PARIS SCHOOL OF ECONOMICS
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The impact of entry and competition of long-term contracts in electricity markets

Theory and some calibration from French data

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Policy questions

- Debates about long-term contracts in electricity markets
  - European Commission procedures against EDF and Electrabel
  - Do LT contracts allow incumbents to foreclose demand and deter entry?
  - These are two markets where the dominant position of the incumbents is largely due to their ownership of nuclear generation capacities
- Are private incentives to invest in nuclear generation sufficient, excessive, or just all right?
  - Fiscal incentives in the US (2005 Energy Act)
  - Strong interest in nuclear investments in France
- Can competition deliver the benefits of low nuclear generation costs to consumers?
  - Deconcentrating ownership of nuclear plants?
  - Facilitating entry?
  - Giving priority to the incumbent?

Organisation of the presentation

- Policy questions
- Modeling duopolistic competition in nuclear electric generation
  - Specifics of electricity markets
  - Static duopolistic price competition
  - Calibration based on French data
- Making nuclear investment endogenous
  - Nash equilibrium of the investment game
  - A large nuclear incumbent followed by new entrants
- Long term contracts
  - Impact on prices, taking capacities as given
  - The strategic use of long-term contracts
  - Impact on social and consumer welfare

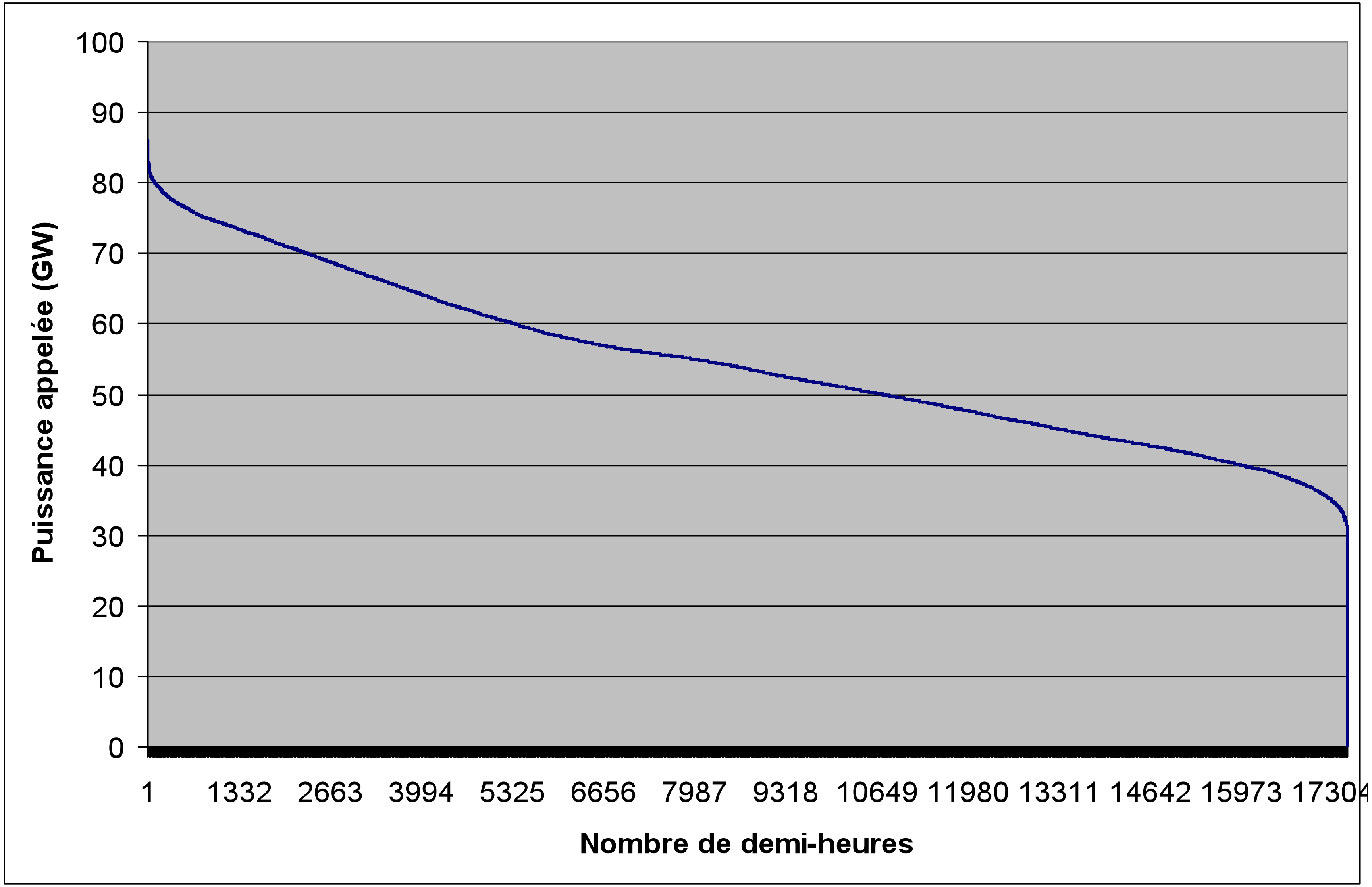
This paper's contribution

- **A novel, simple modeling of electricity markets**
  - **In most of the literature**
    - **Competition in supply functions (very complex, equilibrium multiplicity)**
    - **Elastic demand (at odds with reality)**
  - **This model**
    - **Simple price competition with capacity constraints**
    - **Inelastic demand**
    - **Mixed-strategy equilibria, but relatively simple results**
- **Results at odds with those prevailing in "normal markets"**
  - **Nuclear investment more likely excessive than insufficient**
  - **Competition is relatively ineffective at dissipating monopoly rents**
- **Results about long-term contracts**
  - **Existing literature finds opposite results according to whether competition is Cournot or Bertrand**
  - **Here, both Cournot and Bertrand elements**
  - **Results closer to Cournot model: LT contracts cause spot prices to fall**

