Market power and storage: Evidence from hydro use in the Nordic power market

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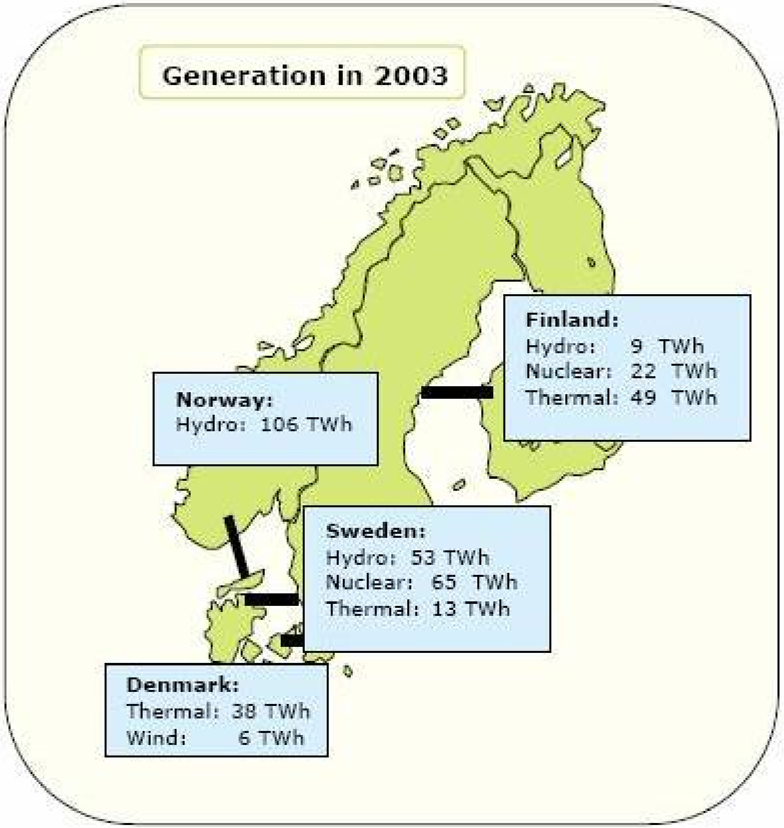
Background

- Market power in storage is hard to detect
  - Price-cost margins depend on expectations that cannot be observed ex post
- Thus: little work on market structure and storage
  - Empirical applications or test

