Technology-Neutral versus Technology-Specific Procurement

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Research Questions

An imperfectly-informed principal needs to procure multiple units of a good that can be produced with heterogeneous sources (technologies)

- **Renewables**: wind, solar, hydro...
- **Energy storage**: batteries, hydrogen, pumped hydro...
- **Central bank's liquidity**: good and bad collateral
- **A firm procuring inputs/services** from various countries

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How should she procure those units?

(and how do the mechanisms used in practice compare among them)

Research Questions

If the principal is indifferent between the various sources....

1. Should she run **technology-specific or -neutral** auctions?
2. Should she allow for **partial separation** across technologies?
3. How does **market power** affect the choice?
4. Should she instead post separate **prices** for each technology?

What are the trade-offs and what do they depend on?

Auctions for Renewables Investments

Worldwide, **106 countries** have conducted renewable auctions

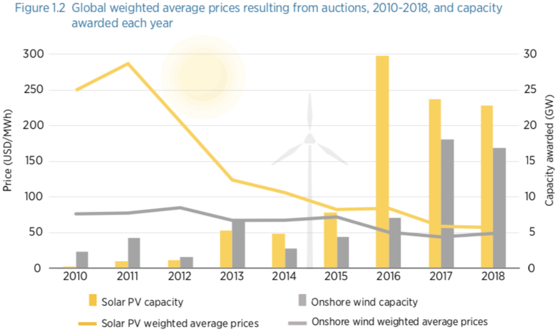

Figure: Volumes and prices of renewable auctions worldwide, 2010-2018. Source: IRENA (2019a)

An Example: Spanish Renewables Auction

- It took place last January 26, 2021
- **Technology Neutral Auction of 3000MW**
- **Minimum quantity of 1000MW for solar PV and Wind**
- Right to sell energy at a fixed price during 12 years
- Once the contract is over, investors receive market prices
- Pay-as-bid auction format

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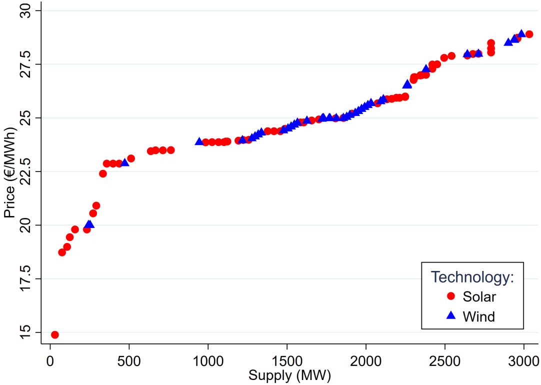

Figure: Winning bids - solar PV and wind

Renewable Support Schemes in Practice

Commonly used renewables support instruments regulate....

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

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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 deflated; minimum quotas
  - Green certificates: some technologies are granted more certificates

An Example: Minimum Technology Quotas in Auctions

		2020	2021	2022	2023	2024	2025
Eólica	Incremento	1.000	1.500	1.500	1.500	1.500	1.500
	Acumulado	1.000	2.500	4.000	5.500	7.000	8.500
Fotovoltaica	Incremento	1.000	1.800	1.800	1.800	1.800	1.800
	Acumulado	1.000	2.800	4.600	6.400	8.200	10.000
Solar Termoeléctrica	Incremento		200		200		200
	Acumulado		200	200	400	400	600
Biomasa	Incremento		140		120		120
	Acumulado		140	140	260	260	380
Otras tecnologías (biogás, hidráulica, mareomotriz, etc.)	Incremento		20		20		20
	Acumulado		20	20	40	40	60

Figure: Calendar of technology-specific minimum quotas (Spain)

An Example: Banding and Tradable Permits

Bands	Support in ROCs/MWh for new generating stations accrediting in the period:	
	2015/16	2016/17
Solar PV (building mounted)	1.5	1.4
Solar PV (ground mounted)	1.3	1.2