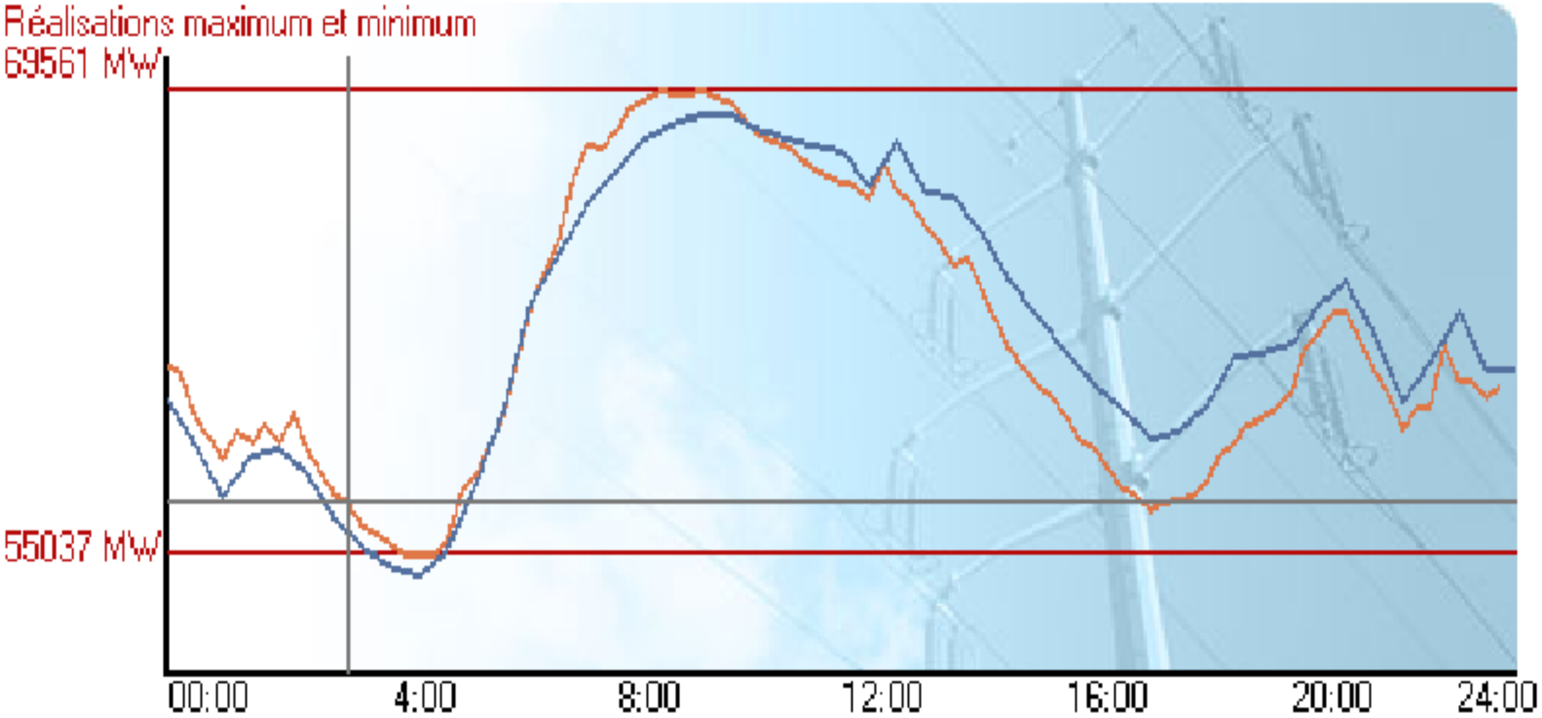
Specifics of electricity markets

- Almost inelastic demand (at least in the short run)
- No storage: supply must meet demand all the time
- Variable demand
  - Minimum around 35 GW
  - Maximum around 90 GW
- Implication: optimal generation mix combines different technologies with different fixed and variable costs
  - High fixed costs, low variable costs for "base" capacity (nuclear)
  - Low fixed costs, high variable costs for "peak" capacity (fossil)
