

Capacity mechanisms and the technology mix in competitive electricity markets

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September 2019



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INDUSTRIAL ECONOMICS

INTRODUCTION

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...

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

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)

Plan for this talk

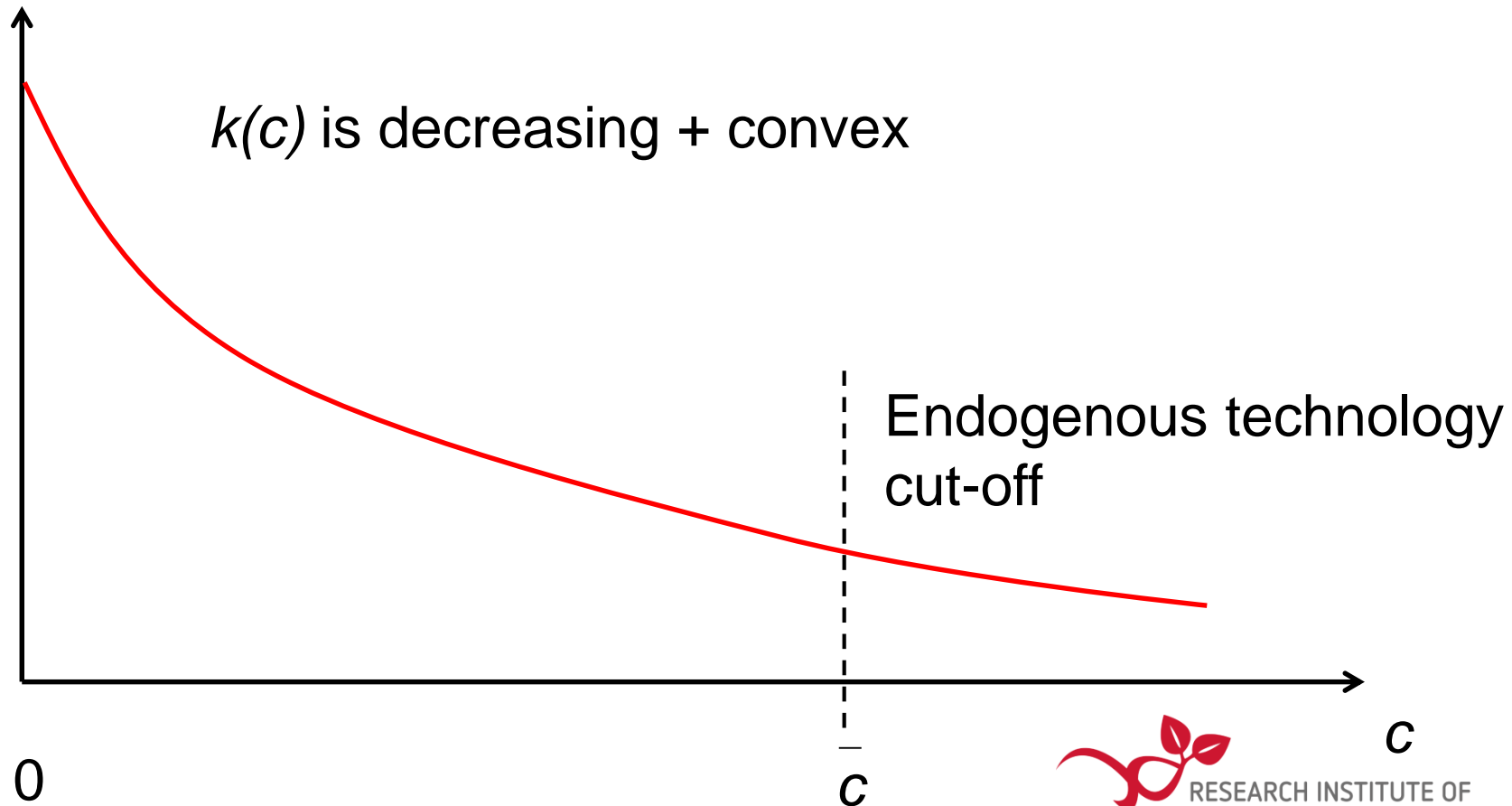
- 1) **Setup of the model**
- 2) **First-best benchmark**
- 3) **Optimal policy design**
- 4) **Extensions**
 - Renewables penetration
 - Optimal strategic reserve

