Capacity Choices in Liberalised Electricity Markets

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Motivation

- Many countries have embarked on a process of liberalisation of their respective electricity sectors.
- Liberalisation has led to:
  - unbundling of activities;
  - introduce competition wherever possible
- Competition in generation and supply; regulation in transmission and distribution
- Generation: introduction of a wholesale electricity spot market (pool) coupled with the privatization and/or decentralization of decisions regarding long run capacity investment.

Motivation

- The literature, both theoretical and empirical, has focused on the final stages of the liberalized electricity game, that is how firms compete to supply energy.

  - Theoretical analysis: Green and Newbery (1992), von der Fehr and Harbord (1993), Borenstein and Bushnell (1999), Borenstein, Bushnell, and Stoft (2000), and García-Díaz and Marín (2000)
  - Empirical literature: Wolfram (1999), Joskow and Kahn (2000), Borenstein, Bushnell, and Wolak (2000)

- All these papers focus on short-run outcomes, and take existing capacity as exogenously given.

- Long-run investment decisions has received less attention.
  - Exception of von der Fehr and Harbord (1997) and Murphy and Smeer (2002, 2005), Grimm y Zoettl (2006), De Frutos y Fabra (2006)

Spain Generation Adequacy since liberalisation

- Capacity reserve built during the previous regulatory regime have been rapidly absorbed due to the steep increase in demand and the lack of new investment.

- Winter 2000-01: tight capacity margins under which the system was operating

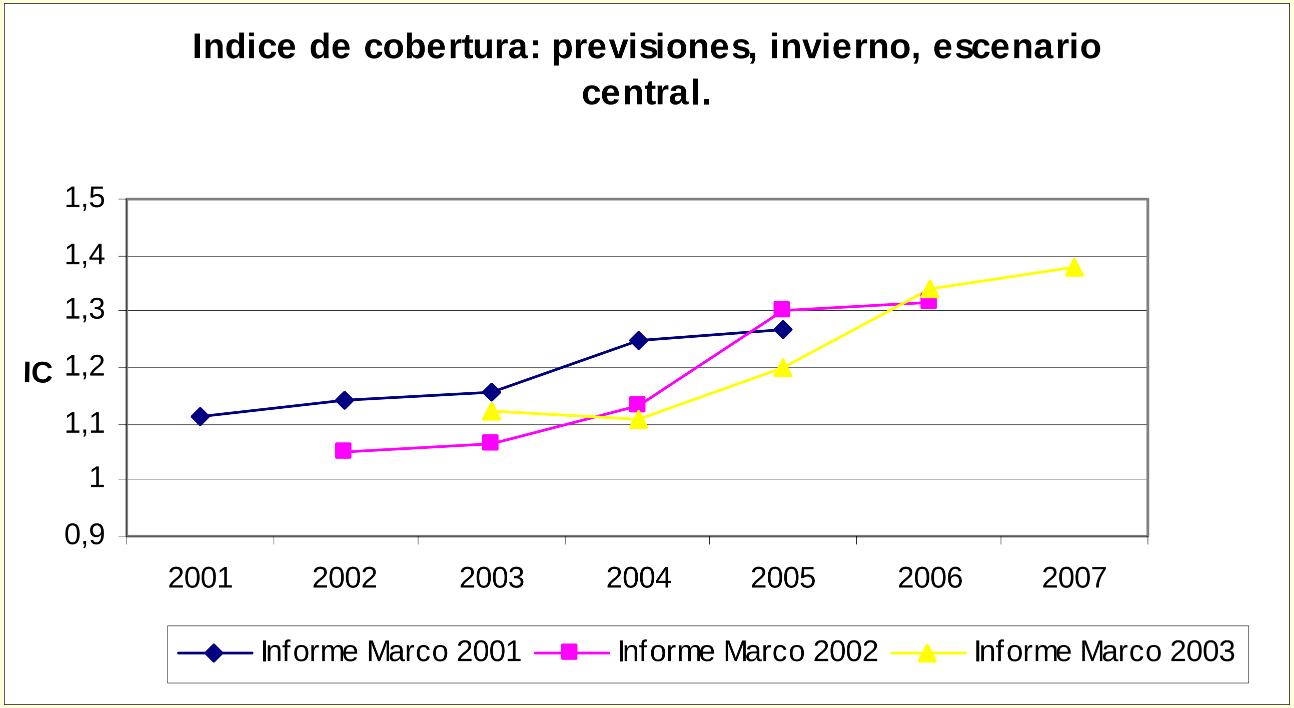
- December-17th-2001: System Operator had to force rolling blackouts in the central region of Spain in order to avoid the collapse of the system.

Spain Generation Adequacy since liberalization

- Regulatory authorities, worried on the stability of the system, requested firms to carry about all the investments plans previously announced.
- New capacity along with exceptionally intense humid seasons, contributed to cover the demand peak registered during last 2002 and first months of 2003.
- Still, even this surge in investment does not seem to be enough to absorb the expected increase in demand: the ratio reserve margin over installed capacity is expected decrease.
- The evolution of electricity plant margins evolution points to a tight situation

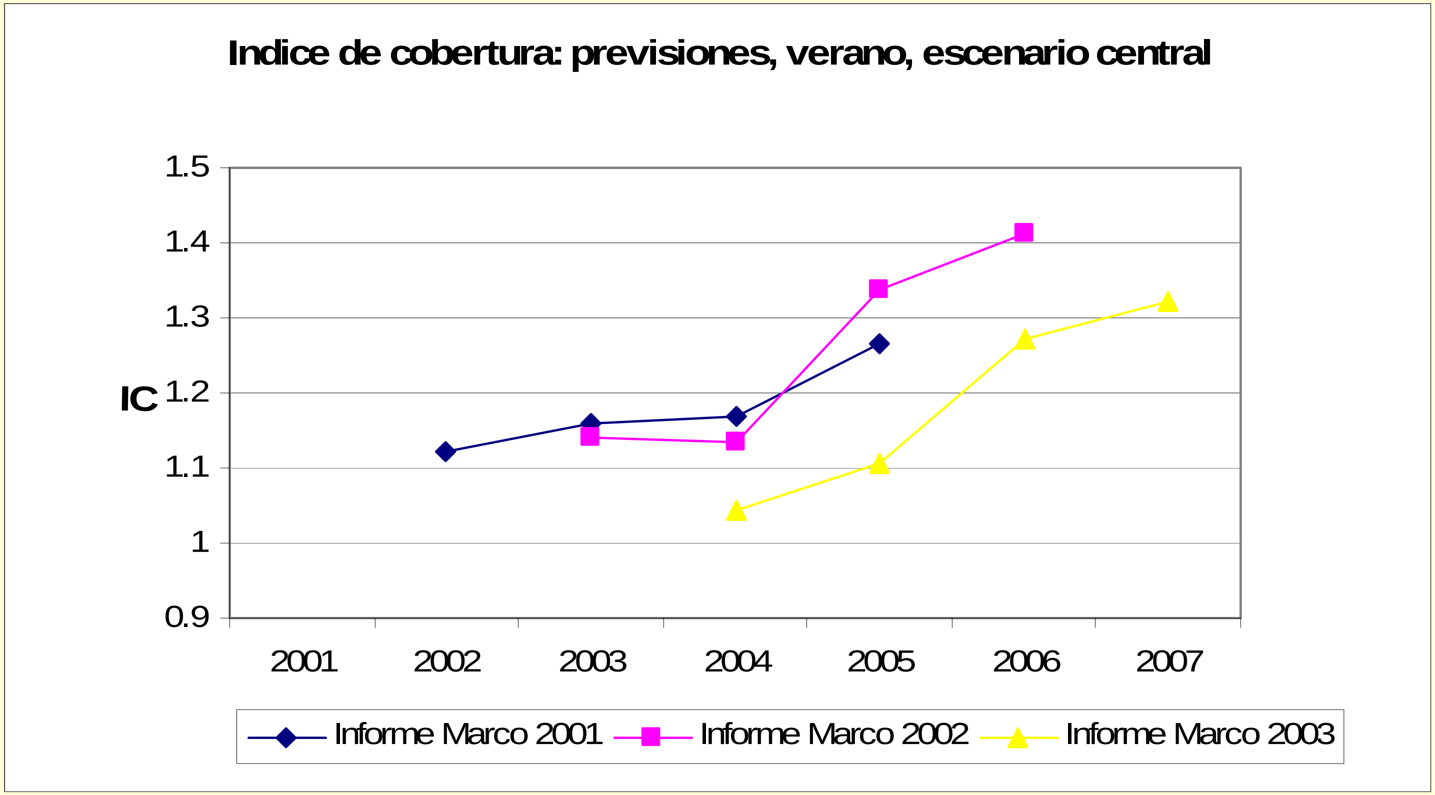
Capacity/Max demand, 5 year CNE forecasts

