Renewables, Allowances Markets, and Capacity Expansion in Energy-Only Markets

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Squeezing earnings of large electricity firms


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The trouble is that power plants using nuclear fuel or brown coal are designed to run full blast and cannot easily reduce production, whereas the extra energy from solar and wind power is free. So the burden of adjustment fell on gas-fired and hard-coal power plants, whose output plummeted to only about 10% of capacity.

- Systematic decrease in electricity firms' operational profitability and a consequent reduction in electricity investments.
- Overcapacity of fossil generation and a larger share of renewable generation are among the main causes, Koch et al. [2014].
- Renewables have not just put pressure on margins, they have transformed the established business model for utilities.

Explore the implications on capacity expansion

- "Conventional power generation as a business unit [...] is fighting for its economic survival." – CFO of RWE.
- Examine the interplay between regulatory efforts, electricity producer's capacity expansion incentives, and equilibrium market prices using a simple, two technology, setup - Böhringer and Rosendhal [2011], Böhringer and Behrens [2015].

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Incentive to withhold capacity investments

- Crucial for our study is the fact that
  1. investments in renewables drives fossil out of the market,
  2. but renewables also produce rent precisely because their marginal cost is below that of fossil generators.
- If the firm was sure (which she of course can't be) that a fossil plant will continue to be marginal, she certainly has an incentive to invest in renewables, provided that the investment cost is low enough.
- Thus, there is a tradeoff that generates an incentives to withhold fossil capacity; among others Murphy and Smeers [2005], Zöttl [2011] and Murphy and Smeers [2012].

The paper in a nutshell - 1

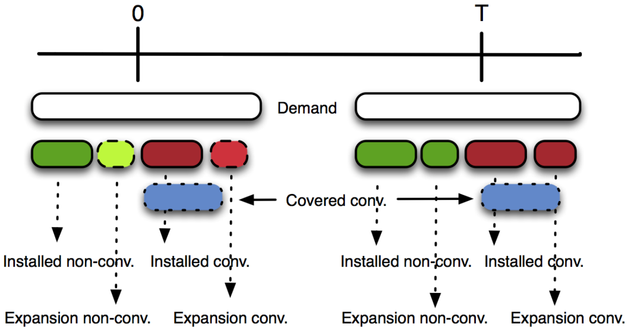
- Simplest possible formulation that allows one to examine the question of capacity expansion in an energy-only market affected by electricity and environmental constraints.
- Derive analytical dependencies between the equilibrium market prices and the capacity expansion decision.
- Illustrate the fundamental tradeoff: "a higher potential for profits from renewables generation sold at the marginal cost of fossil generation is tempered by a lower likelihood of obtaining those profits."

The paper in a nutshell - 2

- Explore the combined effects of increased renewables and an ETS by solving the optimal expansion problem for three marker scenarios, formulated to represent different stages of an ETS (start, middle, and end phases).
- There is a clear incentive to maintain fossil generation under the last two scenarios.
- Producers can pursue two distinct pathways of profit generation:
  1. normal solution: operational profits are the dominating component of expected profits, i.e. sale of renewables generation at a price equal to the marginal cost of fossil generation;
  2. degenerate solution: expected profits are determined by the allowance component, i.e. sale of generation includes non-compliance costs.

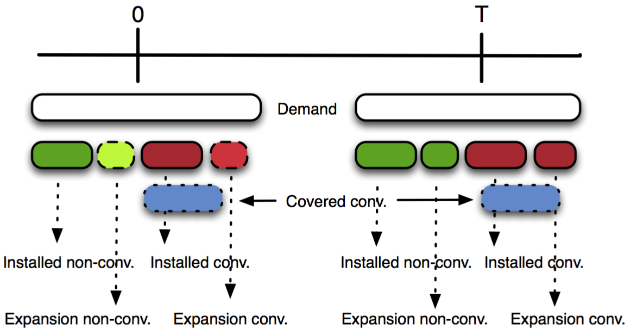
General setting - selecting capacity expansion 1

- One period model with two technologies, green Q_{nc} (non-conventional) and fossil Q_c (conventional) generation.
- Total aggregate electricity demand D (net of auto generation and consumption, more on this later) is uncertain.
- At $t = 0$ companies decide on the optimal capacity expansions (can take negative values, dismantling).



