Estimation ▸ CI per Country ▸ Private Cost per Country

Life-cycle CI and Private Extraction Costs Across Field Discovery Years

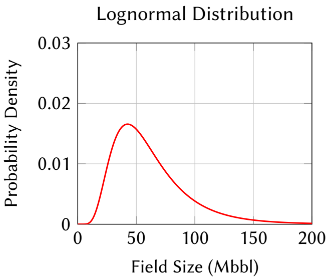


Producer Private cost and Life-cycle CI are not correlated



Modelisation of Yet-To-Find (YTF) Resources in each Basin

- **Ultimate recoverable resources (URR)** per basin are estimated using bayesian inference. YTF: 251 Gbbl (about 25% larger than Rystad YTF, same ballpark as USGS*).
- **Field size distribution in a basin** is lognormal: small fields more frequent.
- **YTF assets' characteristics:** have similar carbon intensities and private cost as observed assets in the same *sizebin* $\times$ *oiltype* $\times$ *basin*.



URR estimation illustration

Optimal Oil Supply maximizes the total surplus net of pollution cost

1. Global isoelastic demand calibrated over 2019 (elasticity of 0.1 in 2022)
2. Limited field reserves
3. Capacity constraints calibrated on observed data : Plateau-decline pattern
4. Production costs measured as average capex and opex costs per bbl
5. Exploration costs calibrated on historical data per basin type (e.g. onshore)
6. Homogeneity of oil barrels in terms of use ; Uniform refining and combustion-related private costs across barrels
7. Clean backstop price at $180/bbleq
8. Carbon cost (\$200/tCO_2eq in 2022) increases as the discount rate does (3%)

Optimal Oil Supply with Exploration

- Ω, universe of proven and YTF oilfields; Υ, universe of YTF; c denotes the clean backstop
- $x_i(t)$, production from field i at date t; $u_t()$ the utility associated to energy demand
- θ_i, carbon intensity in field i; c_i post-discovery private-extraction cost (/barrel) in field i
- $R_{i,t}$ reserves at time t; $\min(k_i, \alpha_i R_{i,t})$ estimated field-extraction capacity at date t
- E_i is the exploration cost based on the supply segment of the field
- μ, 2022 carbon cost (\$200/tCO_2eq)

Optimal production ($x_i(t)$) is the solution of:

$$\mathcal{P}_1(\mu(t)) : \qquad Max \int_0^\infty e^{-rt}\Big(u\big(\sum_{i\in\Omega\cup\{c\}} x_i(t), t\big) - \sum_{i\in\Omega\cup\{c\}} (c_i + \theta_i\mu(t))\cdot x_i(t) - \sum_{i\in\Upsilon} E_i\Big)dt$$

s.t.

$$\int_0^\infty x_i(t)dt \leq R_i \text{ for all } i \in \Omega \quad (1)$$

$$R_i(t+1) - R_i(t) = -x_i(t) \text{ for all } t, i \in \Omega \quad (2)$$

$$0 \leq x_i(t) \leq k_i \text{ for all } t, i \in \Omega \quad (3)$$

$$x_i(t) \leq \alpha_i R_i(t) \text{ for all } t, i \in \Omega \quad (4)$$

$$x_i(t) = 0 \text{ for all } t < t_i, i \in \Omega \quad (5)$$

$$\mu_t = \mu e^{rt} \quad \text{for all } t \quad (5) \quad (6)$$

Model Prediction and Performance

The market model explains well countries' past productions

- Compute the cost-effective supply, $\mu = 0$, with 2016 as the starting date.
- Compare predicted and observed country-level productions: Good match ▸ Graph

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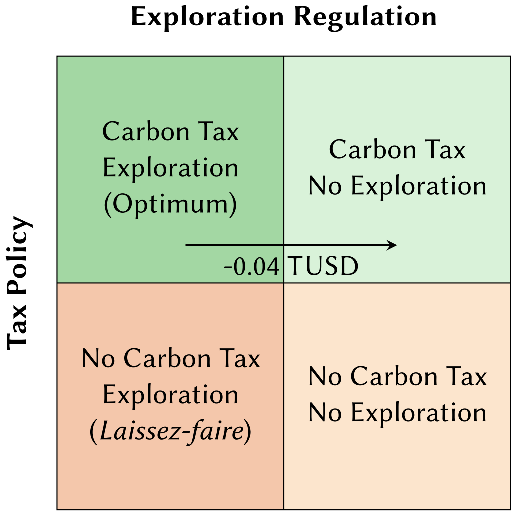
Optimal future supply is in line with the IEA NZE scenario

- With an optimal tax, the calibrated model projects a cumulative oil consumption of 539 Gbl from 2022 to 2060, aligning with IEA's forecast for net-zero by 2050 scenario.
- The clean backstop starts in 2039, ramping up to fully replace oil by the end of 2044.

Main Results: Small Welfare Gains of Exploration with Optimal Tax



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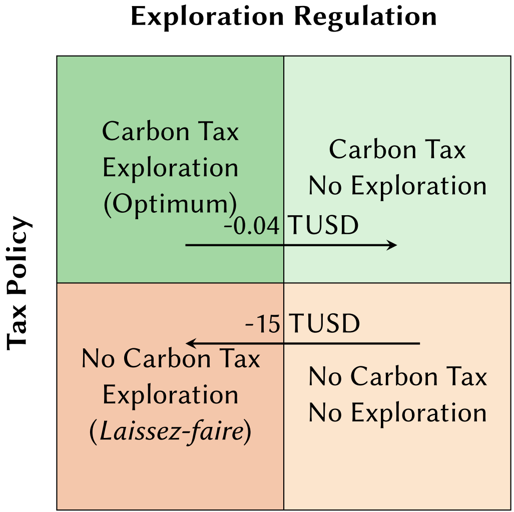

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Sensitivity Analysis

- **Yet-to-find (YTF) resources**
  - URR ± 10 %, URR ± 25 %
  - Exploration cost: x 0, × 2
  - Pareto size distribution for YTF
- **Carbon intensities**
  - Nil upstream CI for all assets
  - Nil upstream CI for YTF only
  - Co-product displacement method
  - AR6, 20-year horizon
- **Private extraction costs**
  - Exclude 10 % of proved reserves
  - LCOE instead of average cost
  - Add production tax (e.g., Royalties)
- **Extraction capacities**
  - No decline constraint
  - Field capacity determined by CAPEX
- **Demand side**
  - Elasticity: 0.05, 0.15, 0.20, 0.30
  - "No elasticity increase" variants
  - Fixed product mix by oil category
  - Clean backstop price: ± 20 %
- **SCC / Discount rate**
  - SCC: \$150 and \$250 / tCO_2
  - Discount rate: 1.5% and 4.5%

Main findings about social costs and benefits of exploration remain unchanged

Policy Implications

- **Suboptimal taxes** (SCC = \$200 /tCO_2e) ▸ Graph
  - Exploration increases welfare only if the tax is above **\$140 /tCO_2e**.
  - A ban without a tax is preferable to any sub-optimal taxes below **\$80 /tCO_2e**.

