# Combining Price and Quantity Controls under Partitioned Environmental Regulation

Sebastian Rausch

*ETH Zurich*
*Center for Economic Research at ETH (CER-ETH)*
*Center for Energy Policy and Economics (CEPE)*
*&*
*MIT*
*Joint Program on the Science and Policy of Global Change*

(joint with Jan Abrell)
*ETH Zurich*

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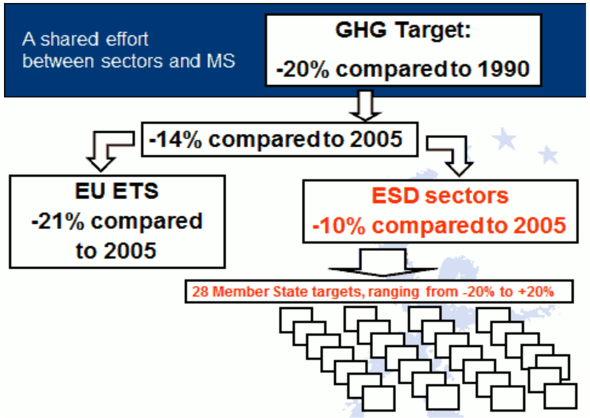
# Motivation

- Emissions Trading Systems (ETS) have become centerpiece of environmental policy in many countries

- Partitioned environmental regulation is political reality

- Prominent example: EU Climate Policy
  - EU Climate Policy: 45% of emissions covered by EU ETS, remainder regulated by individual member states
  - Regulator decides on how EU-wide target is split between ETS and non-ETS partitions



A shared effort between sectors and MS

**GHG Target:**
**-20% compared to 1990**

**-14% compared to 2005**

**EU ETS**
**-21% compared to 2005**

**ESD sectors**
**-10% compared to 2005**

28 Member State targets, ranging from -20% to +20%

- Partitioned regulation + uncertainty about firms' abatement costs and emissions

  ➔ potentially large differences in marginal abatement costs across polluting sources, thus undermining cost-effectiveness

# Research questions

- Can costs of achieving a given environmental target be reduced by designing hybrid ETS regulation when
  (1) ETS covers only subset of pollution (partitioned regulation)
  (2) regulator is uncertain about firms' abatement costs and future emissions
  **?**
- Hybrid policies: (1) ETS + price bounds or (2) ETS + abatement bounds
- How to choose price and abatement bounds under hybrid policies**?**
- Empirical, quantitative implications of hybrid policies in context of EU Climate Policy
  - Expected abatement cost of hybrid regulation relative to existing pure quantity controls**?**
  - Distribution of ex-post cost reductions**?**
  - Performance of alternative hybrid policies: price vs. abatement bounds**?**

# Key contributions

- Re-visit fundamental policy question of combining prices and quantities under partitioned environmental regulation and uncertainty about abatement cost and emissions
    - Ex-post efficient hybrid regulation (Roberts & Spence, 1976; Pizer 2002; Krysiak, 2008)
    - Safety valve and price floors for limiting cost of climate policy (Aldy et al., 2001; Jacoby & Ellerman, 2004; Pizer, 2002; McKibbin & Wilcoxen, 2002)
    - Efficiency cost of partitioned environmental regulation (Böhringer et al., 2006, 2014; Böhringer & Rosendahl, 2009; Dijkstra et al. 2011)
    - Recent literature on “Market Stability Reserve” (Kollenberg & Taschini, 2015; Ellermann et al, 2015; Perino & Willner, 2015)

- Theoretical analysis aimed at understanding economic principles for setting parameters of hybrid policies

- Quantitative empirical assessment of hybrid policies in EU climate policy context (➔ numerical stochastic partial equilibrium model of European carbon market to find optimal policies)

# Model setup

- Economy with two polluting sectors $i \in \{T, N\}$
  - Sector T regulated by emissions trading system (ETS)
  - Sector N regulated by cost-effective measure (e.g., a carbon tax)

- Exogenously given and fixed environmental target: $\overline{e} \geq \sum_i e_i$

