Technology-Neutral versus Technology-Specific Procurement

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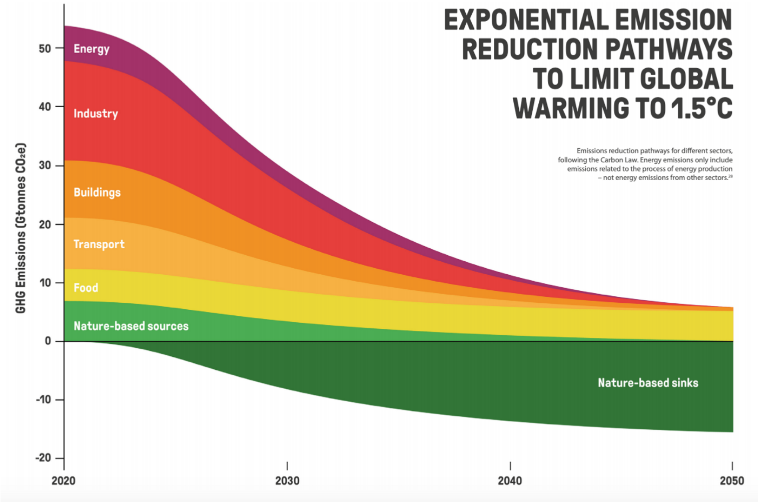
Towards Carbon-Free Economies



Ambitious Renewables Targets

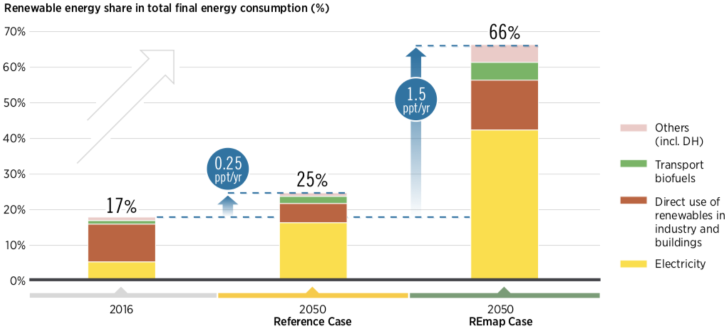


Figure: Renewables share in total final end-use consumption needs to accelerate six-fold compared to current levels. Source: IRENA (2019b)

Investments in Renewables in the Power Sector

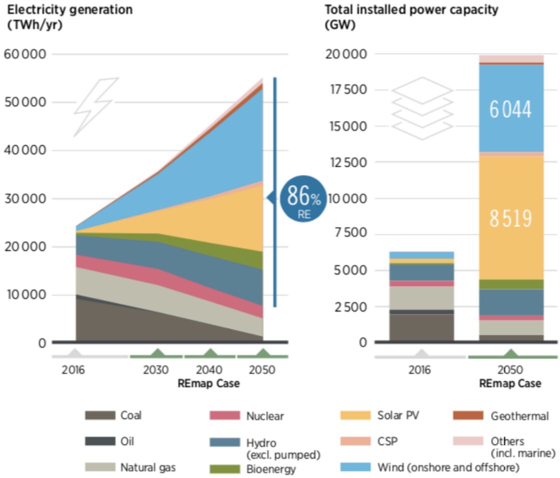


Figure: Electricity generation mix and power generation installed capacity by fuel, 2016-2050. Source: IRENA (2019b)

How to Promote Low-Carbon Investments

Key challenge: there exist multiple technologies

- Multiple renewable technologies (wind, solar, hydro...)
- Multiple storage technologies (pumped hydro, batteries, hydrogen...)

Relevant questions:

1. Should policies be **technology-specific** or **technology-neutral**?
2. Should we rely on **quantity** or on **price instruments**?
3. What are the **trade-offs involved**?

Renewable Support Schemes in Practice

Commonly used renewables support instruments regulate....

- **Quantity:** Auctions, tradable quotas...
- **Price:** Feed-in Tariffs, Feed-in Premiums...

In turn, instruments can be...

