Uncertainty and energy saving investments

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Problem

- Energy saving investments: Replacement of energy-intensive capital
  - central in efforts to reduce primary energy use (fossil fuels)
  - Sectors: electricity, transportation, manufacturing, housing,…
- Energy use response to prices is dynamic
  - Empirical literature following the first oil price shock
- Existing approaches to understanding it based on
  - Exogenous adjustment costs (Pindyck-Rothemberg, 1983 AER)
  - Putty-Clay structure (Atkeson-Kehoe, 1999 AER)

Problem

- Overlooked: “adjustment costs” follow also from **uncertainty and investor caution**
- Yet, uncertainty seems almost defining feature of fuel prices
- Uncertainty of conventional energy cost =uncertainty about the social value of replacement
- Illustration: electricity sector
  - 42 % primary energy, 34 % fossil fuels, 40 % of CO2 in the US
  - Oil price is important determinant of costs

Oil price series in 2008 dollars

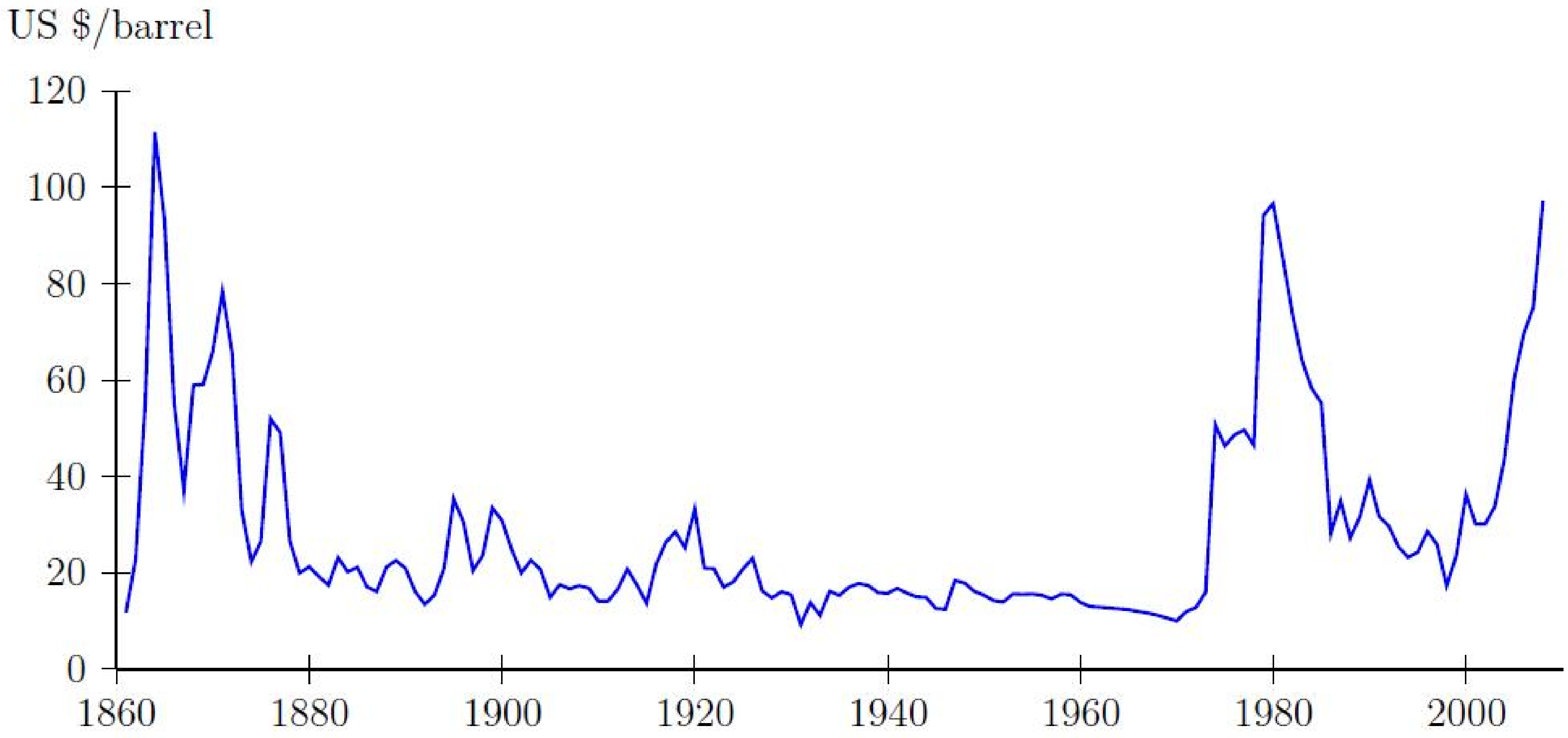
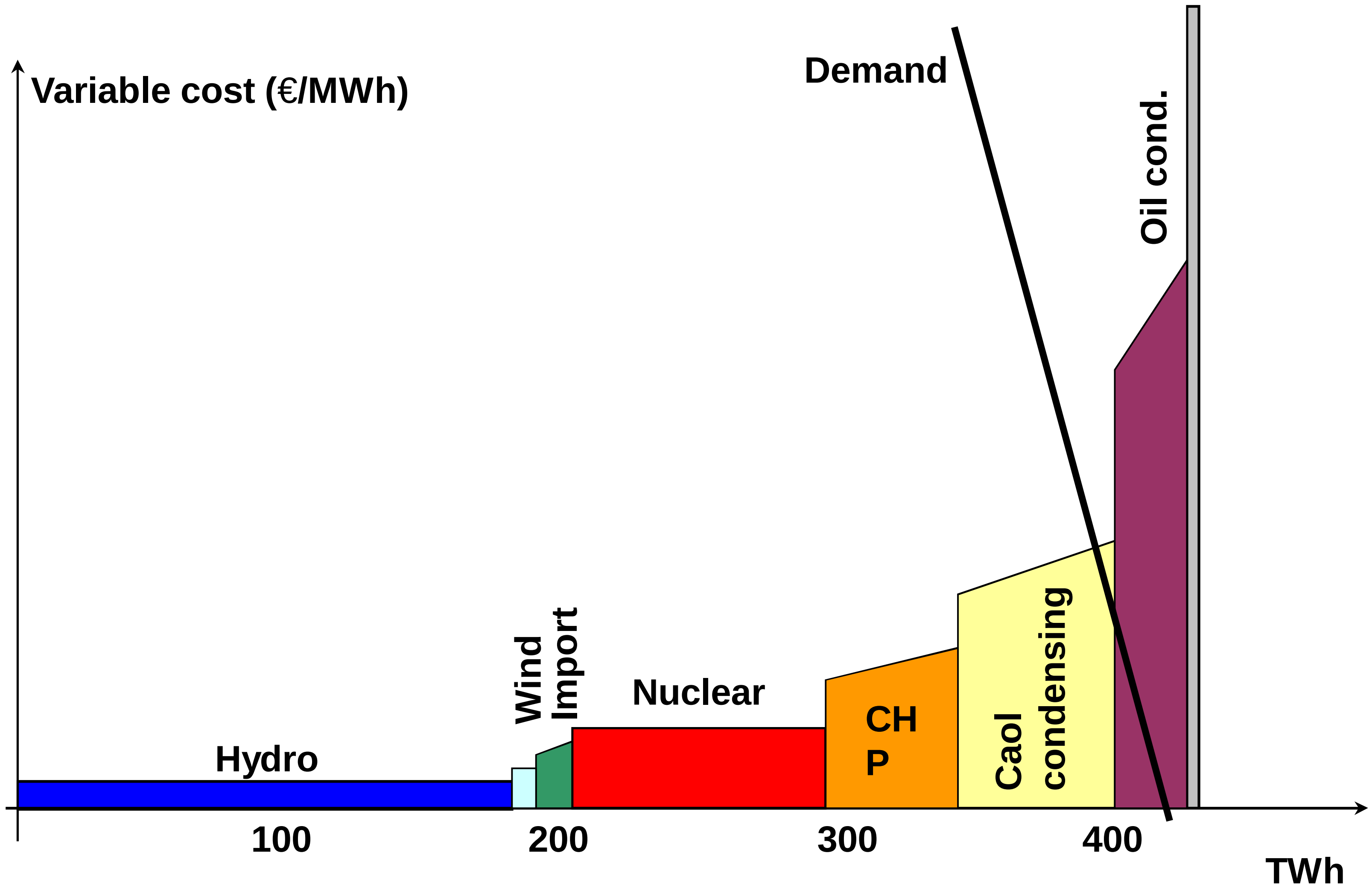
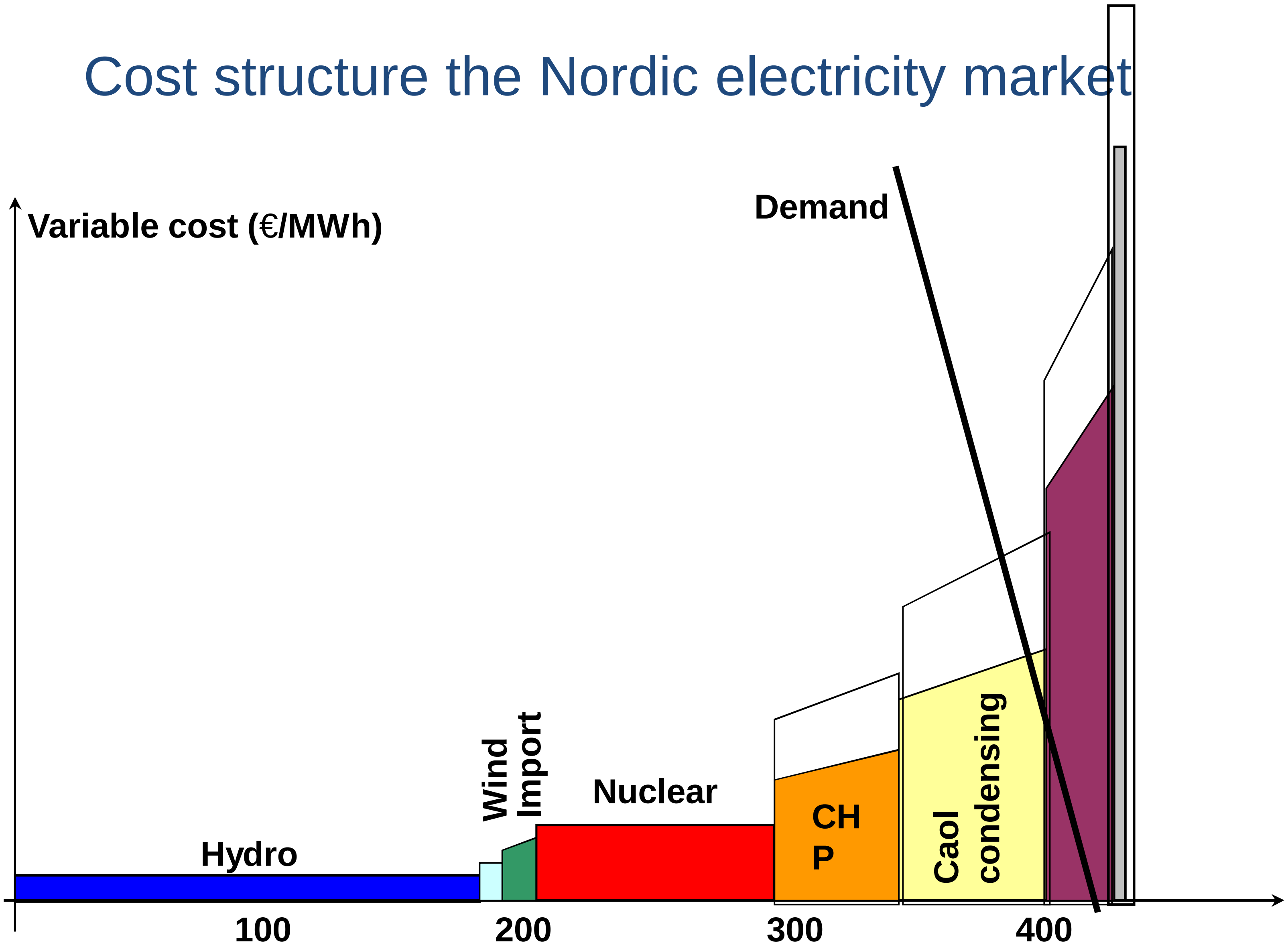


