Carbon Border Adjustment Mechanisms under Asymmetric Information

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1. Introduction

"Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen" (Stern, 2007)

- Global warming: the largest negative externality
- Failure of a unique and global carbon price
- Consequence: emergence of regional regulations (e.g. EU ETS, 2005)
- New issue: **carbon leakage** → reduction of emissions in a region results in increased emissions abroad (European Commission, 2015)
- **Carbon border adjustment mechanism** as a solution to carbon leakage → impose a tariff on the carbon content of imported goods
- European Commission, Proposal for a CBAM (2021): *"In order to import goods covered under the CBAM into the EU, they must declare [...] the embedded emissions in those goods imported into the EU in the preceding year."*
  → Authorities do not necessarily know the carbon content of imported goods
  → Self-declaration: truthful declaration is not going to happen
  → Incentive to **under-report emissions** to pay a lower tax (Laffont & Martimort, 2002)

2. Research question and literature

Research Question

What is the optimal CBAM under asymmetric information about firms' technologies?

This project bridges two main strands of literature in environmental economics and economic theory:

1. Literature on **CBAM** (and more generally, on border tax structures to address **carbon leakage**):
   - Seminal paper: Markusen, 1975; Hoel, 1996
   - Empirical studies: Monjon & Quirion, 2011 ; Bohringer et al., 2012, 2018 ; Morsdof, 2022
   - **Contribution**: issue with verification of reported emissions ⇒ design a CBAM under incomplete information without having to rely on default values
2. Literature on **optimal pollution control and asymmetric information**:
   - Kwerel 1977 ; Dasgupta, Hammond and Maskin 1980 ; Spulber 1988
   - **Contribution**:
     - Environmentally-efficient firms are not cost-efficient
     - No signaling
     - Include exogenous constraints like WTO compliance
     - Consider endogeneous choice of technology
     - Heterogeneous firms, in terms of technology AND damage

3. Model

Consider a market with a mass 1 of firms, consumers and a regulator.

- **Demand**: Perfectly elastic
- **Firms**: Perfectly competitive
  - 2 types of technology: clean (C) with probability λ and dirty (D) with probability $(1-\lambda)$
  - Each firm $i = C, D$ produces a quantity $q_i \geq 0$ of the good sold at a normalized price $\overline{p} = 1$
  - Profits from producing depend on gross profits (revenue - total quadratic costs) and total tax on production paid to the regulator $T_i = t_i q_i$

Clean technology firm: type θ_C

- Produces quantity q_C
- Profits: $\pi_C(q_C, T_C) = q_C - \frac{1}{2\theta_C} q_C^2 - T_C$
- No environmental damage

Dirty technology firm: type θ_D

- Produces quantity q_D
- Profits: $\pi_D(q_D, T_D) = q_D - \frac{1}{2\theta_D} q_D^2 - T_D$
- Total environmental damage: $D(q_D) = \gamma q_D$

  - Assumption: clean firms have a higher cost of production than dirty firms $\theta_C < \theta_D$

3. Model

Regulator: Benevolent social planner who:
(i) maximizes welfare of society,
(ii) can choose to tax firms by choosing a per-unit tax $t_i \geq 0$.

- Values: firms' profits (π_C and π_D) and extracting money through taxation with weight $\beta \in [0, 1]$

  (Laffont & Tirole, 1996 ; see "double dividend")

- Dislikes: environmental damage imposed by dirty firms

$$W = \lambda\Big(\pi_C + (1+\beta)T_C\Big) + (1-\lambda)\Big(\pi_D - \gamma q_D + (1+\beta)T_D\Big) \qquad (1)$$

4.1. Benchmark (complete information)

Welfare-maximizing regulation for domestic firms $\rightarrow$ regulator can perfectly verify domestic firms' technologies.