- Regulator minimizes total expected costs using two policy instruments
  - Allocation of emissions budget across sectors: allocation factor $\lambda = \overline{e}_T / \overline{e}$
  - Price or abatement bounds in ETS: [price floor, price ceiling] or [abatement floor, abatement ceiling]

- Regulator faces uncertainty about firms' abatement costs and future emissions. Strictly convex abatement cost functions:

$$C_i(\underbrace{e_i^0 + \epsilon_i - e_i}_{=a_i(\text{abatement})}, \epsilon_i)$$

$e_i^0$: certain "no intervention" emissions level
$e_i$: emissions level with policy
$\epsilon_i$: random variables

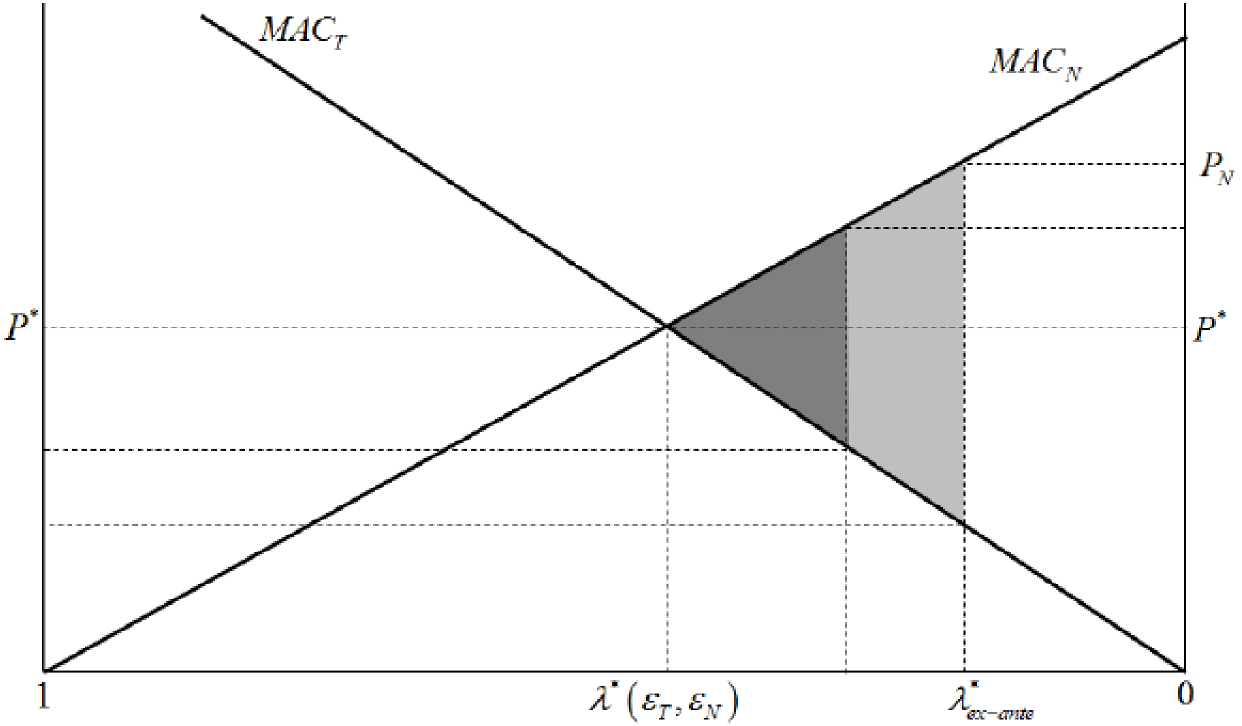
**Uncertainty about baseline emissions**
- GDP growth, energy demand
- Fuel prices

**Technology uncertainty**

- Firms know their abatement cost function and choose cost-minimizing abatement (P=MAC)

- Environmental target always has to be fulfilled; if bounds are binding, ex-post adjustment of sectoral emissions budgets

