Capacity mechanisms and the technology mix in competitive electricity markets

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INTRODUCTION

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Role of capacity mechanisms

Electricity market design:

- ***Capacity market***: System operator sets capacity volume & runs auction (e.g. GB); uniform payment (US)
- ***Strategic reserve***: System operator procures back-up capacity (e.g. Germany, Sweden)

Common justifications:

- Market power => price cap => missing money => underinvestment => capacity mechanism…
- Renewables => merit order effect => ↓ capacity utilization => extra revenue streams needed…
- Other justifications: political economy…

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Contribution of this paper

— New benchmark model of long-run generation investment

— Optimal policy design: price cap + capacity mechanism

— Three types of capacity mechanism:
capacity payment, capacity auction, strategic reserve

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Key features of our model

1) **Continuum of production technologies**
   — Baseload, mid-merit, peaking

2) **Stochastic + inelastic consumer demand**

3) **Forced rationing + system cost externality**
   — Demand > capacity => rolling black-outs
   — System cost externality (e.g. Joskow & Tirole 2007; Fabra 2018; Llobet & Padilla 2018)

4) **Perfect competition**

NB. No DSR, no storage, no ROs, no politics

Related literature

Technology modelling

- Representative technology (Léautier 2016; Fabra 2018)
- Few discrete technologies (Joskow & Tirole 2007; Llobet & Padilla 2018)

Peak load pricing

- Discrete (Crew & Kleindofer 1986, many others)
- Continuous (Zöttl 2010)

Screening curve analysis

- Peak-load pricing + inelastic demand + discrete technologies (Stoft 2002; Bigger & Hesamzadeh 2014; Léautier 2019)

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Plan for this talk

1) **Setup of the model**

2) **First-best benchmark**

3) **Optimal policy design**

4) **Extensions**
   — Renewables penetration
   — Optimal strategic reserve

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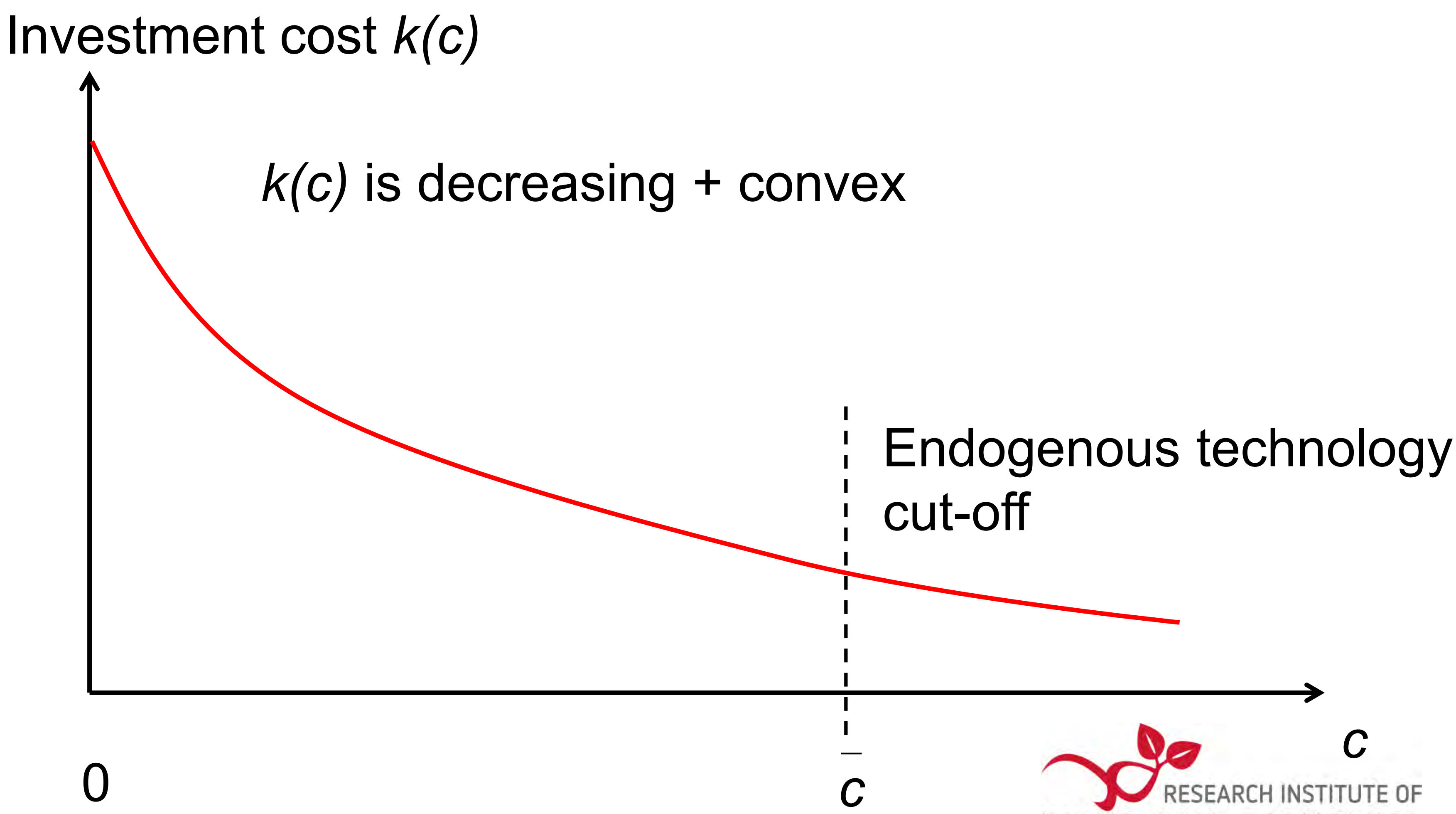
MODEL