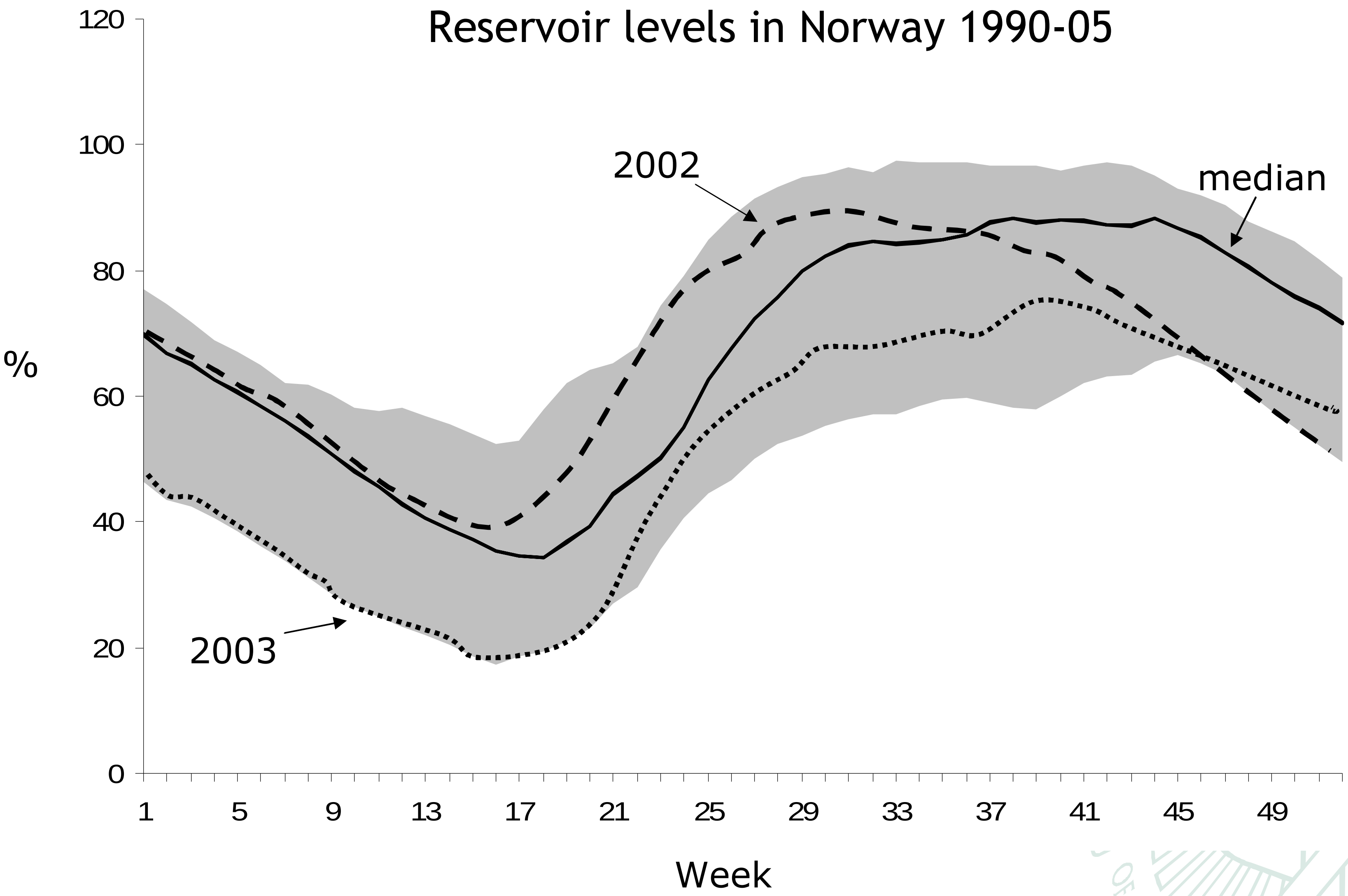
This paper

- This paper uses a power market, Nordic market, as a natural laboratory
- Storage: hydroelectricity
- Market fundamentals are very precisely measured
  - output prices
  - storage levels
  - demand
  - inflow
- A unique opportunity to test if price-cost margins are competitive
  - Expectations can be estimated

