Time Horizons and Emissions Trading

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Introduction

This paper

- Dynamic model of emissions trading
- Supply of allowances depends on conditions prevailing in the market for allowances
    - Price mechanisms: supply increasing in the allowance price
    - Quantity mechanisms: supply increasing in use of allowances
- Policy ends with a hard ban on emissions

The Climate Policy Trinity

1. Cap and trade
   → Who can pollute? How is abatement achieved?
      → California ETS, EU ETS, RGGI, Korea ETS, Swiss ETS, ...
2. Market-based emissions cap
   → How much pollution is allowed?
      → Price floor/ceiling/collar, quantity collar, MSR, liquidity constraints, ...
3. Future ban on emissions
   → When should pollution stop?
      → Zero emissions pledge, permit retirement

Pillar 1: Cap and trade

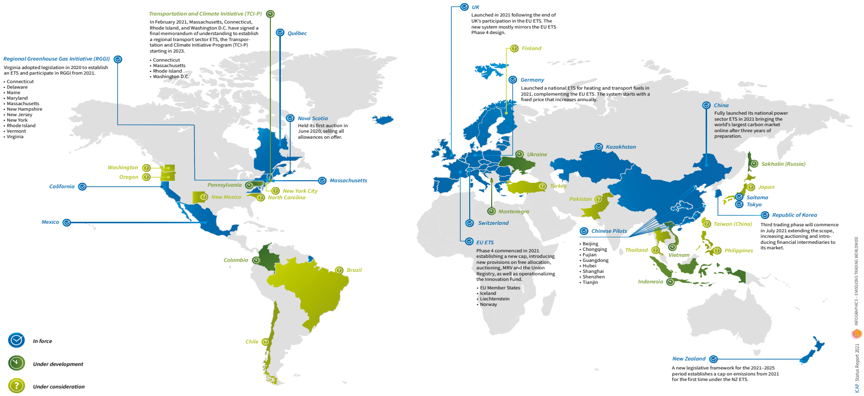
Emissions trading

- Prominent climate policy instrument
- 16% of greenhouse gas emissions worldwide
- Jurisdictions representing 54% of global GDP
- More under way

EMISSIONS TRADING WORLDWIDE

The state of play of cap-and-trade in 2021

The ICAP ETS world map depicts emissions trading systems currently in force, under development or under consideration. As of 31 January 2021, there are 24 ETS in force. Another eight are under development and expected to be in operation in the next few years. These include ETS in Colombia and the Transportation and Climate Initiative Program (TCI-P) in northeastern US States. 14 jurisdictions including Chile, Turkey and Pakistan are also considering the role an ETS can play in their climate change policy mix. If a jurisdiction has multiple systems in force or has a system in force but is at the same time developing or considering an additional system, it is depicted in blue.



Pillar 2: Market-based emissions cap

Supply mechanisms

- Sum total of abatement required depends on emissions cap
- In practice, cap often depends on the market for allowances
- Empirically relevant classes: price and quantity mechanisms (ICAP)
- Common, but do they matter? Yes (Borenstein et al., 2019)


EU ETS
European Union Emission
Trading System
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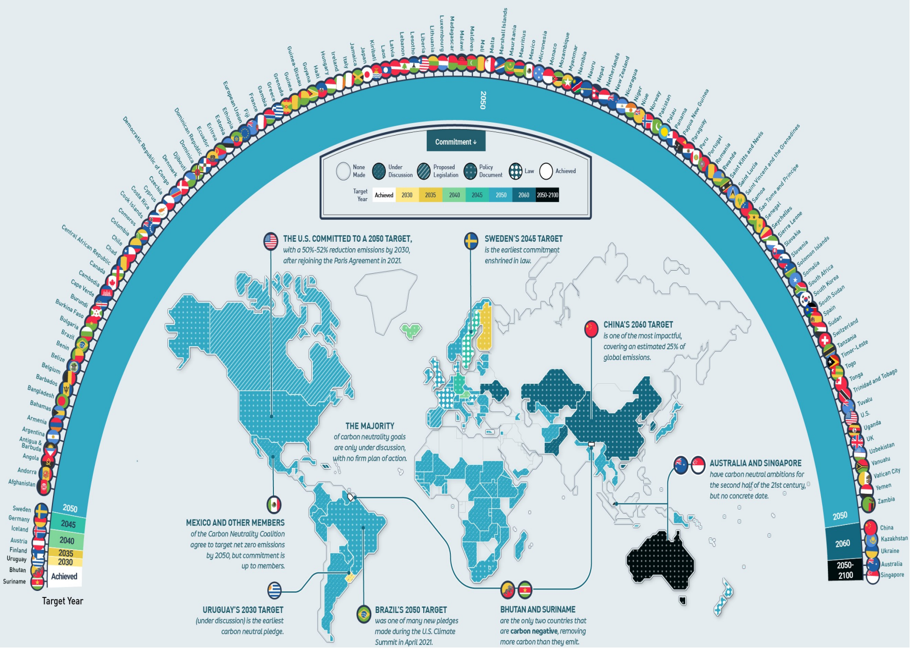
Pillar 3: Hard ban