Figure 1: Crude oil prices 1861-2008 measured in 2008 US Dollars. Source: BP Statistical Review of World Energy, 2009.

Cost structure the Nordic electricity market



Cost structure the Nordic electricity market



Problem

- This paper: how the investor caution (real options mark-up) develops in equilibrium
  - Equilibrium model of investments
  - Quantitative assessment of adjustment delays
  - Consumer price increases needed
  - Role of policies expediting the change
  - Application to an electricity market
- Conceptually close to Leahy 1993 QJE
  - Equilibrium development of real option mark-ups for entrants

Results

- Novel price response follows from just two elements

1. Energy costs uncertain
2. Existing capital heterogeneously hit by higher energy costs

- Uncertainty: uncertainty about the social value of the replacement
- Heterogeneity: adjustment delays

Results

- A contraction-expansion pattern
- As energy costs increase

  short-run output contracts…

  but long-run output recovers.
- Output can expand above the initial level
- Thus, consumer price first increases but finally declines
- similar, in spirit, with the putty-clay implication (Atkeson-Kehoe 1999)
- A simple framework for understanding delays and the role of policies

Results

- Empirical application: the Nordic electricity market
- Elements of the model estimated. Scenarios under various cost assumptions for green technologies
- Results:
  - Mark-ups exceed costs by multiple factors
  - Replacement very costly to consumers
  - Policies: subsidies benefit consumers, although they distort the overall welfare

Model

- Final good demand

$$p = D(q)$$

- Old, energy-using supply
  - Continuum of old units, each using one unit of energy
  - Differ in efficiency in using the energy
  - Marginal cost, or cost of the last producing unit

$$MC(q^f, x).$$

where q^f is the total production from old units and x is the cost of one unit of energy

Model

- New, energy-free supply
  - Each supplies one unit of output
  - zero variable cost (no l.o.g.)
  - Continuum of units, total number k
  - k is thus the new capital stock
- The total inverse supply, given x and k:

$$S(q,k,x) = \begin{cases} 0 \text{ if } q \leqslant k \\ MC(q-k,x) \text{ otherwise.} \end{cases}$$

Model

- Equilibrium for a given x and k

$$p = D(q) = S(q, k, x) > 0$$

- First moving part: energy cost

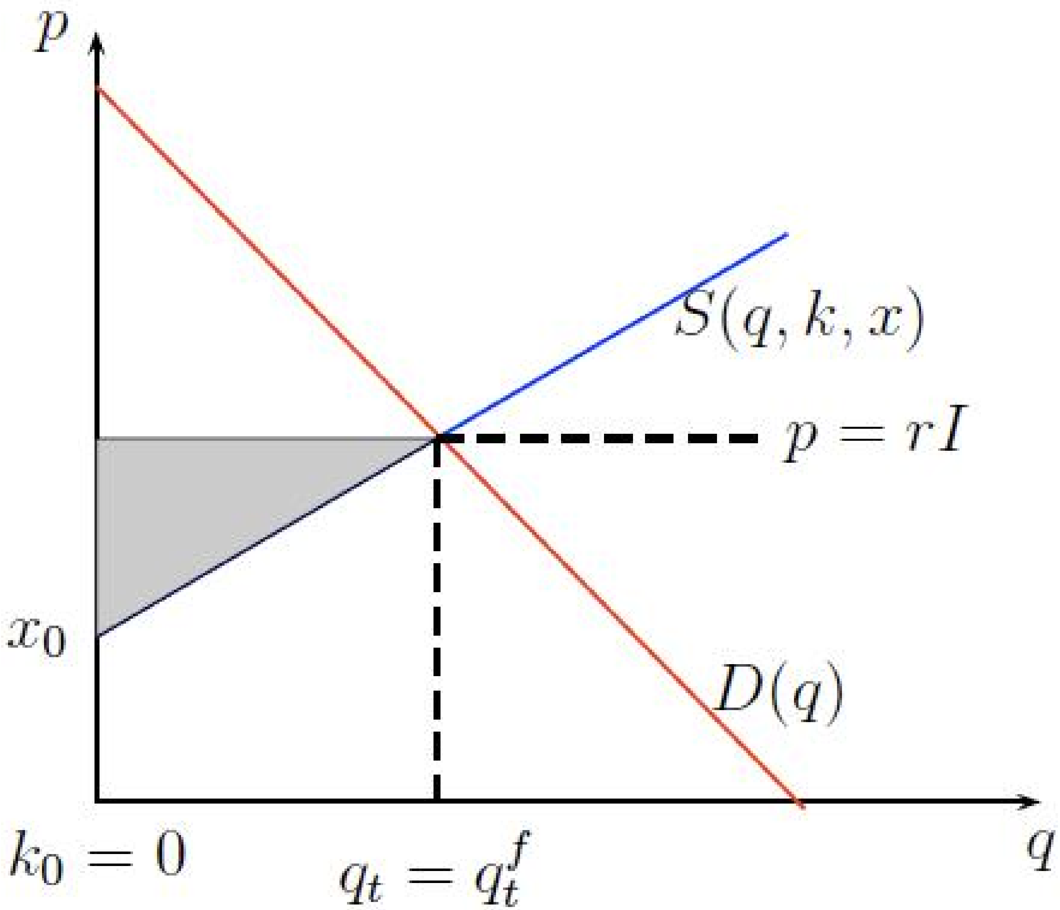
$$dx = \alpha(x)dt + \sigma(x)dw$$

- Second moving part: entry of new capital
  - Risk-neutral entrants
  - upfront cost I
  - interest rate r
  - Once in place, live forever