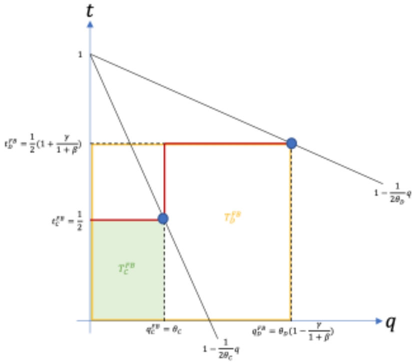
$$W = \lambda\Big(\pi_C + (1+\beta)T_C\Big) + (1-\lambda)\Big(\pi_D - \gamma q_D + (1+\beta)T_D\Big)$$

$$W = \lambda\Big((1+\beta)(q_C - \frac{1}{2\theta_C}q_C^2) - \beta\pi_C\Big) + (1-\lambda)\Big((1+\beta)(q_D - \frac{1}{2\theta_D}q_D^2) - \gamma q_D - \beta\pi_D\Big) \quad (1.2)$$

Benchmark: Welfare-maximizing regulation of domestic firms under complete information

With complete information, the regulator offers the following welfare-maximizing regulation:

- Dirty firms produce less than in laissez-faire: $q_D^{FB} = \theta_D\left(1 - \frac{\gamma}{1+\beta}\right) < q_D^*$
- Clean firms produce their laissez-faire quantity: $q_C^{FB} = q_C^* = \theta_C$
- Firms make zero profits, retrieved through total taxes ▸ Proof



4.2. Regulation of firms located abroad (incomplete information)

- Firms relocate their production plant abroad: type θ_i is private information of firms
- The optimal benchmark regulation is not applicable anymore
  $\Rightarrow$ dirty firms prefer to mimic the clean technology to earn positive profits: $\pi_D(q_C^{FB}, T_C^{FB}) > 0$
- Regulator needs to change the tax structure to induce firms to behave correctly, i.e. ensuring that
  1. Each type of firm chooses the tax and quantity that corresponds to its true technology
  2. All firms still want to participate in the market

$$\max_{q_i, T_i} W = \lambda\Big((1+\beta)(q_C - \frac{1}{2\theta_C}q_C^2) - \beta\pi_C\Big) + (1-\lambda)\Big((1+\beta)(q_D - \frac{1}{2\theta_D}q_D^2) - \gamma q_D - \beta\pi_D\Big)$$

subject to:

$$q_C - \frac{1}{2\theta_C}q_C^2 - T_C \geq q_D - \frac{1}{2\theta_C}q_D^2 - T_D \quad (2)$$

$$q_D - \frac{1}{2\theta_D}q_D^2 - T_D \geq q_C - \frac{1}{2\theta_D}q_C^2 - T_C \quad (3)$$

$$\pi_C(q_C, T_C) \geq 0 \quad (4)$$

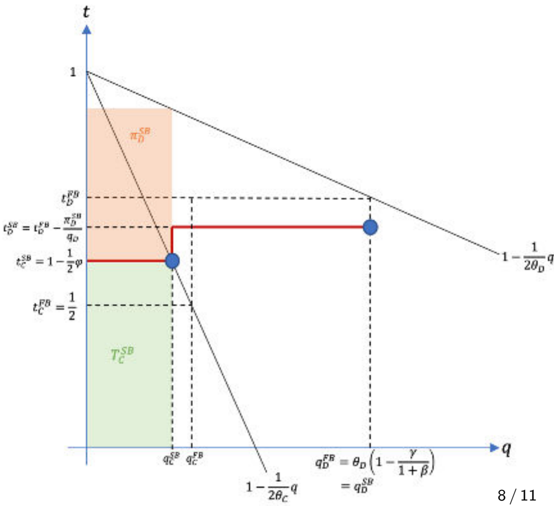
$$\pi_D(q_D, T_D) \geq 0 \quad (5)$$

4.2. Regulation of firms located abroad (incomplete information)

Second-best regulation under incomplete information about foreign firms

When the regulator has no information about foreign firms technologies, he designs the following second-best regulation:

