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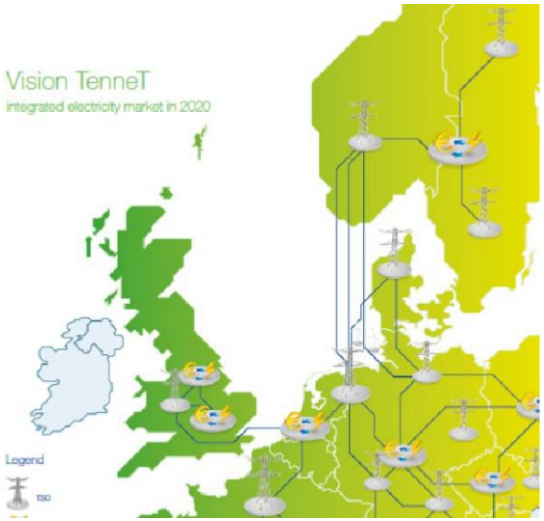
Optimal Regulation of Network Expansion (Preliminary!)

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Example: Cross-border Interconnection in Power Market

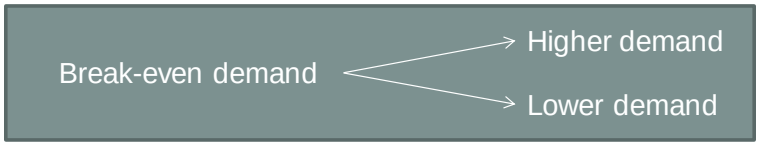


- Daily capacity auctions
  - all capacity is sold at market clearing price
  - prices changes as demand fluctuates
- New investments are necessary
  - Renewable energy (off-shore wind, storage, …)

- Optimal regulation of network owner?
  - When to expand capacity?
  - How to allocate auction revenues?
  - **With asymmetric info** on expansion costs
  - **With uncertain evolution** of demand

Our work combines

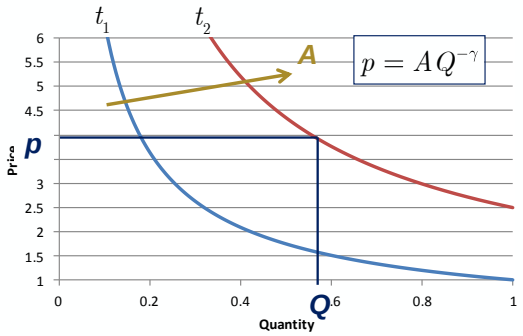
- **Real option theory** (Dixit & Pindyck, 1991)
  - Delaying irreversibly investments in order **to learn more about nature** (i.e. avoid investment if demand is low)



  - The value of waiting → Preservation of a valuable option
- **Optimal regulation** (Laffont & Tirole, 1993, Baron & Meyerson, 1982)
  - Give **information rents** to firm to learn about **investment costs**
  - Trade-off between rent extraction and efficiency (if regulator values consumers more than producers)

Model

- Stochastic demand in continuous time $\boldsymbol{p = A \cdot Q^{-\gamma}}$
  - $\boldsymbol{dA = \mu A dA + \sigma A dz}$, Brownian Geometric motion, growth rate μ
- Capacity Q is (continuously) auctioned (market clearing price p)
  - Usage of network is costless



- **Agent** can (continuously) expand capacity Q (marginal investment costs *c,* which is private information)
  - Investment is irreversible (real option)
  - Adverse selection problem
- **Regulator** wants to implement social optimal expansion
  - But: budget constraint: Finance expansion plus information rents from auction revenues

Perfect Information (regulator knows *c*)