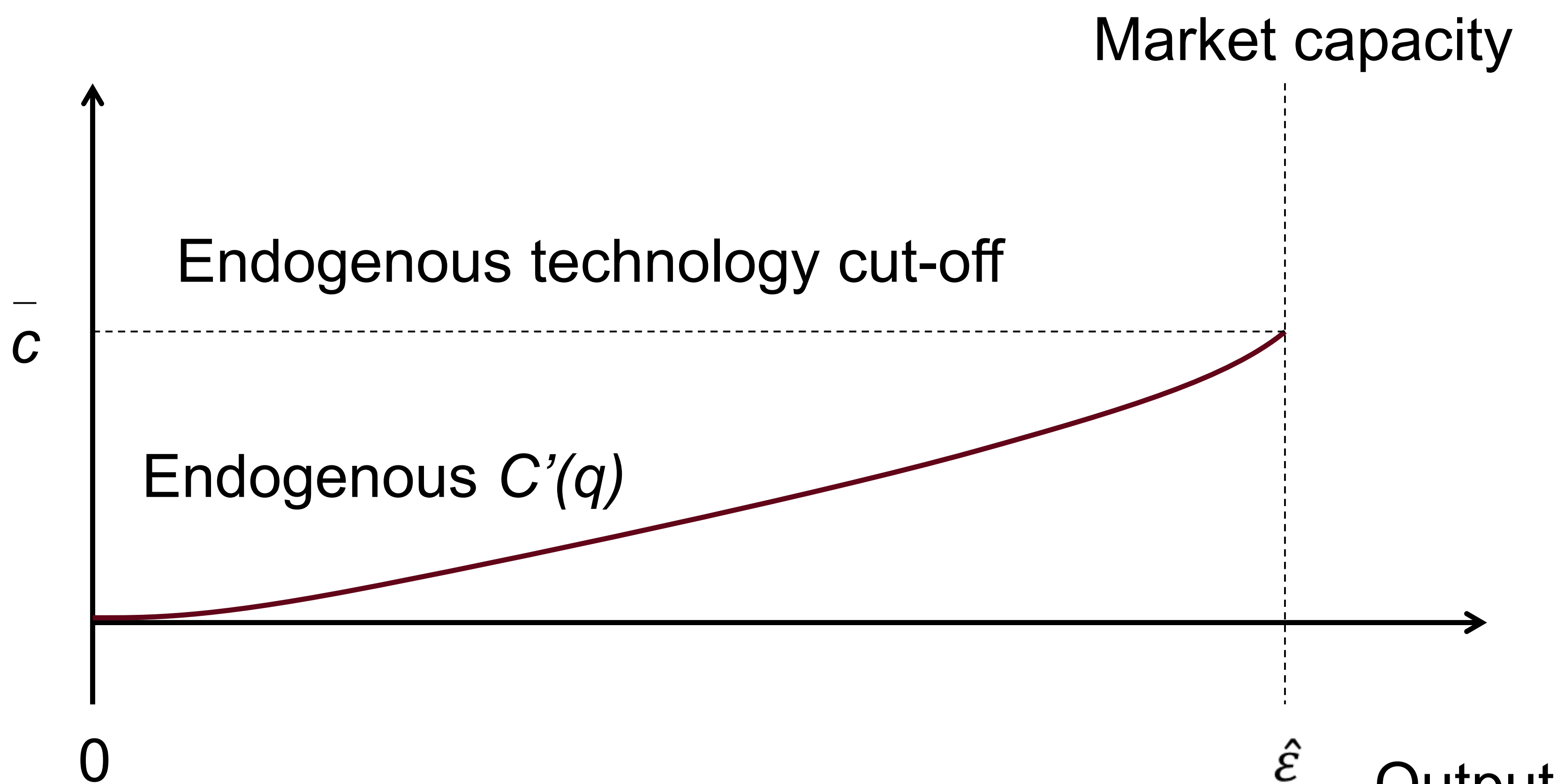
Continuum of technologies

Each technology is indexed by its marginal cost *c*



Stage 1: Investment

Producers choose how much to invest into each technology
=> This generates a marginal cost curve



