The Cost-Effective Choice of Policy Instruments to Cap Aggregate Emissions with Costly Enforcement[1]

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  - minimize aggregate abatement costs of reaching any chosen cap
  - with minimum information requirements for regulators.
- But abatement costs are not the only social costs of capping emissions:
  - + cost of monitoring compliance
  - + cost of sanctioning detected violations
- The literature has not yet given a definite answer on the relative cost-effectiveness of tradable permits vs. emission standards when enforcement costs are brought into the picture.

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- Stranlund (2007) seems to be the first to have addressed this issue of whether it is cost effective to induce compliance or not, in the context of tradable permits
- Stranlund: a regulator could always decrease the costs of a permits program that allows non-compliance with an increasing marginal penalty, by inducing full compliance with a constant marginal penalty.

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- She concludes: "linear penalties are socially preferred and the optimal policy induces compliance" (p. 155).
- Fails to illustrate how does the regulator need to allocate emissions responsibilities and monitoring efforts among different firms in order to minimize the total cost of the pollution control program.

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- under different assumptions of the penalty structure.

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  - the cost-effective design of a program that caps aggregate emissions of a given pollutant from a set of firms based on emissions standards is one in which standards are *firm-specific and perfectly enforced*.
  - an optimally designed system of tradable permits minimizes the **total** expected costs of attaining a certain level of aggregate emissions only under very special circumstances.

4. THE COST-EFFECTIVENESS OF INDUCING PERFECT COMPLIANCE IN A SYSTEM OF EMISSION STANDARDS

- We first present the standard model of compliance behavior of a risk - neutral polluter firm under an emission standard (See Malik 1992; Harford 1978)

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- We then present the problem that a total cost minimizing regulator solves, taking into account the firms' best responses.
- From this problem we derive the condition under which it is cost-effective for the regulator to induce perfect compliance.

4. THE COST-EFFECTIVENESS OF INDUCING PERFECT COMPLIANCE - EMISSION STANDARDS

4.1. A firm compliance behavior under an emission standard

- The (minimum) abatement cost function for firm i, is $c_i(e_i)$, where e_i is its level of emissions, $[c_i'(e_i) < 0$ and $c_i''(e_i) > 0]$

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- The firm is audited with probability π_i.
- If the firm is audited and found in violation, a penalty $f(v_i)$ is imposed.
- Following Stranlund (2007), throughout we assume that the structure of the penalty function is $f(e_i - s_i) = \phi(e_i - s_i) + \frac{\gamma}{2}(e_i - s_i)^2$, with $\phi > 0$ and $\gamma \geq 0$.

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  - otherwise, $e_i(s_i, \pi_i) > s_i$, where $e_i(s_i, \pi_i)$ is the solution to $-c_i'(e_i) = \pi_i f'\left(e_i - s_i\right)$.

4. THE COST-EFFECTIVENESS OF INDUCING PERFECT COMPLIANCE - EMISSION STANDARDS

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- The regulator's problem is:

$$\min_{\substack{(s_1,s_2,..,s_n)\\(\pi_1,\pi_2,..,\pi_n)}} E\left[\sum_{i=1}^{n} c_i(e_i) + \sum_{i=1}^{n} \mu_i \pi_i + \sum_{i=1}^{n} \beta_i \pi_i f(e_i - s_i)\right]$$

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- where:
  - $E[\cdot]$ denotes the regulator's subjective expected value of the program costs
  - μ_i being the cost of inspecting plant i
  - β_i : the cost of sanctioning plant i, per dollar of fine

- Subject to:

$$
\begin{aligned}
e_i &= \bar{e}_i(s_i, \pi_i) \\
\sum_{i=1}^{n} \bar{e}(s_i, \pi_i) &= E \\
s_i &\leq e_i \ \forall i = 1, \ldots n
\end{aligned}
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- From the solution to the regulator's problem we obtain:

4. THE COST-EFFECTIVENESS OF INDUCING PERFECT COMPLIANCE - EMISSION STANDARDS

- **Proposition 1** *When the penalty structure is given, the cost-effective design of a pollution control program that caps aggregate emissions using emissions standards calls the regulator to induce all firms to comply with the standards if and only if*

$$\mu_i \frac{f''(0)}{f'(0)} \leq \beta_i f'(0) \tag{2}$$

for all i. If this condition is not met and the regulator wants to achieve the cap cost-effectively, it should induce those plants for which $\mu_i \frac{f''(0)}{f'(0)} > \beta_i f'(0)$ to violate the emission standards.

