Who Should Drive Green Technology Transitions in Developing Countries: State-Owned Enterprises versus Private Firms

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Introduction: The Problem I

- Technological change essential to avoid severe climate change.
- Green technological change is mostly driven by r&d activities in a small number of (high-income) countries (Dechezleprêtre et al. 2011, Dutz and Sharma 2012, Napolitano et al. 2022).
  - For example: Japan, the U.S., South Korea, Germany, China accounted for roughly 87% of all green patent fillings between 2015-2020 (Sagacious IP 2021).
- However, green technologies can benefit from adaptation to local contexts.
  - Wind turbines on-shore vs. off-shore (preventing erosion) vs. high altitudes (preventing ice formation on rotors)
  - PV installations in high humidity regions (preventing algae formation).
- Domestic companies are often best suited to conduct local adaptations.

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- Many developing countries face the question whether green technological change should be driven by **private firms (POE)** or **state-owned enterprises (SOE)**.
- Often, there is a large incumbent invested in brown technologies (e.g., coal-fired power plants) who could drive the transition to green technologies (incl. adaptation); in some countries this is an SOE, in some it is a POE.
- A POE is typically more efficient but might have wrong incentives; simple policy instruments are usually not sufficient to correct those.
- an SOE is inefficient but more easily controlled.

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Introduction: Preview Findings

- This leads us to the following research question:
  When should we use an SOE or a POE, if a green technology transition could benefit from local adaptation and policy choice is restricted?

- Our key findings:
  - Depending on the setting, both policy options can be beneficial.
  - As expected, the degree of inefficiency is important.
  - However, it is also crucial that different market structures evolve under the two policy options.
  - → With private firms, there is a risk of no investment or overinvestment in r&d, due to strategic behavior.
  - → With an SOE, r&d investments are more often socially optimal, but production is inefficient.

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Outline

Related Literature

- Three related strands of literature:
  (1) Innovation & technology diffusion, (2) environmental policy, and (3) public firms.
- Amongst (3), our paper is most related to the literature on *mixed oligopoly models*, i.e. markets with private and public firm competition.[1]
- Few of those consider environmental aspects (e.g. Bárcena-Ruiz and Garzón 2006), even fewer include green technological change (e.g. Haruna and Goel 2019, Ouattara et al. 2019).
- Most mixed oligopolies compare private and public firms with similar policies present in both cases.
- Our model captures
  - changing market structures
  - different kinds of actors
  - (temporary) co-existence of green and brown technologies, and
  - strategic interactions (Arrow's replacement effect)

[1] See De Fraja and Delbono 1990 for a review on mixed duopoly models.

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General Setting

- We build on the green technology transition model framework developed in Bondarev, Dato, and Krysiak 2021.
- The framework models a technology market with two products: an emission-free/green and polluting/brown technology.
- The brown technology has a quality normalized to 1.
- In our paper, the green technology exists in an international version (quality k_0), which can be adjusted to local conditions (at most $k_0 + \Delta \leq 1$).
- Use of the brown technology generates an external damage d per unit.

Demand I

- There is a continuum of consumers (m) with heterogeneous net-utility $u_j(m)$ from using the brown technology ($j = b$) or the green technology ($j = g$) given the prices p_j.

$$u_b(m) = 1 - m - p_b, \quad u_g(m) = (k_0 + \delta) - \alpha\, m - p_g$$

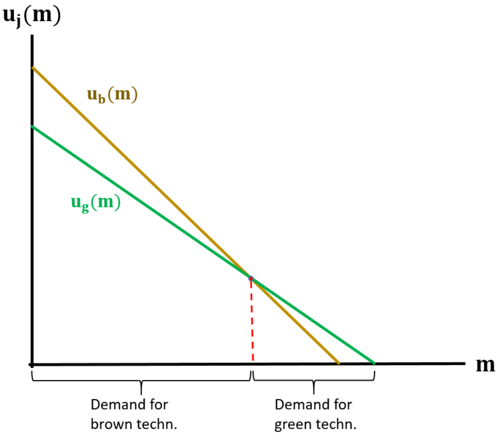
- $0 < \alpha < 1$ describes a market expansion potential.

- $\delta \in \{0, \Delta\}$ is the adaptation level chosen at the adaptation stage.

- Consumers purchase the version of the technology that yields the highest net-utility.