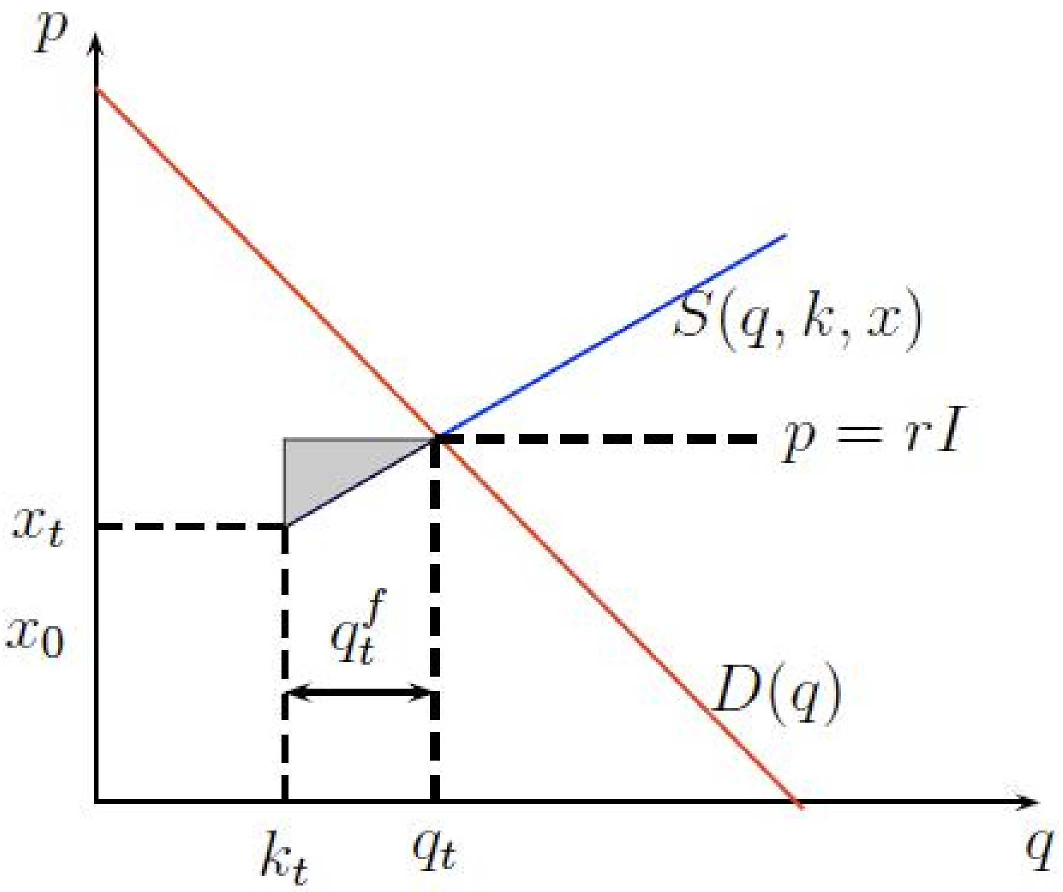
Graphical illustration

- x follows GBM
  - σ=0, no uncertainty; σ>0, uncertainty
  - $\alpha \geq 0$, upward trend
- Demand linear
  - $P=A-Bq$
- Marginal cost linear
  - $MC=x+Cq^f$