5. Characterization of a total cost minimizing program based on emission standards when it is cost-effective to induce perfect compliance

- When the penalty structure is exogenously given to the regulator, and condition (2) dictates that it is cost-effective to induce perfect compliance the optimal policy $(\pi_1^*, \pi_2^*, ...\pi_n^*, s_1^*, s_2^*, ...s_n^*)$ that induces expected compliance is characterized by:

$$E\left[c_i'(s_i^*)\right] + \mu_i \frac{d\pi_i^*}{ds_i} = E\left[c_j'(s_j^*)\right] + \mu_j \frac{d\pi_j^*}{ds_j}, \text{ for all } i \neq j, (i,j) = 1, ..., n \tag{3}$$

$$\text{and } \pi_i^* = \frac{E\left[-c_i'(s_i^*)\right]}{f'(0)}, \text{for all } i = 1, ..., n.$$

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- a result obtained by Chávez, et al. (2009) and Malik (1992)

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- When (2) does not hold:
- **Proposition 2** *If the optimal policy* $(\pi_1^*, \pi_2^*, ...\pi_n^*, s_1^*, s_2^*, ...s_n^*)$ *induces non compliance for all firms, it is characterized by*

$$E\left[c_i'(\bar{e}_i)\right] + \beta_i \pi_i^* f'(\bar{e}_i - s_i^*)\left(\frac{\partial \bar{e}_i/\partial s_i - 1}{\partial \bar{e}_i/\partial s_i}\right) = \tag{4}$$

$$E\left[c_j'(\bar{e}_j)\right] + \beta_j \pi_j^* f'(\bar{e}_j - s_j^*)\left(\frac{\partial \bar{e}_j/\partial s_j - 1}{\partial \bar{e}_j/\partial s_j}\right)$$

$$E\left[c_i'(\bar{e}_i)\right] + \frac{\mu_i}{\partial \bar{e}_i/\partial \pi_i} + \frac{\beta_i f(\bar{e}_i - s_i^*)}{\partial \bar{e}_i/\partial \pi_i} + \beta \pi_i^* f'(\bar{e}_i - s_i^*) = \tag{5}$$

$$E\left[c_j'(\bar{e}_j)\right] + \frac{\mu_j}{\partial \bar{e}_j/\partial \pi_j} + \frac{\beta_j f(\bar{e}_j - s_j^*)}{\partial \bar{e}_j/\partial \pi_j} + \beta \pi_j^* f'(\bar{e}_j - s_j^*)$$

for all $i \neq j$, $(i,j) = 1, ..., n$.

5. Characterization of a total cost minimizing program based on emission standards when it is cost-effective to induce non-compliance

- Furthermore:

$$\frac{\mu_i}{\partial \bar{e}_i / \partial \pi_i} + \frac{\beta_i f(\bar{e}_i - s_i^*)}{\partial \bar{e}_i / \partial \pi_i} = -\frac{\beta_i \pi_i^* f'(\bar{e}_i - s_i^*)}{\partial \bar{e}_i / \partial s_i} \tag{6}$$

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  for all $i = 1, ..., n$.

- We can conclude that the cost-effective level of emission standards are firm-specific whenever abatement and/or enforcement costs differ among firms.