- **Technology specific**: different instruments/levels of support used depending on technology, scale, location, etc.
- **Technology neutral**: all technologies treated equally
- **Hybrid schemes**: corrected technology-neutral approach
  - Auctions: bids of some technologies are deflated
  - Green certificates: some technologies are granted more certificates than others (*banding*)

Auctions versus Price Regulation (FiTs)

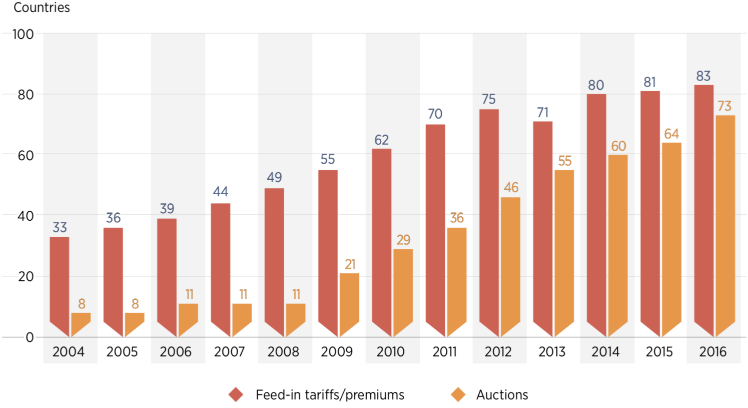


Figure: Auctions versus Price regulation (FiTs)

The Renewables Auction Revolution

Worldwide, **106 countries** have conducted renewable energy auctions
From 2010 to 2018, the auctions' solar PV average prices decreased by 77% and onshore wind prices by 36%

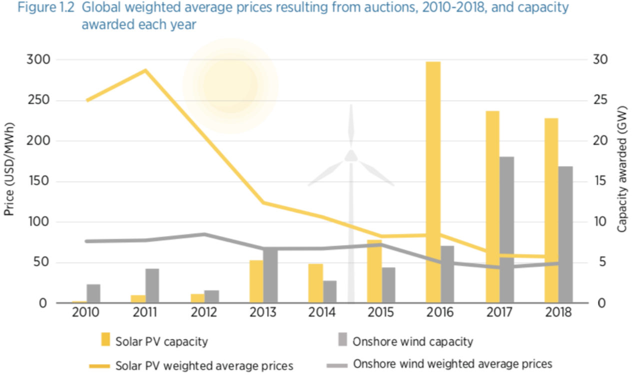


Figure: Volumes and prices of renewable auctions worldwide, 2010-2018.
Source: IRENA (2019a)

Technology-Neutral Auctions in Europe

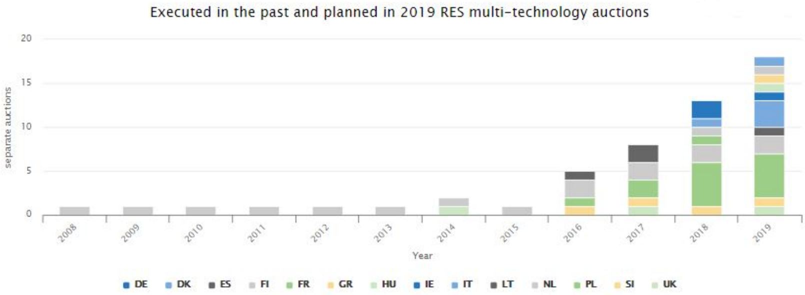


Figure: Increasing number of technology-neutral auctions in Europe

Technology-Neutral Auctions in Europe

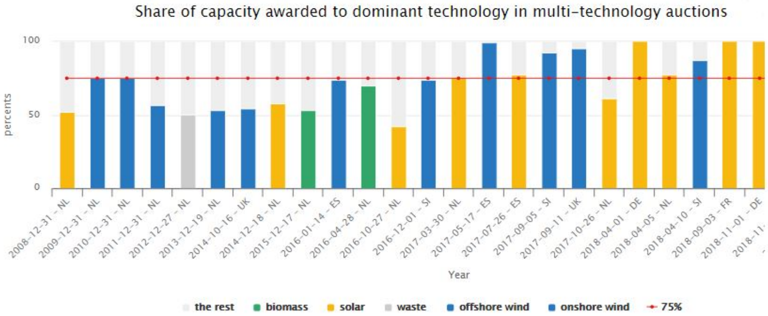


Figure: Share of the dominant technology in technology neutral auctions

Related Literature

1. **Regulation and Procurement**
   - Laffont and Tirole (1993); Laffont and Martimort (2002)
2. **Auctions and Mechanism Design**
   - Segal (2003)
   - Manzano and Vives (2020)
3. **Other multi-good auction settings**
   - Mason and Plantinga (2013)
   - Montero (2001)
   - Klemperer (2010)