MODEL

Continuum of technologies

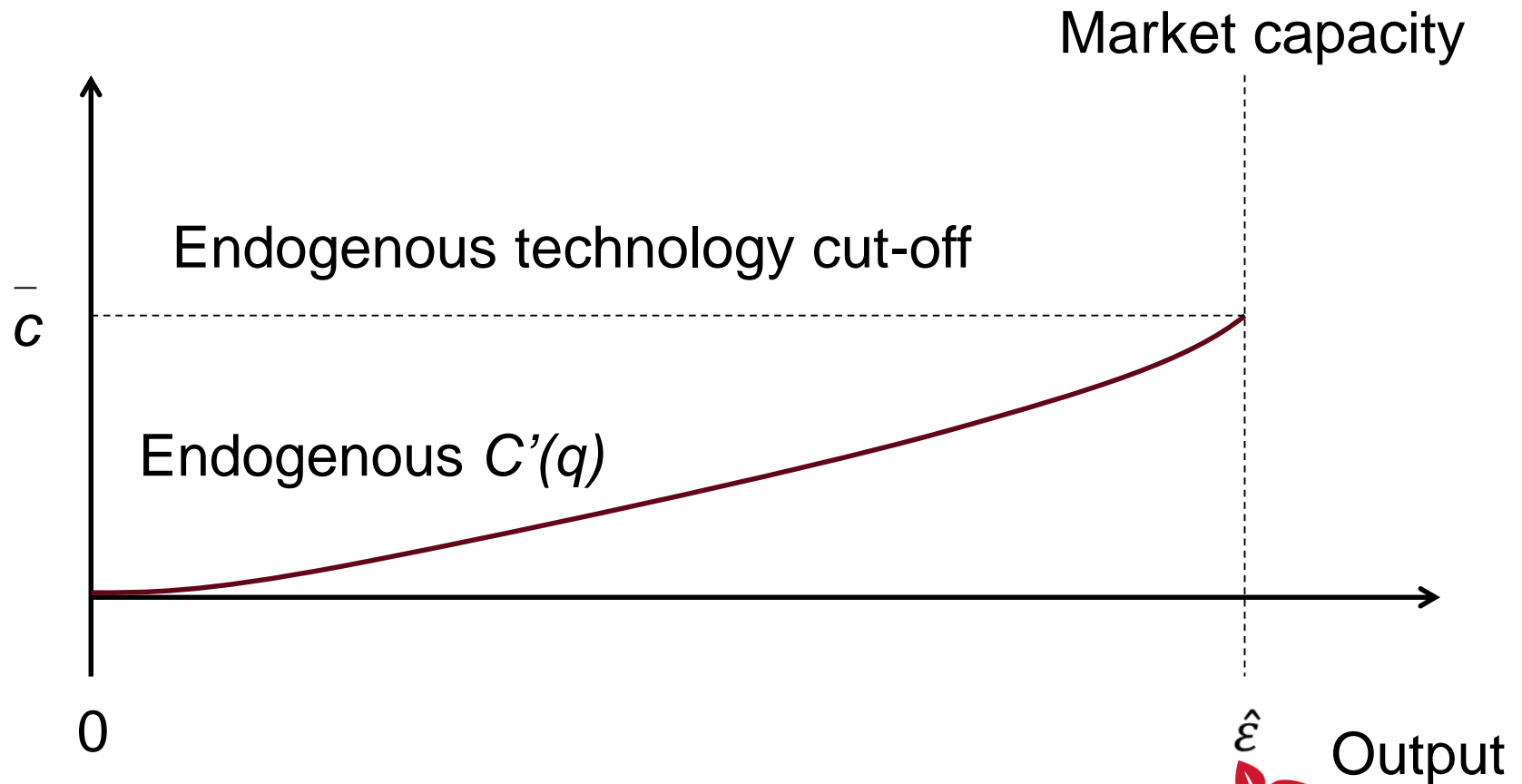
Each technology is indexed by its marginal cost c