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- **An exploration ban only in OECD/BRICS** cuts emissions by **62 %** of a full ban (no spatial leakage here)
  - Increases welfare by 9.4 TUSD versus the unregulated scenario. ▸ Table ▸ Graph

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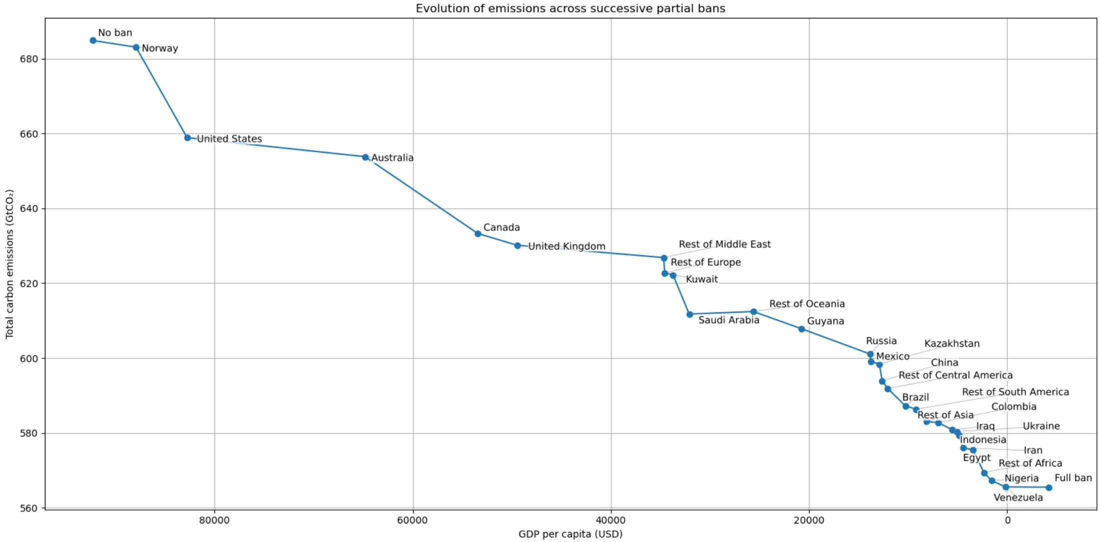
- **Delayed action and stranded reserves**
  - A tax set in 2030 (that keeps cumulative emissions as in first-best) strands **80 %** of post-2021 discoveries. ▸ Map Stranded Discoveries

Which countries to bring onboard for an exploration ban? ▸ Back



Concluding Remarks

- **Abundant high-quality assets in existing reserves:** When combined with a carbon tax, further exploration provides **minimal welfare gains**.
- **Exploration ban as a good (second-best) mitigation tool:** If GHG emissions are mispriced, banning exploration largely increases global welfare.
- **Exploration only justified if taxes near the SCC; current taxes fall far short.**

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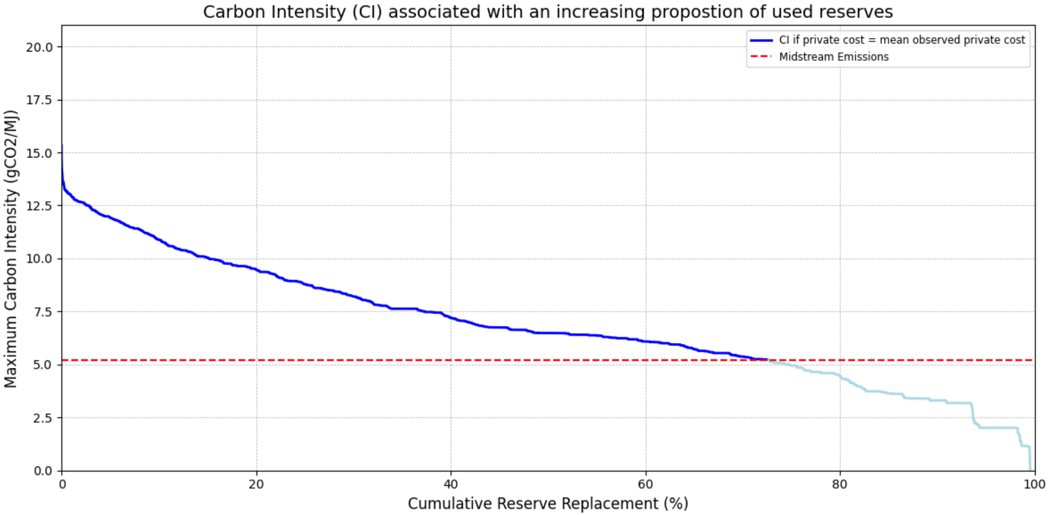
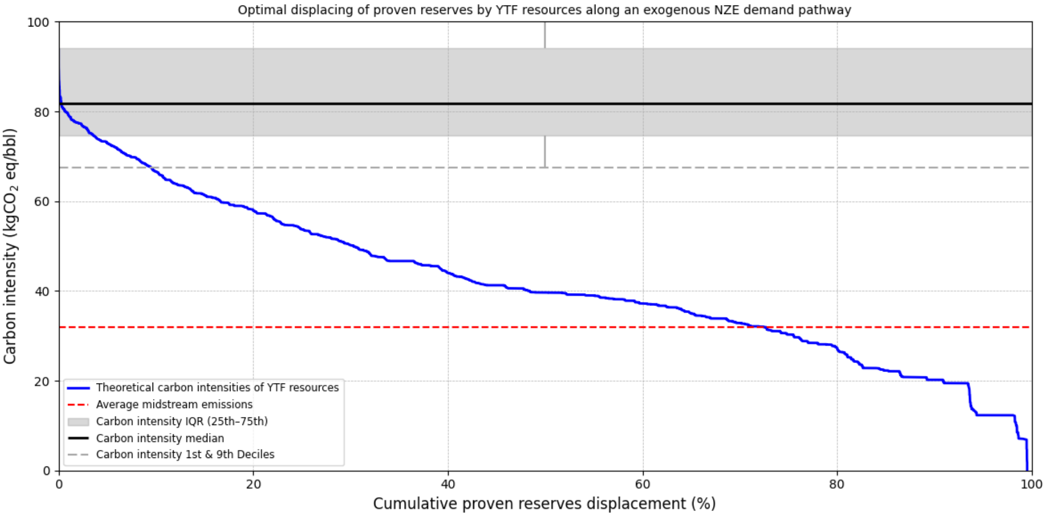
- **Political Feasibility of Exploration bans**
  - Easier than phasing out producing fields (though that is essential for NZE-2050).
  - Impacts on producer surplus varies with instruments (ban vs tax).
  - A ban only in OECD and BRICS country would have a large impact.
  - Exploration bans may lack durability

Thank you! Questions?