Roadmap

1. Model description
2. Technology-neutral auctions
3. Technology-specific auctions
4. Technology banding
5. Adding market power
6. *Price regulation*
7. Simulations: renewable investments in Spain
8. Conclusions

Model Description

Firms and Technologies:

- One good can be produced with two technologies $t = 1, 2$
- Continuum of (risk-neutral) price-taking suppliers of each t

Costs:

- Unit costs $\sim U[\underline{c}_t, \bar{c}_t]$, with $\underline{c}_t = c_t + \theta_t$ and $\bar{c}_t = c_t + \theta_t + C''$...
- ...giving rise to an aggregate cost function, for $t = 1, 2$:

$$C_t\left(q_t\right) = \left(c_t + \theta_t\right) q_t + \frac{C''}{2} q_t^2$$

- Cost shocks: $E[\theta_t] = 0$, $E[\theta_t^2] = \sigma > 0$ and $E[\theta_1 \theta_2] = \rho\sigma \gtrless 0$

Social Benefits:

- $B\left(Q\right)$, where $Q = q_1 + q_2$, with $B' > 0$ and $B'' < 0$
- Ass.: Always optimal to procure units from both technologies

The Planner's Problem

The planner maximizes (expected) **social welfare**:

$$\max W = E\left[B\left(Q\right) - \sum_{t=1,2} C_t\left(q_t\right) - \lambda T(q_1, q_2)\right]$$

- λ: **shadow cost of public funds**
- $T(q_1, q_2)$: planner's total payment from procuring $Q = q_1 + q_2$

The planner must decide between...

1. **Technology-neutral** approach: $Q \rightarrow P(Q)$
2. **Technology-specific** approach: q_1 and $q_2 \rightarrow p_1(q_1)$ and $p_2(q_2)$

Technology-Neutral Auctions

$$\max_{Q} E\left[B\left(Q\right) - \sum_{t=1,2} C_t\left(q_t\right) - \lambda T(q_1, q_2)\right]$$

The market price equals the marginal costs of **both** technologies:

$$p^N = c_1 + \theta_1 + C'' q_1^N = c_2 + \theta_2 + C'' q_2^N$$

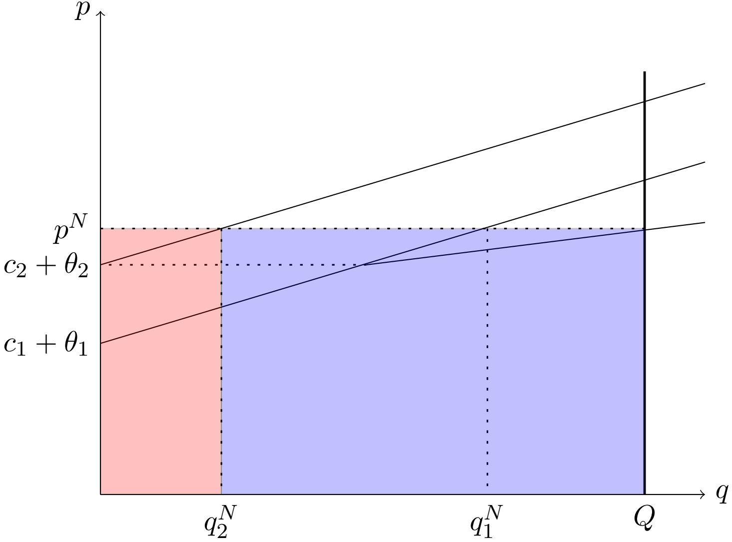
Quantities for each technology are given by

$$q_1^N = \frac{Q^N + \Phi^N}{2} + \frac{\Delta\theta}{2C''} > q_2^N = \frac{Q^N - \Phi^N}{2} - \frac{\Delta\theta}{2C''}$$

where

$$\Phi^N \equiv E\left[q_1^N\right] - E\left[q_2^N\right] = \frac{\Delta c}{C''}$$

Graphical Representation: Technology-Neutrality



Technology-Specific Auctions

$$\max_{q_1,q_2} E\left[B\left(q_1+q_2\right)-\sum_{t=1,2} C_t\left(q_t\right)-\lambda T(q_1,q_2)\right]$$