6. The cost minimizing design of a program based on emission standards

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- The result of this comparison is given in the next Proposition:

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- **Proposition 3** *The optimal policy* $(s_1^*, s_2^*, ..., s_n^*, \pi_1^*, \pi_2^*, ...\pi_n^*, f^*)$ *induces compliance and it is characterized by*

$$(1)\ E\left[c_i'(s_i^*)\right] + \mu_i \frac{d\pi_i^*}{ds_i} = E\left[c_j'(s_j^*)\right] + \mu_j \frac{d\pi_j^*}{ds_j} \text{ for all } i, j = 1, ..., n,\ i \neq$$

$$(2)\ \pi_i^* = \frac{E\left[-c_i'(s_i^*)\right]}{f'(0)} \text{ for all } i = 1, .., n,$$

$$\text{and } (3)\ f^* = \phi(e_i - s_i) + \frac{\gamma}{2}(e_i - s_i)^2 \text{ for all } i,$$

$$\text{with } \phi \text{ set as high as possible and } 0 \leq \gamma \leq \min\left[\frac{\beta_i}{\mu_i}\right] \times \phi^2$$

7. Comparing costs of emission standards and tradable permits

- We have seen that the optimal design of a program based on emissions standards is one in which standards are firm-specific (set according to Proposition 3) and perfectly enforced with a fine structure that can be linear or increasing in the margin, as long as ϕ is set as high as possible and condition (2) holds.

7. Comparing costs of emission standards and tradable permits

- We have seen that the optimal design of a program based on emissions standards is one in which standards are firm-specific (set according to Proposition 3) and perfectly enforced with a fine structure that can be linear or increasing in the margin, as long as ϕ is set as high as possible and condition (2) holds.
- We know from Stranlund (2007) that the optimal design of a program based on tradable permits is one in which the program is perfectly enforced, where every firm is audited with a homogeneous probability $\pi^* = \frac{\bar{p}}{\phi}$ for all i, with $\bar{p}$ being the expected full-compliance equilibrium price of the permits market and $\phi = f'(0)$.

7. Comparing costs of optimally designed emission standards and tradable permits

- **Proposition 4** *A regulator that wants to cap the aggregate level of emissions of a given pollutant from a set of firms will minimize the total expected costs of doing so by implementing firm-specific emissions standards and perfectly enforcing this program according to Proposition 3. A system of tradable permits minimizes the total expected costs of such a pollution control program only if* $\mu_i = \mu_j$ *for all* $i \neq j$, $(i, j) = 1, .., n$.

8. Comparing costs of emission standards and tradable permits when it is cost-effective to induce non-compliance

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- Assume that $\mu_i\gamma > \beta_i\phi^2$ for all i.
- How do the cost of a program based on emission standards compare with one based on tradable permits?
- **Proposition 5** *If a regulator wants set a cap on the aggregate level of emissions of a pollutant and it is cost-effective to induce all firms to violate the regulation ($\mu_i\gamma > \beta_i\phi^2$ for all i), it will minimize the total expected costs of such a regulatory program by implementing a system of firm-specific emissions standards as characterized by Proposition 2.*

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- **Proposition 5** *If a regulator wants set a cap on the aggregate level of emissions of a pollutant and it is cost-effective to induce all firms to violate the regulation ($\mu_i\gamma > \beta_i\phi^2$ for all i), it will minimize the total expected costs of such a regulatory program by implementing a system of firm-specific emissions standards as characterized by Proposition 2.*
- Proposition (5) is robust to the case when μ and β do not differ between firms.

8. CONCLUSIONS

- Whether it is cost-effective to induce full compliance in an emissions control program depends on the relative marginal cost of inspecting versus sanctioning, which in turns depend on the structure of the penalty function.

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- *A program based on firm-specific emissions standards and perfectly enforced (designed according to Proposition 3) minimizes the total expected costs of a program that caps emissions*
- *A system of tradable permits is more costly, unless the cost of monitoring a firm is the same for all firms.*

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- *A program based on firm-specific emissions standards and perfectly enforced (designed according to Proposition 3) minimizes the total expected costs of a program that caps emissions*
- *A system of tradable permits is more costly, unless the cost of monitoring a firm is the same for all firms.*
- When *it is cost-effective to induce all firms to violate the regulation, it is also cost effective to implement a system of firm-specific emissions standards (as characterized by Proposition 2), and not a system of tradable permits.*