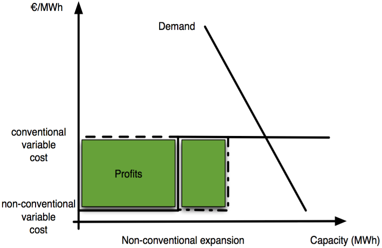
General setting - selecting capacity expansion 2

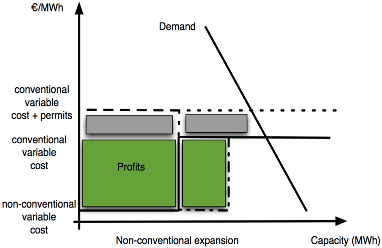
- Electricity and allowances are the relevant markets, with p price per MWh and p_a price per tonne of CO_2.
- C is the total number of allowances available and m the emissions of the fossil plant.
- 'Covered' fossil generation is $H = C/m$ MWh.
- Uncovered fossil generation pay penalty f per tonne.



Energy-only market

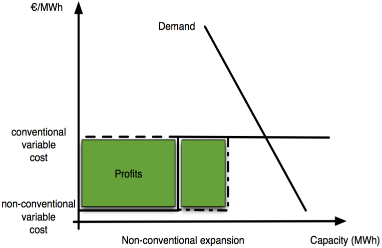
- In energy-only markets the price of electricity is exclusively determined by volumes of electricity supplied.
- When demand is high, non-conventional production is priced at the higher marginal cost of fossil plants

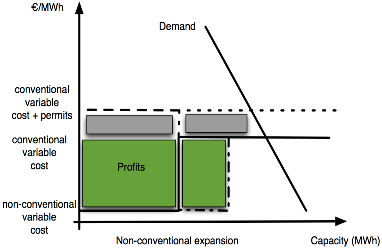




Energy-only market

- The more renewable capacity is created and maintained, the higher is the risk of costly idleness.
- This could quickly outweigh the potential rewards of selling renewable production at higher fossil generation prices.

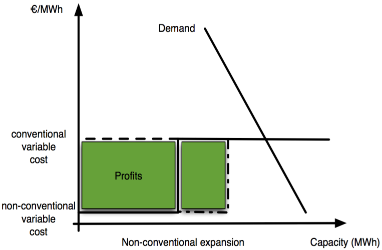


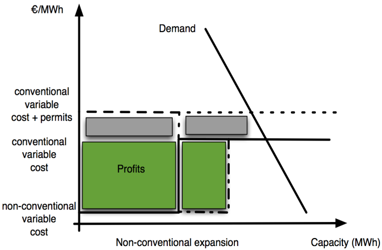


Energy-only market and allowance market

- The impact of the allowances price on the electricity price is modelled by a pass-through coefficient $\beta \in [0, 1]$

$$p = c_{v,c} + \beta m p_a,$$





- Cost pass-through reinforces withholding of fossil generation.

Electricity demand, electricity and allowance price

- At time T, given the post-expansion capacities Q^*_{nc} and Q^*_c, the event space Ω can be split into three regions depending on D :

$$A_1 = \{\omega \in \Omega : D \leq Q_{nc} + Q^*_{nc}\};$$
$$A_2 = \{\omega \in \Omega : Q_{nc} + Q^*_{nc} < D < Q_{nc} + Q^*_{nc} + H\};$$
$$A_3 = \{\omega \in \Omega : D > Q_{nc} + Q^*_{nc} + H\}.$$