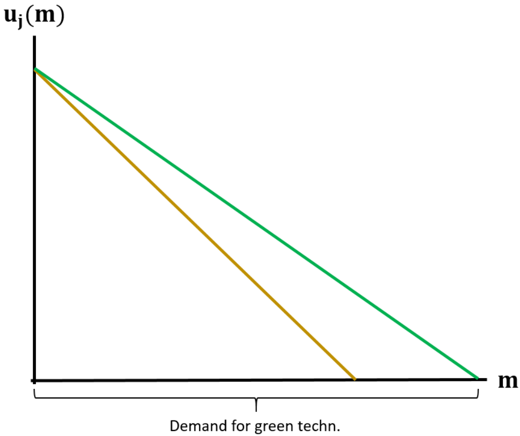
Demand II

$$u_b(m) = 1 - m - p_b, \quad u_g(m) = (k_0 + \delta) - \alpha\, m - p_g$$



Demand III

$$u_b(m) = 1 - m - p_b, \quad u_g(m) = (k_0 + \delta) - \alpha\, m - p_g$$



Supply I

- The brown technology is offered by an incumbent exclusively.
- The green technology can be offered by three types of firms:
  - import without adaptation (perfect competition)
  - adaptation done by incumbent
  - adaptation done by a private entrant
- We distinguish two policy settings:
  - the incumbent is a welfare-maximizing SOE incumbent.
  - the incumbent is a profit-maximizing private firm facing an emission tax t.

Timing

1. Decision between POE and SOE
2. For the POE case, regulator sets the second best tax.
3. **Adaptation stage:** Incumbent is a Stackelberg leader.
4. **Product market stage:** Monopoly, Cournot or perfect competition.

Supply II

- Profits of incumbent (SOE / POE) and entrant are respectively given by

$$\pi_i^{SOE} = (p_b - c - c_s)q_b + (p_g - c - c_s)q_{gi} - \gamma\,\delta_i,$$

$$\pi_i^{POE} = (p_b - c - t)q_b + (p_g - c)q_{gi} - \gamma\,\delta_i$$

and

$$\pi_n = (p_g - c)q_{gn} - \gamma\,\delta_n,$$

where $c_s > 0$ represents the inefficiency of the SOE and $\gamma > 0$ is an adaptation cost parameter.

- Welfare is simply the sum of producer and consumer surplus (and tax revenue) minus environmental damages.

Product Market Stage

Proposition 1. *Given the qualities of the green technology ($k_0 + \delta_i$, $k_0 + \delta_n$, k_0), the following market outcomes are possible: [...]*

Table 1: *Set of market structures*

	brown techn. available		brown techn. phased out	
	$q_b > 0, q_{gi} = 0$	$q_b > 0, q_{gi} > 0$	$q_{gi} > 0, q_b = 0$	$q_{gi} = q_b = 0$
$q_{gn} = 0,\ q_{gf} = 0$	**Case 0** Brown techn. only, Incumbent monopoly	**Case 3** Incumbent monopoly	**Case 5** Incumbent monopoly	**Case 9** No market
$q_{gn} > 0,\ q_{gf} = 0$	**Case 2** Entrant supplies green techn., Incumbent supplies brown techn.	**Case 1** Duopoly, Incumbent supplies brown techn.	**Case 4** Duopoly	**Case 6** Entrant monopoly
$q_{gn} = 0,\ q_{gf} > 0$	**Case 7** Importers supply green techn., Incumbent supplies brown techn.	-	-	**Case 8** Perfect comp.

SOE Adaptation Stage I

Proposition 2.

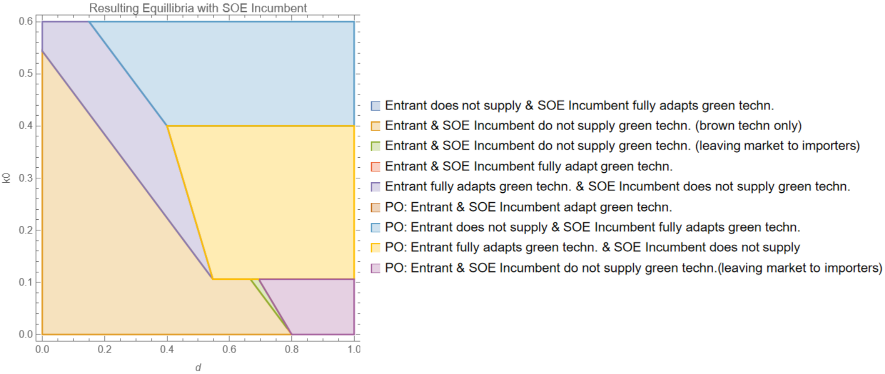
1. *There is never a shared market, only one type of actor (SOE, private entrant, importing firms) supplies the green technology.*
2. *If* $k_0 < \alpha\,(1 - c_s - d)$*, only the brown technology is supplied.*
3. *If* k_0 *is very small, i.e.* $k_0 < -\Delta + \alpha\left(1 - c_s - d + \frac{\sqrt{\frac{\gamma_1\,\Delta}{\alpha}}}{2-\alpha}\left(4\,(1-\alpha) + \alpha^2\right)\right)$*, the green technology is imported without adaptation.*
4. *If* k_0 *is greater but still small, i.e.,* $k_0 < \alpha\,(1-d) + c_s\,(1-\alpha)\,(4 + \Delta - \alpha\,(2-\alpha)\,\sqrt{\frac{3-\alpha}{1-\alpha}})$*, the technology is supplied in an adapted version by private entrants.*
5. *In all other cases, the green technology is supplied in an adapted version by the SOE.*