- Maximize expected discounted welfare

  → Expectation over demand realization paths *A,* discounted at discount rate *r*

$$\mathrm{NPV}\left[Welfare\right]=\mathrm{E}_A\left[\int_t e^{-rt}\ w(Q(t),A(t))dt - cdQ\right]$$

$$w(Q,A)=\int_0^Q p(q,A(t))dq \qquad \text{Flow of social surplus}$$

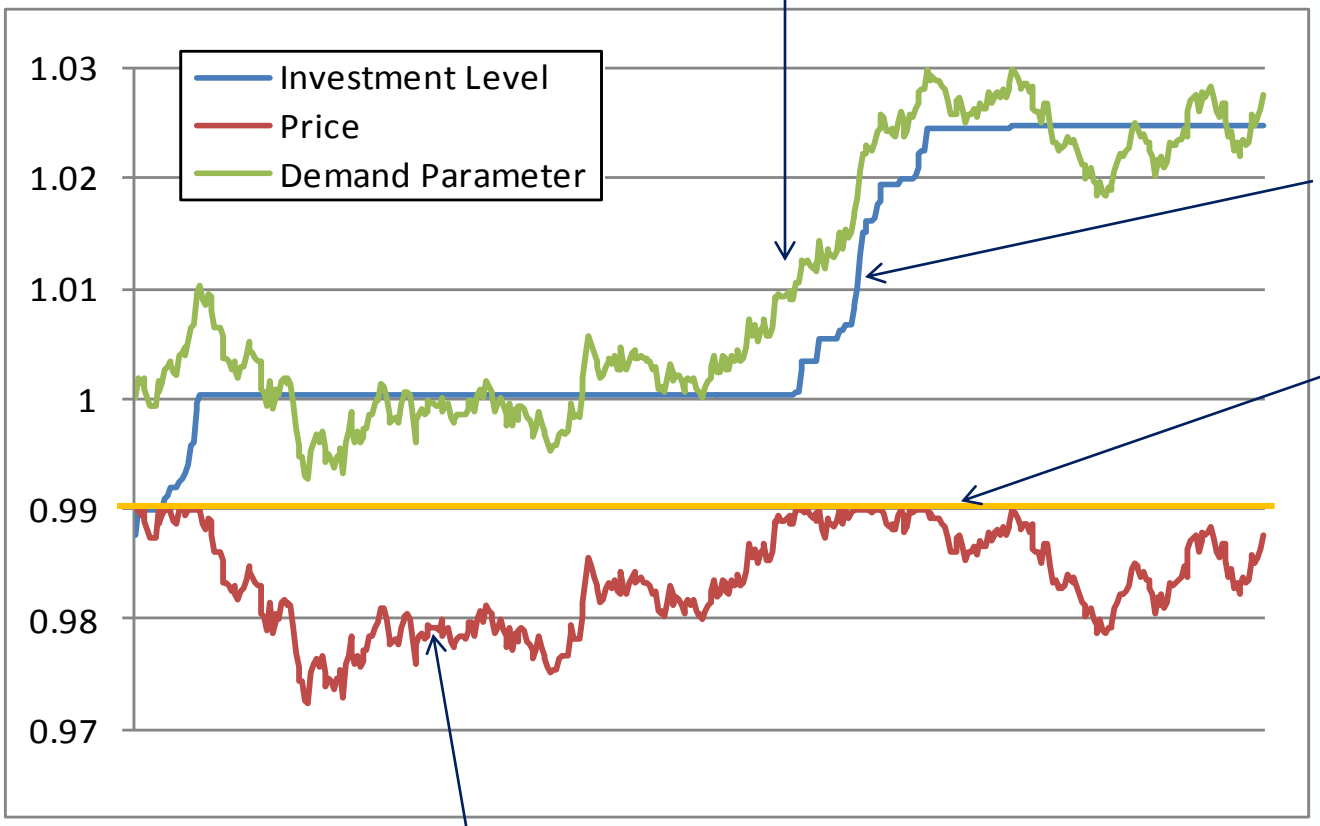
- By choosing an optimal investment strategy *Q(t)*

  which depends on state variables (*Q(t),A(t)*)

→ Stochastic optimization problem (Ito's lemma, ...)

- Optimum: Expand capacity whenever price reaches threshold price $\bar{p}$.

