Economics of Green Innovation and Emission Reduction:

Policy Design for the Energy Transition

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Motivation

- An overview of green investments (in billion USD).

	Green inv. 2024	Increase since 2020	Projected inc. by 2030	Projected inc. by 2040
USA	315	60%	45%	120%
EU	370	65%	50%	130%
China	675	85%	35%	160%
GCC	18	150%	120%	270%
Saudi Arabia	8	150%	130%	300%

- Sources:
  - International Energy Agency (IEA) and BloombergNEF.

Motivation

- China dominates green investments by volume.
- US and EU remain innovation leaders, but slower historical growth.
  - Most of the increase after 2020 is due to:
  - Inflation Reduction Act (US) and
  - Green Deal/Horizon Europe (EU).
- Gulf region started from a lower base, but grew extremely fast.
  - Saudi Vision 2030.
  - R&D by Aramco, PIF, ACWA, among others.
  - UAE energy transition programs.

Motivation

- Many green investments:
  - Renewables, \$690bn. in 2024, and increasing.

Motivation

- Many green investments:
  - Hydrogen energy, USD 4.3 bn. in 2024, but decreasing.

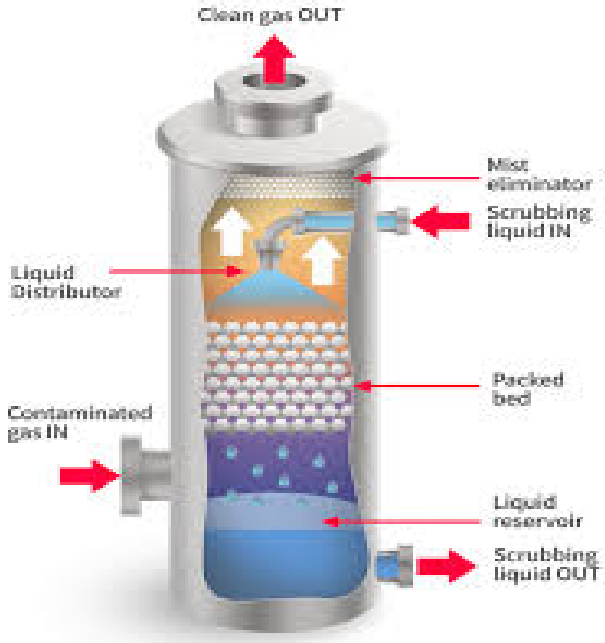
Motivation

- Many green investments:
  - Nuclear energy, \$75bn. in 2024, and increasing.

But, what about abatement?

What about abatement?

- Abatement:
  - Reducing emissions *without* replacing primary energy generation.
- Examples:
  - Carbon capture and storage.
  - Energy efficiency.
  - Grid/digital optimization technologies.



What about abatement?

- Abatement:
  - Often overlooked, yet they account for a large share.
- In 2024, for instance, it accounted for:
  - 20% of total green R&D in the US,
  - 25% in EU,
  - 18% in China,
  - 18% in GCC.

What about abatement?

- Extensively studied...
  - But only since 2007 and later.
  - Game Theory and Industrial Organization models.
- Seminal works by Poyago-Theotoky (2007) and Lambertini et al. (2017), among others.
  - Recent advances by my group of coauthors: 2021, 2022, 2023, 2025.

Outline of the presentation

- Abatement - An example
- Strategic effects
- ERCs and ERJVs
- Recent advances
- Policy implications

An example

- Consider an industry with two firms, 1 and 2.
- Every firm decides how much to invest in abatement, z.
- This investment reduces its emissions:
  - From $e = \alpha q$ (proportional to output)
  - to $e = \alpha q - z$ (reduced by abatement).
- Investments are costly, typically convex in z.
  - Further emission reductions are increasingly expensive.
- Then, firms make their output/price decisions.

An example

- Why do firms invest in abatement?
  - To lower their tax burden.
  - Higher z reduces $e = \alpha q - z$, for a given output q, lowering its net emissions.
  - As a result, the firm pays less in emission fees,

$$Tax = t \times e,$$

    where t denotes the per-unit emission fee.

    - If t remains constant, despite the lower emissions, the firm pays less in taxes (same t, lower e).
    - If t is adjusted downward, the pays even less in taxes (lower t and lower e).
- This provides the firm with lower costs (net of taxes)
  - Improving its competitiveness in later stages.