- Winter



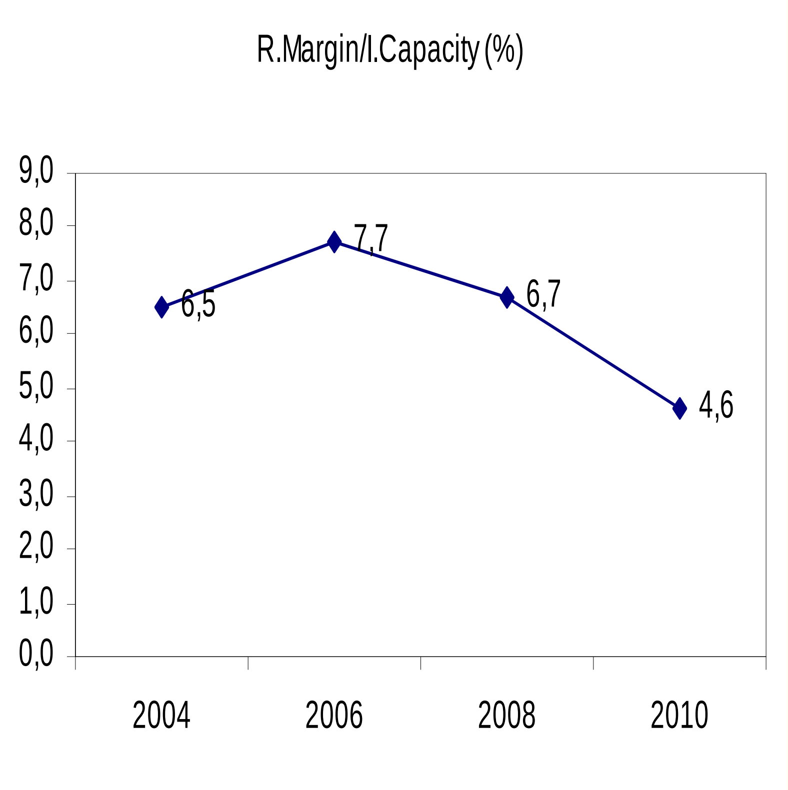
Capacity/Max demand, 5 year CNE forecasts

- Summer



UCTE forecasts

	2004	2006	2008	2010
Power Data (GW)				
Hydro	22,5	22,8	22,9	23,2
Nuclear	7,6	7,6	7,5	7,6
Thermal	31,4	35,2	37,3	39,3
Renewable	6,6	10,1	12,9	15,9
Installed Capacity	**68,1**	**75,7**	**80,6**	**86,0**
Guaranteed Capacity	51,5	55,7	58,2	60,1
Load	**47,1**	**49,8**	**52,8**	**56,1**
Reserve Margin	4,4	5,8	5,4	4,0
Interconnection Capacity	1,8	2,4	3,0	4,1
R.Margin/I.Capacity (%)	**6,5**	**7,7**	**6,7**	**4,6**
Inter.Cap./I.Capacity (%)	2,6	3,2	3,7	4,8
R.Margin+Inter.Cap./I.Cap. (%)	9,0	10,8	10,4	9,4



Source: UCTE

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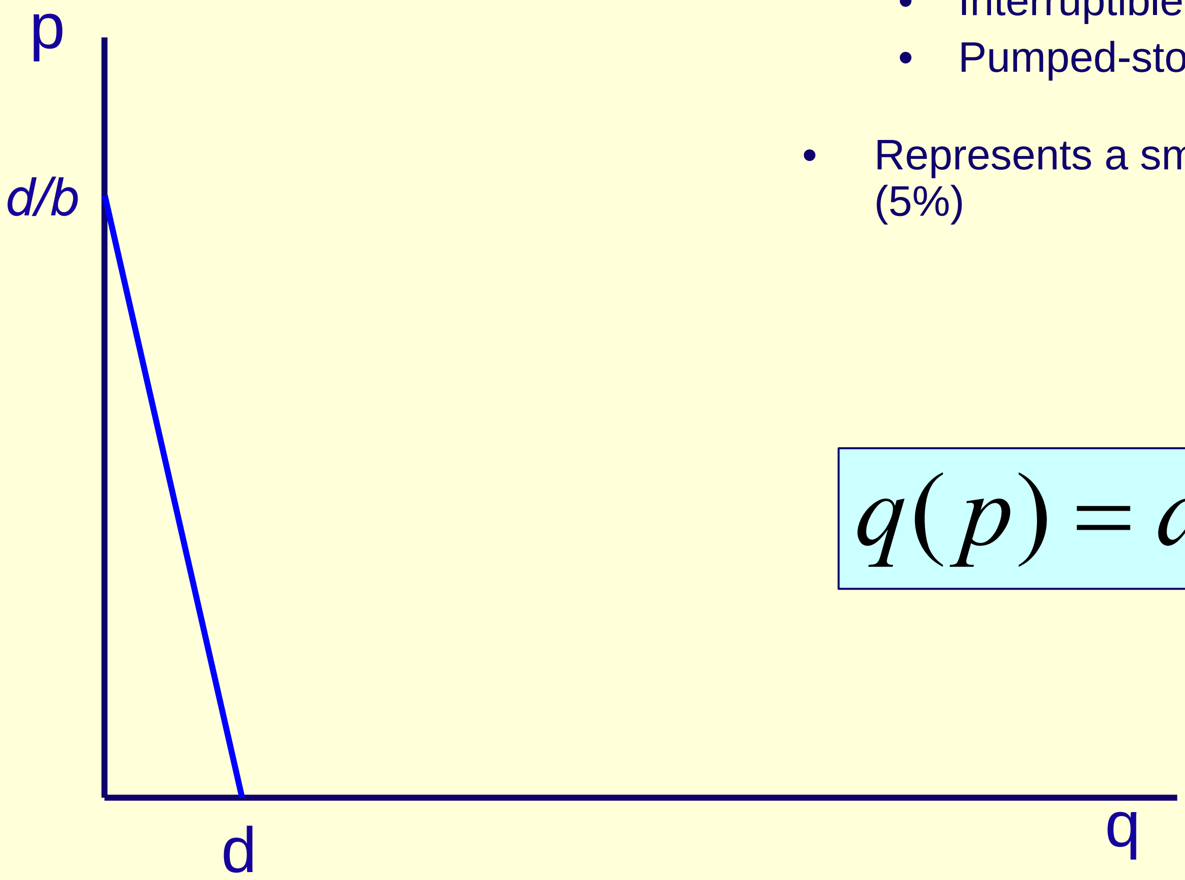
The Model