- Structure of competition / entry barriers
  - Significant entry barriers in nuclear technology
  - Easy entry in fossil fuel generation technology

Electricity demand in France, 2005



Demand on March 26, 2007



Caractéristiques	
Date des données :	26/03/2007
Consommation minimum :	55037 MW
Consommation maximum :	69561 MW

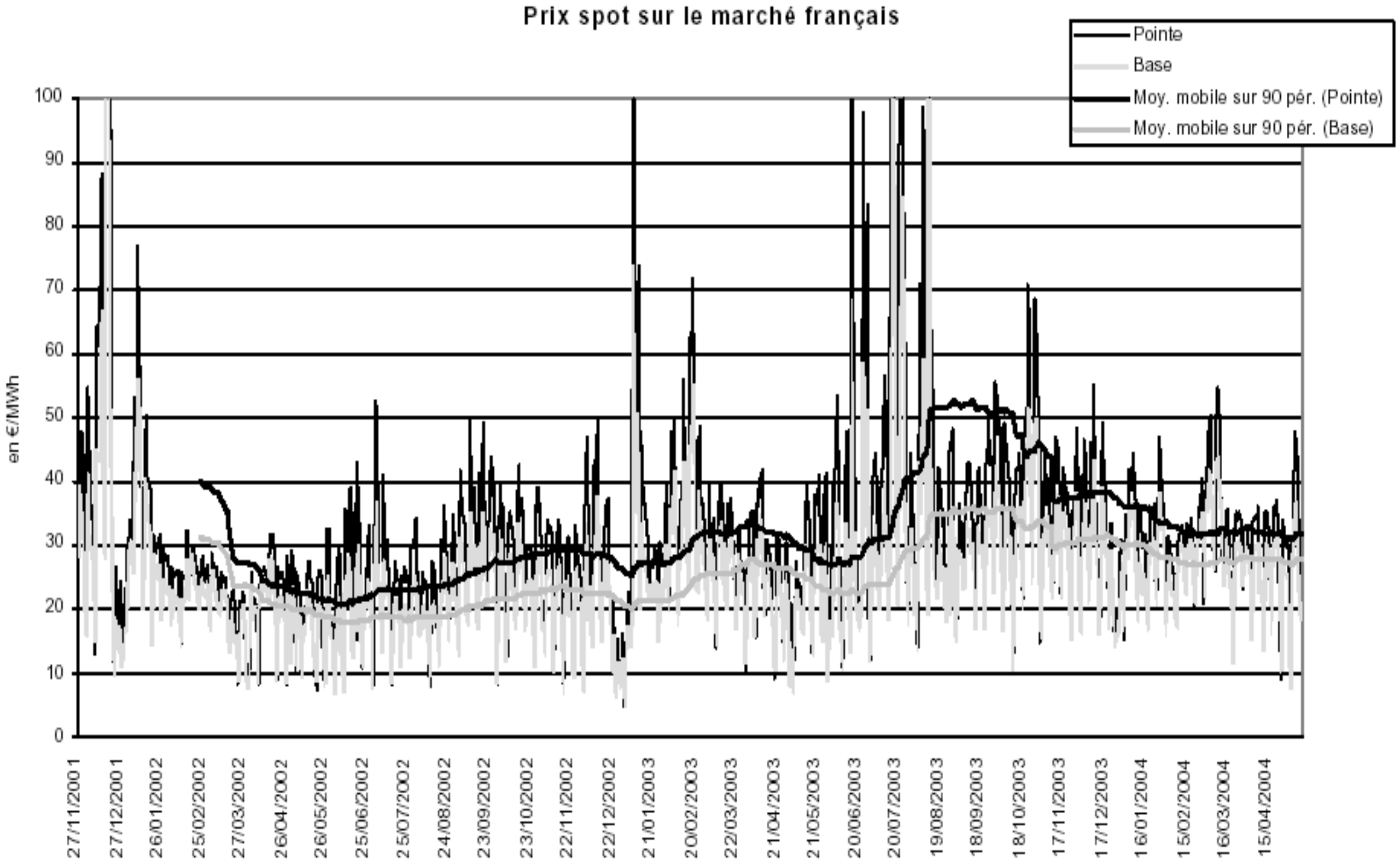
Valeurs instantanées	
Heure :	3:15
Consommation :	56618 MW
Prévision :	55700 MW