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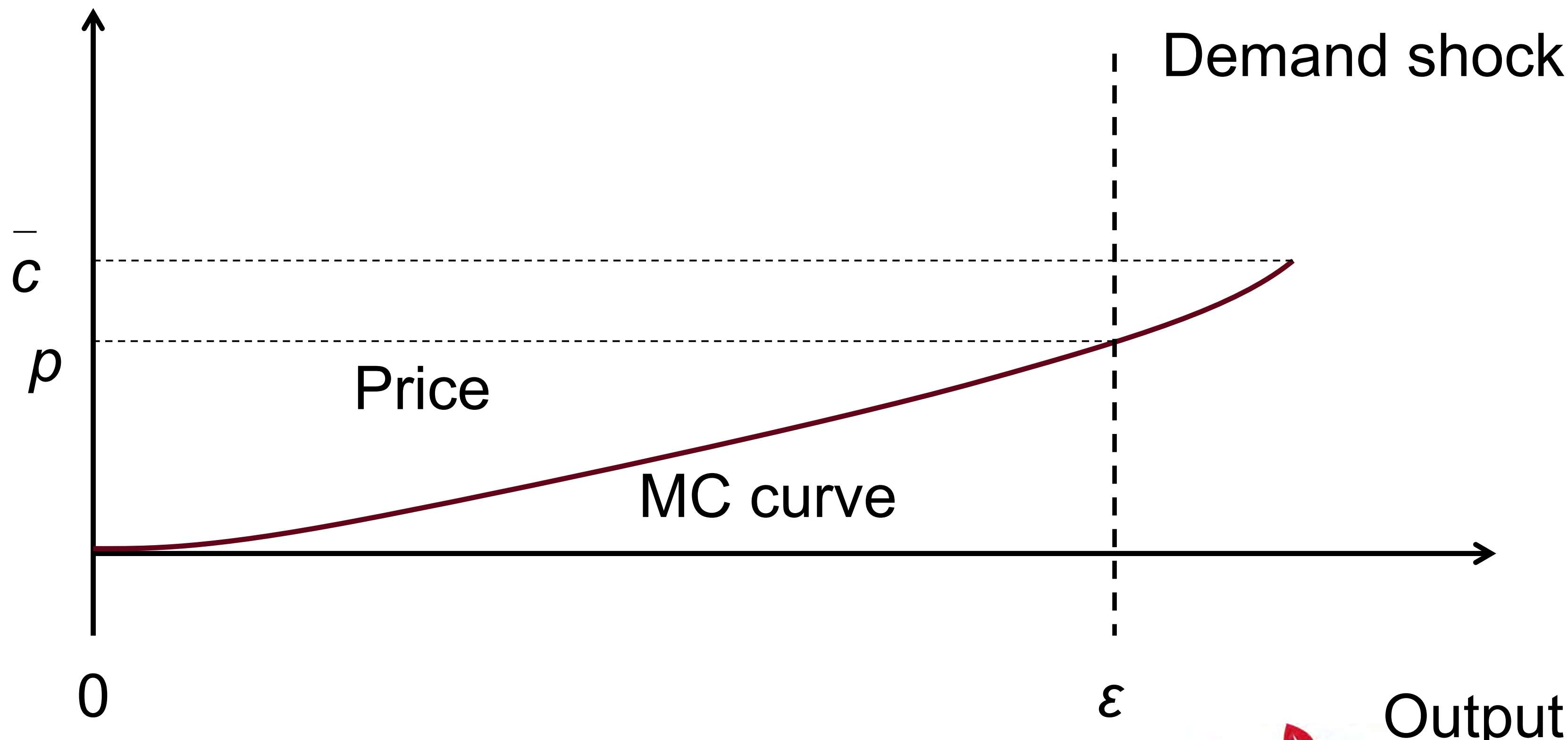