An example

- If fee t becomes less stringent in abatement, then
  - Free-riding incentives arise.
- In plain English:
  - Investing in abatement reduces my tax burden and yours!
  - Positive externality.
  - Firms ignore it, investing below the socially optimal amount ("too little").

An example

- What if there are spillover effects?
  - Then, emissions of firm 1 are

$$e_1 = \alpha q_1 - z_1 - \underbrace{\beta z_2}_{\text{New}}.$$

    (Same for firm 2).
- If $\beta = 0$, spillovers are absent.
- If $\beta \in (0, 1)$, spillovers are present:
  - A share β of your investments reduce my emissions.
  - Less incentives to invest in abatement.
- Empirically, spillovers are small.

Environmental Research Cartels

- We identified two incentives to underinvest.
  - Tax savings.
  - Spillovers.
- How to correct it?

Environmental Research Cartels

- Environmental Research Cartels (ERC):
  - Allowing firms to coordinate their abatement decisions, without sharing their innovations.
  - Legal cartel, but only for investment decisions.
  - Addresses the tax savings externality, but not that arising from spillovers.
- Environmental R&D Joint Ventures (ERJV):
  - Allowing firms to coordinate their abatement decisions and share their innovations.
  - The latter is equivalent to $\beta = 1$.
  - Addresses the tax savings externality and spillovers.

ERC - Policy implications

- Gulf economies could explicitly legalize ERCs.
  - Aramco, SABIC and petrochemicals coordinating their R&D decisions.
  - Particularly useful since green R&D is lower, relatively speaking.
  - Vision 2030 programs could incorporate ERC participation as an "approved collaboration mechanism."
- Formal framework for ERJVs.
  - Focusing on carbon capture in carbon-intense industries, where spillovers matter.

Recent Advances

Extensions

- The foundations were clear around 2017...
- But many questions were still open:
  - What if firms invest sequentially, rather than simultaneously, in abatement?
  - What if firms invest in both cost-reducing R&D and green R&D?
  - What if firms use only a share of their installed abatement capacity?
  - What if firms use their investment in abatement to influence merger approvals?

Being Green First:

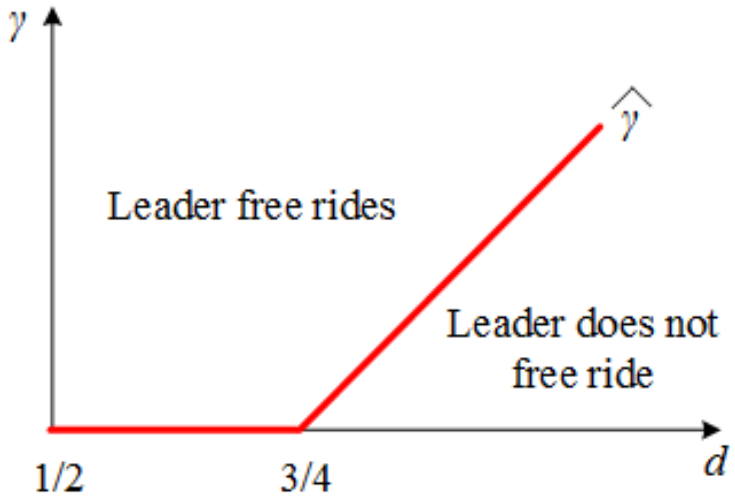
Simultaneous vs. Sequential Abatement Decisions

Sequential investments

- Abatement decisions are simultaneous in small investment projects (e.g., end-of-pipe scrubs).
- Sequential otherwise (e.g., cleaner machinery, filters, or clean-up after an oil spill).
- Examples of large investment projects abound:
  - They may take years to complete.
  - Allowing firms to observe its rival's abatement before choosing its own.

Sequential investments

- First-mover advantage.
- The benefit from investing in abatement stems from a less stringent fee in the next stage.
  - When the leader's cost of investment (γ) is lower than its benefit, the leader invests more than the follower.
  - Otherwise, the leader free-rides off the follower, investing less, which induces the follower to respond investing more.
- This free riding is attenuated by pollution severity, d.



Greener or Cheaper Goods?

Economies of Scope in Green R&D

Greener or Cheaper Goods?