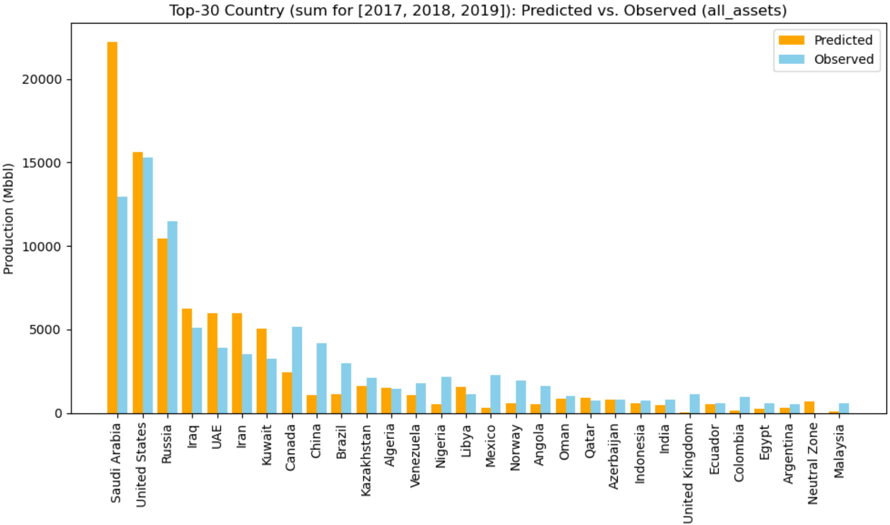
Agnostic approach: What should be the CI of YTF resources to replace % of resources used in the optimal future without exploration? Back



Comparison with observed distribution of upstream and midstream carbon intensities ▸ Back



Top-30 Producing Countries from 2017 to 2019: Predicted vs. Observed



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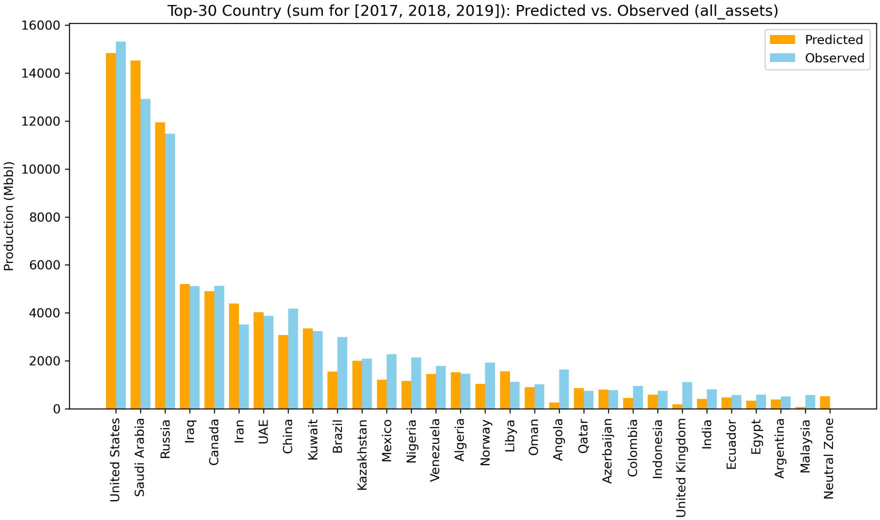

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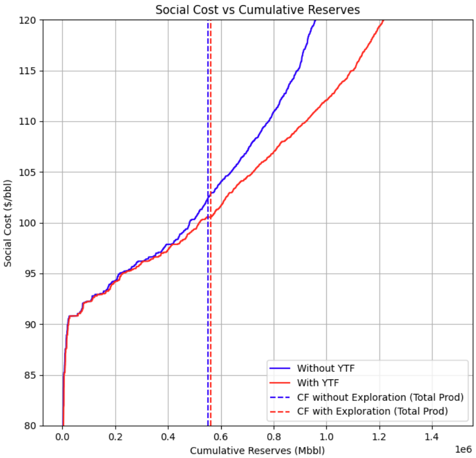
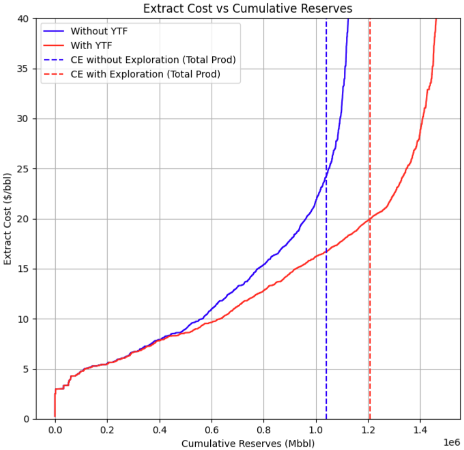
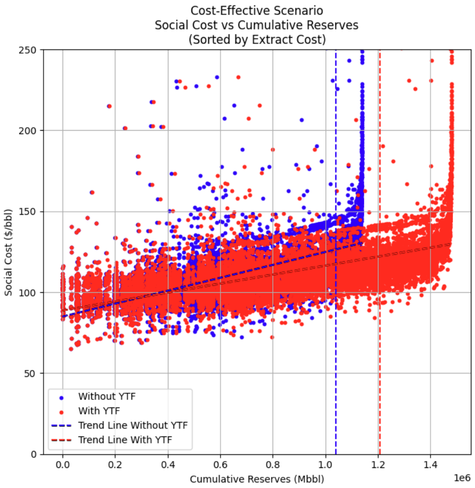
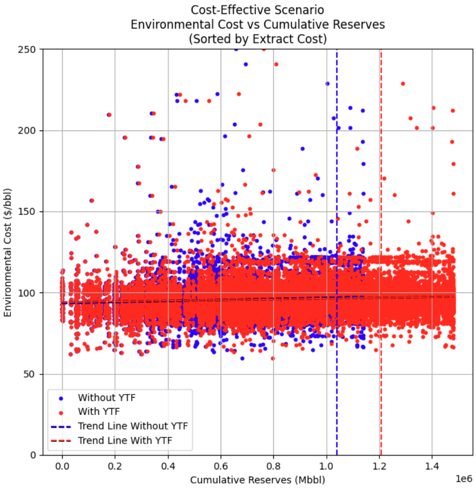
Social supply curve with/without exploration (left) and Private social curves with/wo exploration (right)





Social cost associated with private supply curve





Optimal production

- μ, 2022 carbon cost (\$200/tCO_2eq)
- θ_d, carbon intensity in d; c_d private-extraction cost (/barrel)
- $x_{d,t}$ production from field d at date t; $u_t()$ the utility associated to demand $D_t = \sum_d x_{d,t}$.
- $R_{d,t}$ reserves at time t; $\min(k_d, \alpha_d R_{d,t})$ endogenous field-extraction capacity at date t
- $c_{e,d}$ is the exploration cost based on the supply segment of the deposits