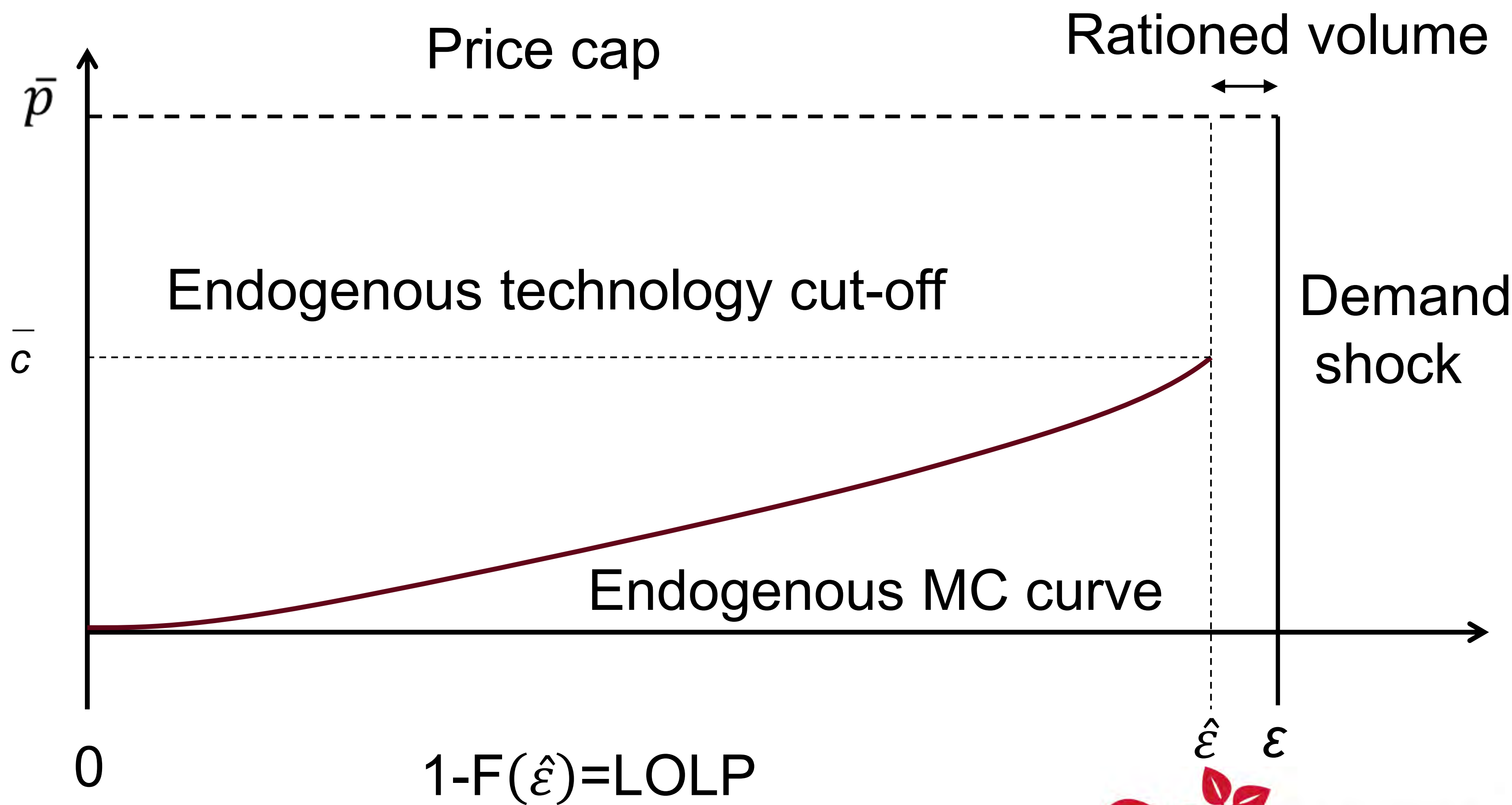
Stage 2: Production

