The EU ETS Market Stability Reserve: Optimal Dynamic Supply Adjustment

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Institut Henri Poincaré
Paris, December 11, 2015

The least-cost benchmark

- Suppose one wishes to reduce aggregate emissions of firms over a T-year horizon to a specified goal $\bar{G}$.
- Only *one* way minimizes the present value of aggregate abatement costs among firms and across time.
- A *necessary* condition for the goal to be achieved at least cost is that, in any one year, all firms have equal marginal costs of abatement.
- The least discounted cost is obtained when common marginal cost of abatement in each year has the same present value.
- The least-cost solution can be implemented using market mechanisms (cap-and-trade, emissions taxes).

Standard theory of cap-and-trade

- With limited borrowing, enough permits must be made available before they would be needed to implement the least cost program.

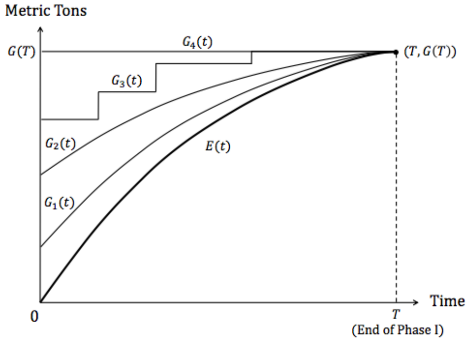

Figure: Salant (2015), RFF Working Paper.

Standard theory of cap-and-trade

- Any allocation path that is uniformly weakly smaller (larger) than another path backloads (frontloads) it.
- The same path of permit prices (and abatement) are obtained when $G(t) \geq E(t)$.
- Otherwise, an artificial permit shortage will be created.
- The permit price will rise to clear the market, inducing too much abatement early in the program and too little later.
- Hence, *"as long as the government makes permits available before they are needed to implement the efficient program, emissions trading with bankable permits will induce ... [abatement] that costs society the least."*
- So, what's the impact of the EC MSR? Limited or no-impact.

Bank and allowance price

- In 2012 the European Parliament "identified the need for measures in order to tackle structural supply-demand imbalances."

Figure: Source DECC (2014).

Fixed cap and rigid allowance supply

- The cap in the EU ETS is fixed and the supply of permits is inflexible and determined within a rigid allocation programme.
- If the allowance price is unrelated to changes in macroeconomic conditions, ETS's value as a co-ordinating mechanism will be diminished.
- The stringency of regulation should respond to fluctuations in economic activity through transparent and predictable rules.
- The allowance allocation programme should respond to changes in economic activity through transparent and predictable rules.

Tier 1 – rigid vs. 'responsive' cap

- Responsive policies would introduce pro-cyclical variability to 'carbon' policy instruments.

	Level of emissions	Carbon price
ETS† with a fixed cap	fixed, acyclical	volatile, pro-cyclical
Fixed carbon tax	volatile, pro-cyclical	fixed, acyclical
ETS with a responsive cap	more volatile, pro-cyclical	less volatile, pro-cyclical
Responsive carbon tax	less volatile, pro-cyclical	more volatile, pro-cyclical

Source: Doda (2014) How to price carbon in good times...and bad. GRI Policy Brief, December 2014.

Tier 2 – rigid vs. contingent allowance supply

- An ideal instrument of central control would be a contingency message whose instructions depend on which state of the world is revealed (economic shock, technology advancement and new policies, for instance).
  - Weitzman (1974); Roberts and Spence (1976);
  - Newell and Pizer (2008).
- "In order to address that problem and to make the EU ETS more *resilient* in relation to supply-demand imbalances, [...], a market stability reserve (MSR) should be established in 2018 and operational as of 2019."
  [EC, 8th July 2015].

Paper in a nutshell and main results

- We model an emissions trading system under adjustable supply (tier 1 and 2) and solve the inter-temporal emission control problem.
- We obtain (closed form) expressions for:
  - individual and aggregate abatement- and permit trading strategies; and
  - the equilibrium permit price.
- Explicit representation of dependencies between the supply management programme and the markets dynamic behaviour.
- We investigate the impact of the EC MSR on the equilibrium dynamics (under risk neutrality).
- Attempt to answer:
  1. Does the EC MSR have an impact on the market?
  2. To what extent the EC MSR makes the system responsive, i.e. reduce (net-demand) uncertainty?