Future ban on emissions

- Rapidly gaining popularity
- $>$100 countries pledged net-zero by $\pm$ 2050 (Van Soest et al., 2021)
- Crucial to meet climate ambitions (Höhne et al., 2021)



Commitment ↓
None Made
Under Discussion
Proposed Legislation
Policy Document
Law
Achieved
Target Year
Achieved
2030
2035
2040
2045
2050
2060
2050-2100
THE U.S. COMMITTED TO A 2050 TARGET,
with a 50%-52% reduction emissions by 2030, after rejoining the Paris Agreement in 2021.
SWEDEN'S 2045 TARGET
is the earliest commitment enshrined in law.
CHINA'S 2060 TARGET
is one of the most impactful, covering an estimated 25% of global emissions.
THE MAJORITY
of carbon neutrality goals are only under discussion, with no firm plan of action.
MEXICO AND OTHER MEMBERS
of the Carbon Neutrality Coalition agree to target net zero emissions by 2050, but commitment is up to members.
AUSTRALIA AND SINGAPORE
have carbon neutral ambitions for the second half of the 21st century, but no concrete date.
URUGUAY'S 2030 TARGET
(under discussion) is the earliest carbon neutral pledge.
BRAZIL'S 2050 TARGET
was one of many new pledges made during the U.S. Climate Summit in April 2021.
BHUTAN AND SURINAME
are the only two countries that are carbon negative, removing more carbon than they emit.
2050
Afghanistan
Andorra
Angola
Antigua & Barbuda
Argentina
Armenia
Bahamas
Bangladesh
Barbados
Belgium
Belize
Benin
Brazil
Bulgaria
Burkina Faso
Burundi
Cape Verde
Cambodia
Canada
Central African Republic
Chad
Chile
Colombia
Comoros
Cook Islands
Costa Rica
Cyprus
Czechia
Democratic Republic of Congo
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Eritrea
Estonia
Ethiopia
European Union
Fiji
France
Gambia
Greece
Grenada
Guinea
Guinea-Bissau
Guyana
Haiti
Hungary
Ireland
Italy
Jamaica
Japan
Kiribati
Laos
Latvia
Lebanon
Lesotho
Liberia
Lithuania
Luxembourg
Madagascar
Malawi
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia
Monaco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Niue
Norway
Pakistan
Palau
Panama
Papua New Guinea
Paraguay
Peru
Portugal
Romania
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
Sao Tome and Principe
Senegal
Seychelles
Sierra Leone
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
South Korea
South Sudan
Spain
Sudan
Switzerland
Tanzania
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tuvalu
U.S.
Uganda
UK
Uzbekistan
Vanuatu
Vatican City
Yemen
Zambia
2060
China
Kazakhstan
Ukraine
2050-2100
Australia
Singapore
2045
Sweden
Germany
2040
Iceland
Austria
2035
Finland
2030
Uruguay
Achieved
Bhutan
Suriname
Target Year

Research question

What is the effect of bringing forward the ban on emissions?