Optimal production is the solution of:

$$P(\mu) : \max_{x_{d,t}} \sum_t [u_t(\sum_d x_{d,t}) - \sum_d (c_d + \theta_d \mu_t) x_{d,t} - \sum_d c_{e,d}] e^{-rt}$$

s.t.

$$\sum_t x_{d,t} \leq R_d, \quad \text{for all } d \quad (1)$$

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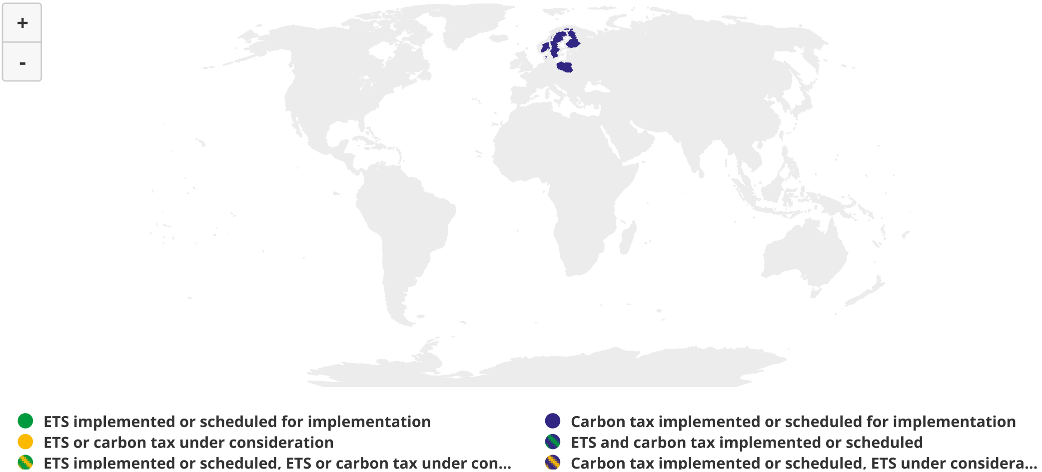
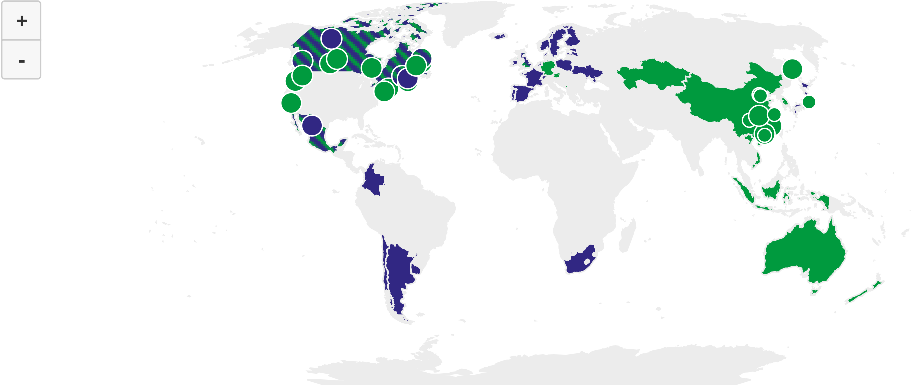
Carbon pricing dashboard as of 1992 (World Bank)



Carbon pricing dashboard as of 2023 (World Bank)



- ETS implemented or scheduled for implementation
- ETS or carbon tax under consideration
- ETS implemented or scheduled, ETS or carbon tax under con...
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▸ Back Motivation ▸ Back Key Takeaways

Main Results: Small Welfare Gains of Exploration with Optimal Tax

Scenario		Private Cost (TUSD)	Environmental Cost (TUSD)	Social Cost (TUSD)	Emissions ($GtCO_2e$)	Δ welfare (/Optimum) (TUSD)
Optimal tax, explo	**1st Best**	69	50	118	249	0
Optimal tax, no explo	**2nd Best**	69	49	118	247	-0.04
No tax, no explo	**2nd Best**	34	112	147	567	-24.40
No tax, explo	**Laissez-faire**	27	138	165	691	-39.08

- With a carbon tax, exploration brings **minimal welfare gains** (0.04 TUSD).
- Very few new oil fields are brought online since they end up being stranded later. Plenty of relatively low-social cost deposits in proven reserves.

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- The absence of regulation yields sharp welfare losses of 39 TUSD with a 2.5x increase in GHG emissions compared to Optimum
- An exploration ban reduces welfare loss by 15 TUSD and GHG emissions by 124 GtCO2e (28% of the impact of introducing optimal CT compared to *laissez-faire*).

Carbon pricing in the 10 largest oil producers as of 2018

Country	Share world supply	Year start–end	Sectors
US ETS	18%		
RGGI		2009-	power
Washington		2017-	industry, power, transport, waste, buildings
Massachusetts		2018-	power
California		2012-	power, road fuel distribution
Canada	5%		
Alberta		2007-17	industry, power
Alberta CCIR		2018-	industry, power, large oil-sands mines
Quebec ETS		2013-	power, industry, distribution, fossil-fuel imports
BC tax		2008-	all except agriculture (from 2013)
Ontario CaT		2017-19	all except agriculture, waste, aviation, sea transport
China ETS	5%		
Shanghai		2013-	power, petrochemicals, aviation, heavy industry
Shenzhen		2013-	power, manufacturing
Tianjin		2013-	petrochemicals, power, oil & gas, heavy industry
Guangdong		2013-	power, cement, steel, petrochemicals
Chongqing		2014-	power, heavy industry
Hubei		2014-	power, heavy industry, petrochemicals
Beijing		2013-	power, heavy industry, petrochemicals

Laissez-faire and Market power

- Our baseline already partly reflects OPEC market power influence as field–level capacities are calibrated on observed data.
- Yet, market power not modeled per se.
- We repeat every policy scenario under *perfect collusion* among all oil producers.
- **Conclusions on the welfare costs of exploration are unchanged:** ▸ Table
  - notice that, without a carbon price, collusion does not impact cumulative emissions: the resource conservation effect is only short-lived.

Policy context

- Differences in CO_2eq emissions/barrel originate from the upstream and midstream sectors
- No direct taxation of upstream emissions in fuel-producing countries

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- Consumer countries: accounting for life-cycle emissions of petroleum products $\rightarrow$ modify the allocation of refiners and distributors' fuel demand towards oil barrels with smaller carbon footprint. A few attempts such as the EU Fuel Quality Directive (2009) and California Low Carbon Fuel Standard (2007).