Paper in a nutshell and main results

- We introduce a stylised MSR (simplified EC MSR) that spans the continuum between a cap-and-trade scheme and a carbon tax.
- We solve the inter-temporal emission control problem and obtain equilibrium dynamics under risk-neutrality and risk-aversion.
- Attempt to answer:
  1. Under which conditions does an MSR have an impact on the system?
- The model provides an analytical tool to select an optimal policy (which minimises expected compliance costs).
- Attempt to answer:
  1. In light of future EC MSR revisions, how to select the optimal policy parameters? (increase responsiveness, yet cost-effective)

The model

- Continuous time, finite time-horizon: $0 \leq t \leq T$, where T is the end of the regulated period.
- Companies are continuously distributed in a set $\mathcal{I}$ under a probability measure m.
- Each firm is characterised by a set of key characteristics: initial endowment of allowances N_0^i, allowance allocation and emissions process.
- Each company controls emissions and trade allowances, depending on the relative cost difference between control costs and trading.
- She has to comply with regulations by offsetting her emissions with an equal number of allowances at time T.

Allowance Supply and Demand

- Below MSR stands for supply management policy.
- Supply - $d\varphi_t^i$ denotes the instantaneous allowance allocation and comprises the pre-MSR allowance allocation schedule and the MSR quantity adjustment.
- Demand -
  - $g_t^i dt + d\varepsilon_t^i$ denotes the pre-abatement instantaneous emissions, where $d\varepsilon_t^i = \sigma_t^i \, dW_t$ is a random shock.
  - α_t^i denotes the rate of change in emissions-intensive production (abatement when $\alpha_t > 0$).
- In aggregate terms, the cumulative amount of allowances in circulation at time t is given by

$$\mathrm{TNA}_t = N_0 + \int_0^t d\varphi_s - \int_0^t g_s \, ds - \int_0^t d\varepsilon_s + \int_0^t \alpha_s \, ds.$$

- Later, this will represent the Total Number of Allowances, the adjustment indicator in the EC MSR.

Individual position and compliance

- The individual allowance net position at time t is

$$X_t^i = N_0^i + \mathbb{E}_t\left[\int_0^T d\varphi_s^i - \int_0^T g_s^i \, ds - \int_0^T d\varepsilon_s^i\right] + \int_0^t \alpha_s^i \, ds - \int_0^t \beta_s^i \, ds,$$

  where
  - $|\beta_t^i|$ is the number of allowances sold ($\beta_t^i > 0$) or bought ($\beta_t^i < 0$) by company i at time t, and
  - $\mathbb{E}_t = \mathbb{E}[\cdot|\mathcal{F}_t]$ represents the conditional expectation.
- Full compliance is required by the end of the regulated period, $\mathbb{E}_t[X_T^i] \geq c^i$ at all times t and $c^i \geq 0$.

Inter-temporal decision problem

- The instantaneous costs of trading and controlling emissions

$$v_t^i = \Pi\alpha_t^i + \varrho(\alpha_t^i)^2 - P_t\beta_t^i + \nu(\beta_t^i)^2.$$

where

  - control costs are quadratic, Π_t and ϱ are the intercept and slope of the marginal control cost; and
  - trading costs and market trading frictions are approximated by linear temporary price impact $P_t - \nu\beta$.

- Company i-th selects emission control- and trading strategies, α^i and β^i, respectively, that minimise the total compliance costs:

$$J(\alpha, \beta) = \mathbb{E}\left[\int_0^T e^{-rt}\, v_t^i\, dt\right] \text{ s.t } X_T^i = c^i \;\; a.s.$$

where r is risk-free interest rate.

Equilibrium strategies and permits price

- An equilibrium is a set $\{(\alpha_t^i, \beta_t^i)_{i\in\mathcal{I}}, P_t; t \in [0, T]\}$ of Markovian strategies that satisfy the market-clearing condition $\int_I \beta_t^i dm(i) = 0$ for all t.
- In equilibrium, the abatement and trading strategies are:

$$\alpha_t^i = \frac{P_t - \Pi_t}{2(\nu + \varrho)} - \frac{\nu r\,(X_t^i - c^i)}{(e^{r(T-t)} - 1)(\nu + \varrho)} \quad \text{and} \quad \beta_t^i = \alpha_t^i + \frac{r\,(X_t^i - c^i)}{e^{r(T-t)} - 1},$$

and the price process is given by

$$P_t = \Pi_t - (X_0 - c)\frac{2re^{rt}\varrho}{e^{rT} - 1} - 2re^{rt}\varrho \int_0^t \frac{d\gamma_s}{e^{rT} - e^{rs}}.$$

where γ_s is the expected net-supply

$$\gamma_s = \mathbb{E}_s \left[\int_0^T d\varphi_u - \int_0^T g_s^i\, ds - \int_0^T d\varepsilon_u \right].$$

- The solution to the control problem includes market's reaction to MSR.