Model

Cap and trade

- N firms
- The policymaker supplies s_{it} allowances to firm i in period t
  - $\rightarrow$ $s_t = \sum_i s_{it}$
  - $\rightarrow$ Determination of s_t discussed shortly
- Firm i must surrender allowances to cover emissions $q_{it} \geq 0$
  - $\rightarrow$ $q_t = \sum_i q_{it}$
- Allowances traded on a secondary market
  - $\rightarrow$ Trade generates allowance price p_t
  - $\rightarrow$ Firms are price-takers – no huge firms, N large
- 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
  - $\rightarrow$ Banked allowances usable to cover future emissions

Time horizon of emissions trading

- The cap and trade scheme ends with a hard ban on emissions
  - $\rightarrow$ Timing of the ban determines time horizon of emissions trading
  - $\rightarrow$ Final period on emissions T
  - $\rightarrow$ Allow $T \rightarrow \infty$, the empirically relevant case
- Ban requires $q_t = 0$ for all i and $t \geq T$
  - $\rightarrow$ Hard constraint: $q_t = 0$ for all $t \geq T$ even if $B_t > 0$

Firms' problem

- Firms choose their emissions q_{it} to minimize the discounted sum of abatement costs subject to the cap and the emissions ban at T
  - $\rightarrow$ Solution to firms' problem: $q_t(p_t, T)$
  - $\rightarrow$ Emissions decreasing in allowance price: $\partial q_t(p_t, T)/\partial p_t < 0$
- Cost-minimization gives $B_T = 0$
  - $\rightarrow$ Allowances used up by period T
  - $\rightarrow$ Emissions banned starting from T, so $B_T > 0$ is capital destruction
- Trade in allowances gives $p_t \approx MAC_t$
  - $\rightarrow$ Sell (buy) allowance when price exceeds (falls short of) marginal abatement cost
  - $\rightarrow$ Assumes market economy, comp. China's pilot ETS (Cao et al., 2021)
- Marginal abatement costs satisfy $MAC_t \approx \beta MAC_{t+1}$
  - $\rightarrow$ Differential Hotelling rule: $\partial p_{t+1}/\partial p_t > 0$

Supply mechanisms

- Firms choose emissions to minimize abatement costs *subject to the emissions cap*
  - → Determined through supply mechanism
- **Price mechanism**: supply increasing in allowance price
  - → $\partial s_t(p_t)/\partial p_t > 0$
  - → Intuition: high price means abatement expensive, efficient to loosen cap
  - → Examples: price floor/ceiling, reserve price, etc.
- **Quantity mechanism**: supply decreasing in bank
  - → $\partial s_t(B_t)/\partial B_t < 0$
  - → Intuition: high surplus means abatement inexpensive, efficient to tighten cap
  - → Examples: quantity-collar (MSR), liquidity provision, etc.
- Intention to balance out supply and demand
- Price-taker assumption: firms take cap as given

Similar but different

- Price mechanism
  - → Uses information on prices to determine quantities
  - → Turns cap and trade into a hybrid policy
- Quantity mechanism
  - → Uses information on quantities to determine quantities
  - → Doubles down on quantity aspect of cap and trade

Equilibrium

Equilibrium

- Equilibrium is reached when total emissions equal total supply
  - $\rightarrow$ Subject to borrowing constraint and ban
  - $\rightarrow$ Gross oversupply ($>$ BAU emissions) ruled out by assumption
- Let p^P denote the equilibrium price vector under a price mechanism:

$$\sum_{t=1}^{T} q_t(p_t^P, T) = \sum_{t=1}^{T} s_t(p_t^P) \implies B_T(p^P) = 0$$

- Let p^Q denote the equilibrium price vector under a quantity mechanism:

$$\sum_{t=1}^{T} q_t(p_t^Q, T) = \sum_{t=1}^{T} s_t(B_t(p^Q)) \implies B_T(p^Q) = 0$$

Supply between periods

Consider a given final period on emissions T

- For $t_1 \leq t_2$, define:

$$S^P(t_1, t_2 \mid p^P) = \sum_{t=t_1}^{t_2} s_t(p_t^P)$$

- For $t_1 \leq t_2$, define:

$$S^Q(t_1, t_2 \mid p^Q) = \sum_{t=t_1}^{t_2} s_t(B_t(p^Q))$$

An earlier ban – another equilibrium

- Now posit another final period on emissions $\bar{T}$, where $\bar{T} < T$
  - $\rightarrow$ The final period $\bar{T}$ is an earlier ban – more ambitious climate goal
- Let $\bar{p}^P$ denote the equilibrium allowance price vector under a price mechanism when the final period is $\bar{T}$
- Let $\bar{p}^Q$ denote the equilibrium allowance price vector under a quantity mechanism when the final period is $\bar{T}$