# 1st best policy vs. 2nd best pure quantity control



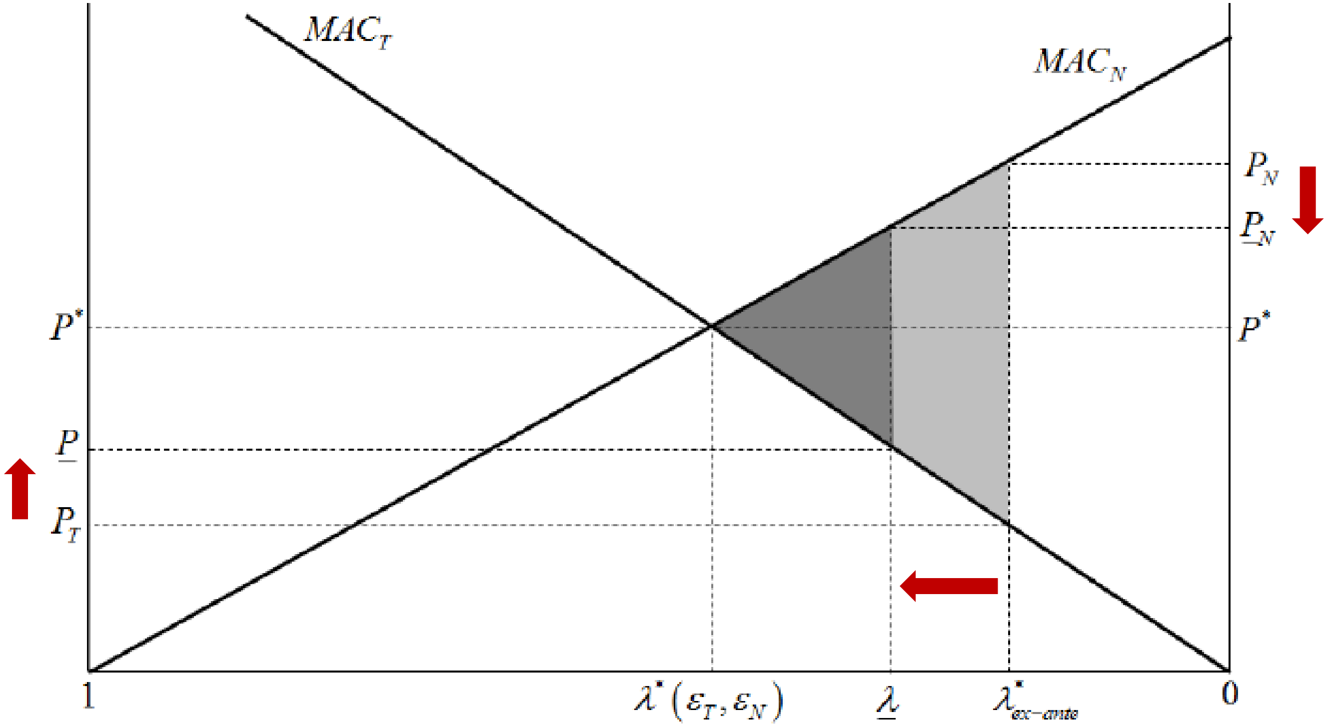
- **1st best:** state-contingent allocation factor, no role for hybrid policies
- **2nd best:** ex-ante allocation factor cannot be conditioned on $\epsilon$ . Optimal choice:

$$\mathbb{E}\left[\frac{\partial C_T\left(e_T^0 + \epsilon_T - \lambda^*_{ex\text{-}ante}\overline{e}, \epsilon_T\right)}{\partial a_T}\right] = \mathbb{E}\left[\frac{\partial C_N\left(e_N^0 + \epsilon_N - (1 - \lambda^*_{ex\text{-}ante})\overline{e}, \epsilon_N\right)}{\partial a_N}\right]$$

- Problem is that (in all likelihood): $\lambda^*_{ex\text{-}ante} \neq \lambda^*\left(\epsilon_T, \epsilon_N\right)$