Event	Electricity demand	Use of conventional capacity	Allowances price, p_a^T	Electricity price, p^T
A_1	Low	None	0	$c_{v,nc}$
A_2	Medium	$< H$	0	$c_{v,c}$
A_3	High	$> H$	f	$c_{v,c} + \beta mf$

Expected electricity price

- Let D (net of auto generation and consumption) be normally distributed with mean μ and standard deviation σ.
- At $t = 0$ the expected electricity price is

$$
\begin{aligned}
\mathbb{E}(p) = {} & \underbrace{c_{v,nc}}_{p|A_1} \times \left(\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Q_{nc}+Q_{nc}^*} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx \right) \\
& \underbrace{c_{v,c}}_{p|A_2} \times \left(\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Q_{nc}+Q_{nc}^*+H} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Q_{nc}+Q_{nc}^*} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx \right) \\
& + \underbrace{(\beta p_a + c_{v,c})}_{p|A_3} \times \left(1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Q_{nc}+Q_{nc}^*+H} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx \right).
\end{aligned}
$$

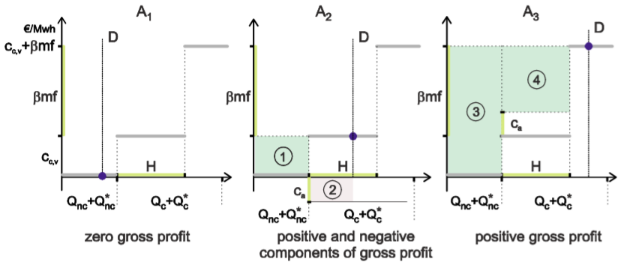
Expected allowance price

- Only in event A3 allowances are not sufficient to cover the emissions and producers have to pay the penalty price, f

$$
\begin{aligned}
\mathbb{E}(p_a) &= f \cdot \mathbb{E}(1_{[H,\infty)}(D - Q_{nc} - Q^*_{nc})) \\
&= f \left(1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Q_{nc}+Q^*_{nc}+H} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx \right).
\end{aligned}
$$

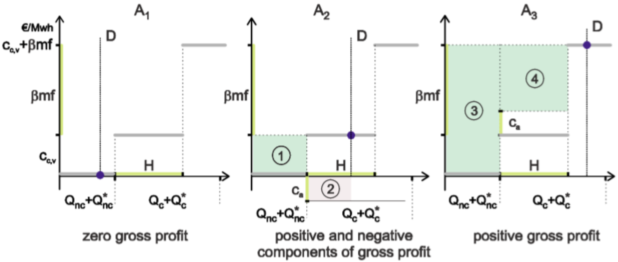
Gross profits G (w/o fixed costs)

- Gross profits can be represented as areas in the merit order curve figures wrt. three events $\{A1, A2, A3\}$.



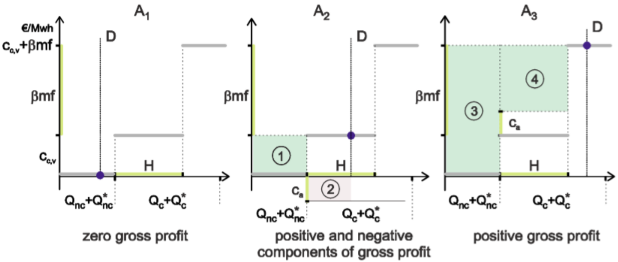
- In this figure:
  - fixed costs are ignored;
  - virtually zero renewable variable costs, $c_{v,nc} = 0$;
  - positive fossil variable costs, $c_{v,c} > 0$;
  - full pass-through, $\beta = 1$.

Low electricity demand, $G|A_1$



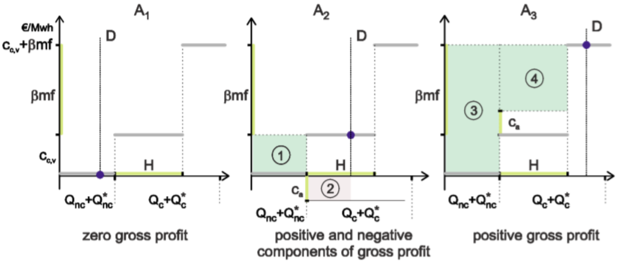
- Low-cost renewable production generates null gross profits, since it is sold at a price equal to its variable costs (i.e. zero).