The EC's Market Stability Reserve

- We can evaluate the policy impact on the abatement distribution and the equilibrium price.
- The EC MSR responds to current market changes by adjusting auction quantities.
- The indicator used to trigger auction quantity adjustments is the amount of allocated and unused allowances, i.e. the size of the privately-held bank of allowances (TNA).
- Specifically
  - 12% of TNA in the reserve, unless this number is less than 100 million allowances (implied withholding trigger of 833 million allowances).
  - allowances are moved from the reserve back into the auction system if the TNA falls below a 400 million allowances trigger.

Contingent supply and the EC MSR

- The aggregate instantaneous abatement α_t is given by

$$\alpha_t = -re^{rt}\frac{X_0(\delta) - c}{e^{rT} - 1} - re^{rt}\int_0^t \frac{d\gamma_s(\delta)}{e^{rT} - e^{rs}}.$$

- Restrict attention to the certainty case.
- When cap is fixed but allowance supply adjustable ($d\gamma_s = 0$),
  1. MSR has no impact (abatement/price paths unchanged) when $\int_0^T d\varphi_u \geq \int_0^T g_s^i ds$.
  2. MSR has limited impact (abatement/price paths tilted) when $\int_0^T d\varphi_u \leq \int_0^T g_s^i ds$.

Stylised supply management policy

- Study the effect of MSR when firms are risk-adverse.
- Consider the following contingency rule for the supply of allowances:
  - At each time t, $\delta \cdot (\mathrm{TNA} - c)\, dt$ allowances are added to or removed from the allocation schedule.
- Let f_t represent the fixed allocation schedule. The dynamics for the TNA is then given by

$$d\mathrm{TNA}_t = f_t dt + \delta(c - \mathrm{TNA}_t)\, dt - g_t dt - d\varepsilon_t + \alpha_t dt.$$

- We derive a probabilistic expression for the quantity indicator as a function of the supply adjustment rate δ governing the contingent policy.

Confidence level of TNA

- Consider the case of risk-neutral firms and Gaussian distributed $d\varepsilon_t$ with mean zero and deterministic volatility κ_t.
- We obtain that $\text{TNA}_t \sim \mathcal{N}(a_t, b_t^2)$ where

$$a_t = N_0^I e^{-\delta t} - \frac{r(e^{rt} - e^{-\delta t})}{(\delta + r)(e^{rT} - 1)}(X_0 - c) + \int_0^t e^{\delta(s-t)}(f_s - g_s + \delta c)\, ds$$

is the mean, and

$$b_t^2 = \frac{e^{2rt}}{V_t^2(\delta, r)} \int_0^t e^{-2rs}\, V_s^2(\delta, r)\, \kappa_t^2\, ds$$

is the variance.

- Let λ denote the probability that the TNA stays within the band $[l_t, u_t]$. We can then compute the following

$$\lambda = \Phi\left(d_t^{(1)}\right) - \Phi\left(d_t^{(2)}\right), \quad d_t^{(1)} = \frac{u_t - a_t}{b_t}, \qquad d_t^{(2)} = \frac{l_t - a_t}{b_t}.$$

Confidence level of TNA

- Any distribution of ε_t yields a probability distribution of TNA_t, parametrised by the adjustment rate δ.
- This also yields quantiles for any given confidence level.
- We can represent the EC's quantity thresholds as quantiles for the TNA for a given confidence level.
- When the MSR adjustment rate is zero, the chosen quantity corridor cannot be maintained with the desired confidence level.