***Role for hybrid policies?***

# Ex-post effects of price floor



- Hybrid ETS regulation with price bounds (similar for abatement bounds):
  - introduces partial state contingency of allocation factor
  - provides hedge against “too large” differences in ex-post MACs across partitions

***How should policy variables (allocation factor, bounds) be chosen?***

***Can hybrid policies reduce abatement costs (expected and ex-post)? By how much?***

# Summary of main theoretical results

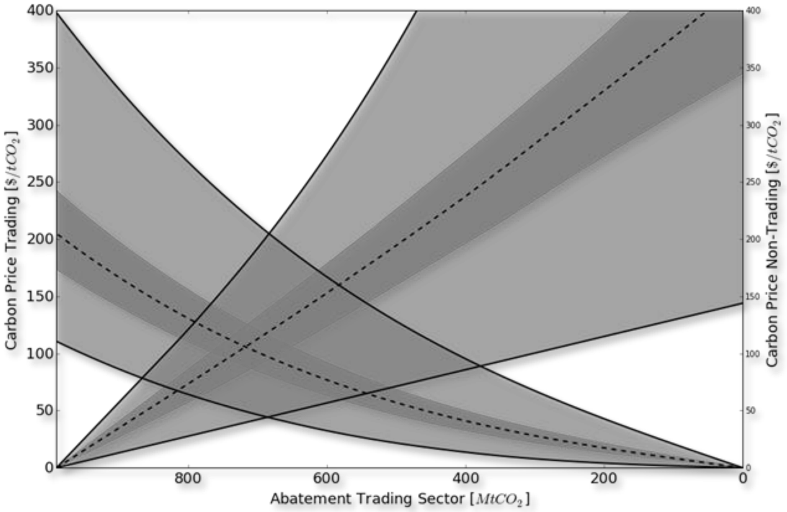
- *Proposition 1* ("Expected costs"): Expected total abatement costs under hybrid policy with price or abatement bounds cannot be larger than those under pure quantity-based policy.
- *Proposition 2* ("Ex-post costs"): An emissions price floor (ceiling) below (above) the optimal permit price does not increase total abatement cost .
- *Proposition 3* ("Inequality of expected MACs"): The ex-ante optimal hybrid policy with price bounds under partitioned regulation allocates the overall environmental target such that the expected marginal abatement costs across partitions differ in the range where price bounds are not binding.
- *Proposition 4* ("Abatement vs. price bounds"): Hybrid policies with abatement bounds fail to address technology uncertainty. Policies with price bounds can address both emissions and technology uncertainty.

***➔ Numerical analysis to further examine hybrid policies***

# Quantitative framework

## Stochastic policy optimization model with partial equilibrium carbon market for Europe

### Derivation & sampling of MAC curves



- Technology uncertainty:
  - Cubic MAC functions OLS-fitted based on price-quantity pairs from CGE model (multi-sector, multi-region, static CGE)
  - Calibration of CES functions for production & consumption based on SAM data (GTAP)
  - Substitution parameters independently sampled from uniform distribution with support [0.5**c*; 1.5**c*], *c*=central case value based on literature
- Baseline emissions uncertainty:
  - Jointly truncated normal shock: ± 15% deviation from baseline emissions
  - Three cases: negative/zero/positive correlation
- Combining uncertainties:
  - Assumption: technology shocks uncorrelated with emissions uncertainty
  - Scenario reduction using “k-means” clustering

# Computational strategy

- $1^{st}$-best and $2^{nd}$-best quantity policies can be solved as standard NLP
- Finding optimal hybrid policies requires solving MPECs
  - a priori unclear in what SOW bounds will be binding (cutoff levels depend on policy choice variables)
  - ➔ endogenous "rationing" mechanism which re-allocates emissions targets when bounds are binding
- MPEC: bi-level optimization problem with equilibrium constraints in lower level (rationing quantities and state-contingent sectoral carbon prices)
- Complementarity-based formulation enables representing policies in terms of constraints on dual variables
- We solve MPEC as reformulated mixed complementarity problem (MCP, Mathiesen 1985, Rutherford 1995) using standard solvers (GAMS, PATH)