SOE Adaptation Stage II

Proposition 2. (continued)

6. *The brown technology is still supplied if and only if*
   - $d < 2\,(1 - c_s)$, *whenever only the brown technology is supplied.*
   - $d < 2\,(1 - c_s - k_0)$, *whenever the green technology is imported without adaptation,*
   - $d < 2\,(1 - c_s - \frac{k_0 + \Delta}{2})$, *whenever the green technology is provided in an adapted version by private entrants,*
   - $d < 2\,(1 - k_0 - \Delta)$, *whenever the green technology is provided in an adapted version by the SOE.*

SOE Adaptation Stage III



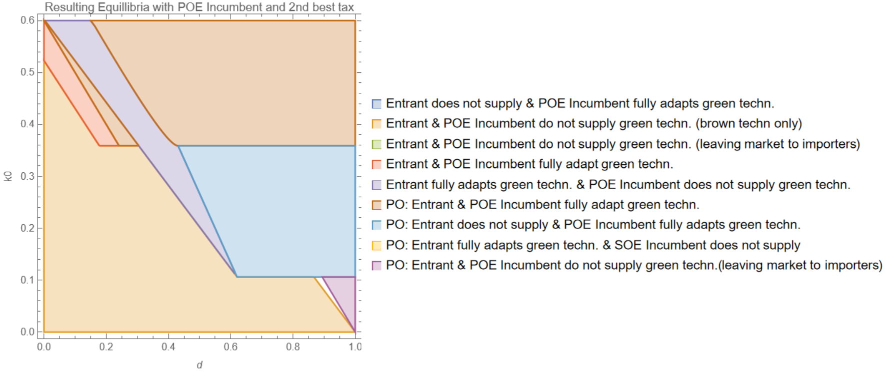
$$\alpha = \frac{4}{5}, \quad c_s = \frac{1}{5}, \quad \Delta = \frac{2}{5}, \quad \gamma = \frac{1}{5}$$

POE Adaptation Stage I

Proposition 3.

1. *Entrant and incumbent share the green technology market (brown techn. still available) if* $max\{\frac{3\,\alpha}{1+2\alpha}(1-d), 3\sqrt{\alpha\,\gamma\,\Delta}-\Delta, \underline{\underline{k_o}}\} < k_0 < min\{1-d-\Delta, 2\Delta\}$.
2. *Only the entrant adapts and supplies the green technology market (brown techn. still available) if* $max\{\underline{k_0}, \frac{2-3\,\alpha}{2}\Delta+\alpha\,(1-\Delta)\} < k_0 < min\{\underline{\underline{k_o}}, \frac{4}{3}(1-d)-\Delta\}$.
3. *Only the incumbent adapts and supplies the green technology market (brown techn. still available) if* $max\{\underline{\underline{k_0}}, \frac{2\alpha}{1+\alpha}(1-d)\} < k_0 < min\{1-d-\Delta, \Delta, 3\sqrt{\alpha\,\gamma\,\Delta}-\Delta\}$.
4. *None of the two firms adapts and supplies the green technology (brown techn. still available) if* $k_0 < min\{\underline{k_0}, \underline{\underline{k_0}}, \frac{2\alpha}{1+\alpha}(1-d)-\Delta, \alpha\,(1-d)\}$.

POE Adaptation Stage II



$$\alpha = \frac{4}{5}, \quad c_s = \frac{1}{5}, \quad \Delta = \frac{2}{5}, \quad \gamma = \frac{1}{5}$$

Welfare and Policy Comparison I

Proposition 4.