Market prices are equal to the marginal cost of **each** technology, $t=1,2$:

$$p_t^S = C'' q_t^S + c_t + \theta_t$$

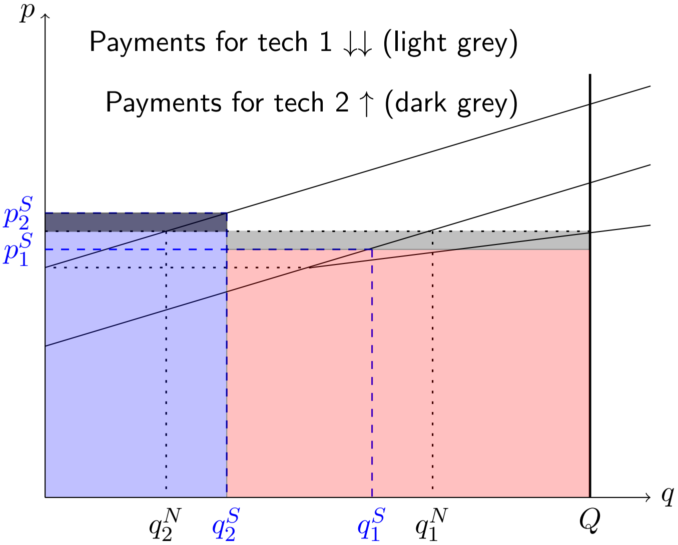
Quantities for each technology are given by

$$q_1^S = \frac{Q^S+\Phi^S}{2} \text{ and } q_2^S = \frac{Q^S-\Phi^S}{2}$$

where

$$\Phi^S \equiv q_1^S - q_2^S = \frac{\Delta c}{C''}\frac{1+\lambda}{1+2\lambda} < \Phi^N$$

Graphical Representation: Technology-Specific



Technology-Neutral *vs* Technology-Specific Auctions

- Total quantity is the same: $Q^N = Q^S$
- Under separation, the **technology allocation is distorted**:

$$q_1^S - E\left[q_1^N\right] = \Phi^S - \Phi^N < 0$$

$$q_2^S - E\left[q_2^N\right] = \Phi^N - \Phi^S > 0$$

- **Payments are lower** under separation:

$$E\left[T^S\right] - E\left[T^N\right] = \frac{C''}{2}\left(\Phi^S - \Phi^N\right)\Phi^S < 0$$

- ...at the expense of **increasing costs**:

$$E\left[C^S\right] - E[C^N] = \frac{C''}{4}\left[\left(\Phi^S - \Phi^N\right)^2 + E[(\Delta\theta)^2]\right] > 0$$

Technology-neutral vs. Technology-specific Auctions

Comparing Welfare under the two approaches:

$$W^N - W^S = \frac{1}{4C''}\left[2\sigma(1-\rho) - \frac{\lambda^2}{1+2\lambda}(\Delta c)^2\right]$$

Rents-efficiency trade-off:

1. 1st term: efficiency gain under tech-neutrality (quantity adjustment)
2. 2nd term: excess rents left with the more efficient suppliers

1. **Tech-neutrality always dominates if**:
   - No concern for rents: $\lambda \to 0$
   - Symmetric ex-ante technologies: $\Delta c \approx 0$
2. **Tech-specificity always dominates if**:
   - Strong concern for rents: $\lambda \to \infty$
   - Perfectly correlated cost shocks: $\rho = 1$

Banding in a technology-neutral auction

Allow for **trading between technologies** to reduce payments?

- Suppose α^B the exchange rate across technologies:

$$\max_{Q,\alpha} E\left[B(Q) - \sum_{t=1,2} C_t(q_t) - \lambda T(q_1, q_2)\right]$$

subject to (equalization of *adjusted* marginal costs)

$$p^B = c_1 + \theta_1 + C'' q_1^B = \frac{1}{\alpha^B}(c_2 + \theta_2 + C'' q_2^B)$$

leading to

$$\begin{aligned} q_1^B &= \frac{Q^B}{1+\alpha^B} + \frac{c_2 + \theta_2 - \alpha^B (c_1 + \theta_1)}{(1+\alpha^B) C''} < q_1^N \\ q_2^B &= \frac{\alpha^B Q^B}{1+\alpha^B} - \frac{c_2 + \theta_2 - \alpha^B (c_1 + \theta_1)}{(1+\alpha^B) C''} > q_2^N \end{aligned}$$