# Simulation analysis

- **Policy assumptions**
  - Environmental target

    Approximate current EU climate policy ("2030 Climate & Energy Framework": cut at least 40% GHG emissions in 2030 relative to 1990)

    ➔ 30% reduction in $CO_2$ emissions

  - $3^{rd}$-best allocation factor (=current policy)

    "Effort Sharing Decision" (EC, 2008) defines reduction targets for non-ETS sectors & data on historical emissions (from EEA)

    ➔ $\hat{\lambda} = 0.41$

- **Assessment of hybrid policies focusing on**
  1. Expected costs
     - $1^{st}$, $2^{nd}$, and $3^{rd}$ best regulation
     - Type and structure of uncertainty
     - Alternative $3^{rd}$ best settings
  2. Ex-post distribution of costs

# Expected cost impacts

| | First-best policy | Second-best policies | | | Third-best policies | | |
|---|---|---|---|---|---|---|---|
| | $\lambda^*$ | $\lambda^*$ | $\lambda^*, \underline{P}, \overline{P}$ | $\lambda^*, \underline{a}, \overline{a}$ | $\hat{\lambda}$ | $\hat{\lambda}, \underline{P}, \overline{P}$ | $\hat{\lambda}, \underline{a}, \overline{a}$ |
| Expected cost (bill. \$/per year) | | | | | | | |
| Total | 39.3 | 41.9 | 40.5 | 40.6 | 52.8 | 40.8 | 40.7 |
| ETS | 24.2 | 25.4 | 24.3 | 24.7 | 11.8 | 24.1 | 24.3 |
| Non-ETS | 15.1 | 16.6 | 16.1 | 15.8 | 41.0 | 16.6 | 16.3 |
| Ex-ante allocation factor $\lambda$ | | | | | | | |
| | *optimal* | .34 | .34 | .33 | .41 | .41 | .41 |
| Carbon permit price (\$/ton $CO_2$) in ETS | | | | | | | |
| min | 37 | 21 | 77* | 51 | 8 | 86* | 54 |
| max | 197 | 278 | 101* | 168 | 174 | 124* | 165 |
| Probability that [lower,upper] price or abatement bound in ETS binds | | | | | | | |
| | – | – | [0.43,0.27] | [0.35,0.5] | – | [0.95,0] | [0.98,0] |
| Expected carbon price (\$/ton $CO_2$) and stdev (in parentheses) | | | | | | | |
| ETS | 86 (18) | 89 (31) | 87 (10) | 88 (21) | 50 (19) | 86 (4) | 87 (20) |
| Non-ETS | 86 (18) | 89 (37) | 88 (37) | 87 (32) | 156 (51) | 88 (41) | 89 (34) |