Perfect competition => producers supply at marginal cost
Consumer demand is inelastic with VOLL equal to p^*
Demand shock ε follows distribution $F(\varepsilon)$ with density $f(\varepsilon)$



Rationing

Demand exceeds the market capacity with probability $1 - F(\hat{\varepsilon})$ => Rationing and price equals price cap.



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System cost externality

We assume rationing has a social cost (beyond VOLL):

—System cost of *controlled* rolling black outs

—Welfare loss due to *uncontrolled* black outs

=> More investment improves reliability (public good)

Let $M(\hat{\varepsilon})$ be the expected system cost associated with black outs, where $M'(\hat{\varepsilon}) \leq 0$ and $M''(\hat{\varepsilon}) \geq 0$

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FIRST BEST

Social planner

Choose cost curve *C'(q)* & technology cutoff $\bar{c}$ to maximize consumer benefit

$$p^* \int_0^{\hat{\varepsilon}} f(\varepsilon)\varepsilon d\varepsilon + p^*\left(1 - F(\hat{\varepsilon})\right)\hat{\varepsilon}$$

net of investment cost

$$\int_0^{\bar{c}} k(c)q'(c)dc,$$

net of expected production cost

$$\int_0^{\hat{\varepsilon}} C(\varepsilon)f(\varepsilon)d\varepsilon + \left(1 - F(\hat{\varepsilon})\right)C(\hat{\varepsilon}),$$

net of expected system cost $M(\hat{\varepsilon})$

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Proposition 1: Optimal technology mix

For given market capacity, total production and investment costs are minimized when:

$$1 - F\left(q(c)\right) = -k'(c)$$

Intuition: Consider two technologies with marginal-cost differential *Δc*. Investing more in low-MC technology:

1) Saves *(1-F(q(c)))Δc* on production costs
2) Raises investment costs by *–k'(c)Δc*

At optimum, social planner is indifferent between alternatives
NB. Does not depend on VOLL or system cost…