Equilibrium reduction in emissions

- Define:

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

$\rightarrow$ $R^P(\bar{T}, T)$ is the reduction in equilibrium emissions realized by bringing forward the ban from T to $\bar{T}$ under a price mechanism

- Define:

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

$\rightarrow$ $R^Q(\bar{T}, T)$ is the reduction in equilibrium emissions realized by bringing forward the ban from T to $\bar{T}$ under a quantity mechanism

Research question specified

What can we say about $R^P(\bar{T}, T)$ and $R^Q(\bar{T}, T)$?

Hypotheses

- Incredibly naive: for $X \in \{P, Q\}$, $R^X(\bar{T}, T) = \sum_{t=\bar{T}}^{T} q_t(p^X, T)$
  - $\rightarrow$ Ignores supply between periods $\bar{T}$ and T and equilibrium effects
- Somewhat naive: for $X \in \{P, Q\}$, $R^X(\bar{T}, T) = S^X(\bar{T}, T \mid p^X)$
  - $\rightarrow$ Ignores equilibrium effects
- This paper: consider all effects

Bounds

Price mechanism: lower bound

Main result 1

$$R^P(\bar{T}, T) \geq S^P(\bar{T}, T \mid p^P) \geq 0$$

→ Reduction in equilibrium emissions in response to an earlier ban is positive and bounded from below under a price mechanism.

→ Price mechanism reinforces earlier ban

→ Bringing forward the ban reduces equilibrium emissions *at least* by the amount of emissions originally supplied after the earlier ban

Price mechanism: intuition

- The bound is clear
  - $\rightarrow$ A ban at $\bar{T}$ preempts emissions after that period
  - $\rightarrow$ Between periods $\bar{T}$ and T, $S^P(\bar{T}, T \mid p^P)$ allowances are supplied
  - $\rightarrow$ Since borrowing is not allowed, those emissions "disappear"
- Now suppose that $B_{\bar{T}}(p^P) > 0$
  - Strictly positive number of allowances banked when final period is T
- Equilibrium when the final period is $\bar{T}$ requires $B_{\bar{T}}(\bar{p}^P) = 0$
  - $\rightarrow$ No capital destruction!
- $B_{\bar{T}}(p^P) > 0$ and $B_{\bar{T}}(\bar{p}^P) = 0$ imply that $\bar{p}_t^P < p_t^P$ for all $t < \bar{T}$
  - $\rightarrow$ Price must go down to support using up allowances faster
- Mechanics of a price mechanism translate a lower price into less supply
  - $\rightarrow$ Emissions prior to $\bar{T}$ go down, too, reinforcing the earlier ban.

Quantity mechanism: upper bound

Main result 2

$$R^Q(\bar{T}, T) \leq S^Q(\bar{T}, T \mid p^Q)$$

- $\rightarrow$ Reduction in equilibrium emissions in response to an earlier ban is bounded from above and possibly negative under a quantity mechanism.
- $\rightarrow$ Quantity mechanism counteracts earlier ban
- $\rightarrow$ Bringing forward the ban reduces equilibrium emissions *at most* by the amount of emissions originally supplied after the earlier ban

Quantity mechanism: intuition

- The bound again is clear
  - $\rightarrow$ A ban at $\bar{T}$ preempts emissions after that period
  - $\rightarrow$ Between periods $\bar{T}$ and T, $S^Q(\bar{T}, T \mid p^Q)$ allowances are supplied
- Now assume that $B_{\bar{T}}(p^Q) > 0$
- When the ban kicks in at $\bar{T}$, equilibrium requires $B_{\bar{T}}(\bar{p}^Q) = 0$
- Firms start using more allowances before period $\bar{T}$
  - $\rightarrow$ Smoothed out over all periods $t < \bar{T}$
- Higher emissions implies less banking in periods $t < \bar{T}$
- Hence, supply of emissions is higher in all periods before $\bar{T}$
  - $\rightarrow$ Under quantity mechanism, $\partial s_t(B_t)/\partial B_t > 0$
  - $\rightarrow$ Since supply is used up in equilibrium, emissions higher
- Reduction in equilibrium emissions is at most $S^Q(\bar{T}, T \mid p^Q)$

Incompatibility

Negative reduction

- Result 2 hinted at the possibility of a negative reduction $R^Q(\bar{T}, T)$
  - $\rightarrow$ Increased emissions due to earlier ban
- Possible?
  - $\rightarrow$ Under what conditions?