Costs (approximation)

	Nuclear	Combined cycle using gas	Gas turbine	Oil-fuelled plant
Annualized fixed cost per KW of capacity	203.2	82,6	43,2	20
Variable cost (€ / MWh)	6.7	31.6	100-200	> 250

Source: French Ministry of Finance, « Coûts de référence de la production électrique », 2003

Spot prices from 2001 to 2004



Source : Powernext, calculs de la mission.

Modeling

- Inelastic demand
- d(K) = number of hours (in a year) such that total demand is below K
- Nuclear technology
  - No variable costs
  - *f* = annualised fixed cost per unit of capacity
- Fossil technology
  - No fixed costs
  - C = marginal cost
  - Free entry (= unlimited supply at price C)
- Optimal nuclear capacity K* determined by

$$f = C(N-d(K^*))$$

Benchmarks: perfect competition and monopoly

Perfect competition with free entry

- (Endogenous) nuclear capacity K_{pcfe} such that profit is zero
- Prices?
  - Zero when nuclear capacity is not fully used ($d(K_{pcfe})$ hours)
  - C when nuclear capacity is fully used ($(N-d(K_{pcfe}))$ hours)
- Profit of incremental nuclear plant is therefore

$$(N-d(K_{pcfe}))C-f = 0$$

- Therefore, $K_{pcfe} = K^*$
- French data (2003 costs)
  - K*=51GW
  - D_{min}=37GW
  - d is linear except at very high values
  - Nuclear plants are marginal 55% of the time
  - Implication: the annual social surplus brought about by nuclear plants is equal to (37 GW * 45% + 14 GW * 22.5%) * 8760h * (31.6-6.7 €/MWh) = € 4.3 billion

Benchmarks: perfect competition and monopoly

- **Nuclear monopoly**
  - **Price is equal to *C* all the time**
  - **Profit is unchanged if monopoly also operates fossil plants**
  - **Total revenue is independent of nuclear capacity**
  - **Therefore, monopoly minimises costs ➔ optimal capacity**

Modeling a nuclear duopoly

- Capacities K_1, K_2 with $K_1 \geq K_2$

- Assumptions
  - Both firms set prices simultaneously
  - Demand is first allocated to the cheaper firm
  - Each firm is paid the price is quoted (discriminatory pricing)

- Equilibrium prices given demand D
  - If $K_1+K_2<D$ then price = C
  - If $K_2>D$ then price = 0 (standard Bertrand competition)
  - If $K_2<D<K_1+K_2$ then…

Duopolistic competition with capacity constraints

P. Dasgupta et E. Maskin, The Existence of Equilibrium in Discontinuous Economic Games, II : Applications, *Review of Economic Studies* (1986), vol. 53, p. 27-41.