Figure: Amount of Renewable Obligation Certicates granted to Solar PV (UK)

Roadmap

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

Model Description

Firms and Technologies:

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Costs:

- 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 parameters: $c_2 - c_1 \equiv \Delta c > 0$
- Cost shocks: $E[\theta_t] = 0$, $E[\theta_t^2] = \sigma > 0$ and $E[\theta_1 \theta_2] = \rho\sigma \gtrless 0$

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Social Benefits:

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

The Principal's Problem

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

$$\max W = E\left[B\left(Q\right) - \sum_{t=1,2} C_t\left(q_t\ ,\theta_t\right) - \lambda T(q_1, q_2, \theta_1, \theta_2)\right]$$

- λ: **shadow cost of public funds**
- $T(q_1, q_2, \theta_1, \theta_2)$: Total payment from procuring $q_1 + q_2 = Q$

The Optimal Mechanism

- The optimal mechanism is a *product-mix auction*
- The regulator announces technology-specific demands:

$$P_t^d(q_1, q_2) = \frac{B'(q_1 + q_2) - \lambda C'' q_t}{1 + \lambda}$$

- Firms bid according to technology-specific supply schedules:

$$P_t^s(q_t) = C_t'(q_t; \theta_t)$$

- The allocation is determined by $P_t^d(q_1, q_2) = P_t^s(q_t)$

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Properties:

1. The regulator overcomes asymmetric information
2. The cost-efficient allocation is distorted to minimize rents
3. The prices of the two technologies are not equalized

Simple Mechanisms in Practice

In practice, regulators do not use mechanisms with these properties

How far are the actual mechanisms from the optimal one?

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Regulators typically decide ex-ante between two approaches:

1. **Technology-neutral**: $Q^N \to p(Q^N)$ and (q_1^N, q_2^N)
2. **Technology-specific**: q_1^S and $q_2^S \to p_1(q_1^S)$ and $p_2(q_2^S)$

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1. A technology-neutral approach is good for **cost efficiency**
2. A technology-specific approach is good for **reducing rents**

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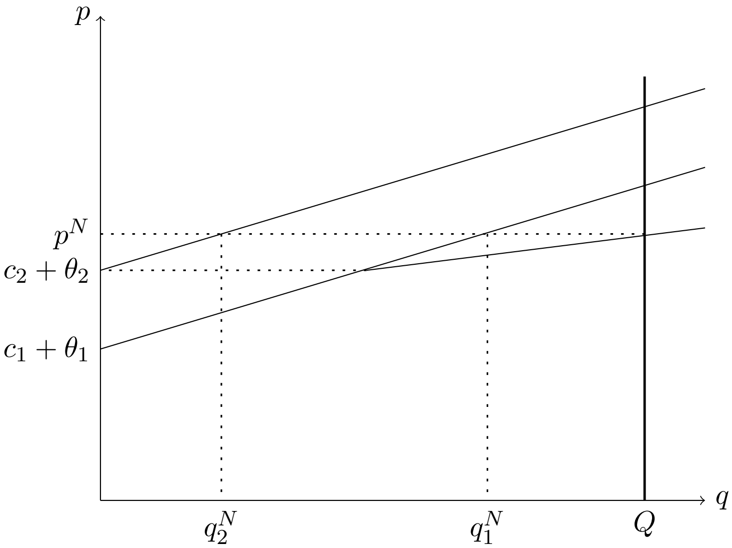
- **Quantities** for each technology are given by

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

where

$$\Phi^N \equiv E\left[q_1^N\right] - E\left[q_2^N\right] = \frac{\Delta c}{C''} > 0$$

