Time Horizons and Emissions Trading

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Motivating observations

Fact 1

A total of 34 supranational, national, state, and local cap and trade schemes are in operation today, with more under way.

Fact 2

17% of global greenhouse gas emissions are regulated through a cap and trade scheme, in jurisdictions accounting for 55% of global GDP. Nearly 1/3 of the world's population lives under an emissions cap.

Fact 3

Emissions trading is an important component in achieving the mid-century net-zero emissions targets to limit global warming adopted by increasingly many jurisdictions.

Fact 4

Through the forces of supply and demand, emissions trading generates an effective and – often – observable price for pollution. Other than a plain tax, the cap and trade pollution price is determined by market fundamentals.

Fact 5

In close to all cap and trade schemes, temporal violations of the period cap are permitted through banking (and, sometimes, borrowing) provisions.

Fact 6

Nowadays most cap and trade schemes deviate from the textbook model of a fixed, exogenous emissions cap. Instead, the supply of allowances is determined through, typically rule-based, stability provisions.

Fact 7

An allowance market is artificial and created by decree – it exists by the will of the government, and so it also ceases to exists by the will of the government.

Introduction

Policy environment

Motivated by these observations, the policy environment in this paper is:

- a dynamic cap and trade scheme, where
- the duration of the policy – the time horizon of emissions trading – is determined by the regulator, and
- the supply of allowances is determined through a rule-based stability provision (supply policy)

Rule-based supply policies

I consider the empirically relevant cases of price- and quantity-based supply policies

- Price-based supply policies
  - → Supply of allowances increasing in the allowance price
  - → Idea: high price signals scarcity, so increase supply
  - → Regional Greenhouse Gas Initiative, California ETS
- Quanity-based supply policies
  - → Supply of allowances decreasing in number of unused allowances in circulation
  - → Idea: many unused allowences signals lack of scarcity, so decrease supply
  - → EU ETS, Swiss ETS

The thought experiment

- The government decides whether or not to organize a cap and trade scheme; hence, it also decides for how long it organizes one
- Does it benefit the environment to have a shorter-lived policy?
  - $\rightarrow$ Focus on emissions *under* the cap
  - $\rightarrow$ Equivalent to a best-case scenario in which there are no emissions outside the cap anyway
  - $\rightarrow$ Should we reach climate neutrality sooner or later?
- How does the answer depend on the supply mechanism in place?

Research question

How does the duration of a cap and trade scheme with a market-based cap affect emissions under its cap?

A note

- There are two – mathematically equivalent – ways to think about what I call the timing of emissions
  - → A cap and trade scheme which ends in some final period T
  - → A complementary policy, independent of the scheme, that bans emissions starting from period T (Perino, Ritz, & Van Benthen, 2022; Gerlagh, Heijmans, & Rosendahl, 2021)

There is also a third interpretation. Suppose that firms, as is often the case, can keep unused allowance for a maximum of m periods to cover emissions in the future. Suppose also that the policymaker phases out the supply of new allowances by some period $\bar{T}$ at the latest. Then if $T = \bar{T} + m$, period T is for all pactical purposes the final period of the scheme.

Sneak preview

1. The reduction in emissions is **bounded from below** and **non-negative** under a price-based supply policy
2. The reduction in emissions is **bounded from above** under a quantity-based supply policy
3. If supply reaches zero before demand does, a shorter time horizon leads to strictly higher emissions under a quantity-based policy
4. Given "symmetric" equilibria, the lower and upper bounds for price- and quantity-based policies, respectively, coincide

Literature

- Price-based supply policies
  - → General: Roberts & Spence (1976, JPubE), Pizer (2002, JPubE)
  - → RGGI/California: Borenstein et al. (2019, AER), Friesen et al. (2022, JEEM)
- Quantity-based supply policies
  - → General: Kollenberg & Taschini (2016, JEEM; 2019, EER), Lintunen & Kuusela (2018, EER)
  - → EU ETS: Perino (2018, NCC), Gerlagh & Heijmans (2019, NCC), Gerlagh, Heijmans, & Rosendahl (2020, ERE; 2021 EcPol; 2022, ERL),Osorio et al. (2021, EP), Perino et al. (2022, NBER)
- Comparing price- and quantity-based policies
  - → Abatement cost: Abrell & Rausch (2016, JPubE), Holt & Shobe (2016, JEEM), Fell (2016, JEEM)
  - → Allowance price stabilization: Heijmans (2022, R&R @ JEEM)