- **No pure-strategy equilibrium**
- **Mixed-strategy equilibrium**
  - **Support of equilibrium strategy: interval**
  - **No atom at lower bound**
  - **Impossible to have two atoms in upper bound**
  - **Atom only in distribution of Firm 1's prices**
  - **Support of the type [m,C]**
  - **Each firm is indifferent along this interval**
  - **Firm 1:** $E\pi_1 = C(D-K_2) = m\,Min(D,K_1)$
  - **Firm 2:** $E\pi_2 = mK_2 = CK_2(D-K_2)/Min(D,K_1)$
  - **Expected price =** $(E\pi_1+E\pi_2)/D = C(1-K_2/D)(1+K_2/Min(D,K_1)) < C$

Nash equilibrium of the investment game

Firm 1's investment incentives

$$E\pi_1 = -fK_1 + CK_1\left[N - d(K_1+K_2)\right] + C\int_{Max(K_2,D_{min})}^{K_1+K_2} (D-K_2)d'(D)dD$$

- **Define $\delta(K_1)=d(K_1+K_2)$ and assume $K_2<D_{min}$ for simplicity**

$$E\pi_1 = -fK_1 + CK_1\left[N - \delta(K_1)\right] + C\int_{D_{min}-K_2}^{K_1} D\delta'(D)dD$$

- **Firm 1's expected profit is the same as the one it would earn as a monopoly facing a demand diminished by K_2**
- **Consequence: firm 1's best response is such that, given K_2, total nuclear capacity is optimal**

$$K_1(K_2)=K^*-K_2$$

Nash equilibrium of the investment game

Firm 2's investment incentives

$$E\pi_2 = -fK_2 + CK_2\left[N - d(K_1+K_2)\right] + C\int_{Max(K_2,D_{\min})}^{K_1+K_2}(D-K_2)K_2 / Min(D,K_1)d'(D)dD$$

- **In any equilibrium, K*1 + K*2 = K***
- **FOC for Firm 2: define** $g(K) = \frac{\partial\pi_2}{\partial K_2}(K_1 = K^* - K, K_2 = K)$

$$g(K) = -f_2 + CK\left[N - d(K^*)\right] - CKd'(K^*) + CKd'(K^*) + \frac{C}{Min(D,K^*-K)}\int_{Max(K,D_{\min})}^{K^*}(D-2K)d'(D)dD$$

$$= \frac{C}{Min(D,K^*-K)}\int_{Max(K,D_{\min})}^{K^*}(D-2K)d'(D)dD$$

- ***g*** **is decreasing, with** ***g(K*/2)<0<g(0)***
- **There exists a single Nash equilibrium, which is asymmetric**
- **If *d* is linear, then**
  - ***K_1 = (3K*-D_{min})/4 = 29 GW***
  - ***K_2 = (K*+D_{min})/4 = 22 GW***

Under assumption that (D_{min},K*)=(37 GW, 51 GW)

Nash equilibrium: profits

- Restriction to case where
  - *d* is linear (tractability)
  - $K^*_1 < D_{min}$ (always true if $D_{min}/K^* > 3/5$, which holds in our calibration)
- Average price is $C\frac{(D_{ave}-K^*_2)K^*}{D_{ave}K^*_1} = C\frac{2K^*}{3K^*-D_{min}} =_{(def)} p(K^*,D_{min})$ (= 0,88 C)
- 88% of the monopoly rent remains in duopoly
- In the case of a symmetric duopoly, it is equal to $C\frac{D_{min}}{D_{ave}}$ (=0,84C)
- Duopoly, whether symmetric or (worse) resulting from Nash equilibrium, dissipates very little of the monopoly rent
  - Intutition: each duopolist can obtain at least a fraction

    $$\frac{D_{ave}-\frac{K^*}{2}}{\frac{K^*}{2}} = \frac{\frac{D_{min}+K^*}{2}-\frac{K^*}{2}}{\frac{K^*}{2}} = \frac{D_{min}}{K^*}$$

    of monopoly profit, i.e. 73%.
- **No adverse impact of duopoly (vs. monopoly) on productive efficiency**