Welfare Gains and Costs of an Exploration Ban: Oil Producers Collude

Policy scenario	**Private cost** (TUSD)	**Env. cost** (TUSD)	**Social cost** (TUSD)	**CO_2eq** ($GtCO_2$)	**Prod.** (Gbbl)	**ΔWelfare /1st best** (TUSD)
Carbon tax, with explo.	68.4	48.3	116.7	242	524	0.00
Carbon tax, no explo.	68.6	48.1	116.8	241	522	-0.03
No carbon tax, no explo.	29.7	113.0	142.7	565	1199	-25.87
No carbon tax, with explo.	21.1	136.7	157.8	683	1453	-41.04

Back to Market Power

Delayed Mitigation Action: Stranded Assets and Welfare Costs

Policy scenario	E. Capex (TUSD)	Social cost (TUSD)	CO_2eq (Gt)	ΔWelfare (TUSD)	Prod (YTF) (Gbbl)	2100 Reserves (YTF) (Gbbl)
CT, with explo.	1	118	249	0.0	539 (14)	742 (33*)
No CT, no explo.	0	147	544	-24.4	1203 (0)	31* (0*)
No CT, with explo.	1	165	691	-39.1	1469 (268)	53* (19*)
CT 2030, with explo.	1	121	252	-0.9	544 (16)	773 (66)
CT 2030, no explo.	0	120	248	-0.7	535 (0)	700 (0)
No CT, no explo. 2030	1	152	604	-27.9	1281 (79)	35* (3*)

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Welfare Gains and Costs of a **Partial Exploration Ban**

Policy scenario	**Private cost** (TUSD)	**Env. cost** (TUSD)	**Social cost** (TUSD)	**CO_2eq** ($GtCO_2$eq)	**Prod.** (Gbbl)	**ΔWelfare /1st best** (TUSD)
Carbon tax, with explo.	68.7	49.7	118.4	249	539	0.0
Carbon tax, partial ban	68.7	49.7	118.4	248	532	-0.0
No carbon tax, partial ban	30.6	122.9	153.4	614	1303	-29.7
No carbon tax, with explo.	26.6	138.1	164.6	691	1469	-39.1

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Welfare Gains and Costs of a **Ban on New Oil Developments**

Policy scenario	**Private cost** (TUSD)	**Env. cost** (TUSD)	**Social cost** (TUSD)	**CO_2eq** ($GtCO_2$eq)	**Prod.** (Gbbl)	**ΔWelfare /1st best** (TUSD)
Carbon tax, with explo./dev.	68.7	49.7	118.4	249	539	0.0
Carbon tax, no explo./dev.	74.7	44.3	119.0	222	478	-1.5
No carbon tax, no explo./dev.	53.6	78.1	131.6	390	833	-13.2
No carbon tax, with explo./dev.	26.6	138.1	164.6	691	1469	-39.1

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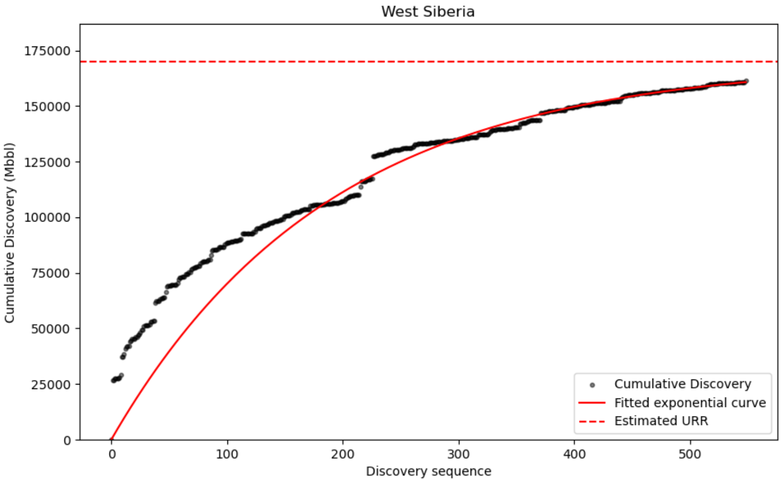
Feasibility of Future Oil-demand Scenarios

Demand scenario	Demand (Gbbl)	Producing fields only	Developed fields only	All proven fields
IEA Net Zero	550	✓	✓	✓
IEA APS	782	✗	✗	✓
IEA STEPS	1034	✗	✗	✗
IPCC Below-1.5° C and 1.5° C Low-OS	666	✓	✓	✓
IPCC 1.5° C High-OS	901	✗	✗	✓
Shell Sky	800	✗	✗	✓
Shell Archipelagos	1066	✗	✗	✗
Equinor Walls	1102	✗	✗	✗
Equinor Bridges	689	✗(✓)	✗(✓)	✓
BP Accelerated	849	✗	✗	✓
BP NZE	693	✗(✓)	✗(✓)	✓
BP New Momentum	1050	✗	✗	✗
TE Momentum	912	✗(✓)	✗(✓)	✓
TE Rupture	793	✗	✗	✓

A tick in parentheses indicates that the scenario becomes feasible if oil produced as a co-product from gas fields is included.

URR estimation (mature basin)



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Estimating CO_2eq intensity (CI) at the field level

3 state-of-the-art datasets/models for CI estimation (Oil-Climate Index).

Upstream (from exploration to the refinery gate)

- Masnadi et al. 2018: public data of 958 fields, 54% of the world oil production (CI based on OPGEE model). Match these fields to those in Rystad.
- Select a reduced-form model to best explain CI with Rystad variables: oil type, gas-to-oil ratio, offshore + other sources: Flaring (satellite data, US NOAA), Steam injection (IEA).
- We use this model to predict CI for the other fields.

Midstream (refining)

- PRELIM model to estimate CI for most common crudes. Link crudes to Rystad deposits using location, oil type, and firms.
- Select a reduced-form model to best explain CI.
- We use this model to predict CI for the other fields.

Downstream (combustion)

- OPEM model to asses for each crude assay, GHG emissions related to combustion.

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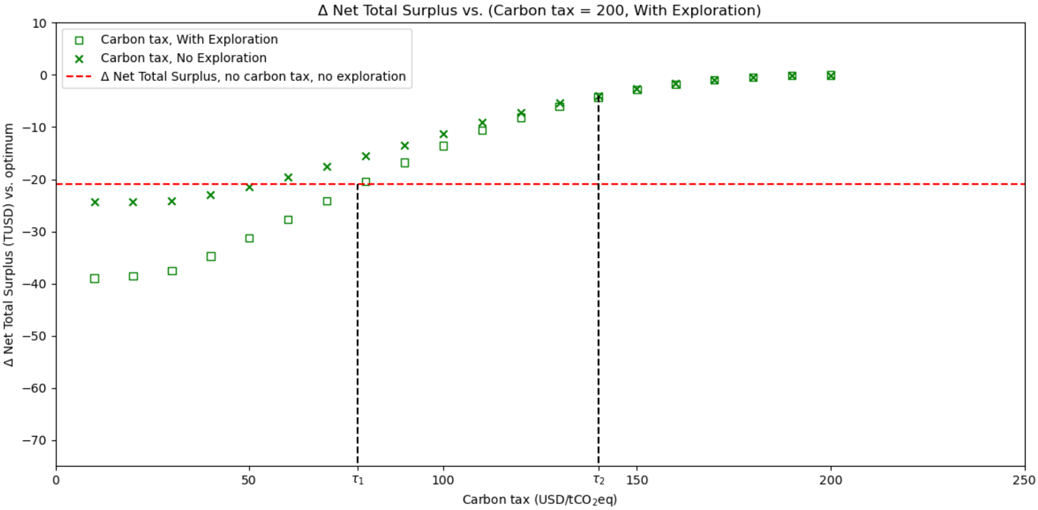
Sub-optimal taxes