Perfect Information (regulator knows c)



1 Realization of demand shocks

2 Market price depends on
(1) investment level *Q*
(2) demand shock *A*

3 Threshold price

$$\overline{p} = \frac{\lambda}{\lambda - 1}(r - \mu)c$$

Investment cost

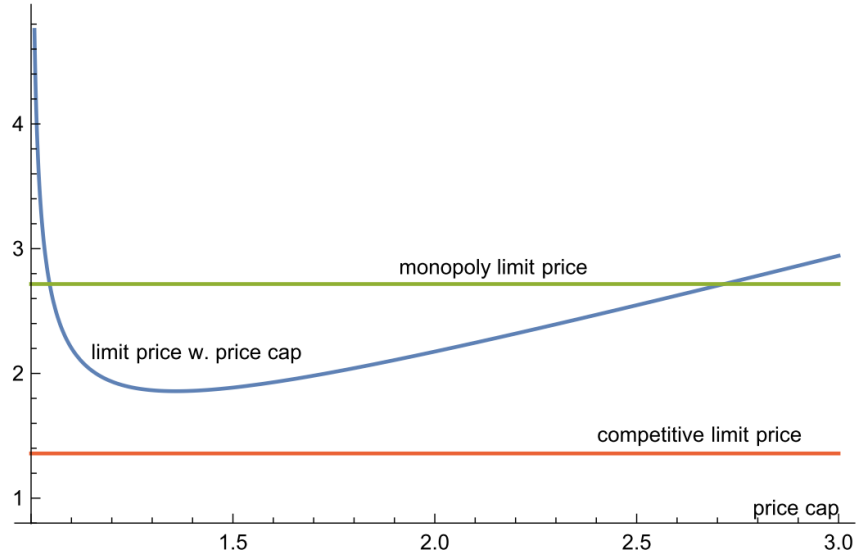
Annuity

Real option correction increases with volatility σ

4 Invest whenever price hits threshold price = demand shock reaches historical maximum

Perfect Information (regulator knows c)

- Firm is **not allowed to withhold capacity** (restrict supply below *Q*)
- Firm will **break-even in expectation** if it receives revenue from selling capacity *(p(Q(t))Q(t))* (*Leahy, 1993; Boiteux, 1960*)
- Firm is **obliged to invest** if price reaches competitive limit price; This level of investments cannot be achieved by setting a price cap *(Dobbs, 2004)*



Adding frictions

- Adverse Selection
  - Agency problem: regulator does observe investment costs, instead
$$c \sim F(c) \text{ on } [c_L, c_H]$$
  - Implies leaving rents $\pi(c)$ to firm with type c
  - Design mechanism to elicit information (screening) and use that to optimize investments. Set a threshold price $p(c)$ for firm with type *c*.
- Budget constraint
  - Firm's remuneration (cost and rents) paid out of income from auction (different from standard Baron-Myerson)
$$\pi(c) \leq E_A \int_t e^{-rt} \left[pQ(p)dt - c\, d_{\bar{p}} Q(t) \right]$$
  - i.e. regulator can tax but not subsidize

Optimization program of the regulator

- Regulator optimizes expected discounted welfare

  Expectation over demand realization *A,* over all possible cost realizations c and discounted at discount rate *r:*

$$\max_{p(c),\pi(c)} \mathrm{E}_c \mathrm{E}_A \left[\int e^{-rt} \; GCS(Q(t))dt - cdQt \right]$$

- Incentive constraint

$$\frac{d\pi(c)}{dc} \leq -E_A \left[\int e^{-rt} d_{\bar{p}} Q(t) \right]$$

By pretending to be a high cost firm, a low cost firm saves investment costs for production volume dQ. To avoid this, the low cost firm is promised an information rent dπ

- Budget constraint

$$\pi(c) \leq E_A \int_t \left[pQ(p)dt - c\, d_{\bar{p}} Q(t) \right]$$

- Participation constraint

$$\pi(c) \geq 0$$

→ Problem can be decoupled in "a Stochastic part" and an "Adverse Selection part". Here: focus on adverse selection.