- “Stylised” electricity system
- “Complete” liberalisation
- Partial equilibrium
- Same weight given to producer and consumer surplus
- Ignores the emergence of alternative technologies
- Model and simulations used to have a feel of the potential magnitudes (e.g capacity shortage) and effectiveness of existing (or defunct) regulatory instruments

Electricity demand that stems from demand-side bids

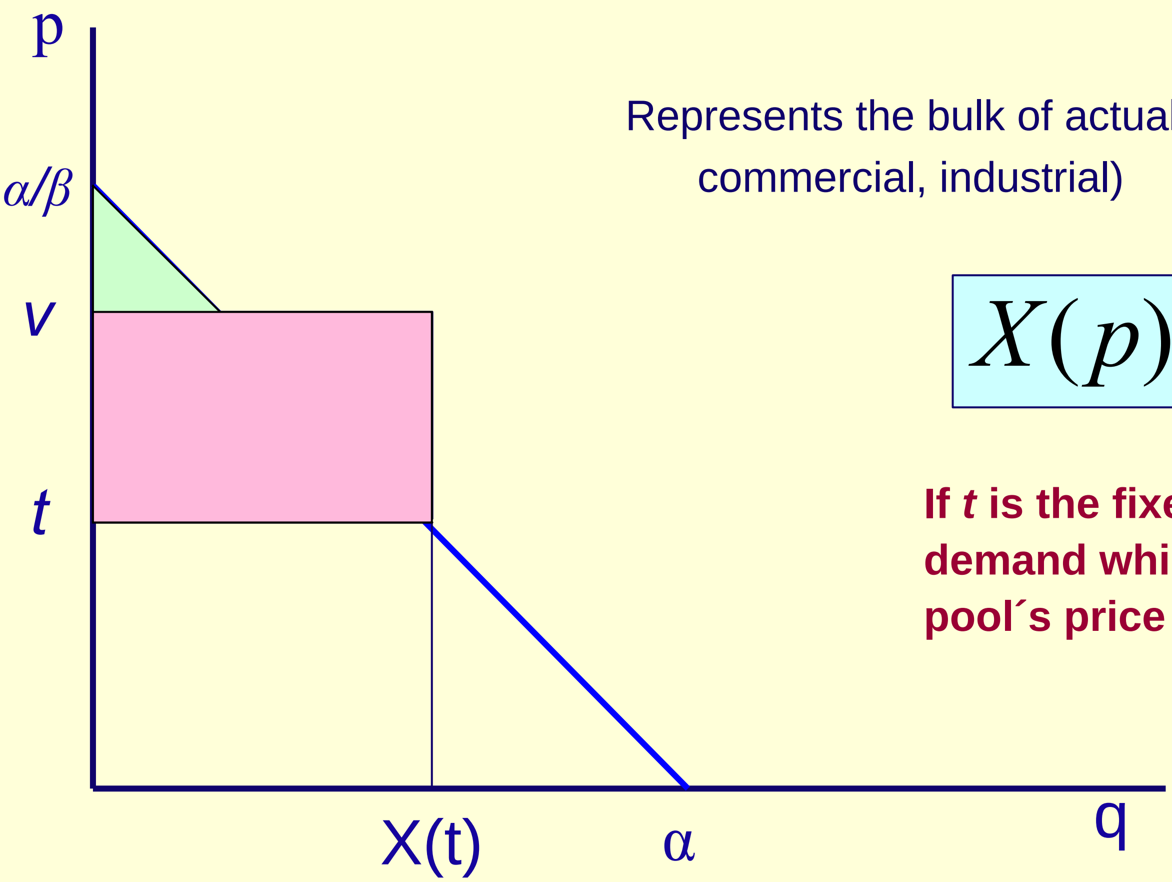


- Interruptible load
- Pumped-storage

- Represents a small part of total demand (5%)

$$\boxed{q(p) = d - bp}$$

Electricity demand stemming from consumers paying a pre-determined fixed tariff



Represents the bulk of actual consumption (domestic, commercial, industrial)