Graphical Representation: Technology-Neutrality



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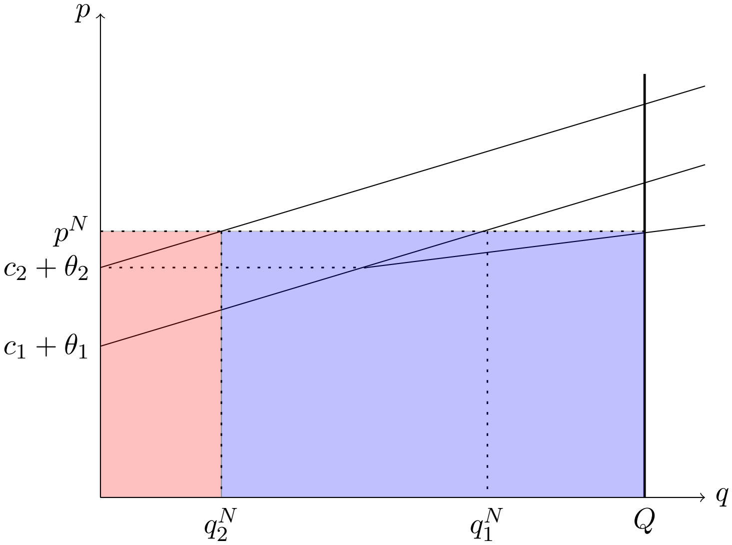

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- This leads to

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

  where

$$\Phi^S(\lambda) \equiv q_1^S - q_2^S = \frac{\Delta c}{C''} \frac{1 + \lambda}{1 + 2\lambda} < \Phi^N = \Phi^S(0)$$

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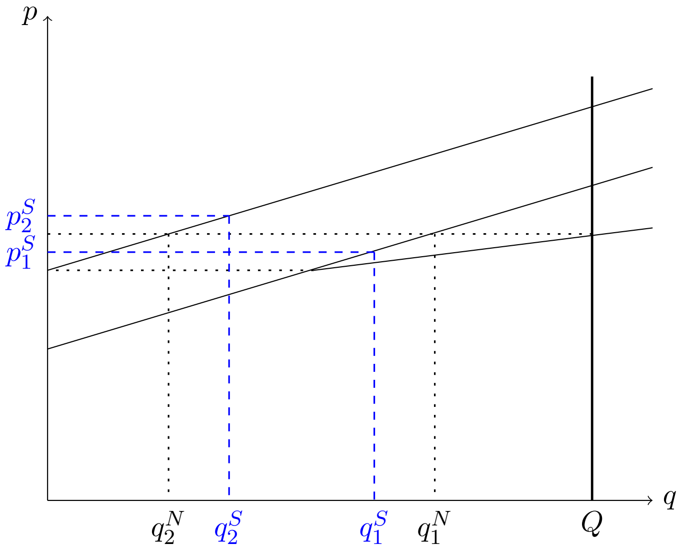

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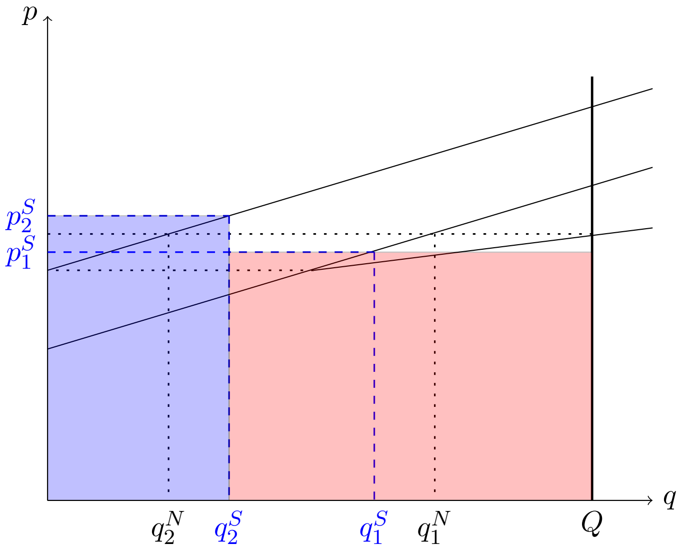