Optimization program of the regulator

- Simplifies to an optimal control problem

$$\max_{\Pi(c),p(c)} \int_{c_L}^{c_H} \left\{ \frac{1}{1-\gamma} p^{\frac{\gamma-1}{\gamma}} - cp^{\frac{-1}{\gamma}} \right\} f(c)dc$$

subject to

$$\dot{\Pi}(c) = -p^{-\frac{1}{\gamma}} \qquad (\nu)$$

$$\Pi(c) \leq \left[p^{\frac{\gamma-1}{\gamma}} - cp^{\frac{-1}{\gamma}} \right] \qquad (\phi)$$

$$\Pi(c) \geq 0$$

- First order condition of Hamiltonian

$$f\{p-c\} = \dot{\nu}\left[(\gamma-1)p+c\right] + \nu$$

Adverse Selection: Solution

- **Inefficient firm**
  - Firm is taxed
  - Price cost mark-up ~ 1/f

$$p(c) = c + \frac{\nu}{f(c)}$$

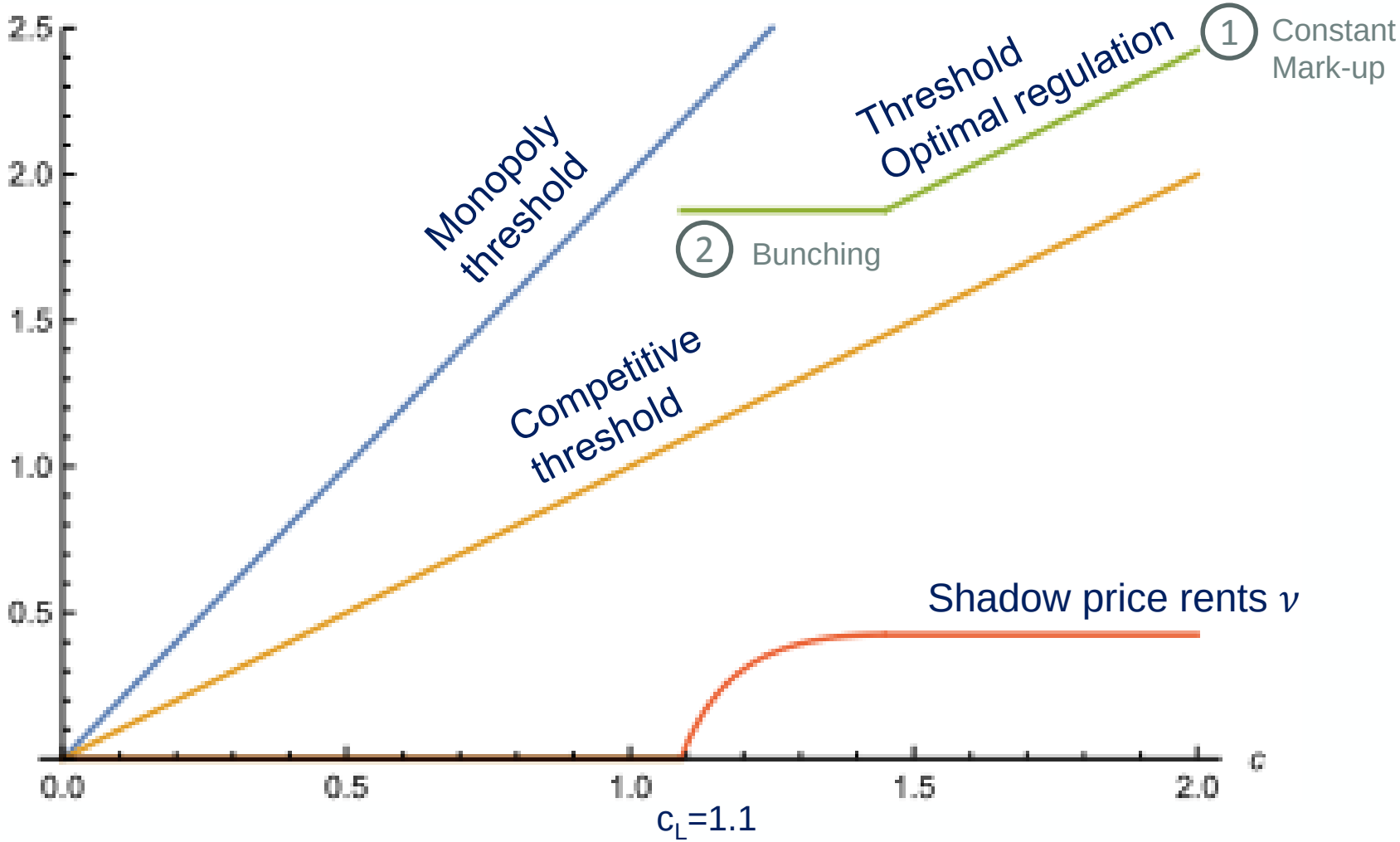
- **Efficient firm**
  - All income is used to pay firm
  - Two regimes
    - Price is constant (bunching) *Gautier and Mitra (2006)*