=> Simpler than peak-load pricing literature, similar intuition

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Proposition 1: Optimal investment

The optimal technology cutoff is determined from:

$$-(p^* - \bar{c})k'(\bar{c}) - k(\bar{c}) - M'\big(q(\bar{c})\big)=0$$

Intuition: Planner continues to invest until:

$$\underbrace{(p^* - \bar{c})\big(1 - F(\hat{\varepsilon})\big) - M'\big(q(\bar{c})\big)}_{Expected\ gain\ in\ stage\ 2\ from\ extra\ unit} - \underbrace{k(\bar{c})}_{Investment\ in\ extra\ unit} = 0$$

Optimality can also be formulated as:

$$\bar{c} = p^* \left(\frac{\eta(\bar{c})}{\eta(\bar{c})+1+M'(\cdot)/k(\bar{c})}\right) \text{ where } \eta(c) = -\frac{ck'(c)}{k(c)}$$

=> If *M(.)=0* then socially-optimal technology cutoff $\bar{c}$ and LOLP $1 - F(\hat{\varepsilon})$ both independent of *F(.)*

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OPTIMAL POLICY

Policy design

Regulator has two instruments:

price cap $\bar{p}$ and uniform capacity payment z

Expected profit of investment into unit of technology with marginal cost c determined by:

1. investment cost $k(c)$
2. spot market profits (scarcity rent)
3. capacity payment z

Competitive entry => in equilibrium, zero profit condition

Proposition 2: Optimal policy

Proposition 1 still holds:

$1 - F\big(q(c)\big) = -k'(c)$ for $c \in [0, \bar{c}]$.

The technology cutoff is determined by:

$$z - k(\bar{c}) - (\bar{p} - \bar{c})\ k'(\bar{c}) = 0$$

Investments are socially optimal when:

$$z + M'\big(q(\bar{c})\big) + (p^* - \bar{p})k'(\bar{c}) = 0$$

There are many combinations that satisfy this condition, e.g. $\bar{p} = p^*$ and $z = -M'\big(q(\bar{c})\big)$.