Pre-emptive investment / incumbency

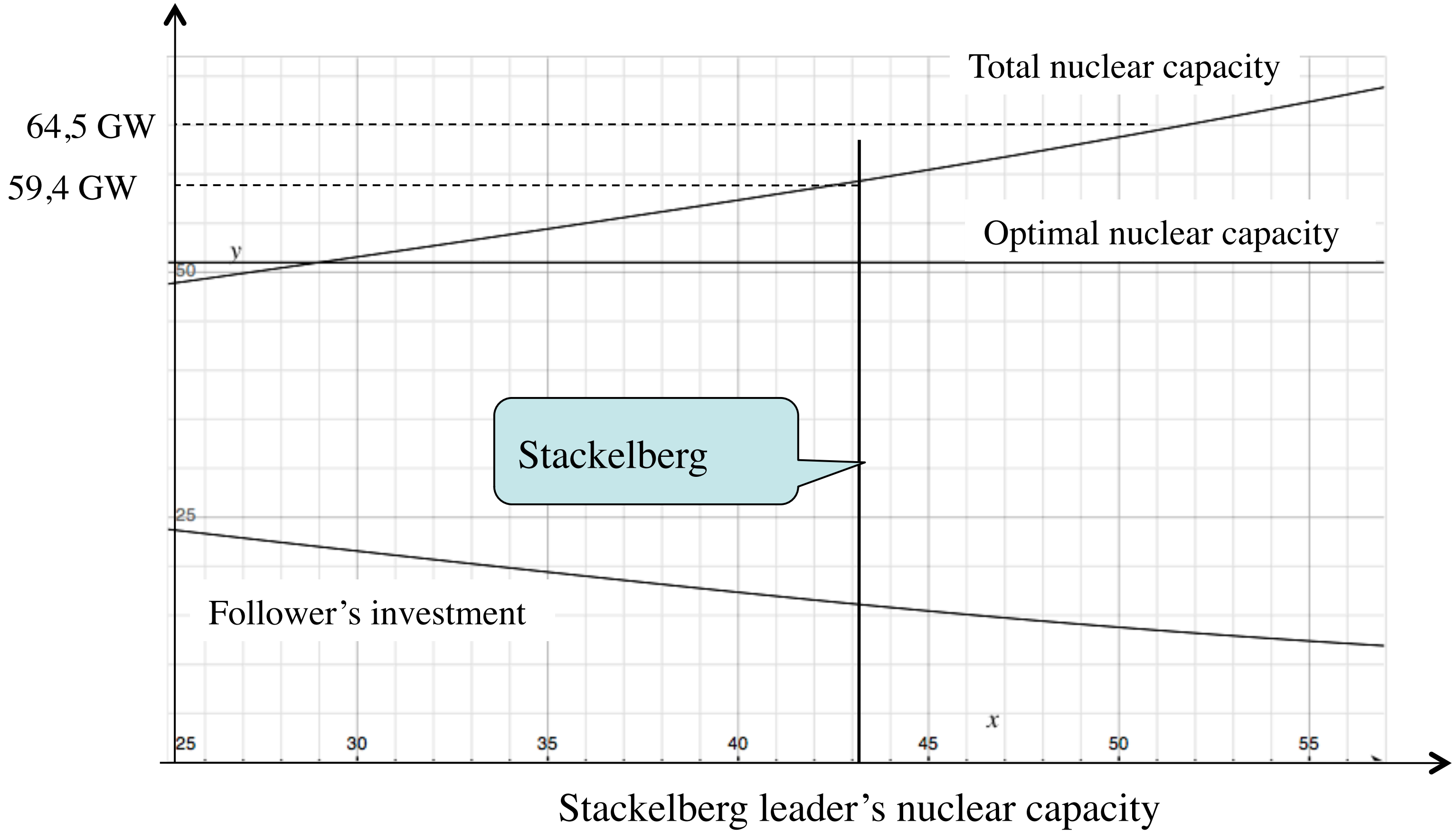
- **If K_1 = K* then entrant has an interest to invest in nuclear generation capacities**
  - **No interest if price = marginal cost when nuclear is marginal**
  - **But this is not the case in duopoly: therefore, incentive to overinvest**
  - **Linear case**