Technology-Banding

- Banding results in a steeper price curve:

$$p^B = \frac{c_1 + c_2 + \theta_1 + \theta_2}{1 + \alpha^B} + \frac{C''}{1 + \alpha^B} Q^B$$

If no uncertainty $(\sigma \to 0)$

- Banding replicates a technology-specific design:

$$\alpha^B = p_2^S / p_1^S$$

- Either design dominates the technology-neutral design, i.e.,

$$W_q^B = W_q^S > W_q^N$$

Technology-Banding

If uncertainty $(\sigma > 0)$

- Suppose $W_q^S > W_q^N$
- There exists a correlation cut-off, $\bar{\rho} < 1$, above which technology-specific auctions also dominate technology banding:

$$W_q^S > W_q^B > W_q^N$$

  - **Case** $\rho = -1$: $W_q^B > W_q^S$ since expected costs are lower under banding but expected payments are the same
  - **Case** $\rho = 1$: $W_q^S > W_q^B$ since both expected costs as well as expected payments are lower under separation

- The critical $\bar{\rho}$ is decreasing in and α^B
- When is the optimal α^B low?
  - When low σ, low λ, small Δc and high C''

Adding Market Power

Consider a monopolist on both technologies:

- It charges the monopoly price for the two technologies
- Under technology-neutral auctions, it allocates production across technologies to minimize costs
- Under technology-specific auctions, it produces the allocated quantities to each technology

Technology-neutral or technology-specific auctions?

- Payments: the same
- Cost efficiency: greater under tech-neutrality

How general is this result for lower degrees of market power?

Adding Market Power

- Existing units divided btw dominant firm (d) and fringe (f)
  - Shares $\omega_d = \omega$ and $\omega_f = 1 - \omega$
- Costs for each firm $i = d, f$ are now given by

$$C_{it}(q_{it}, \theta_t) = (c_t + \theta_t)\, q_{it} + \frac{1}{2}\frac{C''}{\omega_i} q_{it}^2$$

  - **Prices: profit maximization** by dominant firm:

$$\begin{aligned} p^N &= \frac{c_1 + c_2 + \theta_1 + \theta_2}{2} + \frac{C''}{1-\omega^2}\frac{Q}{2} \\ p_t^S &= c_t + \theta_t + \frac{C''}{1-\omega^2} q_t \end{aligned}$$

  - ...resulting in a **higher market share for the fringe**:

$$\begin{aligned} E[q_f^N] - E[q_d^N] &= \frac{1-\omega}{1+\omega} Q^N > 0 \\ q_{ft}^S - q_{dt}^S &= \frac{1-\omega}{1+\omega} q_t > 0 \end{aligned}$$

Technology-Neutral *vs* Technology-Specific Auctions

- Total quantity is the same across approaches $Q^N = Q^S$
- Q^N and Q^S are **decreasing in market power** ω
- Market power distorts the **allocation across firms**
- ...and also, under separation, the **allocation across technologies**:

$$\Phi^S(\omega) = f(\omega, \lambda)\, \Phi^S(0)$$

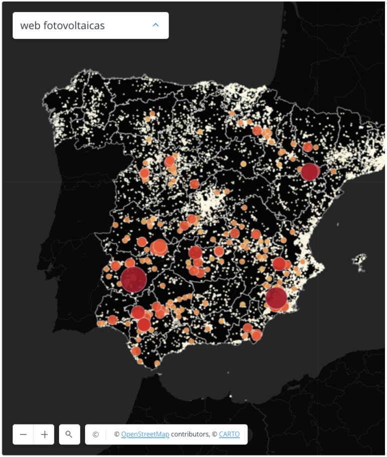
  - The distortion is increasing in λ
  - For high λ, the distortion is increasing in ω
  - For low λ, the distortion is an inverted-U function of ω

Welfare:

- Market power reduces welfare under both approaches
- Greater welfare reduction under technology-specific auctions