- Firms investments in cost-reducing R&D are large and increasing:
  - $625 billion in the US and $310 billion in the EU; OECD.
- Environmental R&D (ER&D) has also increased,
  - Over $100 billion in 2024; IEA.
- Also applies to Saudi Arabia:
  - Petrochemicals, refining, and desalination engage in large cost-reducing investments.

Greener or Cheaper Goods?

- Each investment has separately received attention.
- But firms' simultaneous choice of R&D and ER&D has been largely overlooked.
  - Most chemical companies recognize investing in both.
  - Surveys by Potters and Grassano (2019).

Motivation

- Why not just analyze R&D and ER&D separately?
- We could...
  - If their marginal benefits and costs were additively separable.
  - In English:
    - If a larger investment in one didn't affect firms' incentives to invest in the other.
- But are they separable?

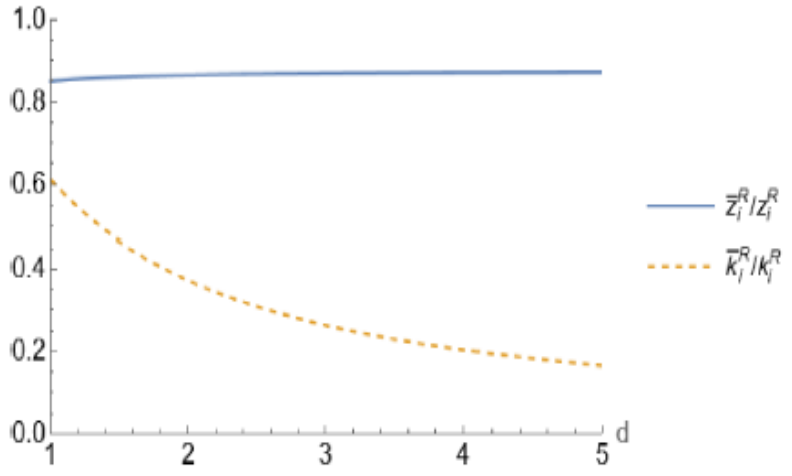
Motivation

- Benefits are likely not separable.
  - If firm 1 invests in R&D, it lowers its production costs, increasing pollution,
  - This triggers a more stringent emission fee,
  - ultimately increasing firms' incentives to invest in abatement.

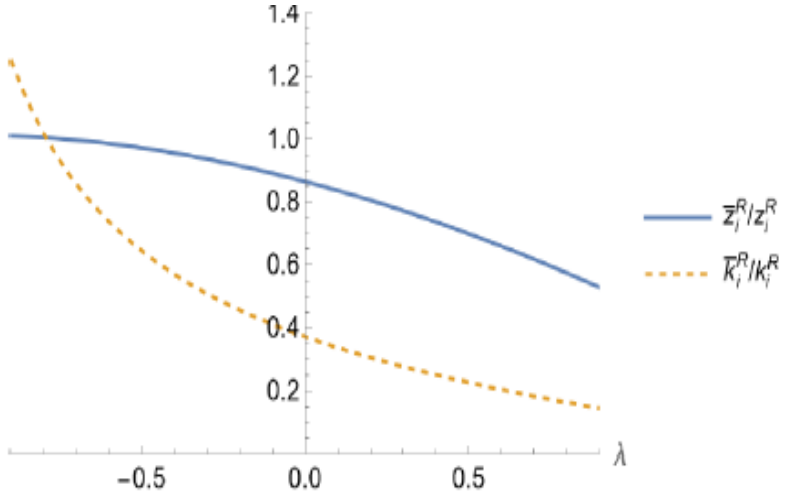
Motivation

- Costs may not be separable either:
  - Waterless dying technologies in the textile industry, Heida (2014).
  - Innovations originally developed to reduce emissions can also be used to reduce costs.
  - We refer to them as "economies of scope" in investments:
    - Investing in multiple forms of R&D is less costly than separately investing in each of them.
- For generality, we also allow for diseconomies of scope in investments.

Investment ratios



(a) Ratios $\overline{z}_i^R/z_i^R$ and $\overline{k}_i^R/k_i^R$ as a function of d.



(b) Ratios $\overline{z}_i^R/z_i^R$ and $\overline{k}_i^R/k_i^R$ as a function of λ.