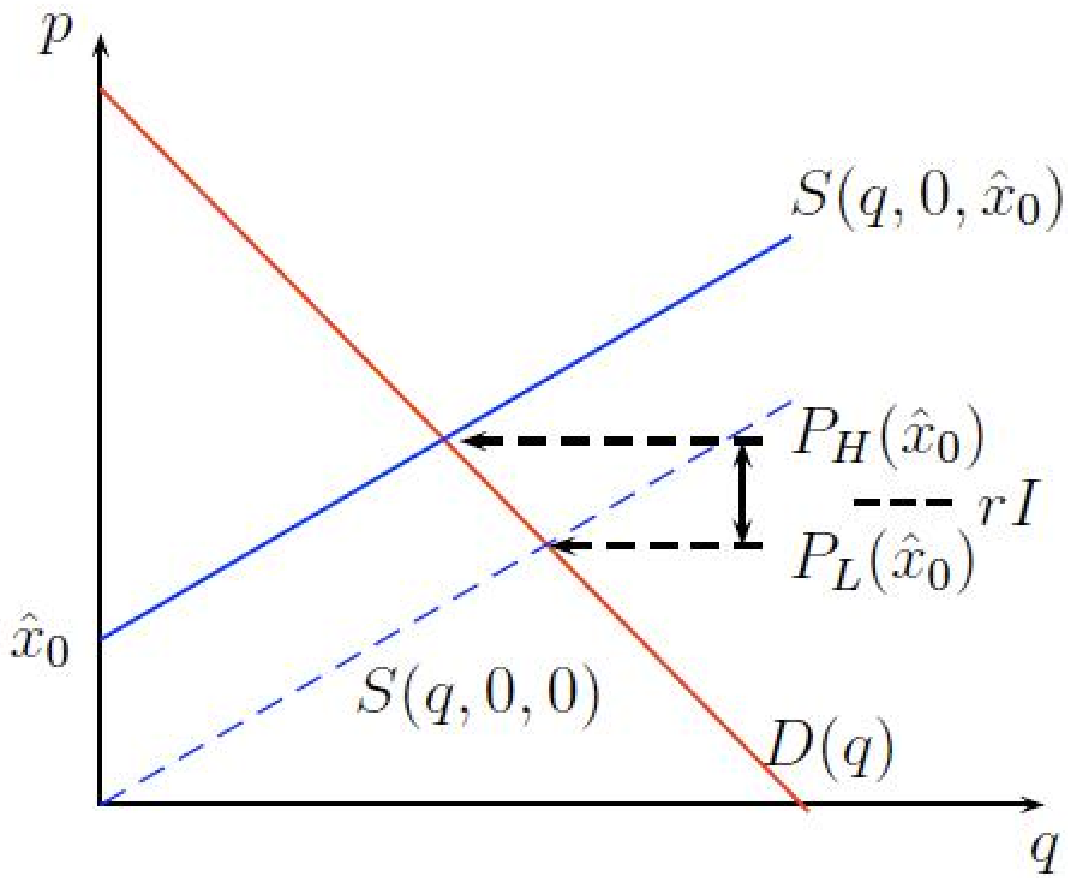
No uncertainty (α>0, σ=0): first entry



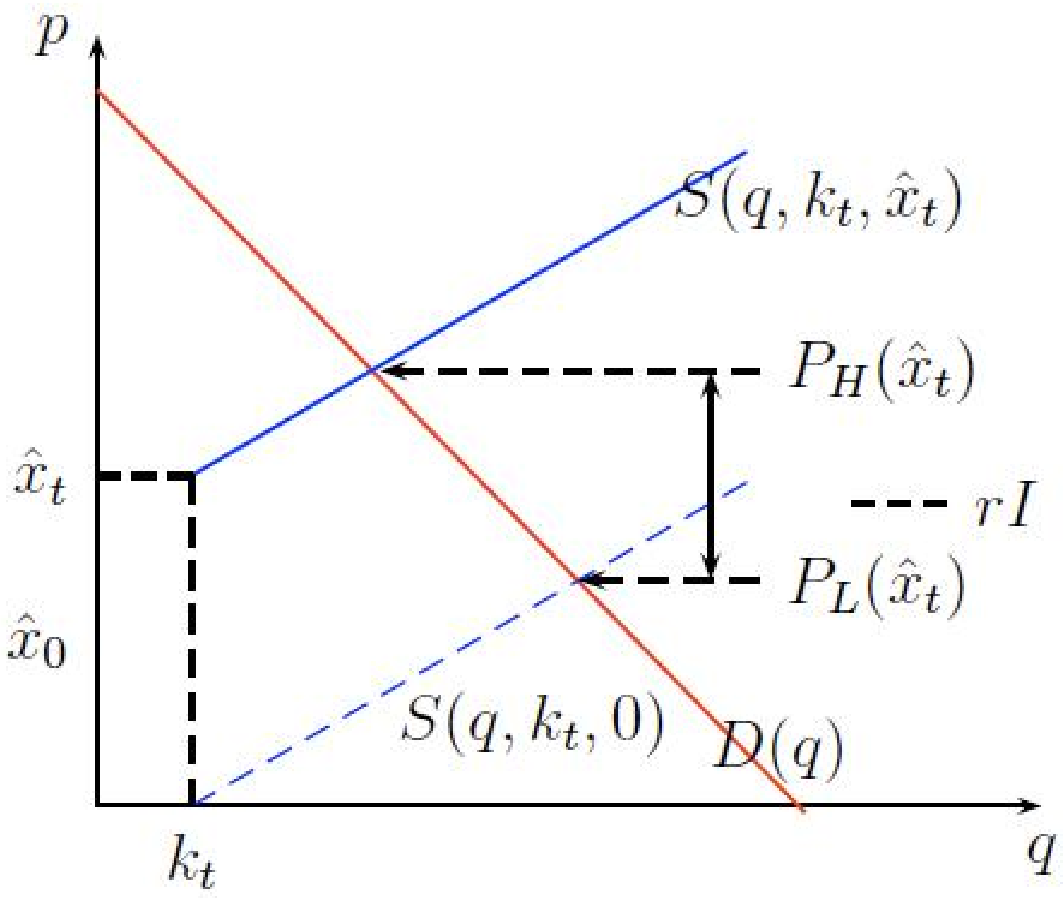
No uncertainty (α>0, σ=0): later entry



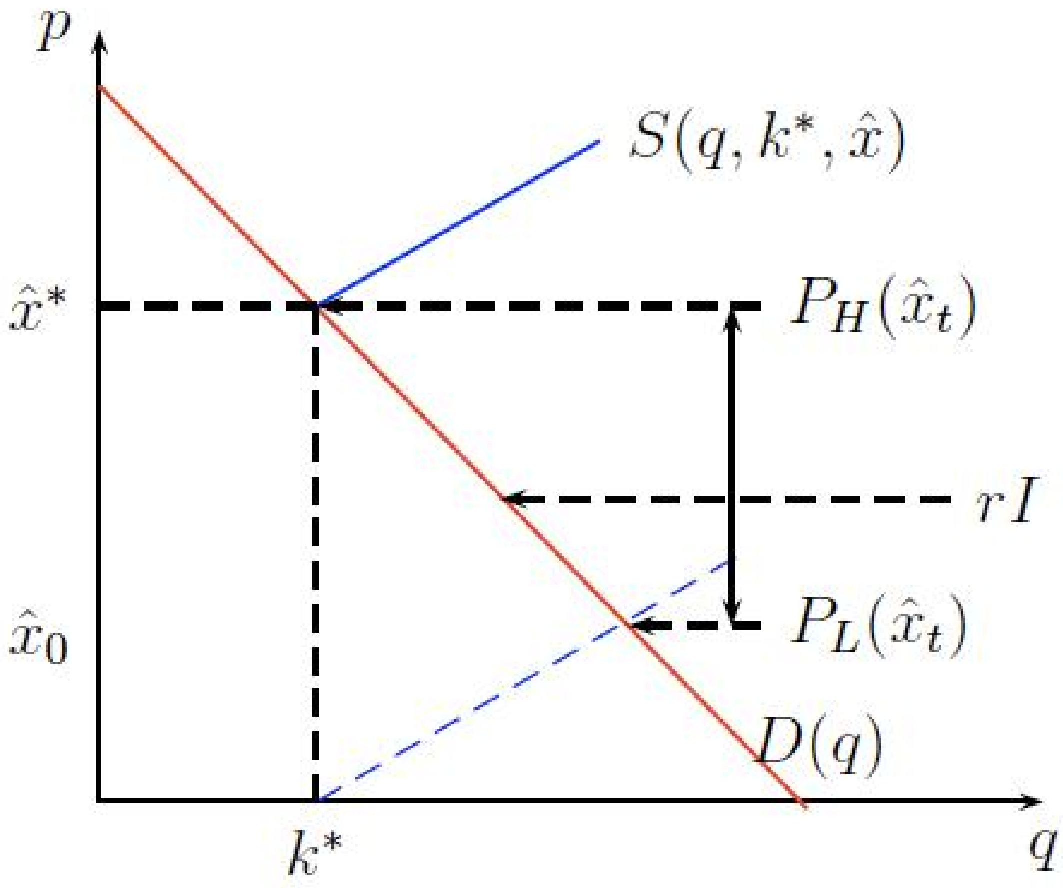
Uncertainty (α≥0, σ>0): first entry



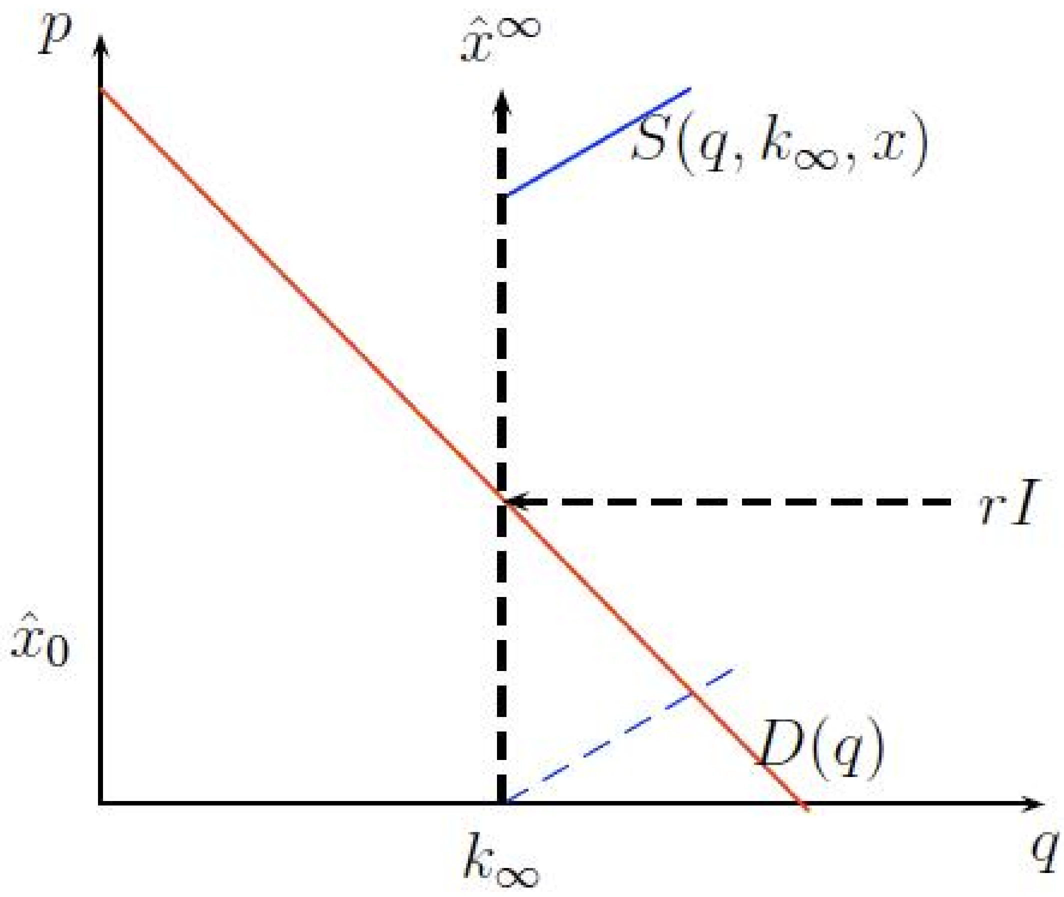
Uncertainty (α≥0, σ>0): output contraction



But output cannot contract more that this…



Output expansion and long-run:



Summary of the linear case and GBM

Proposition 1 *There exists* $\sigma^* > 0$ *such that for* $0 < \sigma < \sigma^*$*, the equilibrium output contracts at investment points* $0 < \hat{x} \leqslant \hat{x}^*$*, and expands for* $\hat{x} > \hat{x}^*$*. Furthermore:*

- *peak price* $P_H(\hat{x}^*)$ *increases in* σ*;*
- *if* $C \to 0$, $P_H(\hat{x}^*)$ *approaches the first entry price;*
- *investor mark-up disappears in the long run:* $P_H(\hat{x}_t) \to rI$ *as* $\hat{x} \to \infty$.