$$K_2 = \begin{cases} K_1\left[-2Ln(K_1/D_{\min}) + \sqrt{4Ln(K_1/D_{\min})^2 + 6(K^* - D_{\min})/K_1}\right]/3 \text{ if } K_1 \geq D_{\min} \\ K_1\left[3(D_{\min}/K_1 - 1) + \sqrt{4(D_{\min}/K_1 - 1)^2 + 3(2K^*/K_1 - 1 - (D_{\min}/K_1)^2}\right]/3 \text{ if } K_1 < D_{\min} \end{cases}$$

- **Excessive nuclear capacities if incumbent's initial capacity is more than its Nash equilibrium value**

- **In real world, this may be offset by other mechanisms (lack of insurance against price volatility)**

Pre-emptive investment / incumbency



Pre-emptive investment / incumbency

- **Stackelberg**
  - K_1 = 43,3 GW
  - K_2 = 16,1 GW
  - K_1+K_2=59,4 GW
  - Excess of nuclear capacity = 16% of optimum
  - Increase in incumbent's profit = 15.5% vs Nash
  - Social loss?
    - 8,4 GW excess nuclear capacity, used on average 41,5% of the time while 55% needed for costs to break even
    - Annual loss = (31.6-6.7 €/MWh)* 8400 * 13,5% * 8760 = € 247 Million

- **What if incumbent starts from optimal capacity and is prevented from selling nuclear assets?**
  - K_1 = 51 GW
  - K_2 = 13,5 GW
  - K_1+K_2=64,5 GW
  - Excess of nuclear capacity = 26,5% of optimum
  - Social loss?
    - 13,5 GW excess nuclear capacity, used on average 33,3% of the time while 55% needed for costs to break even
    - Annual loss = (31.6-6.7 €/MWh)* 13500 * 21,7% * 8760 = € 639 Million

Long-term contracts
…in the real world

- "Nuclear Power: a Hedge against Uncertain Gas and Carbon Prices?" (Fabien Roques, William J. Nuttall, David M. Newbery, Richard de Neufville, Stephen Connors, *Energy Journal*, 2006)
- Allow producers and consumers to protect themselves against the volatility of the price of fossil fuels and emissions permits
  - No organised market for long-term futures
- However, concerns about impact on competition, entry and prices
- Abstract from risk aversion and uncertainty and focus on impact on duopolistic competition

General theories of long-term contracts

- Risk allocation
  - Many models, not addressed here
- Strategic use
  - Change competitors' perceptions about future competition
- Impact on price levels and welfare?
- Depends on type of competition
  - Cournot: Allaz and Vila, JET, 1993
  - Bertrand differentiated: Mahenc and Salanié, JET, 2004
- General conclusion
  - Forward contracts increase (resp. decrease) welfare in Cournot (resp. Bertrand) settings
  - General idea: Stackelberg logic + (Cournot case) prisoner's dilemma

Long-term contracts

1. Taking capacities as given

- **Long-term contract signed by large producer, quantity *A* (constant amount, not far from real world), price *P***
  - **This amounts to subtracting A from both D and K_1**
  - **Impact only when nuclear is marginal and $K_2<D$**
  - $E\pi_1=C(D-A-K_2)+PA = C(D-K_2)+(P-C)A$
  - $E\pi_2=CK_2(D-A-K_2)/Min(D-A,K_1-A)$
  - **Negative impact of Firm 2's profit**
  - **Cause spot prices to fall**
    - **Increase in relative aggregate excess supply (aggregate supply and demand both decrease by same amount *A*)**
    - **Increase in market share symmetry**
  - **But Firm 1 has no interest to offer such contracts at price below *C***