Discussion

Three externalities:
First, assume no regulation:

1. Without econ. of scope.
    - An increase in k_i makes firm i more competitive.
    - Negative externality on its rivals.
2. Next, allow for econ. of scope.
    - An increase in abatement z_i helps firm i to lower its R&D costs.
    - The firm can, then, invest more in k_i.
    - Emphasizing the above negative externality (#1).

Discussion

Three externalities

3. Now, introduce regulation.
    - An increase in z_i lowers the stringency of fee t.
    - Positive externality on its rivals.

- The literature only considers #3,

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    - underestimate k_i,
    - anticipate less pollution, and
    - undertax.

Discussion

Undertaxation.

- It arises even in the absence of economies of scope, $\lambda = 0$.
  - In that setting, #2 does not exist,
  - but #1 still gives rise to higher k_i, output, and pollution than in traditional models.
  - The regulator, then, responds with a fee that is too lax.
- When economies of scope are present, #2 arises.
  - Leading firms to invest more in both, but specially in abatement.
  - This attenuates the magnitude of undertaxation.

Discussion

Practitioners:

- When is undertaxation the largest?
  - When pollution is severe,
  - cost of R&D or ER&D is low, or
  - when industry is less competitive.
- Otherwise, ignoring the multiplicity of investments generates small inefficiencies.

Abatement Capacity and Usage Decisions

Motivation

- In many industries, usage costs for abatement are large.
  - Scrubbers for acid gas control face annual operating costs exceeding $500k for reagents, water treatment, and fan power.
- EPA reports unused end-of-pipe controls, such as wet scrubbers and bag-houses in coal-fired power plants, cement, and chemical industries.
- The literature has assumed full utilization, as if usage costs were negligible.
  - And if firms invested according to installation+usage costs, we shouldn't observe capacity sitting idle.

Motivation

- Why does it matter?
  - Several firms report partial use of installed abatement.
  - Regulators that incorrectly assume full use could set too lax emission fees...
    - leading to socially excessive pollution.

Results

- When installation costs are expensive:
  - We show that full capacity arises in equilibrium.
  - We can, then, identify under which conditions the literature was "right" by assuming full usage.
- When installation costs are less expensive:
  - We find partial usage in equilibrium.
  - Firms consider a "portfolio" of investment and usage pairs...
  - seeking to keep their *net abatement* constant across scenarios.

Results

- Subsidies:
  - They may increase abatement installation
  - But reduce usage,
  - Leading to no significant changes in total emissions.
- Saudi Arabia could condition subsidies:
  - To usage levels.
  - Not just installed capacity.
  - Digital monitoring.
  - Carbon capture in Vision 2030 could be tied to captured CO_2, not just installed capacity.

Abatement Thresholds:

How Merger Prospects Affect Green Investments

Motivation

- In several high-profile mergers, firms increased their green investments years before submitting the merger request.
  - Siemens invested $1.2 billion in offshore wind R&D during 2015-16,
    - prior to its merger with Gamesa in April 2017.
  - Danish Ørsted invested $1.5 billion in US wind and solar projects in 2016,
    - before merging with Lincoln Clean Energy in Aug 2018.
  - Schneider Electric invested $800 million in smart grid and energy efficiency in 2017,
    - before merging with L&T in 2018.