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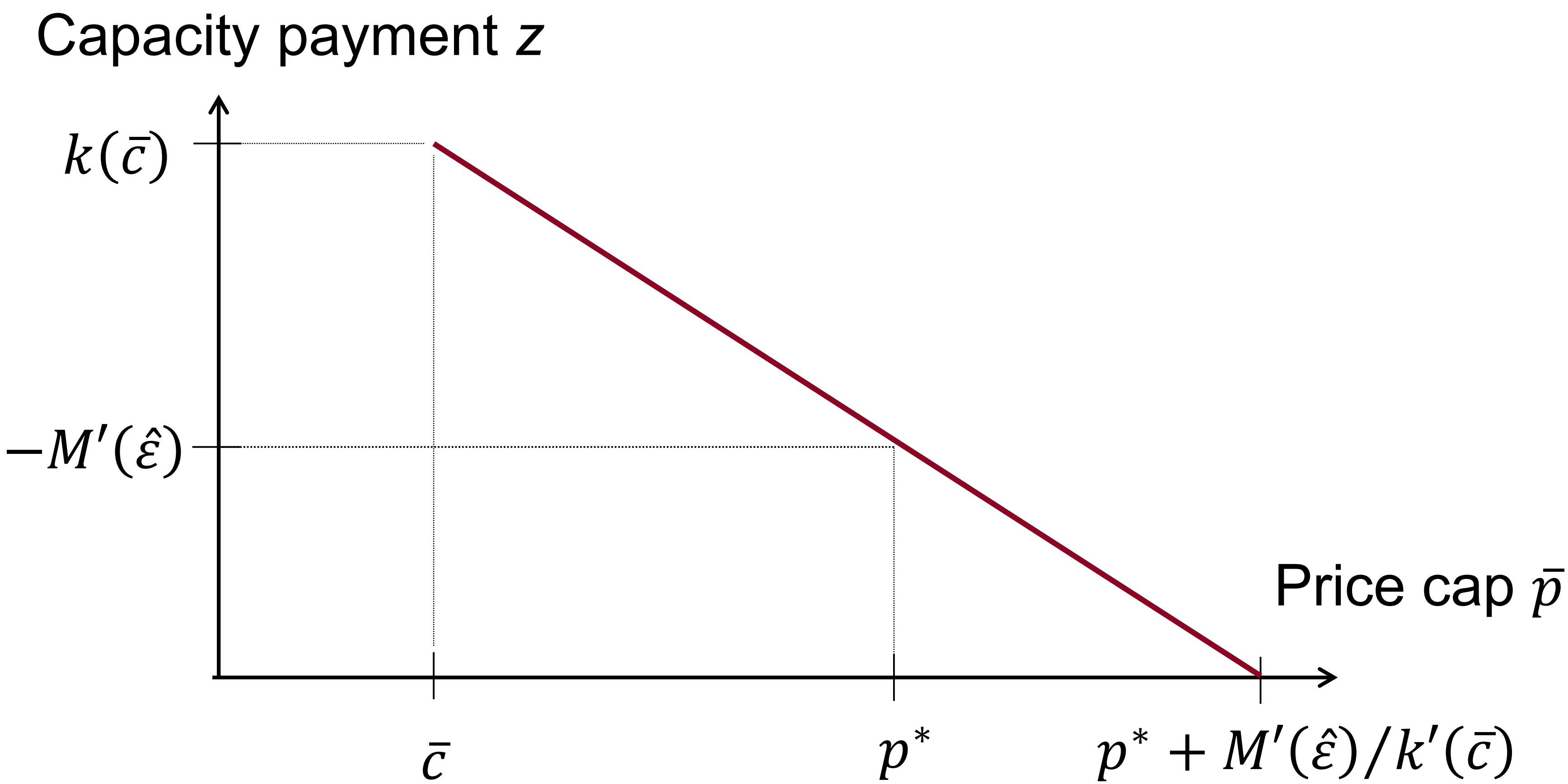
Optimal combinations of price cap and capacity payment