Discussion

- Generality? Other contexts besides electricity?
  - What is essential is the payoff dependence of technologies
  - In manufacturing: the same final-good demand
  - Housing: investments destroy the demand for energy providers (gas, oil, electricity)
  - Transportation: consumer price at the pump; investments affect this price
- Heterogeneity of investors
  - Creates rents
  - Can eliminate the expansion part
  - But will not affect the early mark-up
- General P(k,x)

A sample path

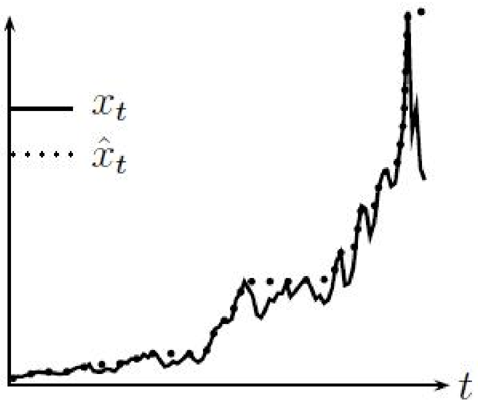


Figure 7: Sample path for the energy price

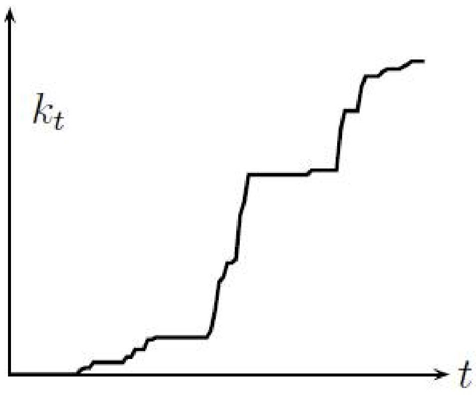


Figure 8: The energy saving capital stock

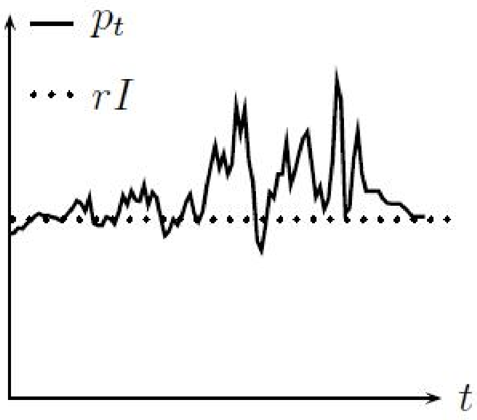


Figure 9: The consumer price path

General analysis

- Price function, p=P(k,x), decreasing in k and increasing in x. Satisfies

$$E \int_0^\infty P(k, x_\tau) e^{-r\tau} d\tau < \infty.$$

- Historical record

$$\hat{x}_t \equiv \sup_{\tau \leq t} \{x_\tau\}.$$

- Equilibrium in Markovian cut-off strategy profile for entrants, x*(k)

General analysis

- Strategy induces the capacity process

$$\{k_t\} \equiv \{\mathbf{k}^* (\hat{x}_t; x^*)\}$$

$$\mathbf{k}^* (\hat{x}_t; x^*) = \inf\{k \geq 0 \,|x^* (k) > \hat{x}_t \}.$$

- Entrant problem

$$F(x_t, \hat{x}_t; \mathbf{k}) = \sup_{\tau^* \geq t} E\left[\int_{\tau^*}^{\infty} P(\mathbf{k}(\hat{x}_\tau), x_\tau) e^{-r(\tau - t)} d\tau - I e^{-r(\tau^* - t)}\right],$$

General analysis

- Free entry condition

$$F\left(x_t, \hat{x}_t; \mathbf{k}\right) = 0.$$

- Zero profit

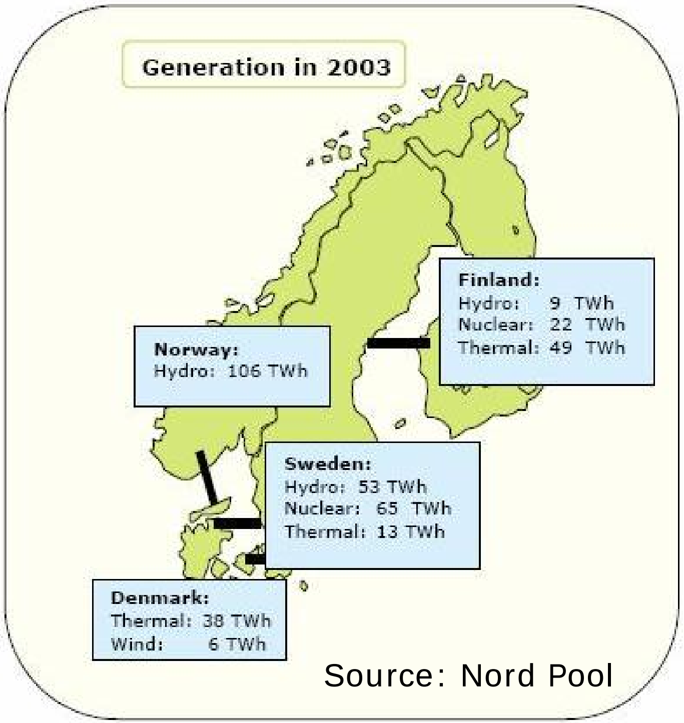
$$E\left[\int_t^{\infty} P(\mathbf{k}\left(\hat{x}_\tau\right), x_\tau)e^{-r(\tau-t)}d\tau\right] - I = 0.$$

- Equilibrium can be calculated using Leahy's (1993) myopia result

Extension

- Does the result depend on the assumption that the old capital cannot exit?
- No. See Murto-Liski 2006
  - Old capital: produce / idle /exit
  - Old capital will finally exit but there is a period of coexistence
  - Contraction-expansion pattern arises