Taking the Model to the Data

Renewable Investments in Spain



(a) Solar Installations

(b) Wind Installations

Technology-Neutral

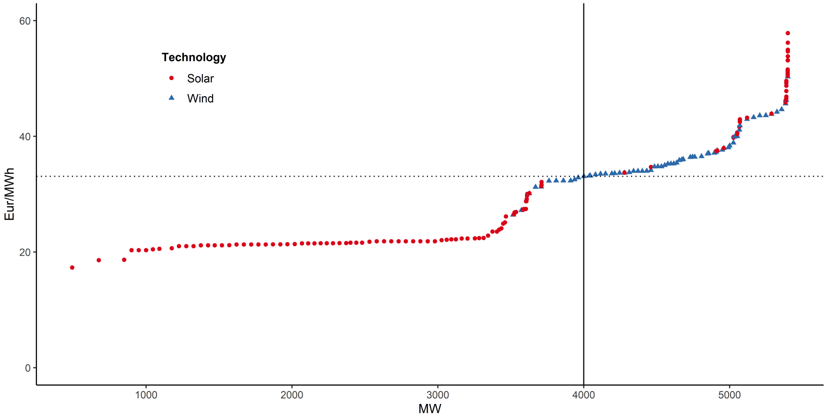


Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Neutral

Technology-Banding

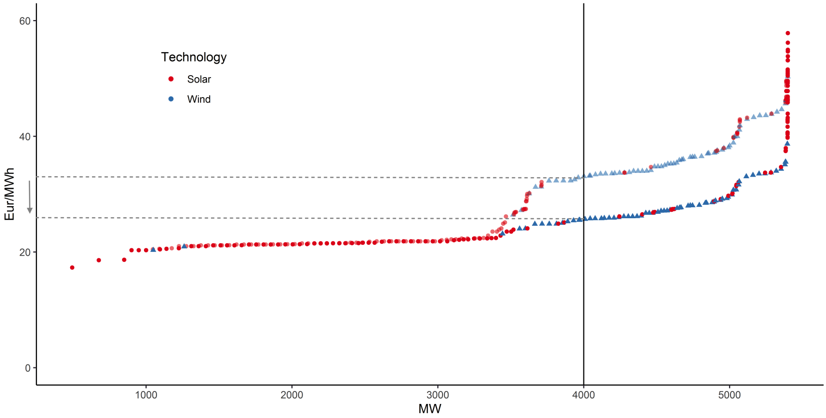


Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Banding

Technology-banding vs. Technology-neutrality

ρ	λ	**Costs**	**Payments**	**Social Costs**	**Banding** α
-0.8	0	1.00	1.00	1.00	1.0
-0.8	0.2	1.01	0.87	0.98	1.3
-0.8	0.4	1.02	0.86	0.96	1.4
0	0	1.00	1.00	1.00	1.0
0	0.2	1.01	0.86	0.97	1.3
0	0.4	1.02	0.84	0.95	1.4
0.8	0	1.00	1.00	1.00	1.0
0.8	0.2	1.01	0.82	0.97	1.3
0.8	0.4	1.01	0.82	0.94	1.3

Table: Technology-banding relative to technology-neutrality

Technology-Specific

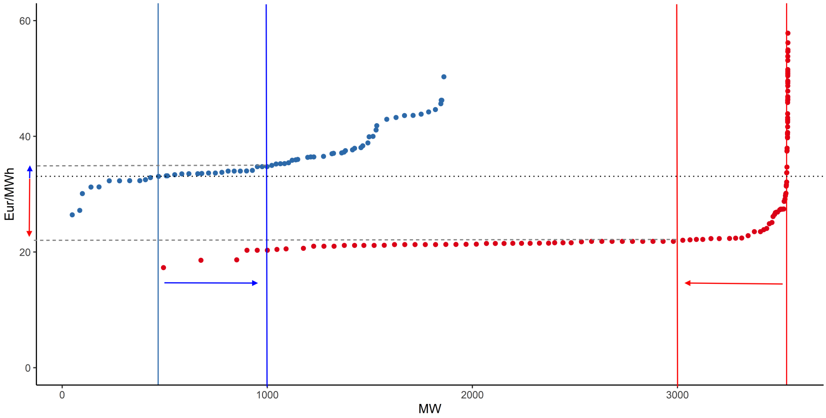


Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Specific

Technology-specific vs. technology-neutral auctions

ρ	λ	**Costs**	**Payments**	**Social Costs**
-0.8	0	1.03	0.73	1.03
-0.8	0.2	1.04	0.72	0.96
-0.8	0.4	1.04	0.71	0.91
0	0	1.02	0.75	1.02
0	0.2	1.02	0.75	0.95
0	0.4	1.03	0.72	0.91
0.8	0	1.00	0.88	1.00
0.8	0.2	1.01	0.76	0.95
0.8	0.4	1.02	0.74	0.91

Table: Technology-specific auctions relative to technology-neutrality

Conclusions

1. When to favour **technology-neutrality** vs **technology-separation**?
2. When to favour **price** versus **quantity** regulation?