Market area

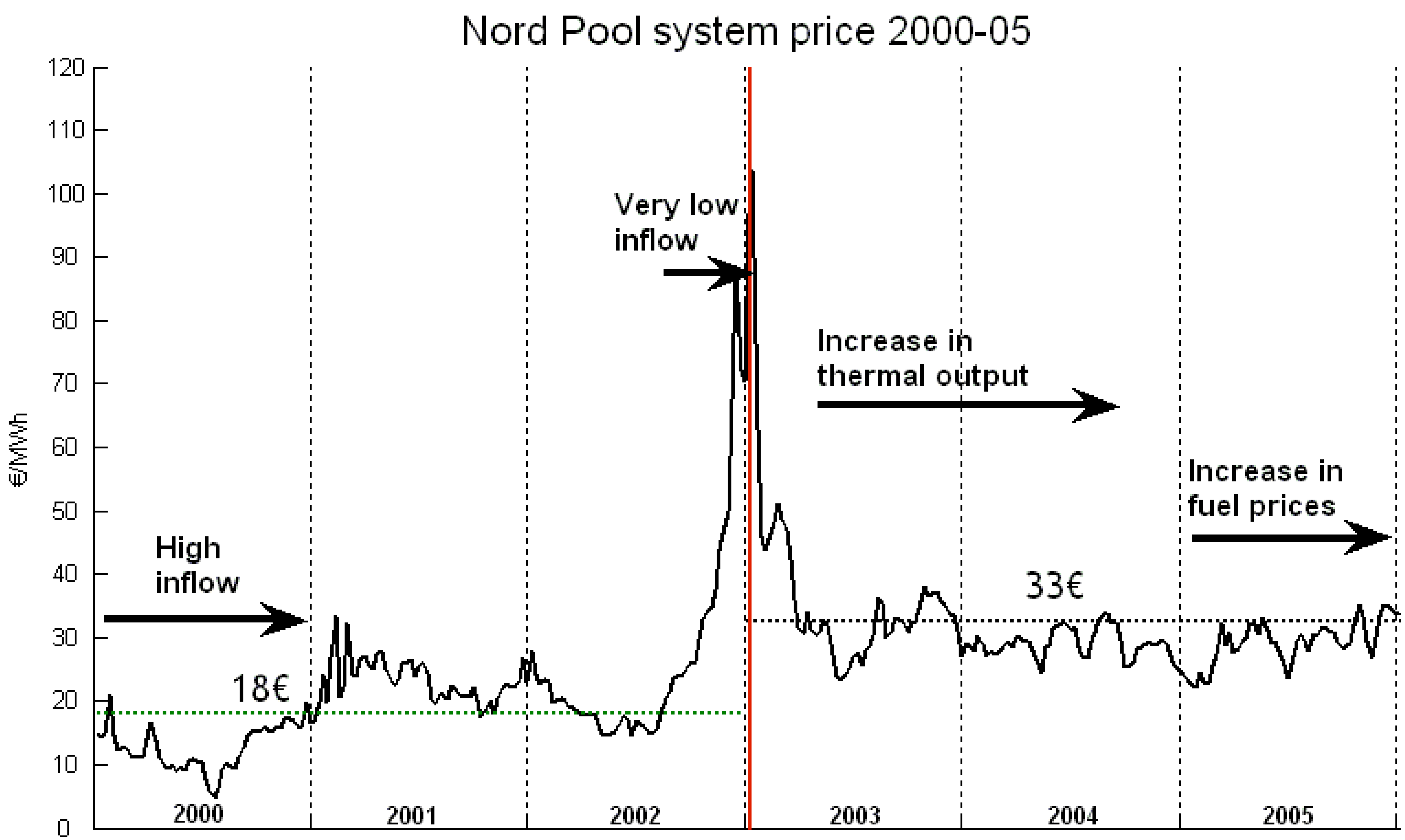


Source: Nord Pool



Reservoir levels in Norway 1990-05
120
100
80
60
40
20
0
%
2002
median
2003
1
5
9
13
17
21
25
29
33
37
41
45
49
Week

HSE


Nord Pool system price 2000-05
€/MWh
120
110
100
90
80
70
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
High inflow
18€
Very low inflow
Increase in thermal output
33€
Increase in fuel prices

We develop a model and an estimation procedure to address:

- **Properties of the efficient market?**
  - exhaustible resource market: weekly price moments are equalized in present value
  - Storage market: moment properties as in storable-good markets
- **How is the market exercised?** Increases:
  - Expected reservoir levels
  - Price levels
  - Price risk
- **The degree of market power in 2000-05?**
  - a welfare loss from inefficient hydro use
  - model can match the behavioral pattern in the data
  - Structural estimation

A model of socially optimal hydro use

- Stochastic dynamic programming
- Social planner minimizes cost of meeting demand
- Aggregated hydro and thermal sectors
- Weekly decisions, infinite horizon
- Market fundamentals:
  - Inflow distribution
  - Demand distribution
  - Thermal power supply
  - Constraints of the hydro system
- Different from industry forecasting models

The key features of the model

Bellman equation:

$$v(s_t) = \max_{u_t \in U(s_t)} \{\pi(s_t, u_t) + \beta E_{s_{t+1}|s_t} v(s_{t+1})\}.$$

where $s_t = (S_t, x_t, \omega_t)$ and $S_{t+1} = \min\{\overline{S}, S_t - u_t + r_t\}$.