Investment cost $k(c)$



Stage 1: Investment

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

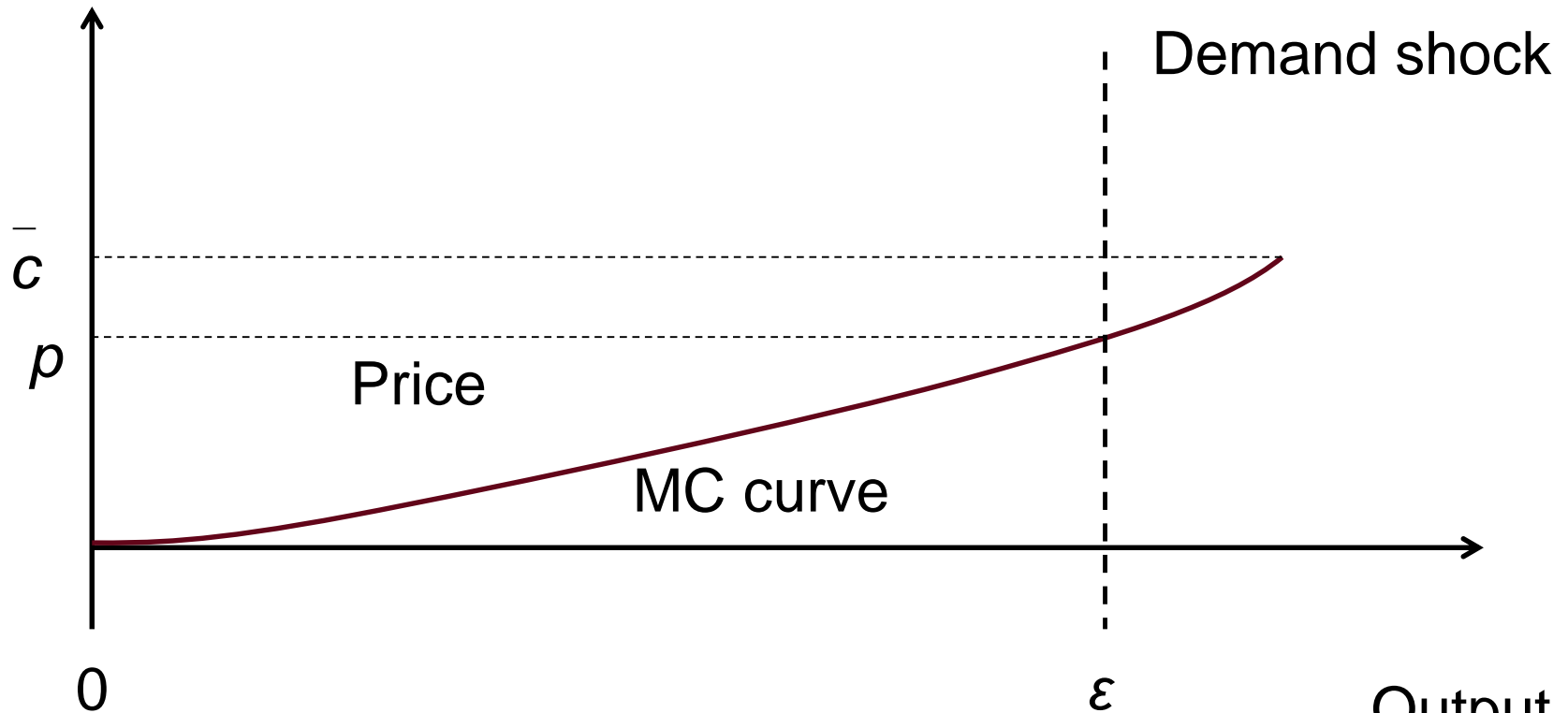


Stage 2: Production

Perfect competition => producers supply at marginal cost

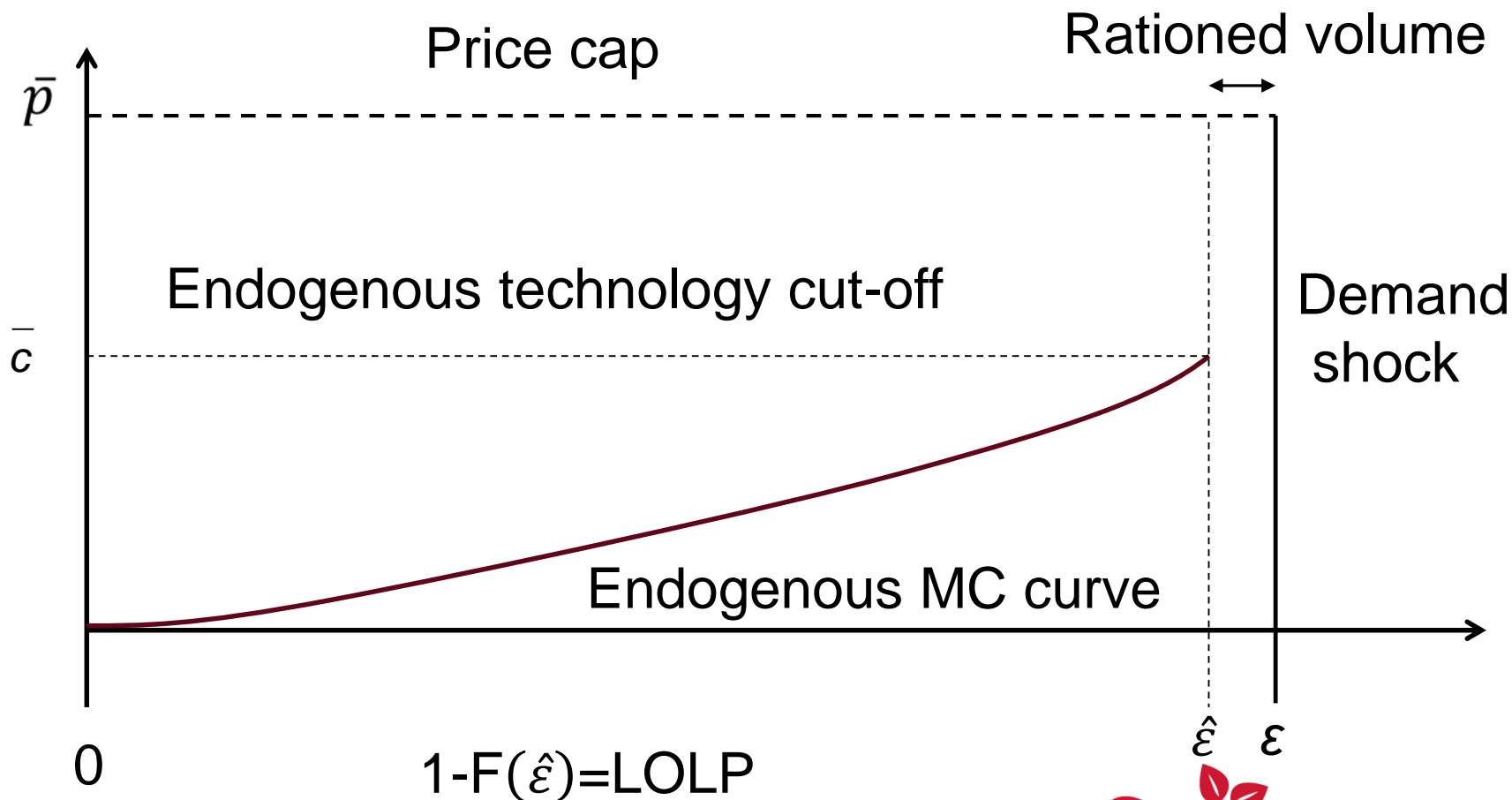
Consumer demand is inelastic with VOLL equal to p^*

Demand shock ε follows distribution $F(\varepsilon)$ with density $f(\varepsilon)$



Rationing

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



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 $M''(\hat{\varepsilon}) \geq 0$