Application:The Nordic wholesale electricity market



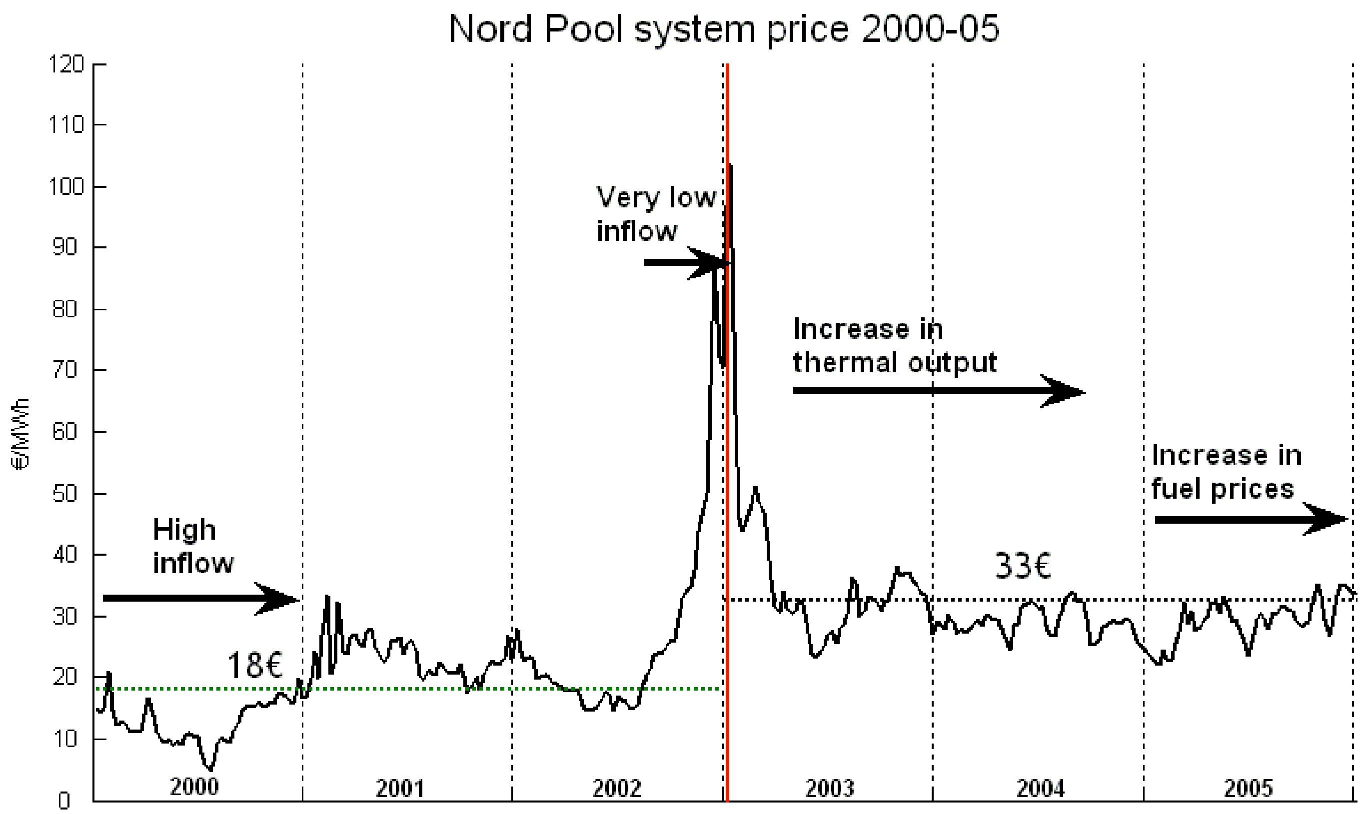
- Diverse set of technologies
- 50% hydroelectricity
  - helps in estimation
- Nord Pool – one price for a large fraction of time
  - We consider weekly prices
- Publicly available data
  - Nord Pool, Nordel

Technologies

	TWh			
	Denmark	Finland	Norway	Sweden
Total generation	37.3	73.4	125.2	146.5
Hydro	.0	12.7	124.1	67.8
Other renewable	5.8	2.0	.3	1.9
Thermal	31.5	58.8	.8	76.7
-Nuclear	.0	21.8	.0	66.6
-CHP, industry	29.4	26.3	.1	5.8
-CHP, other	2.1	10.7	.4	4.3
-gas turbines, etc.	.0	.0	.3	.0

Table 1: Average annual production breakdown by technology 2000-05

Weekly prices 2000-05



Approach to calibration

- Estimate the weekly supply of thermal power
- Use hydro stocks as instruments

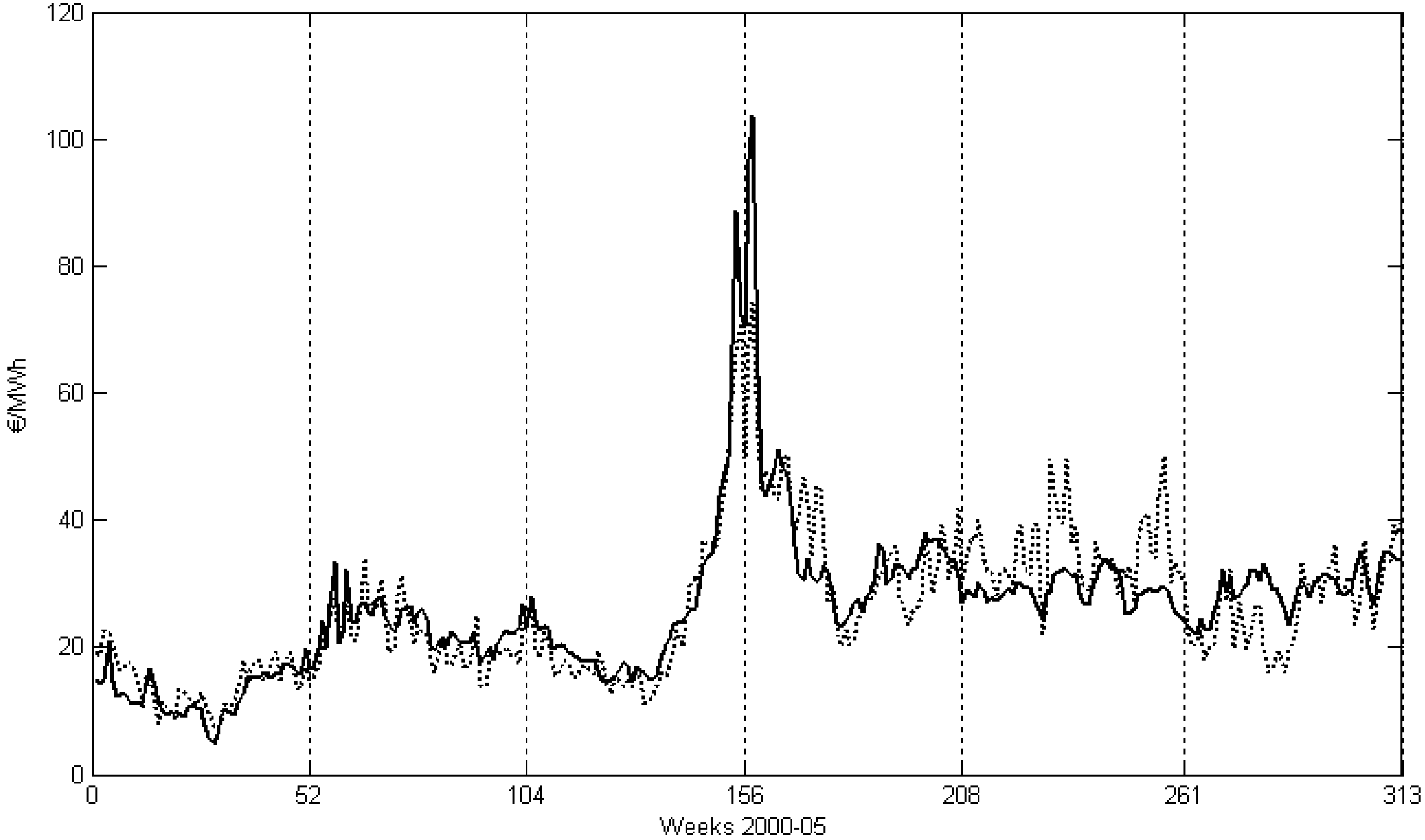
$$q_t^f = \beta_0 + \beta_1 \ln p_t^{elec} + \delta x_t + \gamma d_t + \varepsilon_t,$$

- Estimate the demand process for thermal from data
- Use the supply function to generate annual revenue in the market:

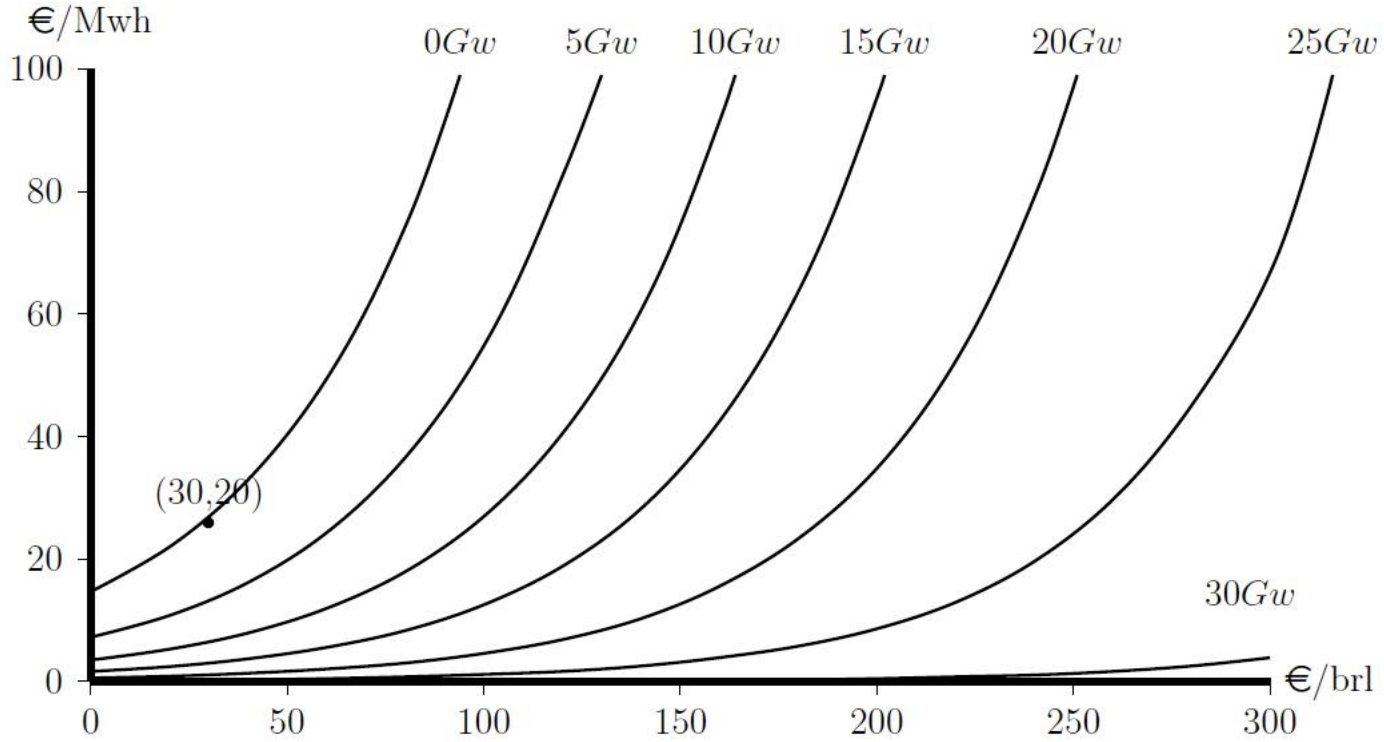
$$P(k, x) = \sum_{i=1}^{12} \int \Pi(i, x, D_i - k) dF_i,$$

- Fuel price follows GBM with drift=0. Volatility<.3

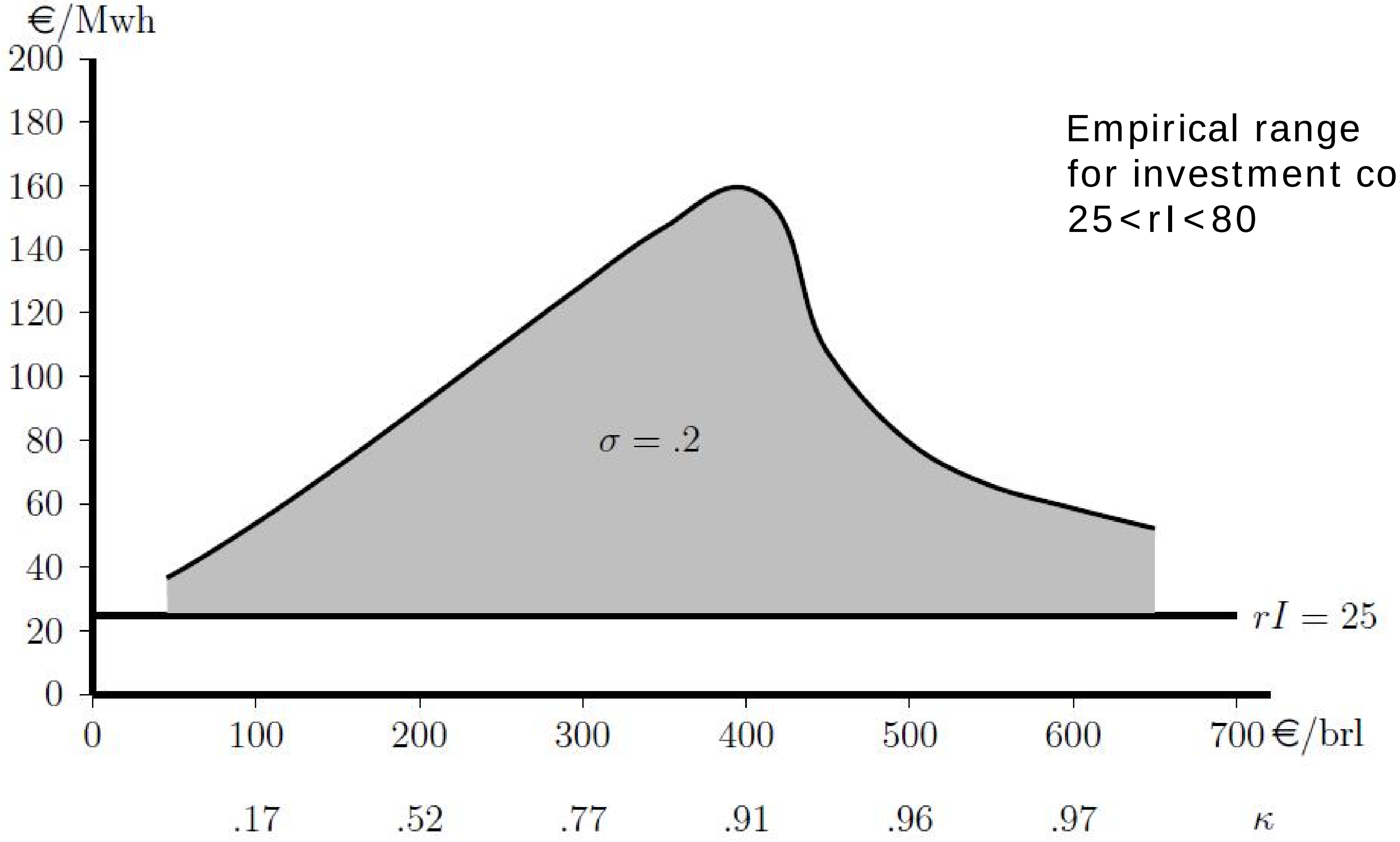
The fit of the estimated supply



Estimated P(k,x)