Medium electricity demand, $G|A_2$



- Area 1: renewable production is sold at cost of fossil production, i.e. a high profit.
- Area 2: fossil production generates negative profits since it is sold at a price equal to its variable costs, so the initial cost of allowances cannot be recovered.

High electricity demand, $G|A_3$



- Area 3: renewable production is sold at cost of uncovered fossil production, i.e. a very high profit.
- Area 4: fossil, covered production also generates positive profits, since it is sold at a price equal to the marginal costs of uncovered production, which includes penalty payments.
- Fossil, uncovered production is sold at no profit.

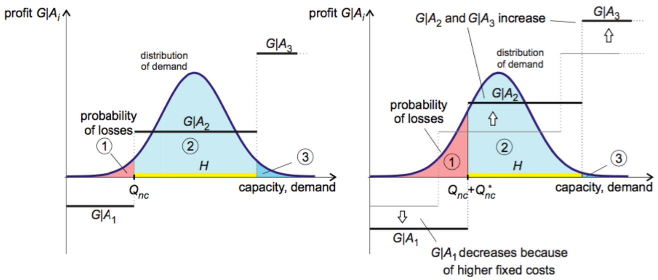
Capacity expansion problem

- The capacity expansion problem can be stated as

$$\begin{array}{rc} & \max_{Q_{nc}^*, Q_c^*} \mathbb{E}(G) \\ \text{s.t.} & Q_{nc}^* > -Q_{nc} \\ & Q_c^* > H - Q_c \end{array} .$$

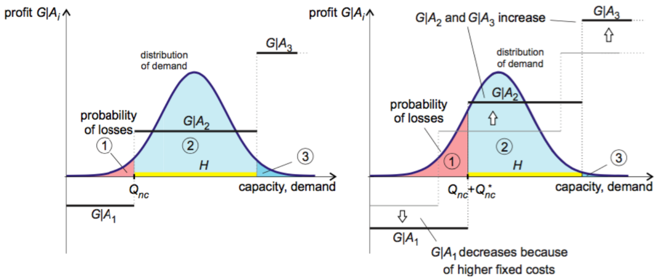
- Provide intuition of the (optimal) tradeoff we must solve, in the case of a positive increase of the renewable capacity (from Q_{nc} to $Q_{nc} + Q_{nc}^*$).
- We describe net profits as a three step function (with levels $G|A_1$, $G|A_2$, and $G|A_3$) where jumps appear when the level of demand determines a different event.

Region of losses



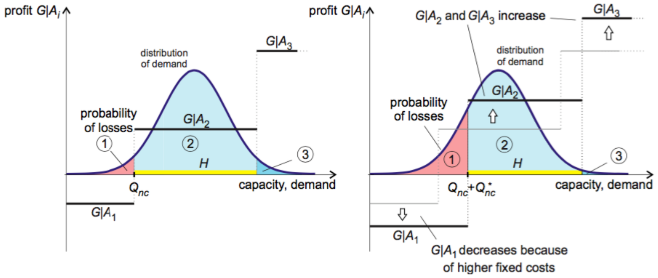
- Area 1 expands as there is a higher likelihood that renewable generation can meet all the demand for electricity.
- At the same time increased fixed costs increase losses within this region.
- This effect clearly decreases the expectation of net profits.

Region where operational profits dominate



- Area 2 reduces.
- The level of net profits within that region $(G|A_2)$ can increase thanks to the additional renewable capacity being sold at the price of the fossil one.
- The final result of this effect is not clear.