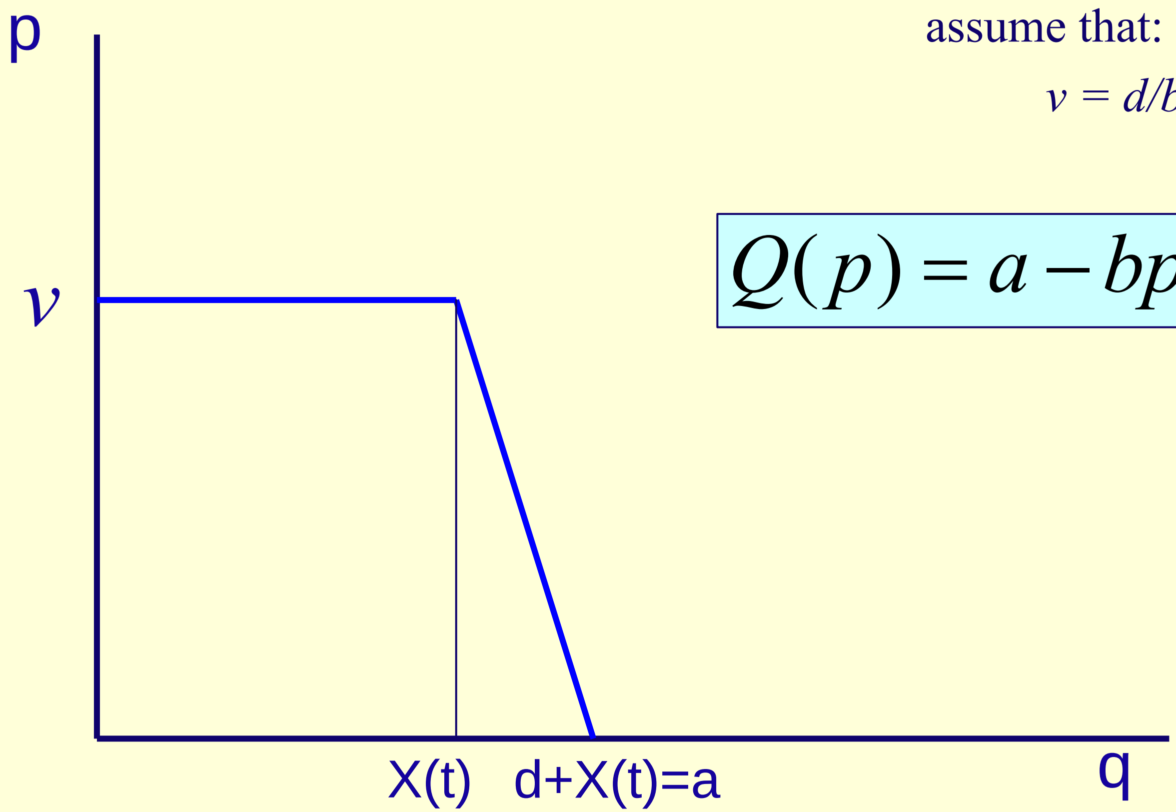
$$\boxed{X(p) = \alpha - \beta p}$$

If *t* is the fixed tariff, *X(t)* is their demand which is independent of the pool´s price

The maximum price that the SO is willing to pay is the average value (*v*) that non-modulable consumers paying tariff *t* give to one unit of electricity. *v* fulfils the condition:

$$\boxed{(v - t)X(t) = \int_{t}^{\alpha/\beta} X(y)\,dy}$$

Aggregate demand that participates in the wholesale market

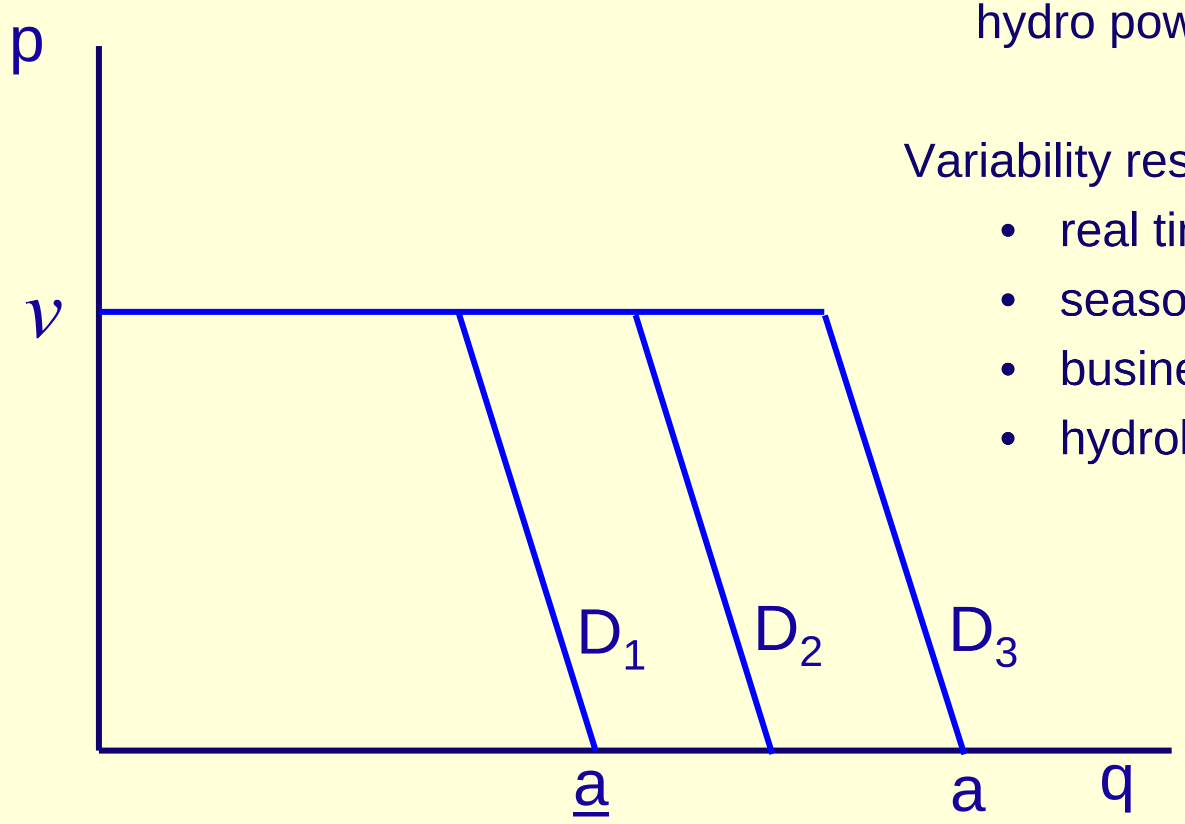


To simplify the formal analysis, we assume that:

$v = d/b$

$$\boxed{Q(p) = a - bp \quad \text{for } p \le v}$$

Residual demand for conventional thermal generators



Peak-load shaving is assumed for hydro power

Variability results from:

- real time fluctuations (hourly)
- seasonal effects and climate
- business cycle
- hydrological conditions

Supply

- **Costs:** We assume that the existing technology mix yields an upward marginal cost schedule up to the level of installed capacity, which we denote *k*.
- We specify the marginal cost function as:

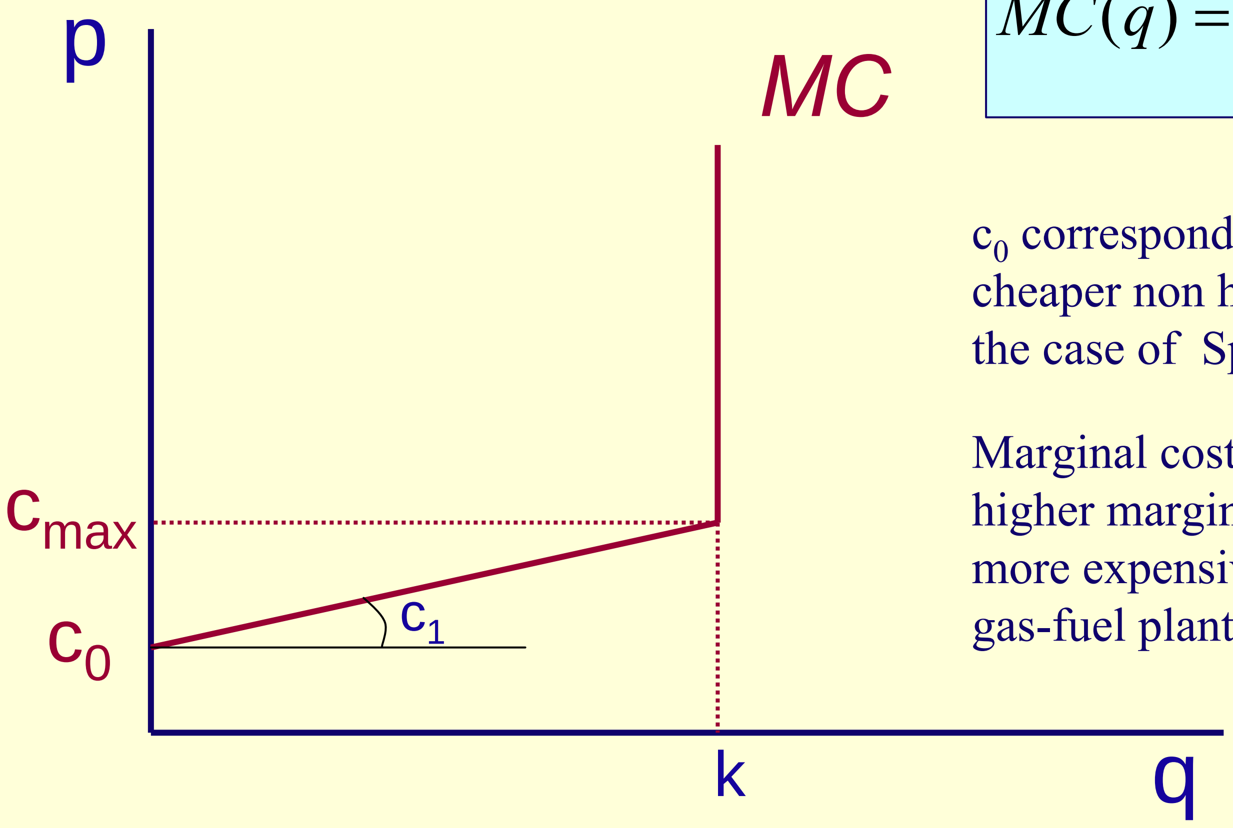
$$MC(q) = \begin{cases} c_0 + c_1 q & for\ q \leq Ak \\ +\infty & for\ q > Ak \end{cases}$$