$$p(c) = cte \Rightarrow \text{Small } c_H/c_L$$

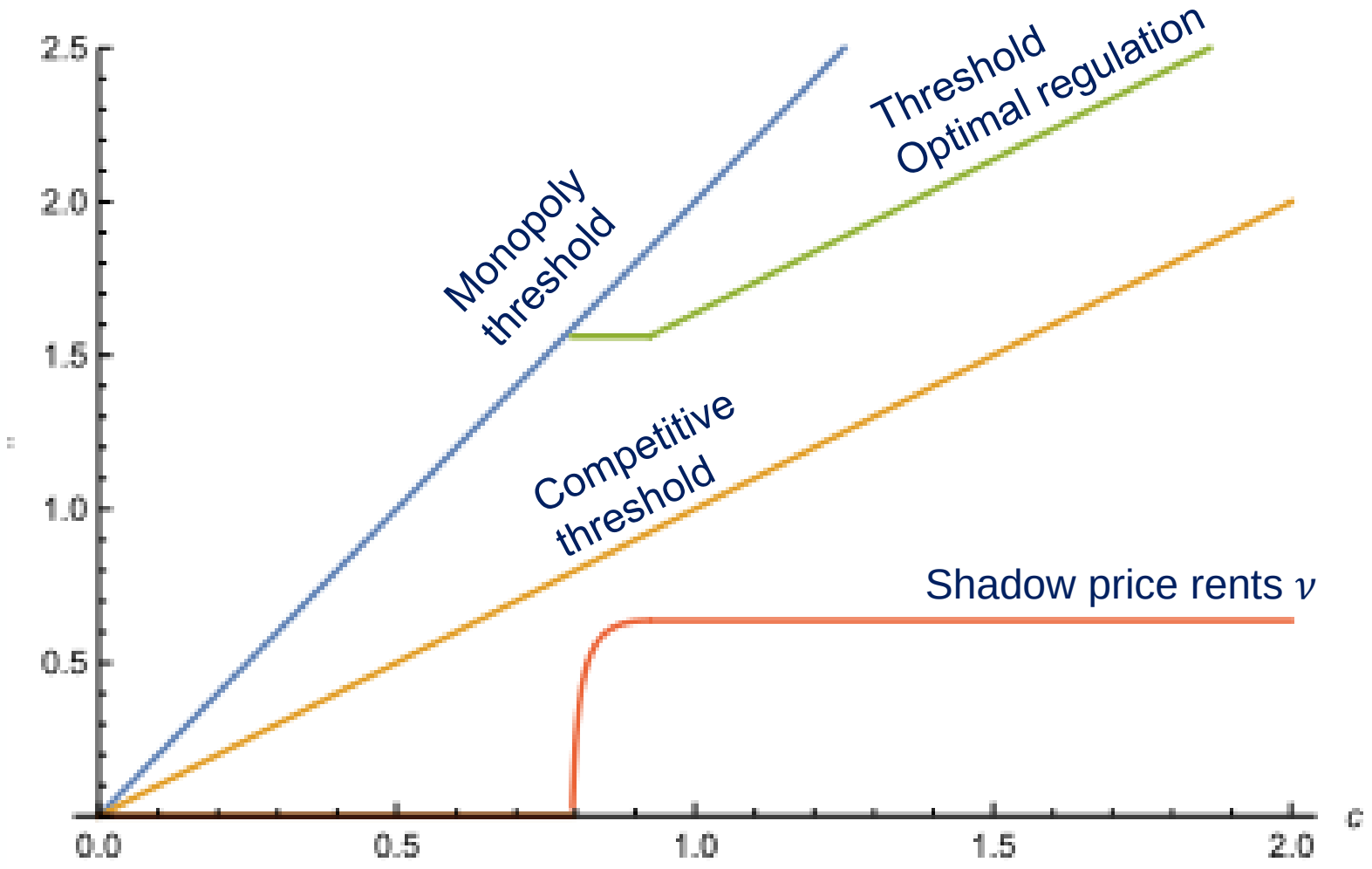
    - Monopoly price

$$p(c) = p^{mon}(c) \Rightarrow \text{Large } c_H/c_L$$

Example: Uniform distribution (Small c_H/c_L)