Region of operational + allowance profits



- Area 3 certainly reduces.
- Profits within that region increase sharply due to: (a) additional renewable capacity being sold at very high unit profit, and (b) covered fossil generation also being sold at a profit.
- Again the sign of this effect is not clear.

General qualitative observations

- Whilst the probability of demand being satisfied by renewable plants (event A_1) increases (along with worsening negative profit), the probability of events A_2 or A_3 decreases.
- Yet the potential profits within regions A_2 or A_3 increase.
- What is the optimal expansion of renewable capacity, especially in an environment with increasing stringency on emissions and higher renewables penetration?

Numerical application - scenarios outlines

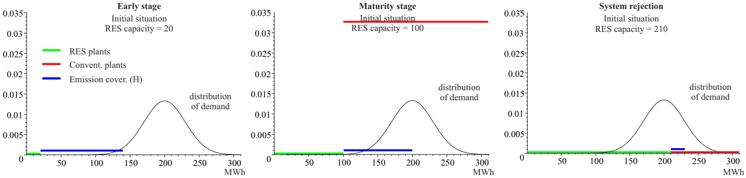
Three stylised stages of an ETS are used to explore the combined effect renewables and cap-and-trade on the capacity expansion decision.

1. Low share of renewables and a relatively generous cap;
2. The share of renewables is larger and the cap is lower;
3. Renewables cover a relatively large amount of the expected demand and the cap is significantly tighter.

Scenario	Q_c (MWh)	Q_{nc} (MWh)	H
1. Early stage	330	20	120
2. Maturity stage	330	100	100
3. System rejection	330	210	20

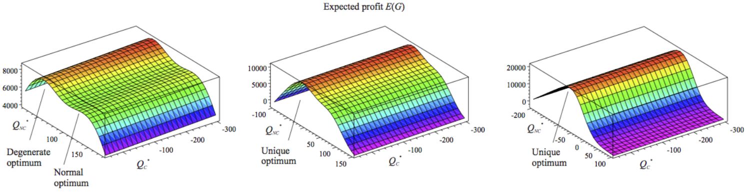
Graphical illustration

- The demand for electricity is normally distributed with the parameters $\mu = 200$ and $\sigma = 30$ (in MWh).



- $\mathbb{E}(G)$ is computed assigning the following values to the various parameters:
  - $m = 1.1$(tonnes$/MWh$),
  - $f = 100(€/tonne)$,
  - $\beta = 1$ (more on this later),
  - $c_{v,c} = 60(€/MWh)$, $c_{v,nc} = 0(€/MWh)$.

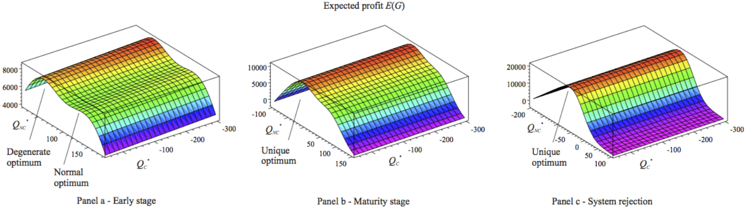
Solution early stage



Panel a - Early stage Panel b - Maturity stage Panel c - System rejection

- The *degenerate* optimum corresponds to a new installed renewable generation of around 58 MWh.
- There is a 53% chance to exceed cap (final renewable generation 78 MWh vs. average demand of 200 MWh).
- The *normal* optimum corresponds to a new installed renewable generation of around 135 MWh.
- There is a 7% chance of completely meeting demand with renewables (final renewable generation 155 MWh vs. average demand of 200 MWh).

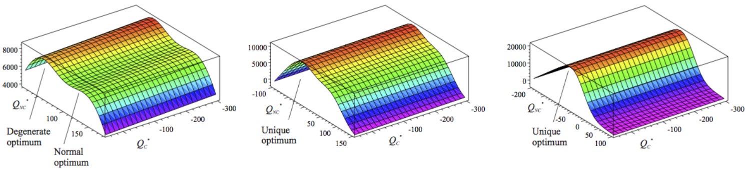
Solution maturity stage



- Initial renewable capacity is 100 *MWh* (50% of the expected demand), substantial potential.
- Despite this, the expansion decision is negative -10 *MWh* (degenerate type).
- Incentive to maintain enough fossil capacity even though there are more stringent environmental constraints (more on the pass-through later).