- **Unitary fixed cost:** *g(k)* represents the unitary cost associated with one unit of new capacity that varies with the number of hours that unit be dispatched (which depends on aggregate capacity *k*)

Costs

Upward marginal cost scheduled up to installed capacity

$$MC(q) = \begin{cases} c_0 + c_1 q & \text{for } q \leq Ak \\ +\infty & \text{for } q > Ak \end{cases}$$



c_0 corresponds to the marginal cost of the cheaper non hydro technology (nuclear in the case of Spain)

Marginal cost increases linearly up to the higher marginal cost associated with the more expensive technology, c_{max} (generally gas-fuel plants)

Characterization of the Social Optimum

- We consider a benevolent regulator that maximizes the surplus of producers and final consumers with equal weight given to each groups.
- We define five distinct regions depending on the relationship between possible realizations of demand and the level of installed capacity.
- In each region we have a welfare function defined as:

$$\boxed{w_r = CS_r(k) + PS_r(k) - g(k)k, \quad r = 1,..,5}$$

Characterization of the Social Optimum

- **Case 1:** *$a \in [\underline{a}, a_c]$:* installed capacity is sufficient to cover demand at price p_c, where p_c is equal to marginal cost

$$W_1 = \int_{p_c}^{v} (a - bp)\,dp + \left[p_c q_c - \int_{0}^{q_c} (c_0 + c_1 q)\,dq \right] - g(k)k$$

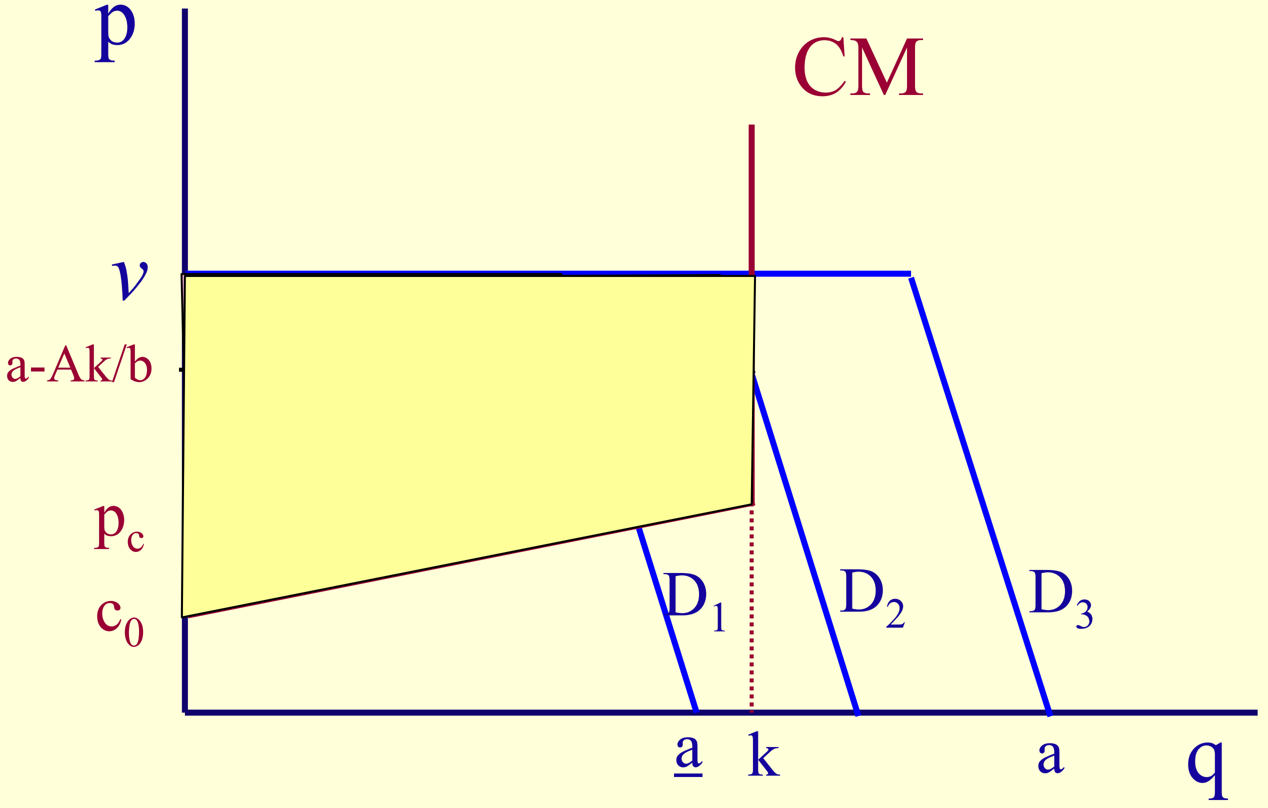
- **Case 2:** *$a \in [a_c, a_m]$:* capacity is sufficient to cover the whole of fixed rate customers, but only a fraction of interruptible load.

$$W_2 = \int_{\frac{a-Ak}{b}}^{v} (a - bp)\,dp + \left[\left(\frac{a - Ak}{b} \right) Ak - \int_{0}^{Ak} (c_0 + c_1 q)\,dq \right] - g(k)k$$

- **Case 3:** *$a \in [a_m, a]$:* realization of demand for which it is not possible to provide energy to all customers, even at *v*.