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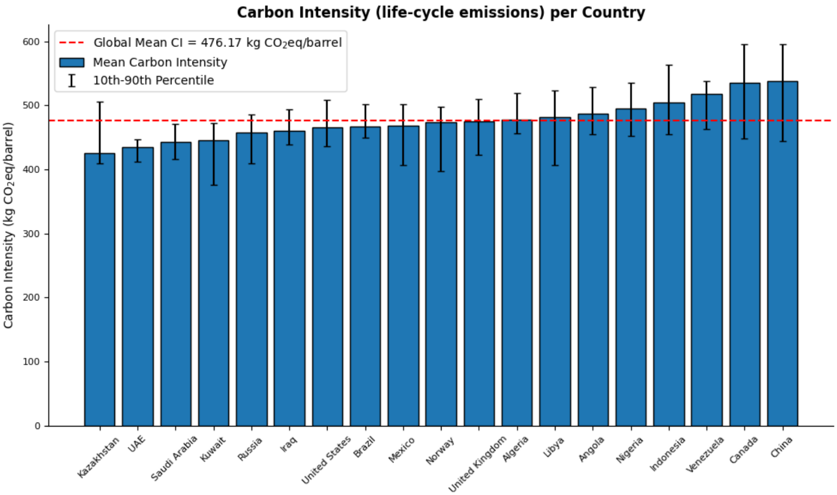
Life-cycle CO_2eq per barrel by country



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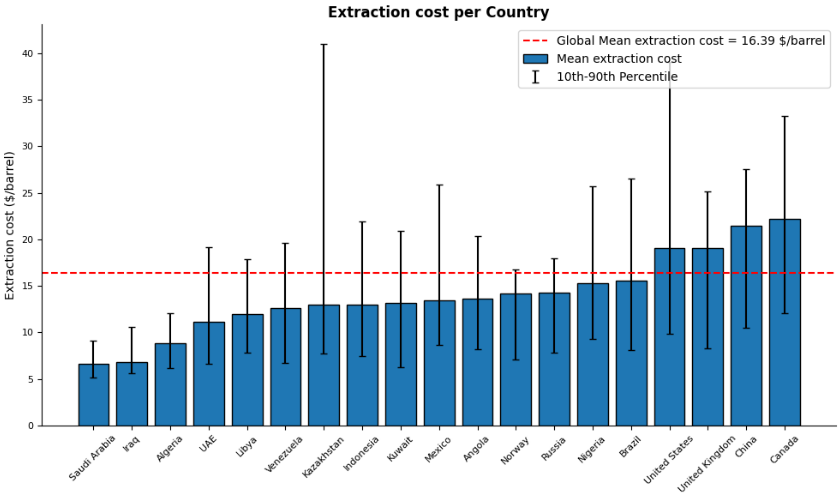
Extraction costs by country



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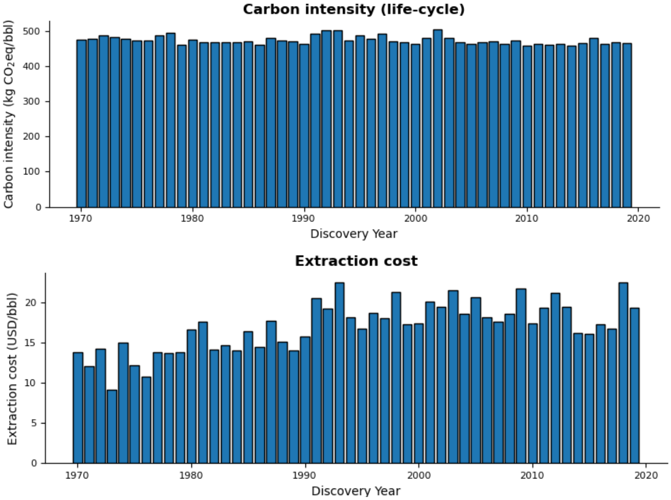
Trends in CI and Costs



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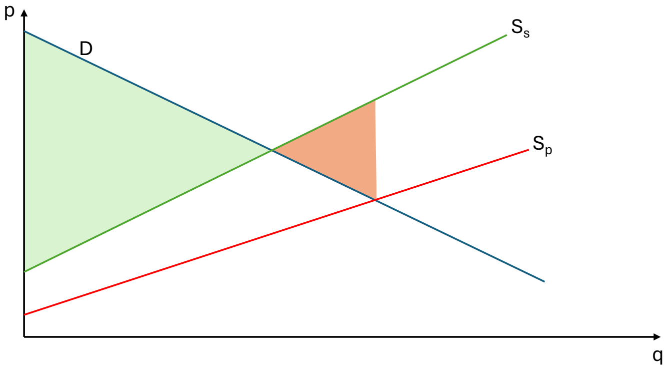
Externality (in production): before exploration



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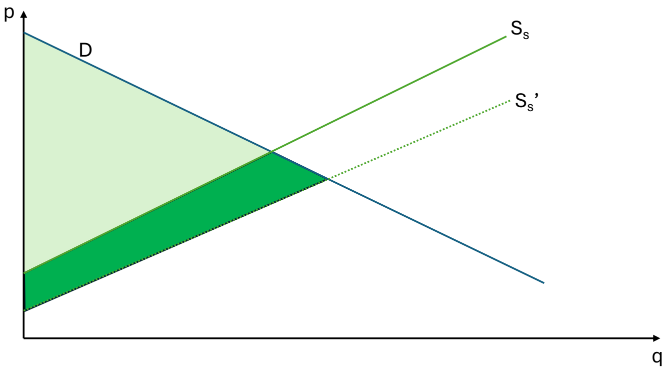
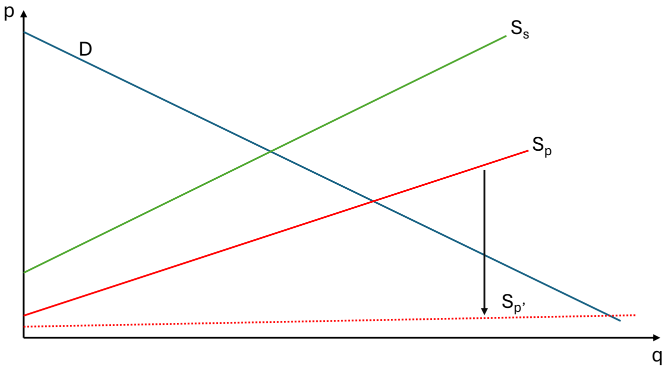
Exploration in a carbon-wise World