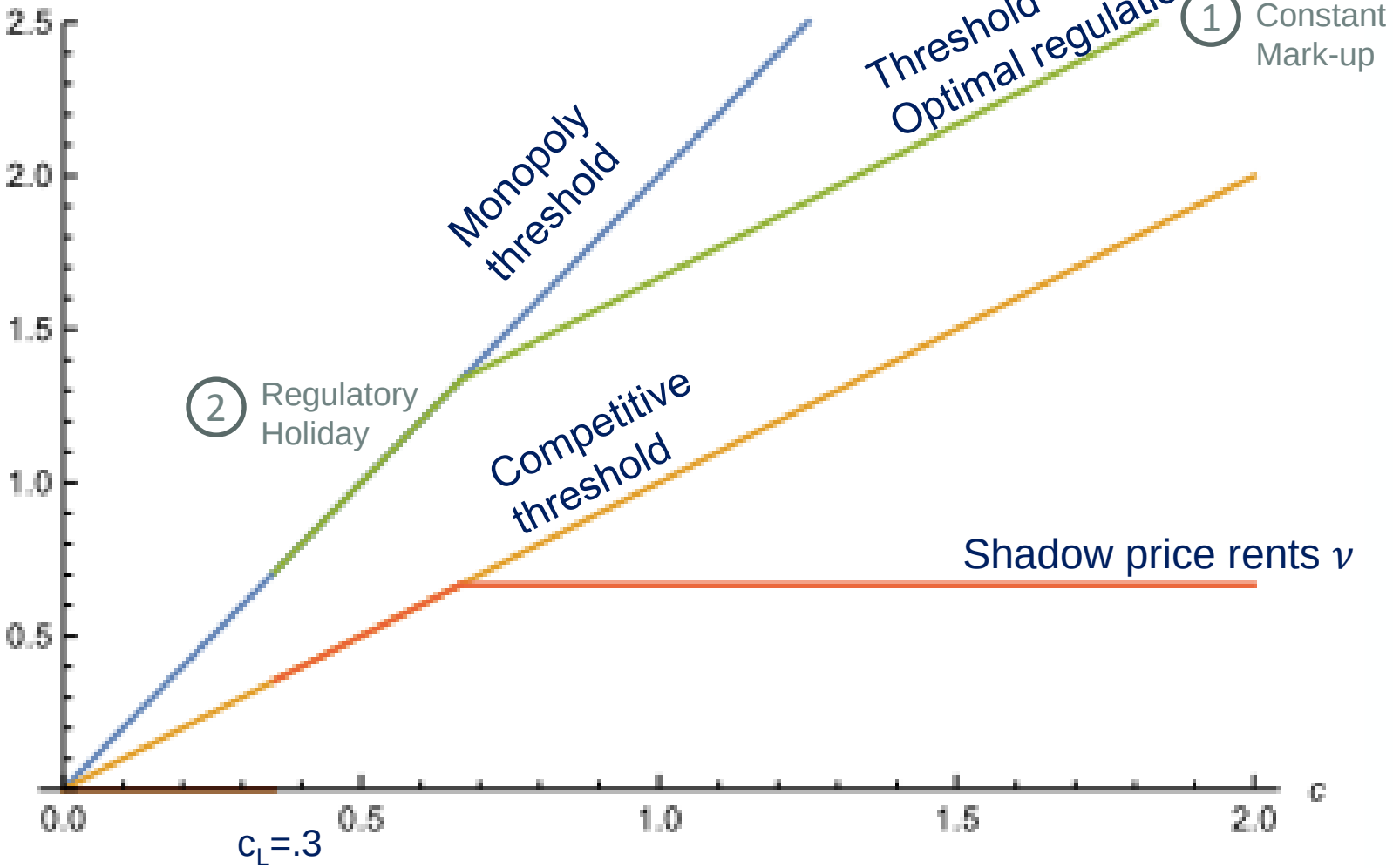


Example: Uniform distribution (Larger c_H/c_L)



c_L=.8

Example: Uniform distribution (Large c_H/c_L)



Conclusion

- **With symmetric information** the regulation of optimal investment consists of two parts:
  - A threshold price with an ***obligation to invest***
  - Obligation to make all capacity available (= peak-load pricing)
- **With imperfect information**
- Firm receives a menu of contracts:
  - Threshold price at which to invest + obligation to make all capacity available
  - Fraction of expected profits the firm can keep
- Contract depends on firm's cost
  - Low cost
    - Firms sets monopoly price *(c.f. regulatory holiday)* or constant price
    - Keeps all expected profits
  - High cost
    - Firm is asked to invest later (but earlier than monopolist
    - Receives fraction of expected profits

Conclusion

- **Threshold price is higher than socially optimal**
  - For high cost firms: to reduce rents for low cost firm
  - For low cost firms: to collect sufficient profits
- **Regulatory holidays** are sometimes used to promote investments
  - Gans & King, (2004) inability to commit to state contingent prices & funding constraints, compares it to patent protection
  - Vogelsang (2010) for truly innovative products

→ Here: regulatory holiday can be used if regulator faces large uncertainty, investments need to be financed from market, and for the most efficient firms.