Thought experiment

Posit a period $T^* < T$ such that:

1. Given the ban at T, equilibrium emissions are strictly positive in T^*
2. Given the ban at T, equilibrium supply of allowances has already (and permanently) dried up by period T^*

Such a T^* need not exist; if it exists, it need not be unique. However, if at least one T^* that satisfies 1. and 2. exists, set $\bar{T} = T^*$. Then $\bar{T}$ satisfies

$$q_{\bar{T}}(p^Q, T) > 0 \tag{$*$}$$

$$s_t(B_t(p^Q)) = 0 \quad \forall t \geq \bar{T} \tag{$**$}$$

Think of pensioners receiving 401(k) benefits

Higher emissions

Main result 3

If $\bar{T}$ satisfies $(*)$ and $(**)$, then $R^Q(\bar{T}, T) \leq 0$

$\rightarrow$ Advancing the ban from T to $\bar{T}$ strictly increases emissions

$\rightarrow$ Quantity mechanisms and zero emissions pledges may be incompatible

Intuition

- If $\bar{T}$ satisfies $(*)$ and $(**)$, early ban kicks in when emissions covered exclusively by banked allowances
- When the final period is T, no supply after $\bar{T}$
  - $\rightarrow$ Advancing ban from T to $\bar{T}$ does not kill supply after $\bar{T}$
- Originally, positive bank at $\bar{T}$
  - $\rightarrow$ Equilibrium response, more emissions before $\bar{T}$ to get $B_{\bar{T}} = 0$
- Higher emissions/less baking translated into more supply under quantity mechanism
- No change in supply after $\bar{T}$, but more supply before $\bar{T}$
- Net emissions go up! 😵
- Think of 401(k) again
  - $\rightarrow$ Firms are like retired people by period $\bar{T}$
  - $\rightarrow$ Wage income dried up and, consuming what they set apart earlier in

Mechanism choice

Comparison

- It seems that price mechanisms outperform quantity mechanisms
- Careful: not so obvious
- Suppose $S^Q(T, \bar{T} \mid p^Q) > S^P(T, \bar{T} \mid p^P)$
  - $\rightarrow$ Upper bound on quantity mechanism reductions above lower bound on price mechanism reductions
  - $\rightarrow$ Possible that quantity mechanism reduces emissions more!
- But: somewhat contrived possibility

Symmetric baselines

- Let the final period be T
- Under the equilibrium price vectors p^P and p^Q, suppose that:

$$s_t(p_t^P) = s_t(B_t(p^Q)) \quad \forall t \leq T \qquad (***)$$

$\rightarrow$ Supply of allowances equal in all periods

- If $(***)$ is satisfied, I say that the supply vectors $(s_t(p_t^P))$ and $(s_t(B_t(p^Q)))$ are symmetric under T

Prices vs. Quantities

Main result 4

If $(s_t(p_t^P))$ and $(s_t(B_t(p^Q)))$ are symmetric under T, then
$$R^Q(\bar{T}, T) \leq R^P(\bar{T}, T)$$

- → Advancing the ban from T to $\bar{T}$ reduces emissions less under a quantity mechanism than under a price mechanism
- → Symmetry under T sufficient, not necessary
  - → For example, $\sum_{t=\bar{T}}^{T} s_t(p_t^P) = \sum_{t=\bar{T}}^{T} s_t(B_t(p^Q))$ also works
- → Symmetry under T intuitive starting point: compare effects for same baselines
  - → Unless comparing apples and oranges, price mechanisms win

Conclusions

Fixing quantity mechanisms

- The problems with quantity mechanisms could be overcome: simply accompany the earlier ban with a manual reduction of supply
- Practical complications
  - → How many allowances should be taken out?
  - → When should they be taken?
- Need for ad hoc solution hints at fundamental distinction
- Quantity mechanism requires additional to work well – price mechanism takes care of itself!

Thank you

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