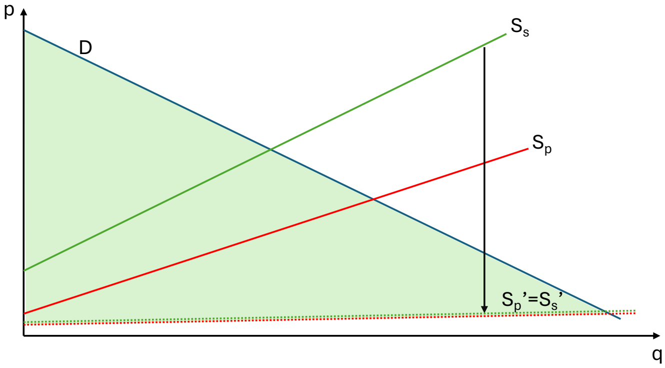
The social supply curve (that ranks oil deposits by their order of increasing **social** cost of production) goes down. Welfare increases (always) if GHG emissions are correctly priced, assuming no decentralization issues. Back

Exploration in a carbon-ignorant World



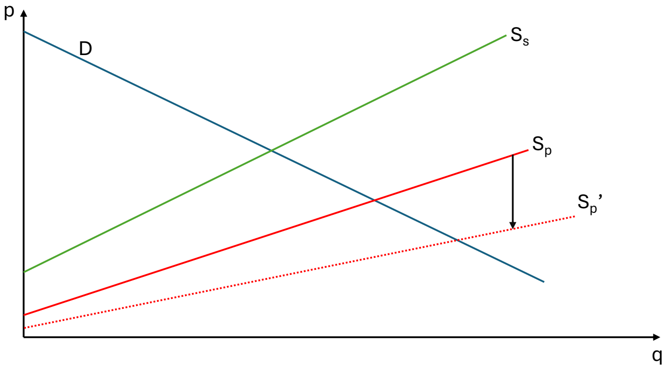
The private supply curve (that ranks oil deposits by their order of increasing **private** cost of production) goes down. ▸ Back

Exploration in a carbon-ignorant World



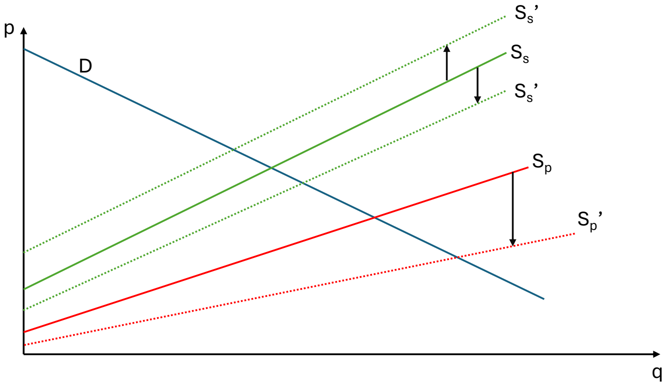
Here, exploration makes new cheap resources with no external cost enter the market, no more externality, welfare increases. The social cost curve associated with the private curves is now identical to the private cost curve. Back

Exploration in a carbon-ignorant World



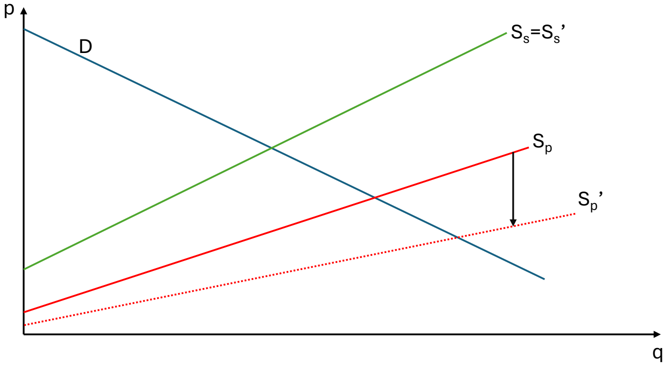
The private supply curve goes down. ▸ Back

Exploration in a carbon-ignorant World



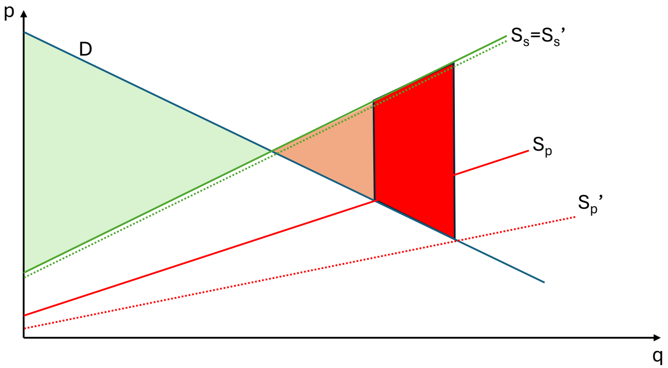
The associated social cost curve can go down or up. ▸ Back

Exploration in a carbon-ignorant World



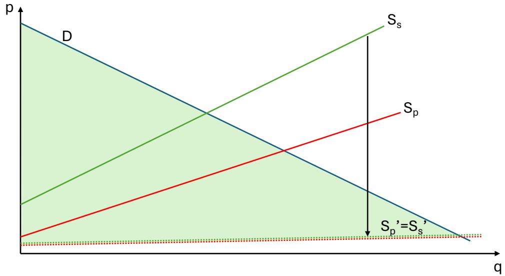
Assume the social cost curve does not move. Back

Exploration in a carbon-ignorant World

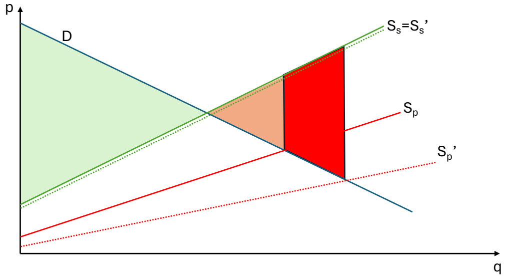


Here, exploration leads to larger market output that translates into larger welfare loss since the social cost per barrel is not reduced enough. ▸ Back

What to expect from exploration in a climate-ignorant World?



(a) An increase in Welfare?



(b) A decrease in Welfare?