$$W_3 = \left[vAk - \int_{0}^{Ak} (c_0 - c_1 q)\,dq \right] - g(k)k$$

Welfare areas

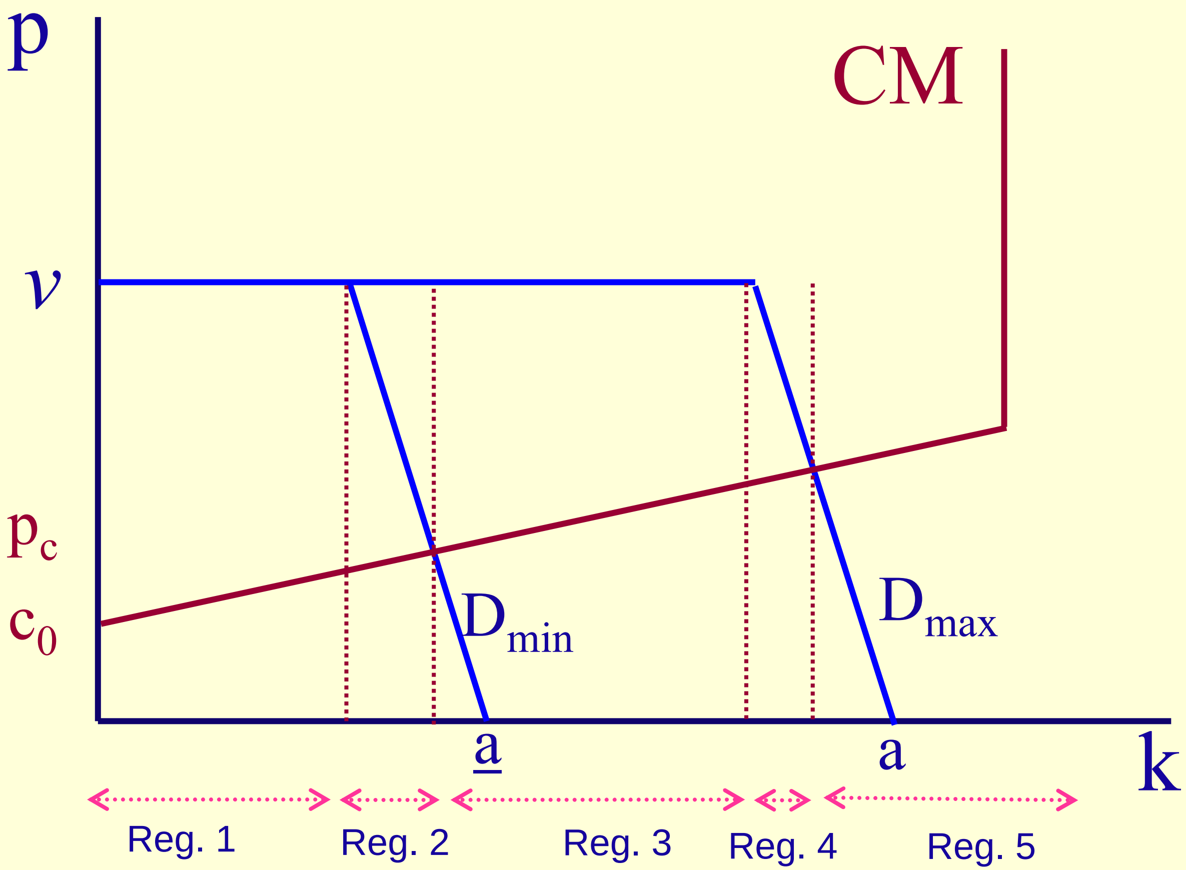


Characterization of the Social Optimum

- To this end we have to define five distinct regions. Ex. Region 3:

$$
\begin{aligned}
w_3 = {} & \int_{\underline{a}}^{a_c} \left[\int_{p_c}^{v} (a-bp)\,dp + \left[p_c q_c - \int_{0}^{q_c} (c_0 + c_1 q)\,dq \right] - g(k)k \right] f(a)\,da \\
& + \int_{a_c}^{a_m} \left[\int_{a-Ak/b}^{v} (a-bp)\,dp + \left[\left[\frac{a-Ak}{b} \right] Ak - \int_{0}^{Ak} (c_0 + c_1 q)\,dq \right] - g(k)k \right] f(a)\,da \\
& + \int_{a_m}^{\bar{a}} \left[\left(vAk - \int_{0}^{Ak} (c_0 + c_1 q)\,dq \right) - g(k)k \right] f(a)\,da
\end{aligned}
$$

Welfare areas



Characterization of the Social Optimum

- The global expected welfare function is given by:

$$w = \begin{cases} w_1 & \text{if} \quad k \in \left[0, \dfrac{\underline{a} - bv}{A} \right] \\ w_2 & \text{if} \quad k \in \left[\dfrac{\underline{a} - bv}{A}, \dfrac{\underline{a} - bc_0}{(1 + bc_1)A} \right] \\ w_3 & \text{if} \quad k \in \left[\dfrac{\underline{a} - bc_0}{(1 + bc_1)A}, \dfrac{\bar{a} - bv}{A} \right] \\ w_4 & \text{if} \quad k \in \left[\dfrac{\bar{a} - bv}{A}, \dfrac{\bar{a} - bc_0}{(1 + bc_1)A} \right] \\ w_5 & \text{if} \quad k \in \left[\dfrac{\bar{a} - bc_0}{(1 + bc_1)A}, +\infty \right] \end{cases}$$

- *w* can not be globally differentiated since it is made-up of five distinct functions.
- We thus obtain the values of *k* that maximize *w* for each of the five segments. Consequently, the optimal level of capacity is the one that gives the highest value to *w*.
- Note that w yields a lower bound of the level of socially optimal capacity. Certainly the true level of socially optimal capacity lies above the one we obtain algebraically.

Capacity investment in decentralized markets

- We model firms' decisions as a two stage game.
  - First stage, which we take to represent long-run decisions, firms simultaneously decide on how much capacity to install.
  - In the second stage (short-run decision) firms compete by making supply bids in a spot market. We assume that firms supply energy competitively. This assumption sits well with existing regulation and simplifies the algebra.

$$p = \begin{cases} c_0 + c_1 q & iff \quad k > q_c(a) \\ P(k) & iff \quad q(a,v) < k \le q_c(a) \\ v & iff \quad k \le q(a,v) \end{cases}$$

- The (endogenous) choice of capacity becomes the central variable in this model.

Capacity investment in decentralized markets

- Private investment decisions in the absence of regulatory intervention: The market is totally "deregulated" :
    - no price caps
    - no vertical integration with suppliers that face regulated final rates
- Under that benchmark scenario, we rule out effective regulatory intervention to prevent price spikes.
- *n* (number of firms) is a finite number, and we assume that firms are symmetric.

Capacity investment in decentralized markets

- We define the profits obtained by firm i that owns capacity k_i, while the rest of the industry's aggregate capacity is k_{-i}.

- The analysis follows the steps of the previous section, that is we distinguish five regions...

$$\Pi_{i,r} = PS_{i,r} - g(k)k_i, \quad r = 1,\ldots,5; \quad i = 1,\ldots,n$$

- We denote *n* as the symmetric firms in the industry.