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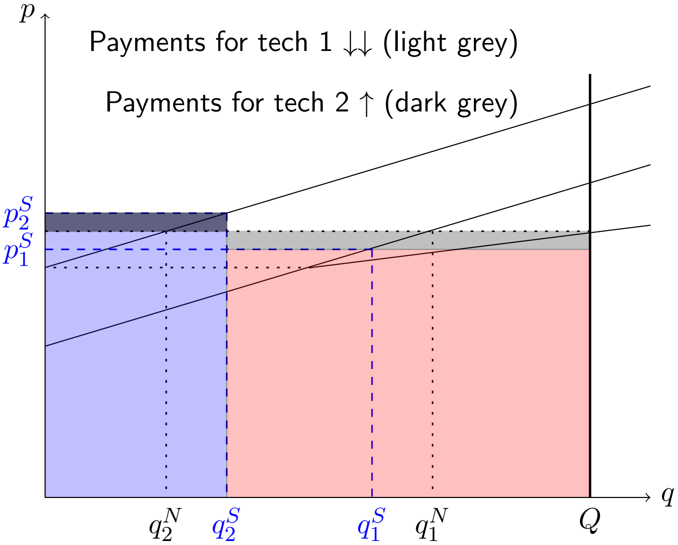

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- ...at the expense of **increasing expected costs**:

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

Technology-neutral vs. Technology-specific Auctions

Comparing Welfare under the two approaches:

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

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

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- **Technology-specific auctions dominate if**:
  - Well informed principal: $\sigma \to 0$
  - Perfectly correlated cost shocks: $\rho \to 1$
  - Strong concern for rents: $\lambda \to \infty$
  - Large ex-ante asymmetries: Δc large

Adding Market Power

Consider a **monopolist** on both technologies:

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

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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

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

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

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

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Welfare:

- Market power reduces welfare under both approaches
- Greater welfare reduction under technology-specific auctions
- ΔW^{NS} is increasing in $\omega \rightarrow$ Technology-neutrality favoured

Further Results (in the paper)

Technology Banding ▸ GO

- The price paid to one technology is increased by $\alpha > 1$
- Technology-neutrality: special case with $\alpha = 1$
- Technology-specific auctions: not a special case of banding
- Technology-specific auctions dominate banding if ρ, λ high enough

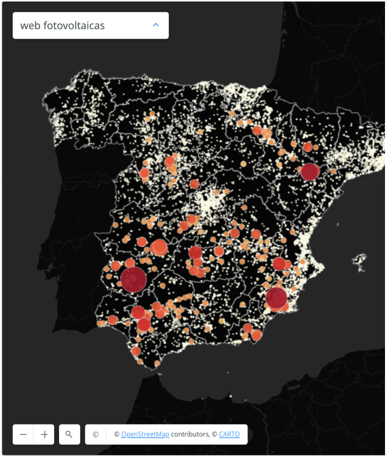
Minimum Technology Quotas

Price Regulation ▸ GO

- Technology-specific prices always dominate a single price
- Comparison Pvs.Q follows a corrected Weitzman formula:
  - Multiple technologies favour price regulation
  - The cost of public funds λ (weakly) benefits price regulation