1. *If the incumbent does not supply the green technology in both options, using a POE is always as least as good as the SOE outcome.*
2. *The same holds, if the POE is forced (by competition of direct importers) to supply the green technology in a quantity that results in a price equal to marginal costs.*
3. *If the POE option results in a shared market with an entrant, the welfare ranking of both options depends on the costs of innovation (γ) relative to the production inefficiency of the SOE (c_s):*
   - 3a. *If the SOE supplies the green technology, the POE option is advantageous, whenever*

     $A_7 < c_s < A_8$
   - 3b. *If the SOE lets the entrant supply the green technology, the POE option is advantageous, whenever*

     $A_9 < c_s < A_{10}$

Definitions of $A_7 - A_{10}$

Welfare and Policy Comparison II

Proposition 4. (continued)

4. *In all other cases, there is a threshold $\bar{c}$ for the production inefficiency of the SOE (c_s), so that for $c_s < \bar{c}$, welfare is higher in the SOE option and the opposite holds for $c_s > \bar{c}$. The thresholds that are relevant for the different cases are specified in Table 3 (see Appendix).*

Conclusion

- We use a theoretic model to investigate whether (and under what conditions) a green technology transition with local adaptation should be driven by a relatively inefficient SOE or a POE under second best regulation.
- We show that this does not only depend on the degree of inefficiency, but also on the different market structures that arise under both options.
- There are indeed cases where a inefficient SOE incumbent is preferable: It sets prices more aggressively leading to higher diffusion, avoids wasteful overinvestment into innovation, and does not protect sales of the brown technology.
- Our results could be especially relevant for applications where either market power is important (as in the energy markets of many countries) or where high gains can be expected from adapting technologies (which induces too many firms to exert r&d efforts).

Thank you for your attention.

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Appendix I

- We define: $\underline{k_0} = \{k_0 : A_1 = 0\}$, $\underline{\underline{k_0}} = \{k_0 : A_2 = 0\}$, and $\underline{\underline{\underline{k_0}}} = \{k_0 : A_3 = 0\}$
- Further,

$$A_1 := \Delta\left(8\,k_0 - \alpha(4-3\,\alpha)^2\gamma - 8\alpha(1-d)\right) + 4\,(k_0 - \alpha(1-d))^2 + 4\,\Delta^2,$$

$$A_2 := \frac{4\alpha(1-d)^2 + (\Delta+k_0)(\alpha\,(3\Delta-8\,(1-d)) + \Delta + 3\,\alpha\,k_0 + k_0)}{4\,(1-\alpha)\,\alpha} - (1-d)^2,$$

$$A_3 := \frac{1}{9(1-\alpha)\,\alpha}[\Delta(8\alpha\Delta + 9\alpha(-(1-\alpha)\gamma - 2(1-d)) + \Delta) + 9\alpha(1-d)^2 + 2k_0(\alpha(8\Delta - 9(1-d)) + \Delta) + (8\alpha+1)k_0^2] - \frac{(+3\Delta + 3\,k_0 - 4\,(1-d))^2}{(4-3\,\alpha)^2}$$

- and

$$A_4 := \frac{9\,(4-\alpha)\,\alpha\left((1-d-k_0-\Delta)^2 - 2\,\Delta\,(1-\alpha)\,\gamma\right) + (1-\alpha)\,(\alpha+5)\,(k_0+\Delta)^2}{1-\alpha}$$

Back to Back to Proposition 3

Appendix II

- We define:

$$A_4 := \frac{9\,(4-\alpha)\,\alpha\,\Big((1-d-k_0-\Delta)^2-2\,\Delta\,(1-\alpha)\,\gamma\Big)+(1-\alpha)\,(\alpha+5)\,(k_0+\Delta)^2}{1-\alpha}$$

- and

$$A_7 := k_0 + \Delta - \frac{\sqrt{2}}{3}\sqrt{4\,(k_0+\Delta)^2 - 9\,\alpha\,\gamma\,\Delta}$$

$$A_8 := k_0 + \Delta + \frac{\sqrt{2}}{3}\sqrt{4\,(k_0+\Delta)^2 - 9\,\alpha\,\gamma\,\Delta}$$

$$A_9 := 1 - d - (k_0+\Delta)\,\frac{(3-\alpha)}{4-\alpha} - \frac{(2-\alpha)\,\sqrt{A_4}}{3\,\alpha\,(4-\alpha)}$$

$$A_{10} := 1 - d - (k_0+\Delta)\,\frac{(3-\alpha)}{4-\alpha} + \frac{(2-\alpha)\,\sqrt{A_4}}{3\,\alpha\,(4-\alpha)}$$

Back to Back to Proposition 4