- No distortion of the quantity produced by dirty firms compared to the first-best regulation: $q_D^{SB} = q_D^{FB}$.
- A downward distortion of the quantity produced by clean firms compared to first-best: $q_C^{SB} = \varphi q_C^{FB}$ where $\varphi = \frac{\theta_D \lambda(1+\beta)}{\theta_D(\lambda+\beta)-\theta_C \beta(1-\lambda)} < 1$.
- Dirty firms earn positive profits: $\pi_D^{SB} = q_C^{SB^2}\left(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\right)$. No profits for clean firms.
- Lower total taxes for both types of firms: $T_D^{SB} = T_D^{FB} - \pi_D^{SB}$ and $T_C^{SB} = q_C - \frac{1}{2\theta_C} q_C^2$ ▸ Proof



4.3. Regulation of firms located abroad and WTO compatibility

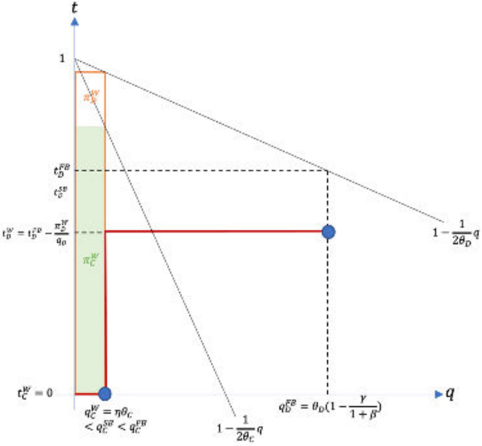
Simplifying assumption: WTO does not allow to charge outside firms more than the Pigouvian level (Pauwelyn, 2013 ; Cosbey et al., 2019).

$\Rightarrow T_C^W = 0$ and $T_D^W \leq \gamma q_D$

WTO-compatible regulation and incomplete info.

The regulator offers the following WTO-compatible regulation to firms abroad:

- No distortion of the quantity produced by dirty firms. An additional downward distortion of clean firms production: $q_C^W = \eta\theta_C$ where $\eta = \frac{\theta_D(\lambda-(1-\lambda)\beta)}{\lambda\theta_D-(1-\lambda)\beta\theta_C} < \varphi < 1$.
- An increase or a decrease of dirty firms' profits. Positive profits earned by clean firms.
- No tax imposed on the clean firms. A higher or a lower total tax imposed on dirty firms: $T_D^W = T_D^{FB} - \pi_D^W$. ▸ Proof



4.4. Endogenous choice of technology and incentive compatibility

- Assume that firms may choose to invest in R&D to get the clean technology
- The regulator would like to incentivize firms to adopt the “good” behavior, which is to invest in the clean tech (no environmental damage)
- However, because the clean technology is less cost-efficient ($\theta_C < \theta_D$), it is impossible to do so
- Clash between two types of incentives: incentive to tell the truth and incentive to invest

5. Conclusions & Future Work (1/2)

- This theoretical paper provides insights on how a regulator can impose a carbon price on firms located abroad by creating a CBAM, when technology of production is private information of the firms.

- The current main takeaways are:
  - Not possible to reach the optimal welfare.
  - The regulator must choose (fairly complex) non linear tax structures, specifying taxes and the maximum quantity allowed given the chosen tax.
  - Welfare decreases compared to the full information optimum, but (at least) pollution does not increase because the quantity produced by dirty firms stays constant.
  - We can impose a higher total tax on polluting firms when they are more cost-efficient.
  - International agreements may impose more distortions.
  - It is impossible to incentivize firms to invest in the clean technology when it is less cost-efficient.

Thank you!

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Appendix: Proof of Proposition 1 ▸ Back

The regulator solves the following problem:

$$\max_{q_i, T_i} W = \lambda\Big((1+\beta)\Big(q_C - \frac{1}{2\theta_C}q_C^2\Big) - \beta\pi_C\Big) + (1-\lambda)\Big((1+\beta)\Big(q_D - \frac{1}{2\theta_D}q_D^2\Big) - \gamma q_D - \beta\pi_D\Big)$$