Solution system rejection stage

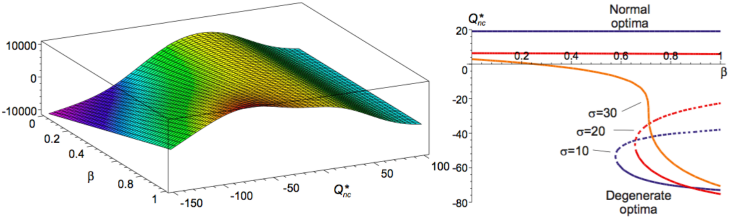
Expected profit $E(G)$



Panel a - Early stage Panel b - Maturity stage Panel c - System rejection

- Initial renewable capacity is 210 MWh and exceeds expected demand.
- Substantial dismantling -63 MWh (degenerate type).
- As before, incentive to maintain enough fossil capacity even though there are more stringent environmental constraints (more on the pass-through later).

Sensitivity analysis of β



a - Expected profit E(G) with σ=30

b - Stationary points of E(G)

- Operational component and not allowance component drives expected profits when β low (and vice-versa).
- Renewable capacity is either expanded or maintained (and vice-versa).

Conclusions

- We explore the set of tradeoffs which define the capacity expansion decision for electricity producers under electricity and environmental constrains.
- The price pushing effect means that, even when the volume of allocated allowances is low, reflecting a systematic decarbonisation of the system, producers have an incentive to maintain a reserve of fossil generation and reduce investment in renewables.
- Understanding the tradeoffs and expected outcomes of producers' capacity expansion while under the influence of an ETS is critical for crafting effective environmental legislation and reform.

Thank you very much for your attention.

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Experiencing climate change in Montréal

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References I

C. Böhringer and M. Behrens. Interactions of emission caps and renewable electricity support schemes. *Journal of Regulatory Economics*, 48(1):74–96, 2015. ISSN 0922-680X. doi: 10.1007/s11149-015-9279-x. URL http://dx.doi.org/10.1007/s11149-015-9279-x.

C. Böhringer and K. E. Rosendhal. Greening electricity more than necessary: On the cost implications of overlapping regulation in EU climate policy. *Schmollers Jahrbuch*, 131(3):469–492, 2011. ISSN 1865-5742. doi: 10.3790/schm.131.3.469. URL http://dx.doi.org/10.3790/schm.131.3.469.

N. Koch, S. Fuss, G. Grosjean, and O. Edenhofer. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. *Energy Policy*, 73:676–685, 2014. ISSN 0301-4215. doi: http://dx.doi.org/10.1016/j.enpol.2014.06.024. URL http://www.sciencedirect.com/science/article/pii/S0301421514003966.

References II

F. Murphy and Y. Smeers. Withholding investments in energy only markets: Can contracts make a difference? *Journal of Regulatory Economics*, 42(2):159–179, 2012. ISSN 0922-680X. doi: 10.1007/s11149-012-9184-5. URL http://dx.doi.org/10.1007/s11149-012-9184-5.

F. H. Murphy and Y. Smeers. Generation capacity expansion in imperfectly competitive restructured electricity markets. *Operations Research*, 53(4):646–661, 2005. doi: 10.1287/opre.1050.0211. URL http://dx.doi.org/10.1287/opre.1050.0211.

G. Zöttl. On optimal scarcity prices. *International Journal of Industrial Organization*, 29(5):589–605, 2011. ISSN 0167-7187. doi: http://dx.doi.org/10.1016/j.ijindorg.2011.01.002. URL http://www.sciencedirect.com/science/article/pii/S0167718711000051.