- **One-size does not fit all**: preferred instrument varies case-by-case
- **Rent-efficiency trade-off:**
  - Technology separation is good for **reducing rents**
  - Technology neutrality is good for **cost efficiency**

- **Technology separation tends to perform better when...**
  - small cost uncertainty, high cost correlation, large cost differences, flat cost curve, low market power

Note of caution:

- **Constraints when implementing** *optimal* technology separation
- "Bad" technology separation might be worse than neutrality
- ...even in settings where optimal technology separation dominates

Thank You!

Questions? Comments?

More info at nfabra.uc3m.es and energyecolab.uc3m.es

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Price Regulation

- Two tech-specific prices dominate a single tech-neutral price

$$\max_{p_1,p_2} E\left[B\left(\sum_{t=1,2} q_t(p_t)\right) - \sum_{t=1,2} C_t(q_t(p_t)) - \lambda T(p_1,p_2)\right]$$

- Quantities adjust so that **each** market price equals the marginal costs of **each** technology:

$$p_t = c_t + \theta_t + C'' q_t(p_t)$$

One price vs. one quantity (Weitzman)

- One price dominates one quantity iff

$$W_p^S - W_q^S = \frac{2\sigma}{(C'')^2}\left(B'' + \frac{C''}{2}\right) > 0$$

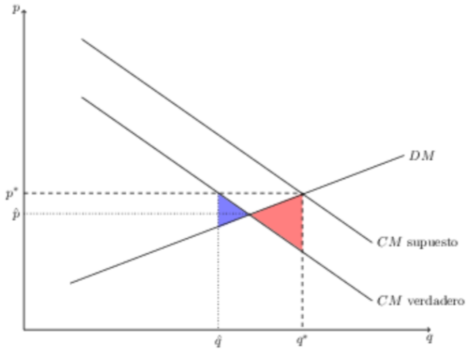

Figure: P vs Q: Price regulation is superior when marginal benefit is relatively flat

One price vs. one quantity (Weitzman)

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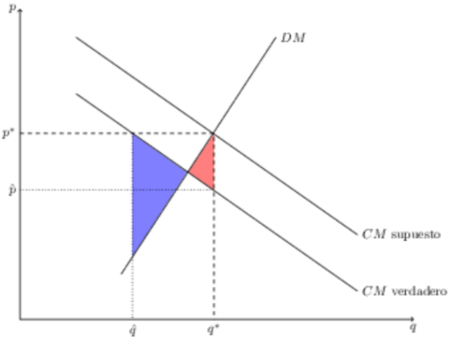

Figure: P vs Q: Quantity regulation is superior when marginal benefit is relatively steep

Two Prices *vs* Two Quantities

- Two prices dominate two quantities iff

$$W_p^S - W_q^S = \frac{\sigma(1+\rho)}{(C'')^2}\left(B'' + \frac{C''}{2}\frac{2}{1+\rho}\right) > 0$$

- **Modified Weitzman (1974)'s formula**
  - A relative more convex cost favours prices because mistakes on the supply becaomse costlier than on the benefit side
  - With multiple technologies, prices favoured (costs more convex)
- **Cost correlation:**
  1. $\rho = 1$: the two technologies behave as one (Weitzman)
  2. $\rho < 1$: prices perform relatively better than with a single technology
  3. $\rho \to -1$: prices are superior (no benefit uncertainty)
- **Cost of public funds:**
  - λ does not affect comparison (equal expected payments)

Two Prices *vs* a Single Quantity

- Two prices dominate a single quantity iff

$$W_p^S - W_q^N = \frac{\lambda^2}{1+2\lambda}\left(\frac{\Delta c}{2C''}\right)^2 + \frac{\sigma(1+\rho)}{(C'')^2}\left(B'' + \frac{C''}{2}\right) > 0$$

Decomposing the welfare effects:

- 1st term $(W_p^S - W_p^N)$:
  - Rent-extraction gain from using two prices *vs* one price
- 2nd term $(W_p^N - W_q^N)$:
  - Weitzman's gain from using one price *vs* one quantity

- **Note:** We can have $W_q^N > W_p^S > W_q^S$
  - While two prices allow for more quantity adjustment than two quantities, technology neutrality is the only instrument that allows quantities to fully adjust