Profits enter negatively in the welfare function, so the regulator chooses $\pi_C^{FB} = \pi_D^{FB} = 0$.
To maintain these profits at zero, he has to offer, in the regulation, the following total taxes:
$T_C^{FB} = q_C - \frac{1}{2\theta_C}q_C^2$ and $T_D^{FB} = q_D - \frac{1}{2\theta_D}q_D^2$.
The solution of this problem with respect to quantities is given by deriving the first-order conditions:

- $q_C^{FB} = \theta_C$
- $q_D^{FB} = \theta_D\Big(1 - \frac{\gamma}{1+\beta}\Big)$

As a consequence; we can rewrite total taxes as their exact expressions:
$T_C^{FB} = \frac{1}{2}\theta_C$ and $T_D^{FB} = \frac{1}{2}\theta_D\Big(1 - \frac{\gamma^2}{(1+\beta)^2}\Big)$.

Appendix: Proof of Proposition 2 (1/3) Back

$$\max_{q_i,T_i} W = \lambda\Big((1+\beta)\Big(q_C - \frac{1}{2\theta_C}q_C^2\Big) - \beta\pi_C\Big) + (1-\lambda)\Big((1+\beta)\Big(q_D - \frac{1}{2\theta_D}q_D^2\Big) - \gamma q_D - \beta\pi_D\Big)$$

subject to: (2), (3), (4), (5).

Note: we need $q_C < q_D$ for both (2) and (3) to hold simultaneously.
The problem usually arises from dirty technology firms, so ignore (2) and check that it is satisfied ex-post.
Constraint (3) can be rewritten $\pi_D \geq \pi_C + q_C^2\Big(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\Big)$.
Constraint (4) imposes non-negative profits for clean firms, and the second term on the RHS is strictly positive, so (5) is necessarily satisfied and can be ignored.
Because π_C and π_D enter negatively in the welfare, the regulator would like to set them at their lowest value possible. As a consequence, both remaining constraints hold with equality: the regulator chooses $\pi_C = 0$ and $\pi_D = q_C^2\Big(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\Big)$.

Appendix: Proof of Proposition 2 (2/3)

Back

Proceeding by substitution, the simplified maximization problem rewrites:

$$\max_{q_D, q_C \geq 0} \; \lambda\left((1+\beta)\left(q_C - \frac{1}{2\theta_C}q_C^2\right)\right) + (1-\lambda)\left((1+\beta)\left(q_D - \frac{1}{2\theta_D}q_D^2\right) - \gamma q_D - \beta q_C^2\left(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\right)\right)$$

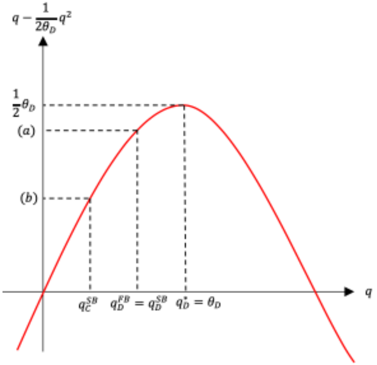
Computing the first-order conditions and using the constraints give the following solutions:

- $q_D = \theta_D\left(1 - \frac{\gamma}{1+\beta}\right)$
- $q_C^{SB} = \theta_C \frac{\theta_D \lambda (1+\beta)}{\theta_D(\lambda+\beta) - \theta_C \beta (1-\lambda)}$
- $\pi_D^{SB} = q_C^2\left(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\right)$
- $\pi_C^{SB} = 0$
- $T_D^{SB} = T_D^{FB} - \pi_D^{SB}$
- $T_C^{SB} = q_C^{SB} - \frac{1}{2\theta_C} q_C^{SB^2}$

Appendix: Proof of Proposition 2 (3/3) ▸ Back

Showing that $T_C^{SB} < T_D^{SB}$ is straightforward with a graphical illustration.

$$T_D^{SB} = T_C^{SB} + \underbrace{q_D^{SB}\left(1 - \frac{1}{2\theta_D} q_D^{SB}\right)}_{(a)} - \underbrace{q_C^{SB}\left(1 - \frac{1}{2\theta_D} q_C^{SB}\right)}_{(b)} \Rightarrow \text{need to show that } (a) > (b).$$