Taking the Model to the Data

Renewable Investments in Spain



(a) Solar Installations

(b) Wind Installations

Technology-Neutral

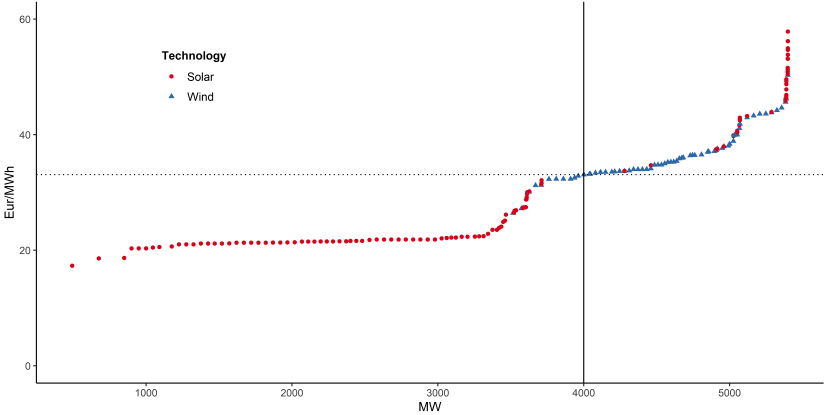
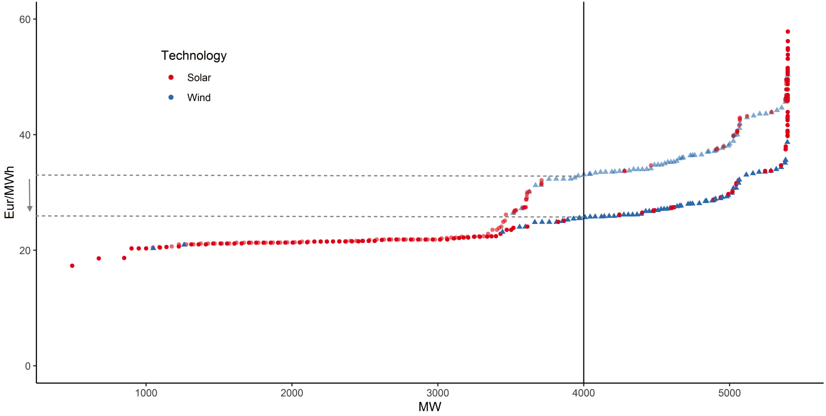


Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Neutral

Technology-Banding



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Technology-Specific

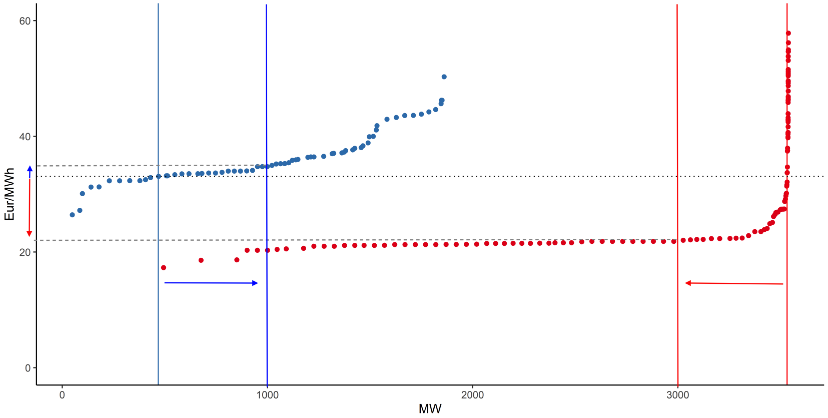

Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Specific

Costs relative to the optimal mechanism

		Costs			
ρ	λ	Neutral	Specific	Banding	MTQs
-0.8	0	1.0000	1.0331	1.0000	1.0000
	0.2	0.9932	1.0284	1.0036	1.0038
	0.4	0.9886	1.0274	1.0067	1.0031
0	0	1.0000	1.0167	1.0000	1.0000
	0.2	0.9919	1.0084	1.0021	1.0011
	0.4	0.9878	1.0171	1.0080	1.0006
0.8	0	1.0000	1.0009	1.0000	1.0000
	0.2	0.9910	1.0000	1.0010	1.0017
	0.4	0.9864	1.0043	0.9963	1.0075

Payments relative to the optimal mechanism

Table: Simulation results relative to the optimal mechanism

		Payments			
ρ	λ	Neutral	Specific	Banding	MTQs
-0.8	0	1.0500	0.7687	1.0500	0.9881
	0.2	1.3876	0.9947	1.2130	1.0125
	0.4	1.4087	0.9996	1.2099	1.0180
0	0	1.0301	0.7730	1.0301	0.9940
	0.2	1.3574	1.0186	1.1642	1.0125
	0.4	1.3746	0.9944	1.1560	1.0135
0.8	0	1.0069	0.8896	1.0069	1.0005
	0.2	1.3288	1.0125	1.0951	1.0023
	0.4	1.3493	1.0011	1.1120	0.9909