Adjustment rate δ and the TNA

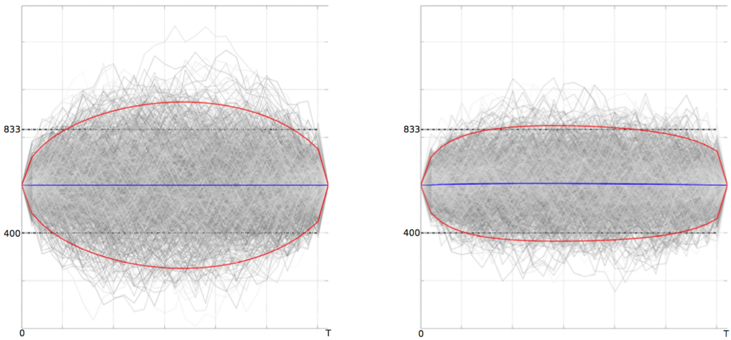

Figure: Exemplary illustration of the total number of allowances in circulation (TNA). Left-hand graph: No mechanism. Right-hand graph: Positive adjustment rate. Red lines: 95%-confidence interval.

Contingent supply under risk-aversion

- We can evaluate the policy impact on the abatement distribution and the equilibrium price.
- The aggregate abatement follows the dynamics

$$d\alpha_t = \left(r\alpha_t + \frac{V_t(\delta, r)(r-\mu)}{2\varrho V_t(0,r)} \Psi_t \right) dt + \frac{V_t(\delta, r) k_t}{2\varrho V_t(0,r)} \, dW_t.$$

- The price process Ψ_t follows the dynamics

$$d\Psi_t = \left(r + \frac{V_t(\delta, r)}{V_t(0,r)} (\mu - r) \right) \, \Psi_t \, dt - \frac{V_t(\delta, r)}{V_t(0,r)} k_t dW_t.$$

where $V_t(\delta, r) = (\delta + r)/(e^{(\delta+r)(T-t)} - 1)$.

Supply adjustment rate

- High adjustment rate, then
  - TNA is tight and low variability of the net-demand;
  - $V_t(\delta, r) \rightarrow 0$;
  - rate of return $\rightarrow r$;
  - volatility term $\rightarrow 0$.
- Low adjustment rate then the TNA is unconstrained and the net-demand risk mitigation of the mechanism vanishes.

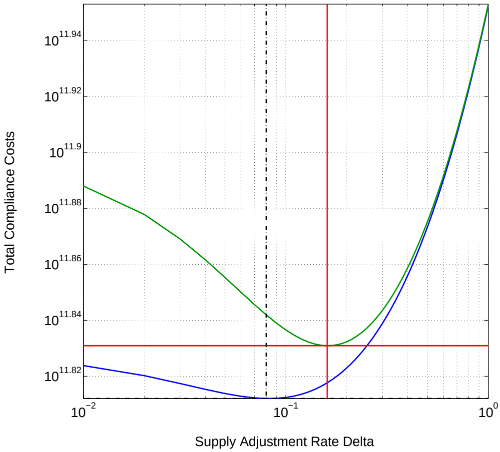

Figure: Expected total compliance costs (log scale) as a function of the adjustment rate δ when $r = 2\%$, $\mu = 3\%$, $\varrho = 0.25 \cdot 10^{-9}$ Euros/tonne^2, $\Pi = 10$, $c = 500$ million allowances, a historical price volatility of $k = 0.25$ Euros yearly and expected emissions of $g_t = 4$ billion tonnes yearly. Companies are identical and have an initial supply of 2 billion allowances and a time horizon of $T = 30$ years. The ex-ante planned allocation starts at 2 billion allowances and decreases linearly by 2%. The green line represents the expected total compliance costs under risk-aversion. Costs are minimised when $\delta = 16\%$ yearly (marked by the vertical red line). The blue line represents the expected total compliance costs under risk-neutrality for which costs are minimised when $\delta = 8\%$ yearly (marked by the dotted line).

Net-demand risk premium and adjustment rate

- Case $\delta = 1$
  - very tight band for the TNA, net-demand variability diminishes, the required risk-premium approaches zero;
  - average RADR converges to the risk-free rate r, (tax system).
  - reduction in net-demand variability comes, however, at a high cost (horizontal dotted line).
- Case $\delta = 0$
  - the band for the TNA is loose, the net-demand variability on allowance prices is unaffected, and there is a positive risk-premium.
  - average RADR is higher than r
  - allowance prices volatility is unconstrained and total compliance costs are 'uncontrolled' (and on average high).