FIRST BEST

Social planner

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

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

net of investment cost

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

net of expected production cost

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

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

Proposition 1: Optimal technology mix

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

$$1 - F(q(c)) = -k'(c)$$

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

- 1) Saves $(1-F(q(c)))\Delta c$ on production costs
- 2) Raises investment costs by $-k'(c)\Delta c$

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

Proposition 1: Optimal investment

The optimal technology cutoff is determined from:

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

Intuition: Planner continues to invest until:

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

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

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 \Rightarrow in equilibrium, zero profit condition

Proposition 2: Optimal policy

Proposition 1 still holds:

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

The technology cutoff is determined by:

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

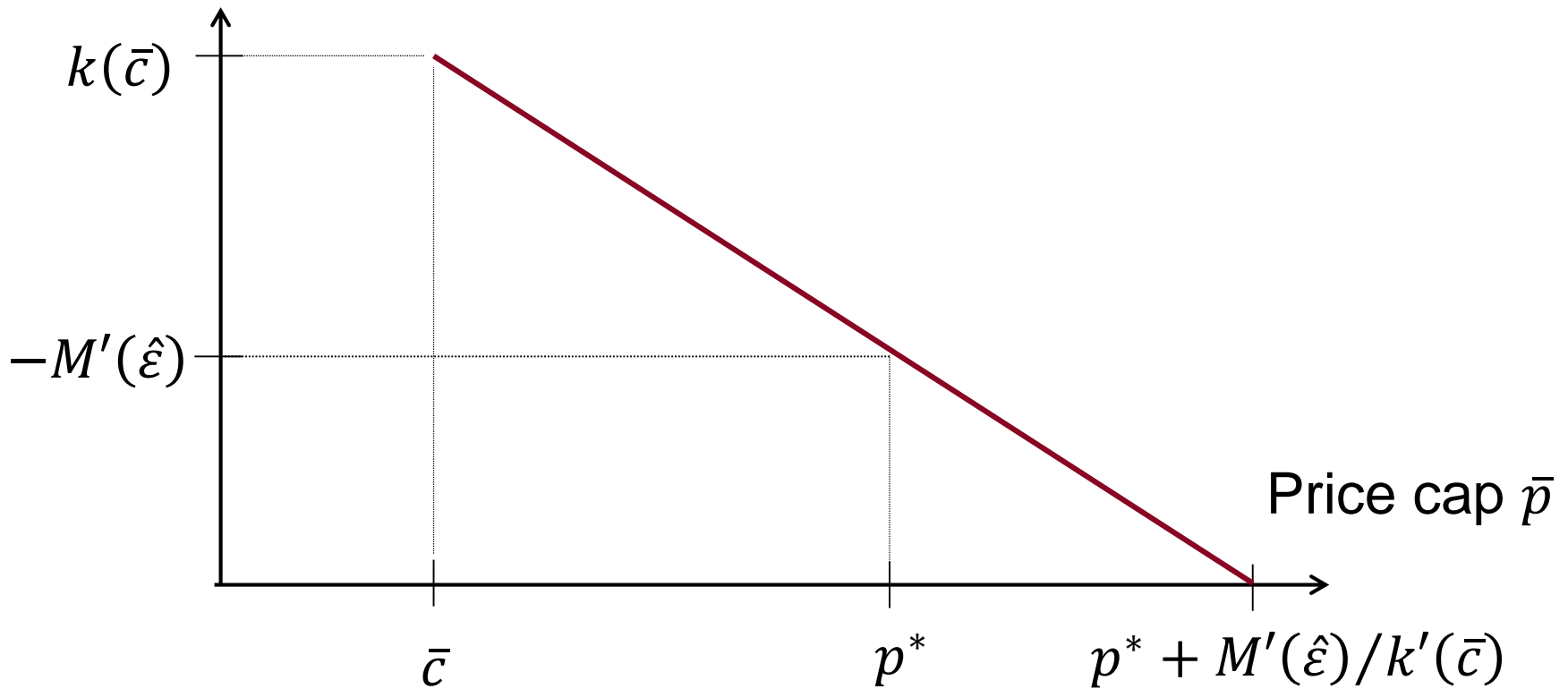
Investments are socially optimal when:

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

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

Optimal combinations of price cap and capacity payment

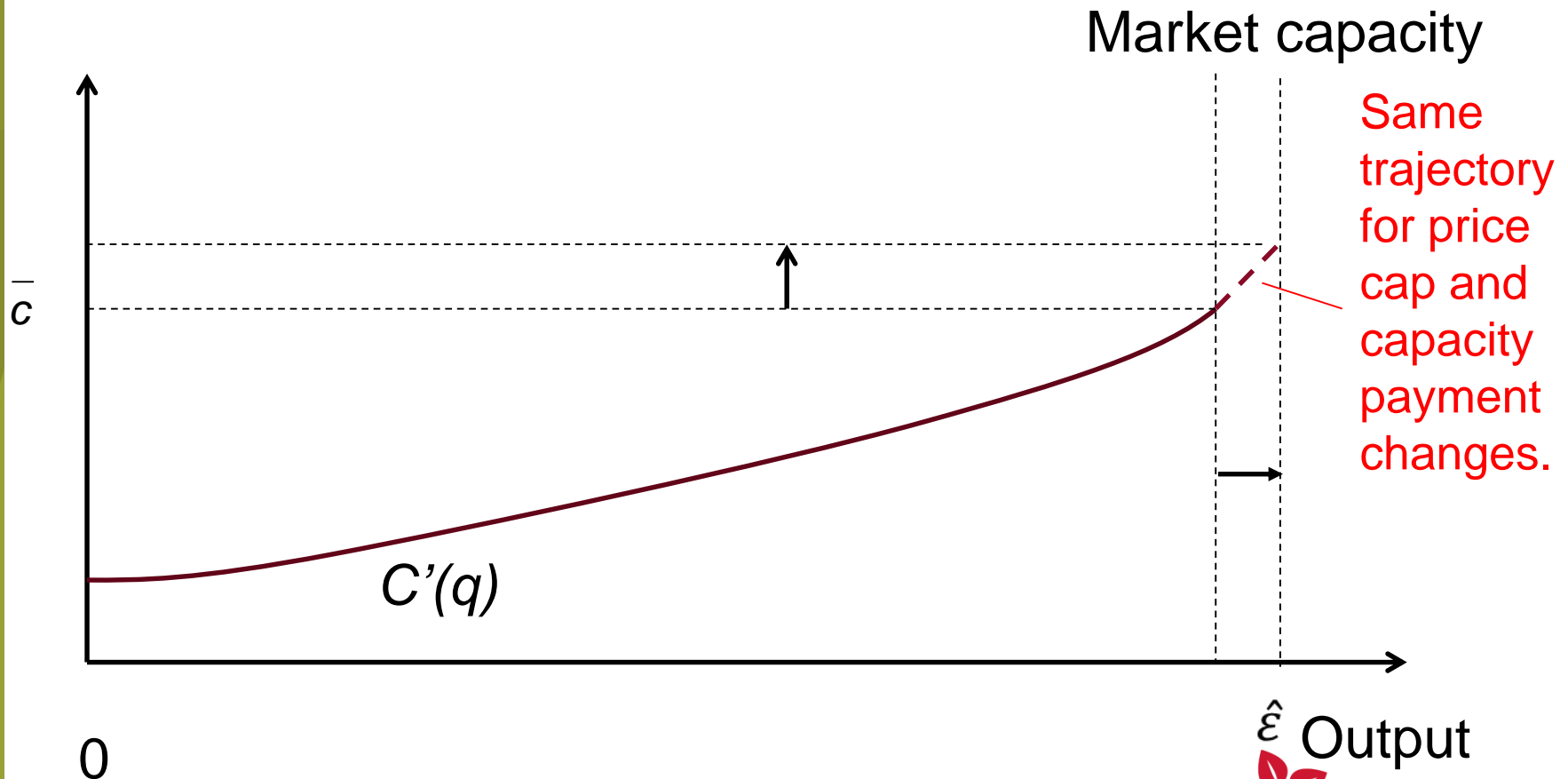
Capacity payment z



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

EXTENSIONS

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

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

CONCLUSION

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