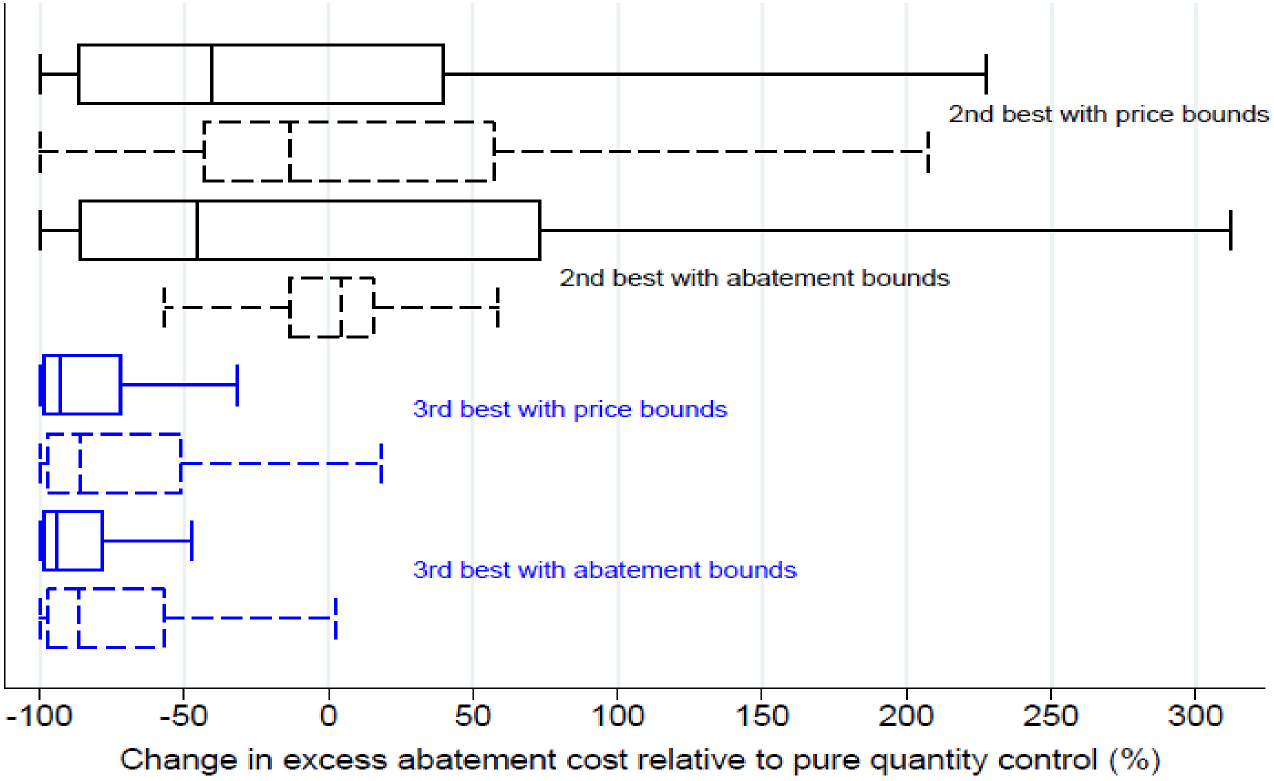
**Hybrid policies substantially reduce expected excess costs relative to 1st best policy**

- 2nd best, price bounds: by 53% or 1.4 bill.\$/per year
- 3rd best, price bounds: by 89% or 12 bill.\$/per year
- ➔ hedging against large differences in sectoral MACs (more narrow min/max, smaller stdev)

**Ex-ante optimal hybrid policies in 3rd best**

- effectively work as tax
- are almost as good as 2nd best hybrid policies

# Ex-post costs of hybrid policies (relative to pure quantity control)



Solid = negative correlation
Dashed = positive correlation

Boxes = IQR & median
Outside values = min/max

- Distribution of ex-post cost savings depends on policy design, ability to cope with different types of uncertainty, correlation structure between sectoral emissions
- Probability for cost savings under 2nd best
  - Negative correlation: .67 for price and abatement bounds (cost savings slightly more dispersed for abatement bounds)
  - Positive correlation: .49 for price bounds; .14 for abatement bounds (abatement bounds not very effective hence “narrow” distribution around zero)
- Ex-post cost savings virtually guaranteed under 3rd best policy

# Conclusions

- Hybrid ETS policies (with price or abatement bounds) introduce partial state contingency allowing to hedge against differences in MACs across partitions.
- Hybrid policies substantially reduce expected excess costs relative to pure quantity-based regulation
  - 2nd best: up to 56% (1.5 billion$/year)
  - 3rd best (=current EU Climate Policy): up to 89% (12.1 billion$/year).
- Sizeable ex-post costs savings from hybrid policies.
  - Probability for price bounds 49-67% and abatement bounds 14-66% depending on correlation of sectoral emissions.
- Price bounds more effective to reduce costs than abatement bounds
- Hybrid policy with abatement bounds much less effective if sectoral emissions are positively correlated
- Hybrid policies provide way to correct previously made sub-optimal policy choices under partitioned regulation (emissions budget split)
  - Bounds then narrow ➔ hybrid policy effectively mimics a price-based system
  - 3rd best hybrid policies almost as good in terms of expected costs as 2nd best pure quantity control