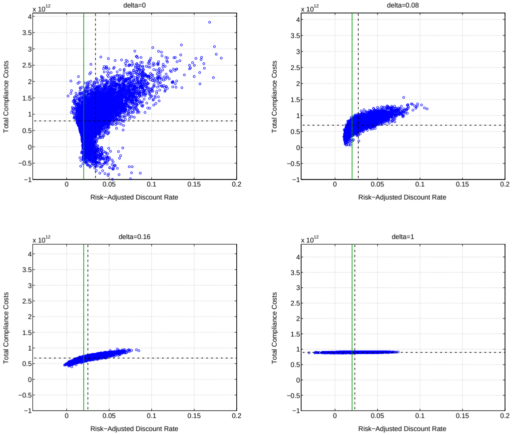

Figure: Risk-adjusted discount rates versus total costs under risk-aversion for $r = 2\%$, $\mu = 3\%$, $\varrho = 0.25 \cdot 10^{-9}$ Euros/tonne^2, $\Pi = 10$, $c = 500$ million allowances, a historical price volatility of $k = 0.25$ Euros yearly and expected emissions of $g_t = 4$ billion tonnes yearly. Companies are identical and have an initial supply of 2 billion allowances and a time horizon of $T = 30$ years. The ex-ante planned allocation starts at 2 billion allowances and decreases linearly by 2%. Each blue dot represents one of 10^4 model simulations. The vertical dotted line marks the average risk-adjusted discount rate. The horizontal dotted line marks the average total compliance cost.

Price-based vs. quantity-based mechanism

- Consider a price-based mechanism where the objective of the policy is to maintain the rate of return of the allowance price around a target rate.
- Given the policy parameter η, in analogy to the previous problem:

$$\min_{\eta} \mathbb{E}^{\mathbb{P}} \left[w_T^*(\eta) \right]$$

- Enforcing a specific rate of return $\vartheta(\eta)$ is equivalent to the implementation of a tax.
- When the price-band is set wider, the permit price reflects economic shocks and total compliance costs are controlled more loosely.

Conclusions

- We model an emissions trading system under adjustable supply and obtain closed form solutions for the dynamic market behaviour under uncertainty:
  - the expressions for aggregate and individual emission control- and trading strategies;
  - the market-clearing price process.
- We capture the feedback between the equilibrium dynamics and the supply management mechanism.
- We show the EC MSR has no or limited impact on the market when the cap is fixed.

Conclusions

- We propose a stylised supply control mechanism that spans the continuum between price and quantity policy outcomes.
- We solve the control problem with risk-neutral and risk-averse companies and investigate the MSR's impact on the system dynamics.
- The model offers an analytical tool to select an optimal policy which minimises expected compliance costs.
- We provide some insights into the relationship between price-based and quantity-based contingent supply mechanisms.

Thank you very much for your attention.

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Risk-averse companies

- Let μ denote the historical rate of return of the difference $\Psi = P - \Pi$ and let k_t denote its time-dependent volatility.
- Then we obtain the risk-adjusted discount rate

$$\vartheta_t = rt + \frac{1}{2}\int_0^t \zeta_s^2 \Psi_s^2 \, ds - \int_0^t \zeta_s \Psi_s \, dW_s,$$

  where dW_t is a Gaussian random shock and $\zeta_t = (r - \mu)/k_t$.
- We also obtain the Radon-Nikodým density $d\mathbb{Q}/d\mathbb{P} = e^{-\vartheta_T + rT}$, where $\mathbb{Q}$ and $\mathbb{P}$ denote the risk-neutral and objective measure, respectively.

The regulator's problem

- Problem of selecting a supply adjustment rate δ that minimises the expected aggregate compliance costs:

$$\min_{\delta} \mathbb{E}^{\mathbb{P}}\left[w_T^*(\delta)\right] = \min_{\delta}\left\{\mathbb{E}^{\mathbb{Q}}[w_T^*(\delta)] + \text{Cov}^{\mathbb{Q}}\left(e^{\vartheta_T(\delta)-rT}, w_T^*(\delta)\right)\right\},$$

where instantaneous costs are given by

$$v_t = \int_{\mathcal{I}} \Pi\alpha_t^i + \varrho(\alpha_t^i)^2 - P_t\beta_t^i + \nu(\beta_t^i)^2 \, dm(i)$$

and $w_T = \int_0^T e^{-rt} v_t \, dt$ represent the present value of aggregate total costs.