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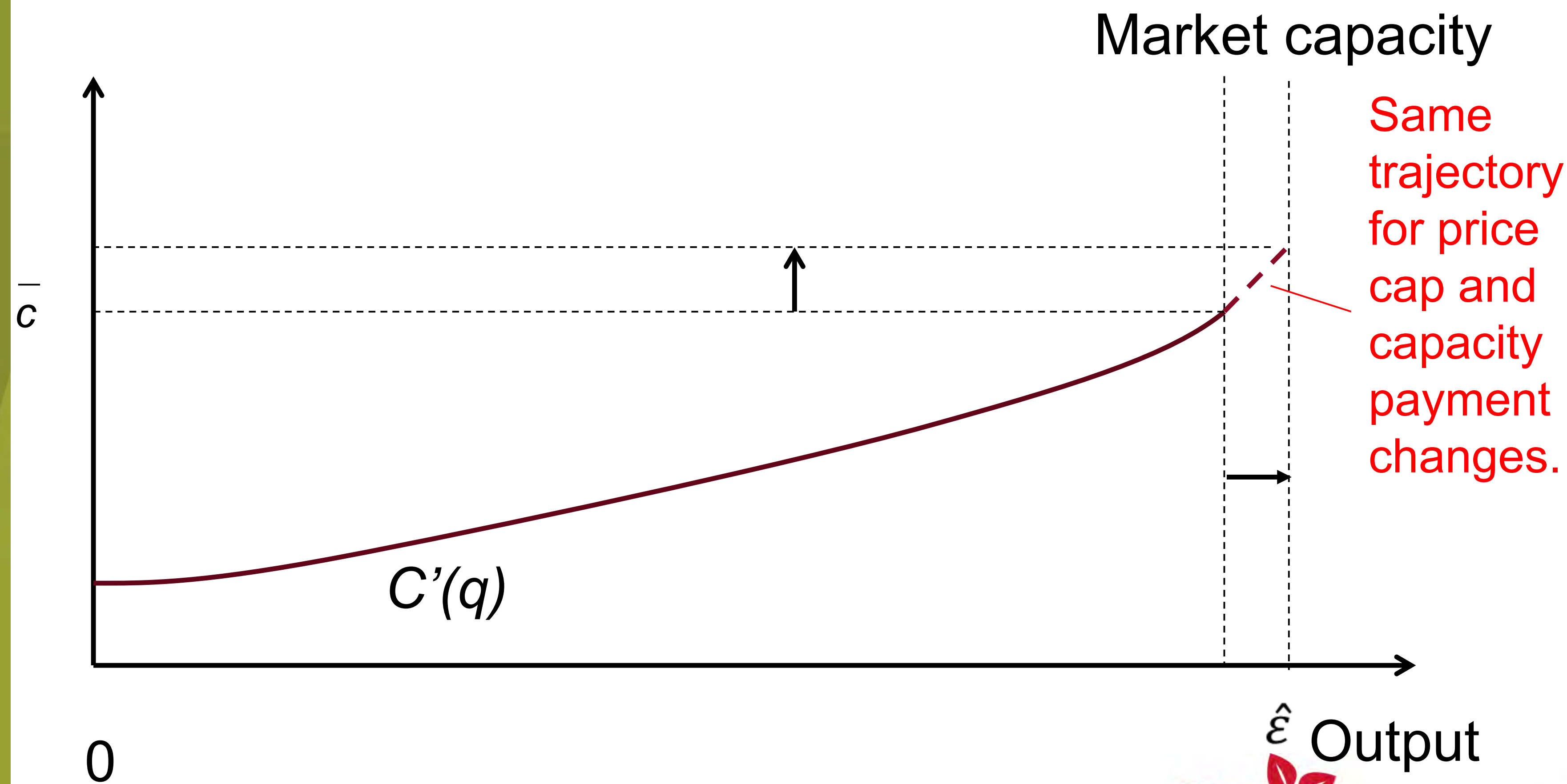
Capacity payment influences only investment into peaking plant

Capacity payment raises technology cutoff

— Investments below old cutoff unchanged



NB. Same logic for higher price cap

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EXTENSIONS

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Extension 1: Renewables

Competitive fringe with installed capacity *w* (zero MC)

—Net demand for conventional plant $F(\varepsilon, w)$ where $F_w > 0$

—System-cost externality $M(\varepsilon, w)$ where $M_w \geq 0$ *and* $M_{\varepsilon w} \leq 0$

—"Firm capacity" = complement to intermittent RE

Effect A *(Merit order)*: For a given technology mix, more RE crowds out conventional supply

Effect B (*System complementarity)*: More RE raises optimal technology cutoff and reduces socially-optimal LOLP

—Higher social value of peaking plant

=> Overall equilibrium impact on socially-optimal conventional capacity is ambiguous, depends on whether A or B dominates

=> More RE raises optimal capacity payment

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Extension 2: Socially-optimal strategic reserve

Capacity payment *z* now is discriminatory: only paid reserve plant – *how to avoid market distortions*?

- Reserve plants only produce when non-reserve market has been exhausted and, when used, are paid competitive clearing price of reserve
- Energy-only market for non-reserve plants, which are paid price cap when reserve is used: =>
  1) Energy-only market is isolated from reserve
  2) Extra payment to non-reserve when reserve used is, in expectation, equal to capacity payment

=> Overall equilibrium identical to Proposition 2

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CONCLUSION

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Conclusions

New benchmark model

Long-run investment in competitive electricity markets:

1. Continuum of technologies
2. System-cost externality
3. Policy design: price cap & capacity payment

Main findings

—Optimal combinations of policy instruments

—Regulation only influences investment into peakers

—More RE raises social value of peakers, and can justify higher capacity payments

—Equivalent design of socially-optimal strategic reserve

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