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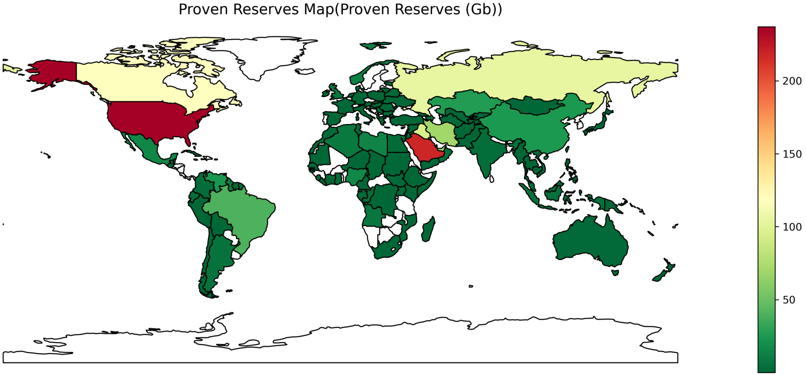
Proven Reserves in the World



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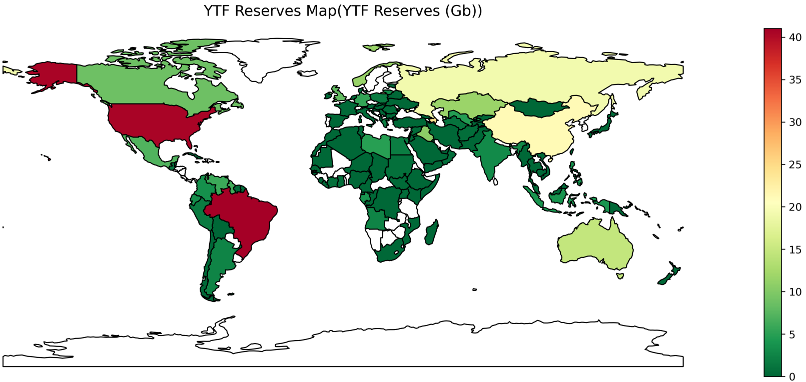
YTF in the World



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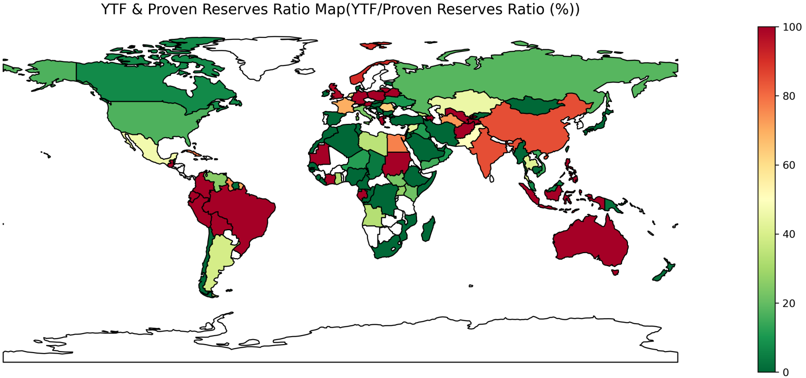
Ratio of YTF/Proven Reserves in the World



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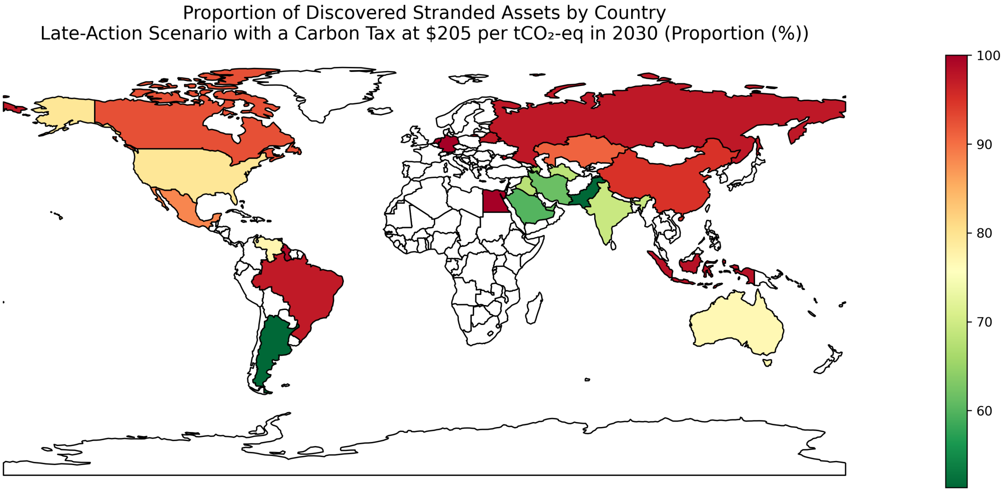
Stranded Assets



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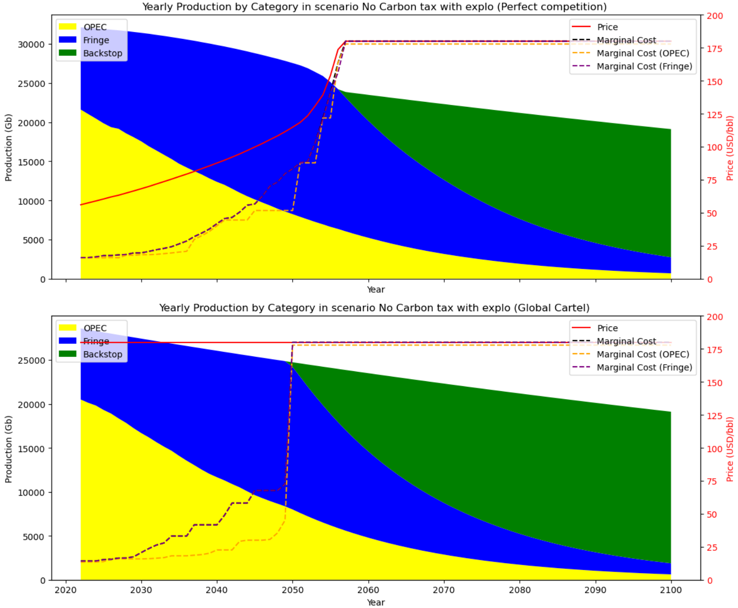
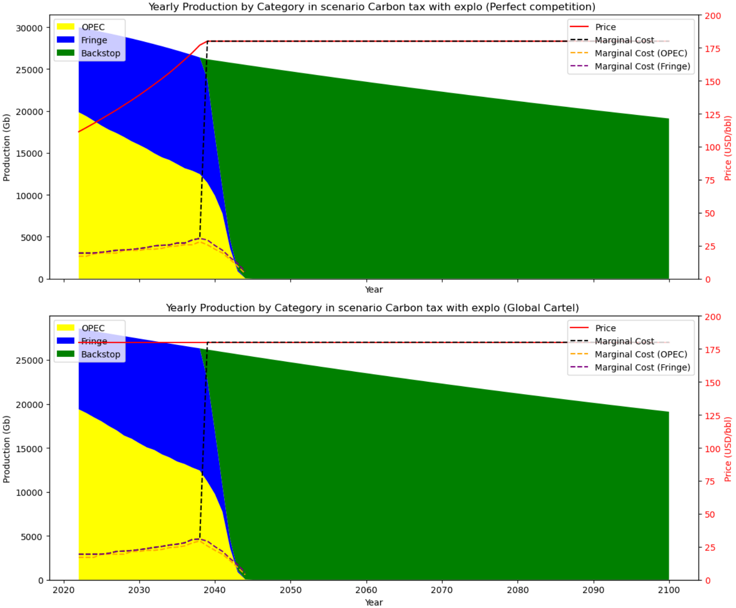
Market Power without a carbon tax



Market Power with a carbon tax



References I

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