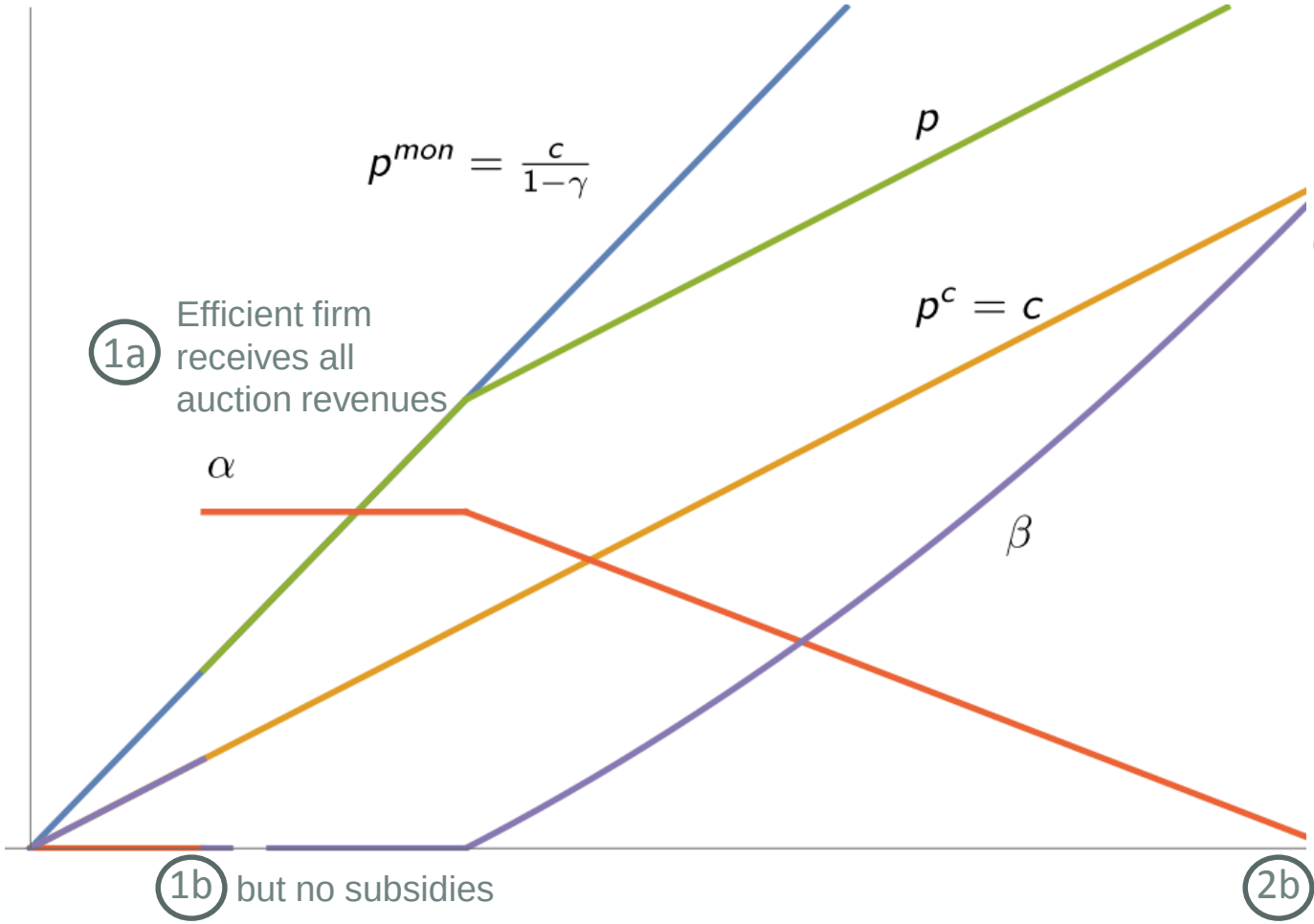
Implementation Issues

- **Direct mechanism** might be hard to enforce
  - Contracting on raising capital and investment levels?
  - Hard to detect deviations in practice (investments take time)
- **Implementation:** replace obligation to invest with
  - Penalty for undelivered demand (Leautier, Armstrong and Vickers 2000)
  - Treat states with high and low prices differently (Form of basket regulation; Armstrong and Vickers, 1991).
- **Without perfect commitment by the regulator**
  - Renegotiation with firms to invest earlier (Laffont & Tirole, 1990)
  - Expropriation for firms with positive rents (Laffont and Tirole, 1988)
  - Can we find an implementation that requires the least commitment power by the regulator?

Implementation: Taxes and Subsidies

- **Implementation with taxes and subsidies**
  - Subsidize operation of transmission line (β)
    - Similar to a "capacity payment" *(Cramton & Stoft).*
    - Brings down privately optimal investment threshold
  - Taxing away fraction of income (1 - α)
    - So no net subsidy from regulator's viewpoint
  - Profit of firm: $\pi = \alpha pQ - cQ + \beta Q$
  - Firm chooses from a menu $\alpha(\beta)$

Implementation: Taxes and Subsidies



1a Efficient firm receives all auction revenues

1b but no subsidies

2a Inefficient firm receives full compensation for investments

2b But no auction revenue

Problem: Inefficient firm would mimic contract of efficient firm!
All rents & no subsidy is always better than no rents!