Motivation

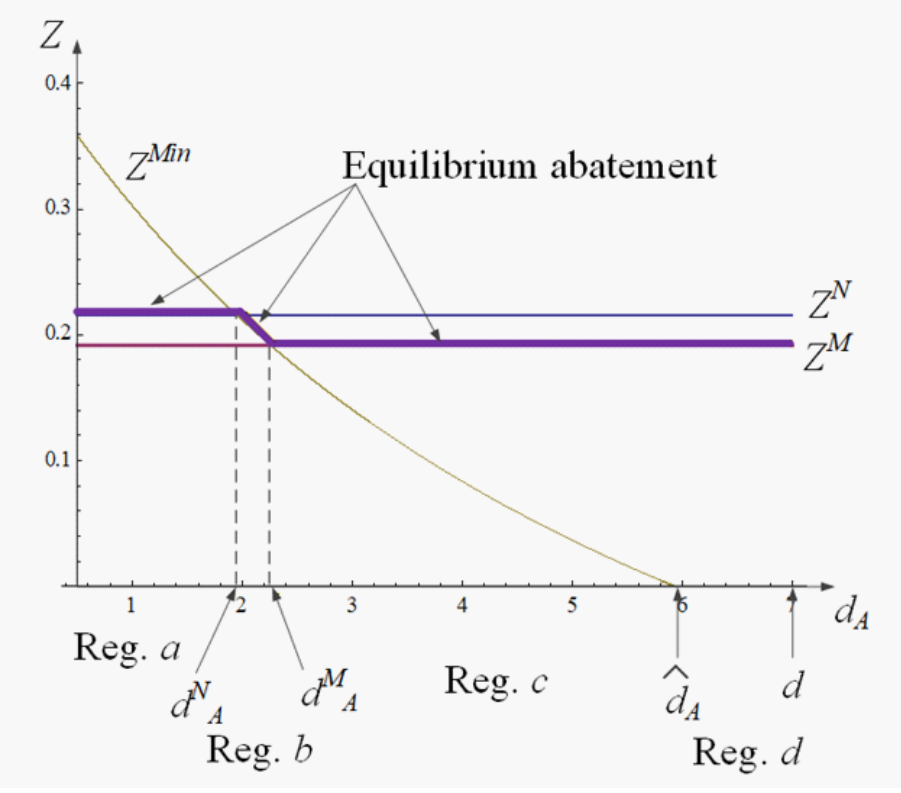
- Firms often portray these investments as part of their larger "sustainability goals."
  - But can there be another reason?
- We show that these investments influence antitrust evaluations,
  - improving the chances of mergers being approved.

Motivation

- We consider the following time structure:
  - In the first stage, every firm invests in abatement.
  - In the second stage, the EPA sets a per-unit emission fee.
  - *In the third stage, firms decide whether to submit a merger request to the antitrust authority (AA).*
  - *In the fourth stage, the AA approves/block the merger.*
  - In the fifth stage, firms compete.
- New stages *in italics*.

Motivation

- We show the presence of "abatement thresholds":
  - The AA approves the merger only when total industry abatement exceeds a minimum amount.
  - When the AA assigns a moderate weight on pollution.


Z
0.4
0.3
0.2
0.1
Z^{Min}
Equilibrium abatement
Z^N
Z^M
1
2
3
4
5
6
7
d_A
Reg. a
d^N_A
d^M_A
Reg. b
Reg. c
$\hat{d}_A$
d
Reg. d

Motivation

- Results draw a parallel with public good games with threshold effects.
  - Larger abatement induces less stringent emission fees
    - Like donations from one indiv. increase the total public good.
  - Greater abatement facilitates merger approvals.
    - Like contributions are only matched if aggreg. donations meet the threshold.
- Latter effect is new in the environmental econ literature.
  - Ameliorates free-riding incentives in abatement.
  - Robust to extensions.

Implications - Env. policy

- Abatement is higher when firms anticipate a potential merger.
  - Requiring less stringent emission fees.
- In other words:
  - If the EPA ignored merger prospects...
  - it would set socially excessive fees.

Implications - Merger policy

- When the AA places a moderate weight on pollution:
  - Abatement increases.
- If the AA assigns a high weight on pollution:
  - (Still lower than the EPA, but high)
  - investment behavior is unaffected.

Implications - Merger policy

- Our results help inform current debate about merger guidelines.
- What merger guidelines should countries follow?
  - E.U., Australia, and Japan, Hanawalt et al. (2024).
  - *Partial*, not full, regulatory alignment between agencies is the most effective at increasing abatement.
- Saudi's General Authority for Competition (GAC) could:
  - Adopt explicit welfare criteria when reviewing mergers...
  - But not assign the same weight as the Energy Ministry (MEWA).
  - Increasing firms' incentives to invest in green technologies.

Are we done?

No, many research lines are still open!

Other research lines

- Firm heterogeneity:
  - Allowing for asymmetric abatement efficiencies.
- Spillovers:
  - Input spillovers (using tech. from other firms) and output spillovers (free-riding the outcome/innovation of other firms).
- Disruptive investments:
  - Investing in abatement may affect my production costs.
- Allowing for investments in climate adaptation.
- Allowing for mixed oligopolies (public and private firms).
- Patenting or licensing green innovations.

Thank you!