Social Costs relative to the optimal mechanism

ρ	λ	Social Costs Neutral	Specific	Banding	MTQs
-0.8	0	1.0000	1.0331	1.0000	1.0000
	0.2	1.0662	1.0222	1.0423	1.0054
	0.4	1.1180	1.0188	1.0693	1.0077
0	0	1.0000	1.0167	1.0000	1.0000
	0.2	1.0591	1.0103	1.0319	1.0032
	0.4	1.1105	1.0138	1.0572	1.0082
0.8	0	1.0000	1.0009	1.0000	1.0000
	0.2	1.0530	1.0023	1.0183	1.0018
	0.4	1.0974	1.0033	1.0317	1.0024

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**
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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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Related Literature

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

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Banding in a technology-neutral auction

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- Suppose α is the exchange rate across technologies:

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

subject to (equalization of *adjusted* marginal costs)

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

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leading to

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

Technology-Banding

- Banding results in a steeper price curve:

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

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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:

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- 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''

BACK

Technology-Banding

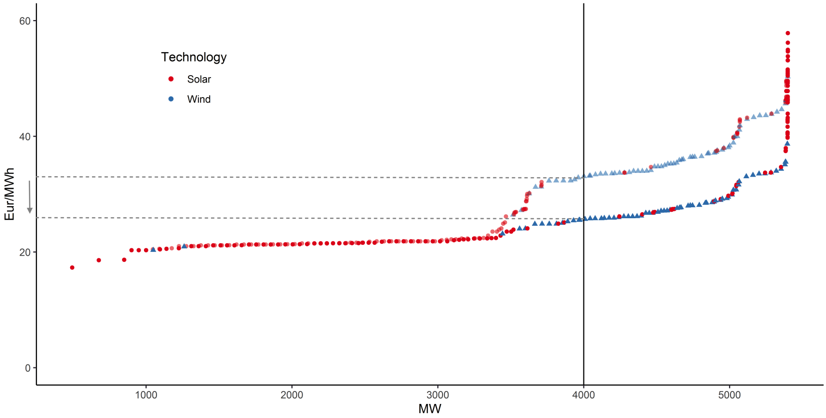

Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Banding

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

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- 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

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

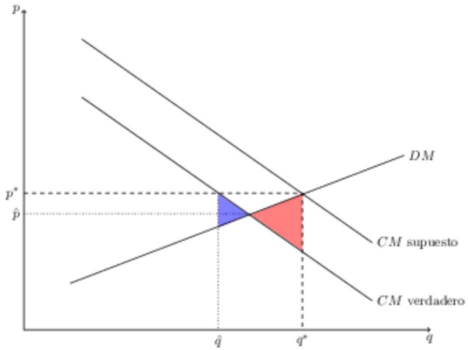

Figure: P vs Q: Price regulation is superior when marginal benefit is relatively flat

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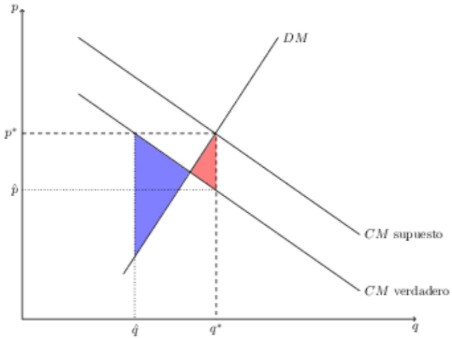

Figure: P vs Q: Quantity regulation is superior when marginal benefit is relatively steep

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 becomes costlier than on the benefit side
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- **Cost of public funds:**
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BACK

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- *Conjecture:* moving ex-ante vs. ex-post is relatively better the higher (λ, ρ, ω), and the lower σ.

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