Long-term contracts

1. Taking capacities as given

- **Long-term contract signed by small producer, quantity *A* (constant amount, not far from real world), price *P***

$$\Delta\Pi_2 = PA + \Pi_2(D - A, K_2, K_1 - A)$$

$$\Delta\Pi_2 > 0 \text{ if } P \geq CE\left[\frac{D - K_2}{K_1}\right]$$

  - **Firm 2 has an interest in signing long-term contracts at prices below the expected spot price**
  - **But this increases future spot prices**
    - **At the limit, return to monopoly if small producer contracts its entire capacity long-term**

Long-term contracts

2. As a tool to deter competitor's investment

- **Type of competition: two variants**
  - **Long-term contract signed before Nash equilibrium of the capacity choice game**
  - **Long-term contract signed by incumbent with large capacity, before entrant decides its nuclear capacity**
- **Type of contract: two variants**
  - **"Base", i.e., constant amount of power**
  - **Time-varying amount proportional to overall consumption**

Long-term contracts

2. As a tool to deter competitor's investment

- **Case 1: "base" LT contract by incumbent followed by Nash equilibrium in capacities**
  - **Equivalent to assuming a lot of dismantling and new investments ahead**
  - **Amounts to subtracting fixed amount A from demand and from K_1**
  - **Nash equilibrium of capacity choice game (d linear, $K_1<D_{min}$ over relevant range)**
    - **$K_1(A)-A = (3(K^*-A)-(D_{min}-A)/4 = K_1(0)-A/2$ implying that $K_1(A) = K_1(0)+A/2$**
    - **$K_2(A) = K_2(0)-A/2$**
  - **$E\pi_1=C(D-K_2(0)-A/2)+PA = C(D-K_2(0)+(P-C/2)A$**
    - **Incumbent willing to offer LT contracts at any price greater than C/2**
  - **Future spot price is $g(A) = Cp(K^*-A, D_{min}-A) = \frac{2C(K^*-A)}{3K^*-D_{min}-2A} > \frac{C}{2}$ so that consumers would be willing to accept LT contracts offered at some prices above C/2**
  - **$g'(A)<0$: LT contracts signed by incumbent causes future spot prices to fall**
  - **Two effects**
    - **Greater relative excess demand (pushes prices downwards)**
    - **Greater market share asymmetry (pushes prices upwards)**
    - **The first effect dominates**

Long-term contracts

2. As a tool to deter competitor's investment

- **Case 1: "base" LT contract by incumbent followed by Nash equilibrium in capacities**

  - **Consider the following game**
    - **Assumption: a small fraction of consumers (with constant aggregate demand = A) can enter into LT contracts (predictable enough demand)**
    - **In Stage 1, incumbent can offer these consumers LT contracts (take-it-or-leave-it offer)**
    - **In Stage 2, these consumers can accept of reject LT contracts**
    - **In Stage 3, incumbent and entrant simultaneously invest**
    - **In Stage 4, spot market**
    - **Incumbent willing to offer LT contracts at any price greater than C/2**

  - **Equilibrium**
    - **All consumers who can enter into LT contracts are offered one at price *g(A)*, accept it**
    - **The surplus of all consumers increases (wrt to prohibition of LT contracts)**
    - **Entrant's investment and profit fall**
    - **Total investment and total surplus are unaffected: still optimal nuclear capacity**

  - **Similar result in the case of time-varying LT contract (proportional to *D*)**

Long-term contracts

2. As a tool to deter competitor's investment

- Case 2: LT contract with Stackelberg competition
  - Timing
    - Stage 1: incumbent simultaneously offers LT contracts (up to some exogenous maximum) and invests
    - Stage 2: entrant invests
    - Stage 3: spot market competition for all realizations of demand
  - Results
    - LT contracts are a (partial and cheap) substitute for pre-emptive investment
    - Comparative statics
      - Less nuclear investment (closer to optimum)
      - Increase in social surplus
      - Increase in incumbent's profit, decrease in entrant's
      - Ambiguous effect on prices / consumer surplus