Capacity investment in decentralized markets

- Firm *i*'s global expected profit function is given by:

$$\pi_i = \begin{cases} \pi_{i,1} & \text{if} \quad k \in \left[0, \dfrac{\underline{a} - bv}{A} \right] \\ \pi_{i,2} & \text{if} \quad k \in \left[\dfrac{\underline{a} - bv}{A}, \dfrac{\underline{a} - bc_0}{(1 + bc_1)A} \right] \\ \pi_{i,3} & \text{if} \quad k \in \left[\dfrac{\underline{a} - bc_0}{(1 + bc_1)A}, \dfrac{\overline{a} - bv}{A} \right] \\ \pi_{i,4} & \text{if} \quad k \in \left[\dfrac{\overline{a} - bv}{A}, \dfrac{\overline{a} - bc_0}{(1 + bc_1)A} \right] \\ \pi_{i,5} & \text{if} \quad k \in \left[\dfrac{\overline{a} - bc_0}{(1 + bc_1)A}, +\infty \right] \end{cases}$$

- *π* can not be globally differentiated since it is made-up of five distinct functions.
- We thus obtain the values of *k* that maximize *w* for each of the five segments. Consequently, the optimal level of capacity is the one that gives the highest value to *π*.

Comparing social optima and decentralized outcome

- **Proposition:** With a finite number of generators, a decentralized outcome unambiguously yields a socially sub-optimal level of installed capacity.
- **Intuition:**
  - The marginal revenue derived from the marginal unit is always larger for the benevolent planner as compared to a private agent, while costs are the same for both.
  - Firms earn very high profits by installing less capacity and letting prices go up (and not only during annual peaks).
- **Corollary:** At the social optimum installed capacity is below peak demand. (This partly reflects our definition of the social optimum).
  - Capacity is not dispatched a sufficient number of hours to cover incremental fixed costs.

Simulations using Spanish data

- Uncertainty:
  - Hourly distribution of demand (OMEL and REE).
  - Demand predictions for 2008
  - Expected hydro capacity (using historical data).
- Averages value of electricity from VOLL and GDP per MWh.: 3005 euros.
- 0-10% modulability: hydro pumping and demand derived from large interruptible consumers.

Simulations using Spanish data

- Cost function derived from Spanish installed capacity
- Cost of new capacity based on Combined Gas Cycle technology
- Average availability ratio: 92,5 %
- Several scenarios:
  - Free entry: upper bound determined by necessity to cover fixed costs and minimum size of generation plant (CCGT).
  - Very large increase in the number of active participants in the Spanish market in the near term: 20 firms.
  - Number of established generators: n=4.

Optimal conventional thermal capacity

Base case:

Number of firms (n): 4, 20, 78
Modulability: 5 %

VOLL: 3005 Euros/MWh

Marginal cost (MC) of base load technology (BLT): 7.99 Euros/MWh

Marginal cost of peak-load technology: 29.15 Euros/MWh

Average Availability Ratio: 92.5%

	Social optimum	***k* to cover peak demand**	***k*, *n* =78**	***k*, *n* =20**	***k*, *n* =4**
Capacity (MW) **(% availability capacity over maximum demand)**	**30680** **(100%)**	**32460** **(105.1%)**	**30260** **(98.6%)**	**28340** **(92.4%)**	**20970** **(68.4%)**
Unsatisfied demand (%)	**0.005%**	**≅0.00%**	**0.007%**	**0.05%**	**7.72%**

Simulations: welfare

	PO % of SO	CS % of PO	PS % of PO
$n = 4$	91.1	33.0	67.0
$n = 20$	99.9	95.3	4.7
$n = 78$	99.997	98.9	1.1

- The social optimum requires 30680 MW of conventional thermal capacity by 2008 (approx. 64.400 MW total capacity).
- The socially optimal level of capacity does not cover peak demand. In part, this is due to our definition of the social optimum.
- The private outcome is clearly sub-optimal when the number of firms is reduced
- With n = 4, 7.72% of total demand is unsatisfied.
- Variations in the number of agents generates large transfers between producers and consumers.

Sensitivity analysis

Marginal cost, $n = 20$. Changes in the cost of peak technology has a marginal effect

MC base	MC peak	SO (MW)	PO (MW)	PO as % SO
0	29.21	30680	28340	92.37
29.21	29.21	30680	28340	92.37
7.99	7.99	30690	28350	92.38
7.99	50	30670	28340	92.40

Changes in the fixed unitary cost, $n = 20$. $g(k)$ that corresponds to 7500 hours of operation.

€/MW, 7500 hours/year	SO (MW)	PO (MW)	PO as % SO
3	31220	28710	91.96
9	30380	28140	92.63

Sensitivity analysis

- The gap btween the SO and the PO falls as the degree of modulability increases.
- The level of installed capacity associated with the PO and the SO falls for lower values of the VOLL.

Regulatory mechanisms

- **Capacity payment**: consists in paying a monetary amount to generation units that have declared their availability (i.e., have made supply bids), irrespective of whether they are actually dispatched or not.

- **Price adder**: a capacity charge (CC) is added to the price of energy.

  CC is defined as CC = LOLP · (VOLL - P)

  LOLP= Prob [Demand > Availability Capacity]

- We define the expected profits functions including these regulatory mechanisms and simulate

- Capacity requirement may be viewed as an intermediate case of the two mechanisms described above (see Ruff (1999) for an in-depth discussion of this issue).

Capacity payment

- We analyse the capacity payment currently in place in Spain (till October 1 2007?), whereby the amount received by each firm is determined through a two-stage procedure:

1. The total amount paid to firms (TCP) is obtained by multiplying a monetary amount Y by the system's total demand D:

$$TCP = Y\,D$$

2. TCP is distributed proportionally to firms on the basis of their declared availability. Thus, the payment to firm *i* if it declares k_i capacity available and total capacity is *k,* is given by:

$$TCP_i = YD\frac{k_i}{k}$$

Simulation results

Capacity Payment

- Firms have extremely strong incentives to maintain a situation of tight capacity.
- The amount that needs to be paid to achieve the optimum capacity is very high.