Model

Cap and trade

- Polluters, firms for simplicity
  - $\rightarrow$ Small: take price and supply as given
- s_t the supply of emissions allowances in period t
- Allowances traded on a secondary market
  - $\rightarrow$ Trade generates allowance price p_t
  - $\rightarrow$ m_{it} firm i's net position
- q_{it} the emissions of firm i in period t; $q_t = \sum_i q_{it}$
- If $q_t < s_t$, the surplus is banked
  - $\rightarrow$ $b_t = s_t - q_t$ and $B_t = \sum_t b_t$
  - $\rightarrow$ Banking, no borrowing: $B_t \geq 0$ for all t
  - $\rightarrow$ Limited possibility to violate periodic cap
- Scheme exists for T periods

The firms' problem

In every period t, each firm i solves

$$\min_{\{q_{i\tau}\}_{\tau=t}^{T}} \quad \sum_{\tau=t}^{T} \beta^{\tau-t} \left[C_{i\tau}(q_{i\tau}^0 - q_{i\tau}) + p_\tau m_{i\tau} \right]$$

subject to the relevant policy constraints. Here,

- C_{it} is the firm i's (expected) convex abatement cost function in period t
- q_{it}^0 are firm i's BAU emissions in period t
- β is the discount factor

The firm's problem – solved

Solving the firms' problems yields two familiar results:

(i) Individual and aggregate demand for emissions, $q_{it}(p_t)$ and $q_t(p_t) = \sum_i q_{it}(p_t)$, are decreasing in the allowance price:

$$\frac{\partial q_{it}(p_t)}{\partial p_t} \leq 0 \quad \text{and} \quad \frac{\partial q_t(p_t)}{\partial p_t} \leq 0$$

(ii) Cost-minimizing allowance prices are positively correlated over time:

$$\frac{\partial p_{t+1}}{\partial p_t} > 0$$

An immediate corrollary to (i) is that banking $b_t(p_t)$ is increasing in p_t, since $b_t(p_t) = s_t - q_t(p_t)$.

Price mechanisms

Definition (Price mechanism)

A cap and trade scheme operates a *price mechanism* if the supply of allowances in any period t is weakly increasing in the prevailing allowance price p_t. Formally, for any period t and any two price levels p_t and p'_t it holds that $s_t(p_t) \geq s_t(p'_t)$ if and only if $p_t > p'_t$.

→ Intuition: high price means abatement expensive, efficient to increase supply

→ Examples: price floor/ceiling, reserve price, etc.

→ For clarity, I may occasionally use superscript P to signify variables determined under a price mechanism

Quantity mechanisms

Definition (Quantity mechanism)

A cap and trade scheme operates a *quantity mechanism* if the supply of allowances in period t is weakly decreasing in the aggregate excess supply at the start of period t. That is, for any period t and any two B_t and B'_t, it holds that $s_t(B_t) \geq s_t(B'_t)$ if and only if $B'_t > B_t$.

- $\rightarrow$ Intuition: high surplus means demand low, efficient to tighten cap
- $\rightarrow$ Examples: quantity-collar (MSR), liquidity provision, etc.
- $\rightarrow$ For clarity, I may occasionally use superscript Q to signify variables determined under a quantity mechanism

Anticipation and the demand for emissions (two lemmas)

- Imagine that firms, for some reason, anticipate an increase in the price of allowances in period $\tau \leq T$.
  - $\rightarrow$ The anticipation starts in period 0
- How does this anticipated increase affect the demand for emissions – and hence the bank of allowances – in all periods $t \in \{0, 1, ..., T\}$?
- When supply is determined through a *price mechanism*, the bank $B_t^P(p)$ is increasing in the allowance price p_τ:

$$\frac{\partial B_t^P(p)}{\partial p_\tau} \geq 0$$

- When supply is determined through a *quantity mechanism*, the bank $B_t^Q(p)$ is increasing in the allowance price p_τ:

$$\frac{\partial B_t^Q(p)}{\partial p_\tau} \geq 0$$

Equilibrium

Time horizon of emissions trading

- Recall one of our motivating facts: the period in which the cap and trade scheme ends is chosen by the regulator
- Consider hence two periods, $\bar{T}$ and T, such that $\bar{T} < T$
- How much can we reduce emissions by having the scheme end in $\bar{T}$, rather than T?
- Constructive approach:
  - $\rightarrow$ Calculate equilibrium emissions when the scheme ends in T
  - $\rightarrow$ Do the same when the scheme ends in $\bar{T}$
  - $\rightarrow$ Do this for both price and quantity mechanisms
  - $\rightarrow$ Compare