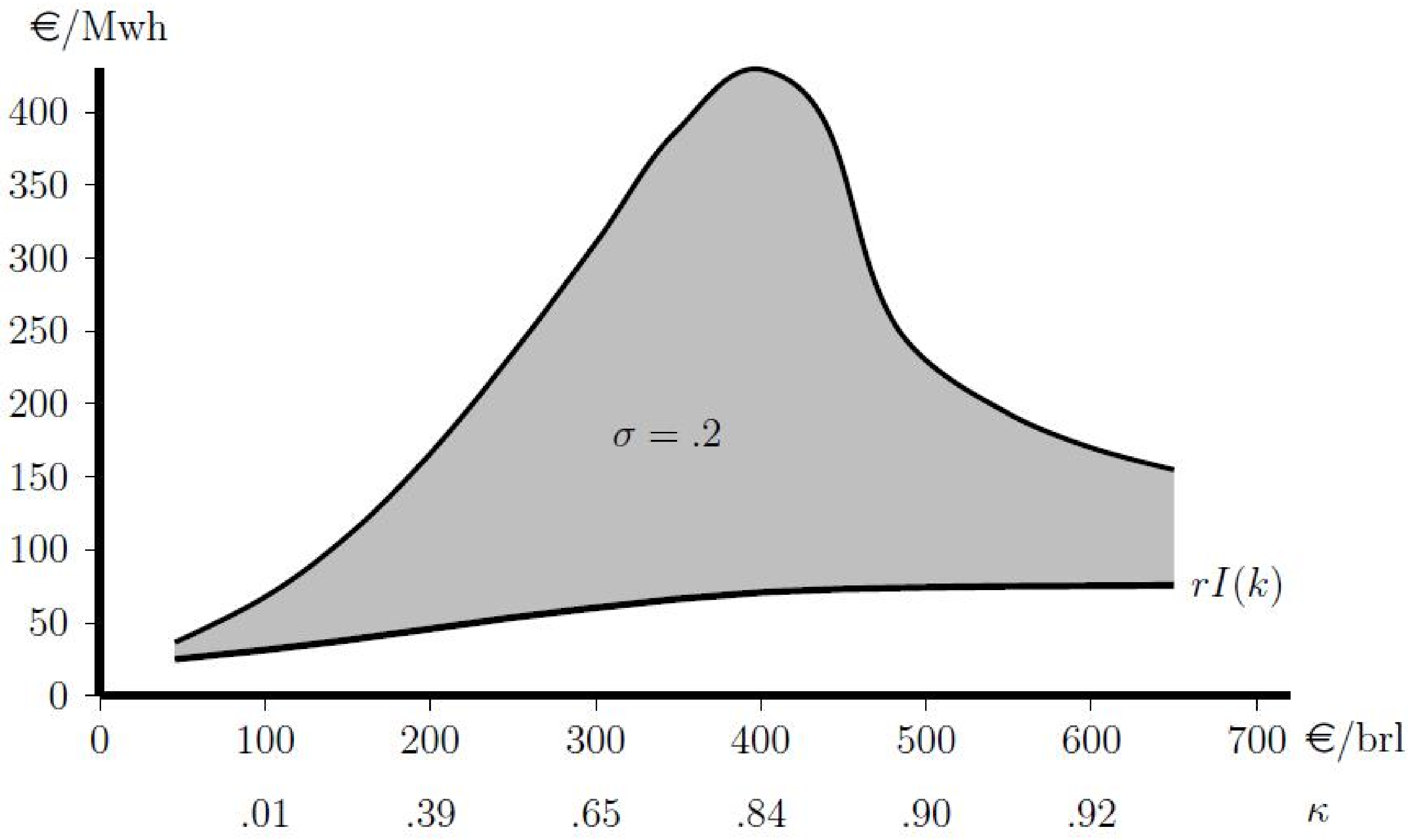


Results: equilibrium mark-up

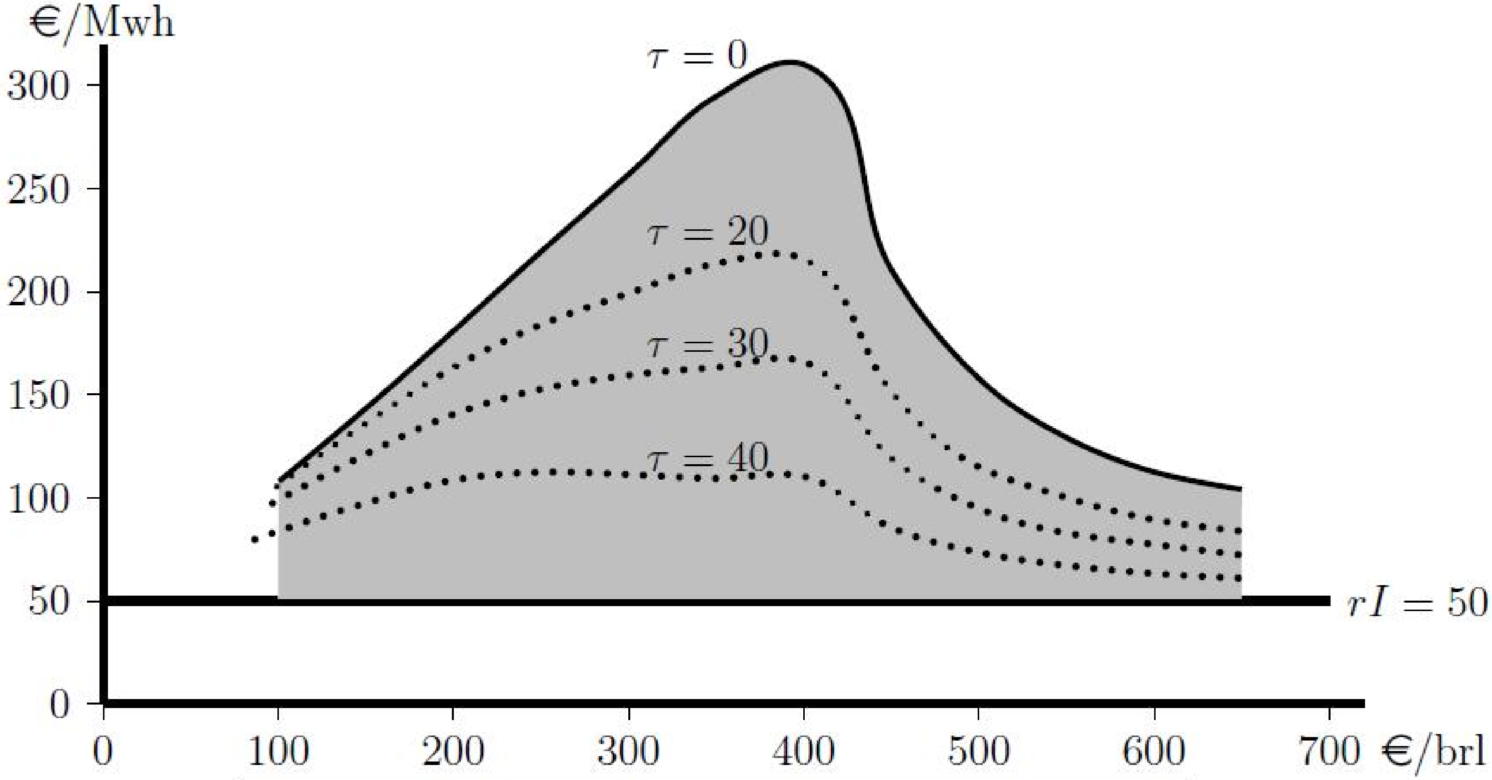


Empirical range
for investment cost
25<rI<80

Results: heterogeneous entry costs



Results: feed-in tariffs for entrants (σ=.2)



100	200	300	400	500	600	
.01	.37	.67	.87	.92	.94	$\kappa_{\tau=0}$
.01	.40	.72	.90	.95	.97	$\kappa_{\tau=20}$
.03	.43	.76	.92	.99	.98	$\kappa_{\tau=30}$
.07	.49	.82	.96	1.00	1.01	$\kappa_{\tau=40}$

Welfare results (σ=.2)

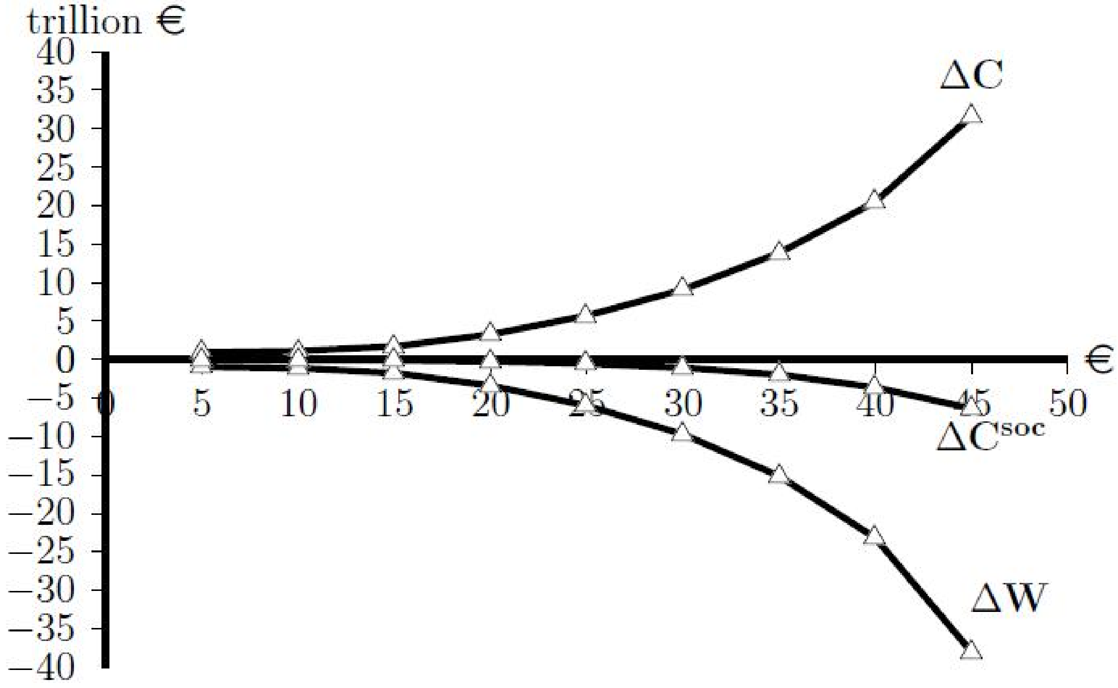


Figure 16: Consumers' gain (ΔC), producers' loss (ΔW), and the total welfare loss (ΔC^{soc}) for tariff levels $\tau = 5, 10, 15, ..., 45$. All expressions evaluated at the fuel price of the first entry when $\tau = 45$.

Conclusion

- Extensions:
- the explicit supply of energy requires an exhaustible resource approach
  - We have taken the energy cost as an exogenous process
- Macroeconomic impacts: our price propagation channel is new
  - We have a partial equilibrium model