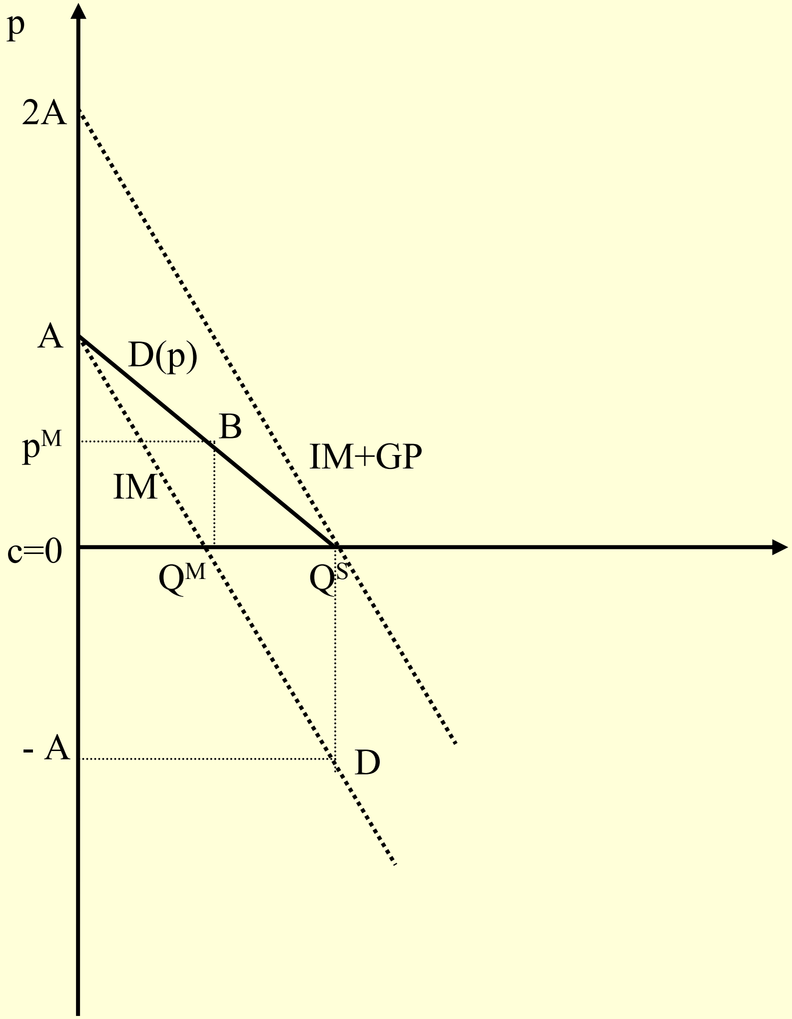
n=20

Price cap (€/MWh)	**"Optimal" Capacity Payment (€/MWh)**
3005.05	3091
1800	2509
600	2007
180	1846

- Simple intuition: in order to induce firms to install the optimal level of capacity, the payment must be such that the marginal revenue of private firms shifts and coincides with social marginal revenue. Illustration with a monopolist

Simulation results

Capacity payment



D(p)=A-p

Q^M: decentralised outcome

Q^S: social optimum

Unit CP=A: the capacity payment is prohibitively costly

Transfer, $-AcQ^SD$, larger than maximum surplus, AcQ^S

Having more agents reduces the pecuniary cost of the capacity payment, but does not eliminate the inefficiency of these transfers.

Simulation results

Capacity payment, with and without a price cap

- With the current Spanish capacity payment, the maximum possible payment (**13,247 €/MWh**) does not induce a socially optimal level of capacity

- Having a cap reduces capacity and the monetary amount required to achieve the social optimum. However, the latter remains prohibitive

n=20

Price cap (€/MWh)	*K* private without CP (MW)	% w.r.t *K* social (%)	*K* private with CP. (MW)	% w.r.t. *K* social (%)	Capacity Increase (MW)
3005.05	28340	92.37	28372	92.48	32
1800.00	28150	91.75	28194	91.90	44
600.00	27250	88.82	27344	89.13	94
180.00	25600	83.44	25850	84.26	250

Simulation results: Price Adder, with and w/o a price cap

- In a fully liberalized market, a “strictly defined” price adder is totally ineffective to achieve the social optimum.

LOLP=Prob [Demand > Availability Capacity]

- Maintaining capacity tight increases LOLP; the higher LOLP the more firms are paid.
- However, if the cap remains above 180€/MWh, the reduction in capacity induced by the cap is almost fully compensated by the price adder.
- “Caps” below 180 €/MWh induce a large reduction in capacity

n=20

Price cap (€/MWh)	Private Capacity (MW)	% Optim.Cap. (%)	*K* private with Price adder (MW)	% Optim.Cap. (%)	Capacity increase (MW)
3005.05	28340	92.373	28983	94.47	643
1800.00	28150	91.754	28983	94.47	833
600.00	27250	88.820	28898	94.19	1648
180.00	25600	83.442	28829	93.97	3229

Simulation results

Price Adder

- A Price Adder with a modified LOLP allows to achieve the social optimum but the cost remains prohibitive.

  LOLP=Prob [Demand + RM > Availability Capacity], where RM is a reserve margin on maximum demand.

n=20

Price cap (€/MWh)	RM (MW)
3005.05	1044
1800.00	931
600.00	831
180.00	798

Effectiveness of the regulatory mechanisms

- The simulations clearly indicate that, in an oligopolistic context, neither mechanism induces a socially optimal level of capacity.

- The capacity payment in force in Spain is (potentially) very costly.

Alternative Regulatory Intervention:

Price cap on average annual spot prices

This situation occurs if one of the following conditions are met:

- Generators and energy suppliers are vertically integrated, and the latter are subject to an administratively set tariff to which all customers can opt.
- Rules governing stranded costs (as the Spanish case).
- Firms expect a strong regulatory response in the event of a sustained and visible increase in prices.
- Regulation explicitly sets this price-cap.

Alternative Regulatory Intervention:

Price cap on average annual spot prices

- Introducing an annual average price-cap proves to be a powerful tool to improve welfare in liberalized electricity markets.

- However, this instrument fails to solve the problem entirely if the regulated annual average price-cap is **higher** than the annual average price associated with $K=K^s$.

Conclusions (1)

- In “truly” liberalised market and a reduced number of agents, a decentralised outcome yields a level of capacity that is clearly inferior to the social optimum.
- Simulations indicate that the two mechanism fail to achieve their declared objective.

Conclusions (2)

- Given a level of installed capacity, the payment to firms increases with demand (D). In other words, firms are paid more when the reserve margin is tight.

- Thus, in a closed oligopoly, firms have a double incentive to maintain a narrow margin.

- Both mechanism vary across time, and have been characterised by regulatory uncertainty.

- In the current Spanish situation, the “Garantía de Potencia” (CP) has been useful to maintain old capacity.

Conclusions (3)

- If UK-like de-concentration is not a realistic option, some form of regulation (explicit or implicit) will be required to induce investment and protect consumers.
- Lowering barriers to entry (both existing and *de novo*) capacity.
- Interconnection with other electricity systems to mitigate market power.

Conclusions (4)

- Alternative mechanisms:
- Payment independent of the reserve margin? Or with the opposite slope?
- De-coupling the incentives to maintain existing capacity and the incentives to invest in new capacity
- Pre-determined for the expected lifetime of a generating plant (or that varies according to pre-determined criteria).

Conclusions (5)

- Prospective changes (October 2007):
- De-coupling: distinct instruments for existing and new capacity
- Long term incentive: fixed amount for each MW of “new” capacity (*de facto*, only for CCGT)
- Medium-term incentive (yearly, not well defined yet): payment for making capacity available during situations of tight capacity. Heavy penalties for defaulting.

Conclusions (6)

- Possible problems with the proposed system changes (October 2007):
- Slope of the long-term payment: agents are paid more when capacity is tight
- Not yet clear what happens if the reserve margin (yet to be defined) falls below 1.05.

Conclusion (7)

- Capacity markets?
- Implications of size asymmetries on strategic behavior: pre-emption?
- Dynamic issues
- Impact of Renewable Energies

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