Equilibrium

- Equilibrium is reached when total emissions equal total supply
- Price adjusts to bring about equilibrium
- We need four equilibrium price vectors
  - $\rightarrow$ p^P : price mechanism, ends at T
  - $\rightarrow$ $\bar{p}^P$: price mechanism, ends at $\bar{T}$
  - $\rightarrow$ p^Q : quantity mechanism, ends at T
  - $\rightarrow$ $\bar{p}^Q$: quantity mechanism, ends at $\bar{T}$

Equilibrium reduction in emissions

- Define:

$$R^P(\bar{T}, T) = \sum_{t=1}^{T} q_t(p^P) - \sum_{t=1}^{\bar{T}} q_t(\bar{p}^P)$$

- Define:

$$R^Q(\bar{T}, T) = \sum_{t=1}^{T} q_t(p^Q) - \sum_{t=1}^{\bar{T}} q_t(\bar{p}^Q)$$

Research question specified

What are the properties of $R^P(\bar{T}, T)$ and $R^Q(\bar{T}, T)$?

Results

Price mechanism: lower bound

Main result 1

$$R^P(\bar{T}, T) \geq \sum_{t=\bar{T}}^{T} s_t^P(p_t^P) \geq 0$$

→ Reduction in equilibrium emissions is **non-negative** and **bounded from below** under a price mechanism

→ Having the scheme end in $\bar{T}$ reduces equilibrium emissions **at least** by the amount of emissions originally supplied after $\bar{T}$

→ Price mechanism **reinforces** shorter time horizon of emissions trading

Quantity mechanism: upper bound

Main result 2

$$R^Q(\bar{T}, T) \leq \sum_{t=\bar{T}}^{T} s_t^Q(B_t(p^Q))$$

→ Reduction in equilibrium emissions is **bounded from above** under a quantity mechanism.

→ Having the scheme end in $\bar{T}$ reduces equilibrium emissions **at most** by the amount of emissions originally supplied after $\bar{T}$

→ Quantity mechanism **counteracts** shorter time horizon of emissions trading

Higher emissions

Main result 3

If (i) $s_t^Q(p_t^Q) = 0$ for all $t \geq \bar{T}$ and (ii) $\exists \tau \geq \bar{T} : q_\tau(p_\tau^Q) > 0$, then
$$R^Q(\bar{T}, T) < 0$$

- → Note: (i) and (ii) are sufficient, not necessary, conditions
- → In the interpretation of $\bar{T}$ as the period starting from which an overlapping emissions policy becomes binding, similar results were found by Gerlagh, Heijmans, & Rosendahl (2021), Osorio et al. (2021), and Perino, Ritz, & Van Benthem (2022)
- → Estimations for EU (Osorio et al., 2021): positive demand until at least 2060, supply runs out by 2040.

Prices vs. Quantities

- It seems that price mechanisms outperform quantity mechanisms
- Not so obvious
  - → Upper bound on quantity mechanism reductions above lower bound on price mechanism reductions
  - → Possible that quantity mechanism reduces emissions more!
- Contrived possibility

Prices vs. Quantities

- It seems that price mechanisms outperform quantity mechanisms
- Not so obvious
  - $\rightarrow$ Upper bound on quantity mechanism reductions above lower bound on price mechanism reductions
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Main result 4

If $s_t^P(p_t^P) = s_t^Q(B_t^Q(p^Q))$ for all $t = 1, ..., T$, then $R^Q(\bar{T}, T) \leq R^P(\bar{T}, T)$

Discussion

Discussion of the assumptions

1. Negative emissions, e.g. "net zero"
   → Same economic mechanism, bounds depend on cost of negative emissions
2. Non-zero emissions targets
   → Same economic mechanism, ugly formulas
3. Commitment
   → Supply is determined through the same *function* whether the scheme exists for T or $\bar{T}$ periods; boundedness results generalize
4. Rule-based supply policies
   → With the notable exception of Korea ETS, non-discretionary policies are the global norm
5. Efficiency and welfare
   → Are higher emissions necessarily bad for welfare? Probable for stock pollution and convex damages

Digestion: Information Economics

Why the dissimilar performance of apparantly similar instruments?

- Quantities are unable to properly summarize information in the market
- Prices **unambiguously** signal scarcity
  - → High prices means high overall demand for emissions
- Quantities are, at best, an **ambiguous** signal of scarcity
  - → A large surplus is only informative about demand in the future *relative* to demand today
  - → Relative demand not particularly informative about demand overall
- Compared to quantities, prices are highly efficient information aggregators

Thank you

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