Appendix: Proof of Proposition 3 (1/3) Back

$$\max_{q_i, T_i} W = \lambda\Big((1+\beta)\Big(q_C - \frac{1}{2\theta_C}q_C^2\Big) - \beta\pi_C\Big) + (1-\lambda)\Big((1+\beta)\Big(q_D - \frac{1}{2\theta_D}q_D^2\Big) - \gamma q_D - \beta\pi_D\Big)$$

subject to: (6), (7), (8), (9), (10), (11).
We ignore (6) as the problem of incentives arises from dirty firms. Constraint (8) is directly implied by (10). Of constraints (7) and (9), only one can be binding. We can show that (9) is irrelevant and (7) is binding at the optimum. Proceed by contradiction: if (9) binds before (7), there is a problem of incentives (dirty firms make positive profits by choosing the clean regulation). Therefore, constraint (7) on dirty firms is binding at the optimum, and we have $\pi_D = q_C - \frac{1}{2\theta_D}q_C^2$. Proceeding by substitution, the simplified maximization problem rewrites:

$$\max_{q_D, q_C} W = \lambda\Big(q_C - \frac{1}{2\theta_C}q_C^2\Big) + (1-\lambda)\Big[(1+\beta)\Big(q_D - \frac{1}{2\theta_D}q_D^2\Big) - \gamma q_D - \beta\Big(q_C - \frac{1}{2\theta_D}q_C^2\Big)\Big]$$

Appendix: Proof of Proposition 3 (2/3) ▸ Back

Solutions:

- $q_D = \theta_D \left(1 - \frac{\gamma}{1+\beta}\right)$
- $q_C^W = \theta_C \frac{\theta_D(\lambda - (1-\lambda)\beta)}{\lambda\theta_D - (1-\lambda)\beta\theta_D}$
- $\pi_D^W = q_C^W \left(1 - \frac{1}{2\theta_D} q_C^W\right)$
- $\pi_C^W = q_C^W \left(1 - \frac{1}{2\theta_C} q_C^W\right)$
- $T_D^W = T_D^{FB} - \pi_D^W$
- $T_C^W = 0$

Prove that $q_C^W < q_C^{SB}$. By replacing each quantity by its expression, we get $\beta^2(1-\lambda)(\theta_D - \theta_C) > 0$. This is true as long as $\theta_D > \theta_C$.

Appendix: Proof of Proposition 3 (3/3)

Back

Compare the profits of dirty firms in second-best with respect to WTO. Recall, we can write: $q_C^{SB} = \varphi q_C^{FB}$ where $\varphi = \dfrac{\theta_D \lambda(1+\beta)}{\theta_D(\lambda+\beta) - \theta_C \beta(1-\lambda)} < 1$ and $q_C^W = \eta\theta_C$ where $\eta = \dfrac{\theta_D(\lambda - (1-\lambda)\beta)}{\lambda\theta_D - (1-\lambda)\beta\theta_D} < \varphi < 1$. We can write: $\pi_D^{SB} = \theta_C^2\varphi^2\Big(\dfrac{1}{2\theta_C} - \dfrac{1}{2\theta_D}\Big)$ and $\pi_D^W = \theta_C\eta\Big(1 - \dfrac{1}{2\theta_D}\theta_C\eta\Big)$.

Study the conditions under which we have $\pi_D^W > \pi_D^{SB}$:

$$\theta_C\eta\Big(1 - \frac{1}{2\theta_D}\theta_C\eta\Big) > \theta_C^2\varphi^2\Big(\frac{1}{2\theta_C} - \frac{1}{2\theta_D}\Big) \Leftrightarrow \eta - \frac{\theta_C}{2\theta_D}\eta^2 - \frac{1}{2}\varphi^2 + \frac{\theta_C}{2\theta_D}\varphi^2 > 0$$

This inequality holds for η and φ close, which happens when β small ($\to$ 0) and/or λ high ($\to$ 1). On the contrary, when β high ($\to$ 1) and/or λ small ($\to$ 0), the sign reversed and we have $\pi_D^W < \pi_D^{SB}$.