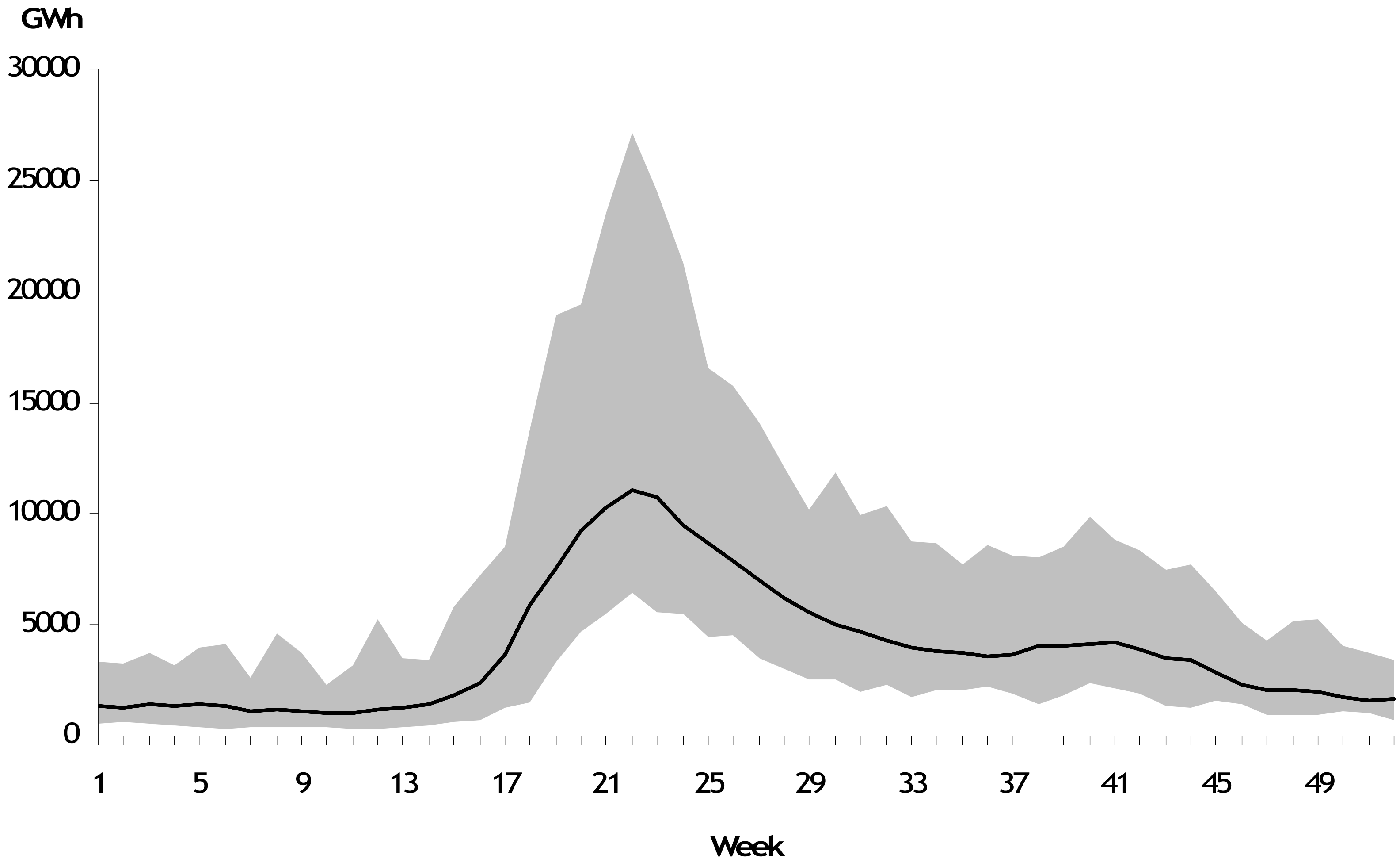
Demand and inflow are stochastic:

$$x_t \sim G_\omega(x) \qquad r_t \sim F_\omega(r)$$

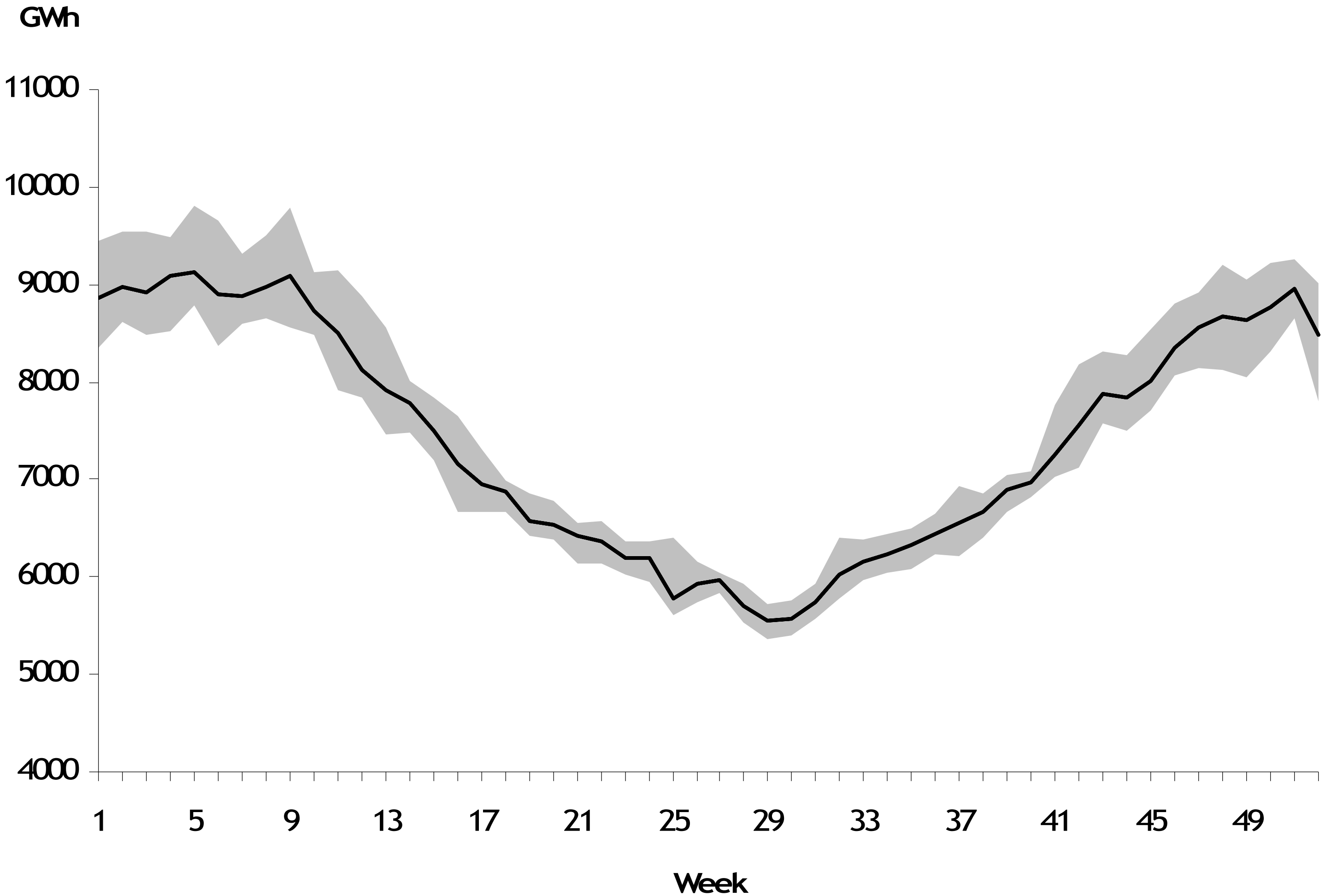
The planner minimizes costs of thermal output:

$$\pi(s_t, u_t) \equiv -C_\omega(x_t - u_t)$$

Inflow distribution in the Nordic market area 1980-99

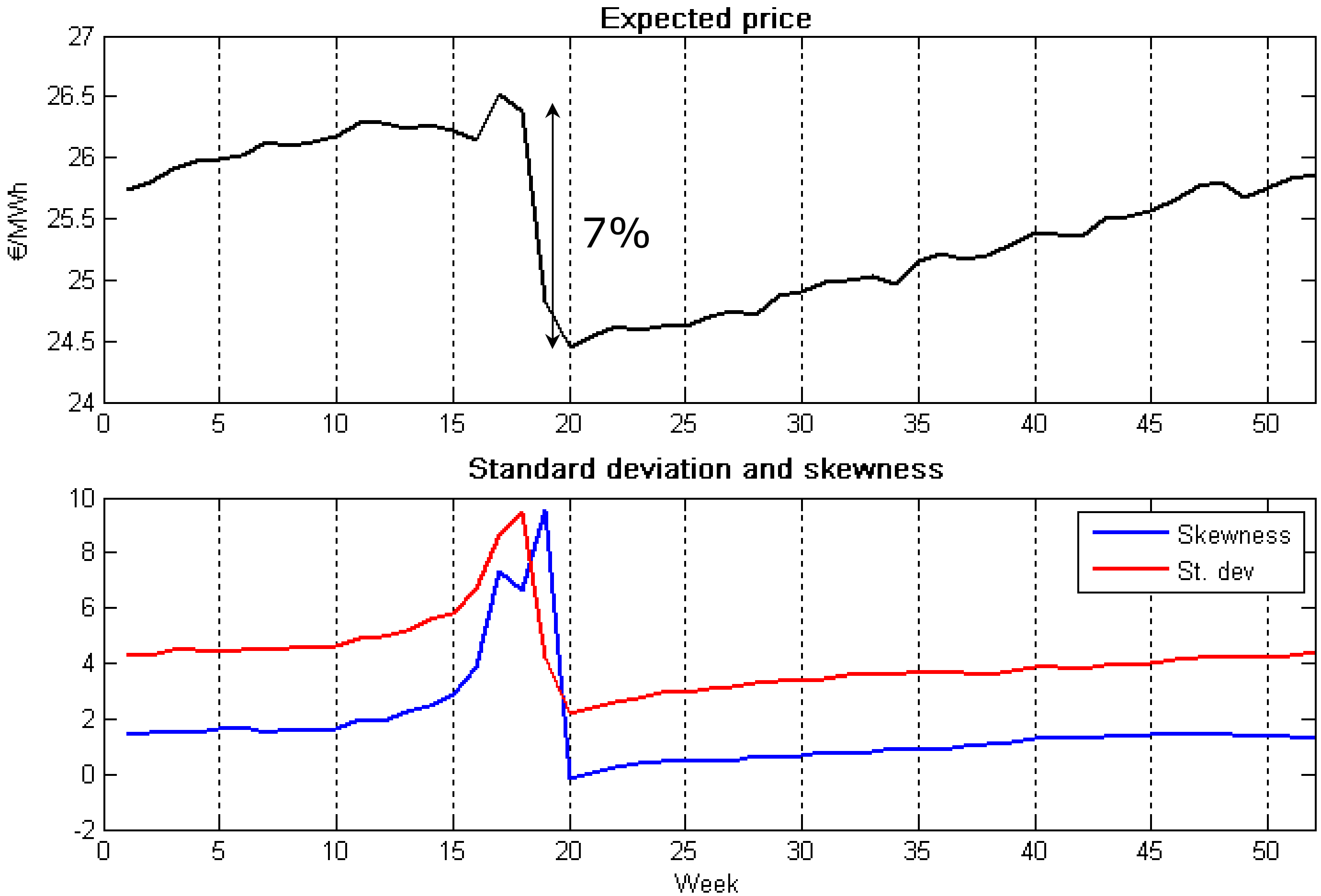


Demand in the Nordic market 2000-05



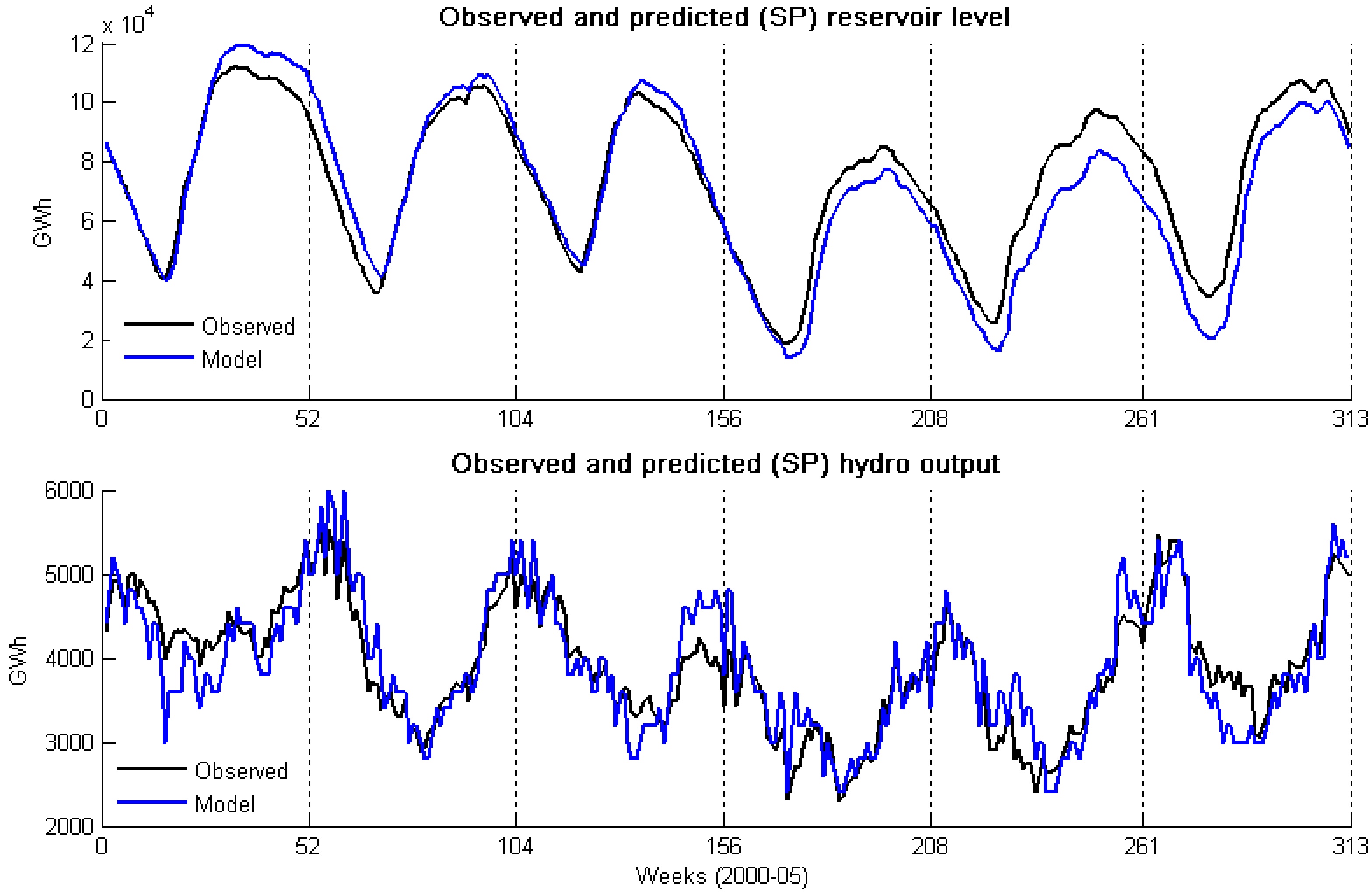
HSE

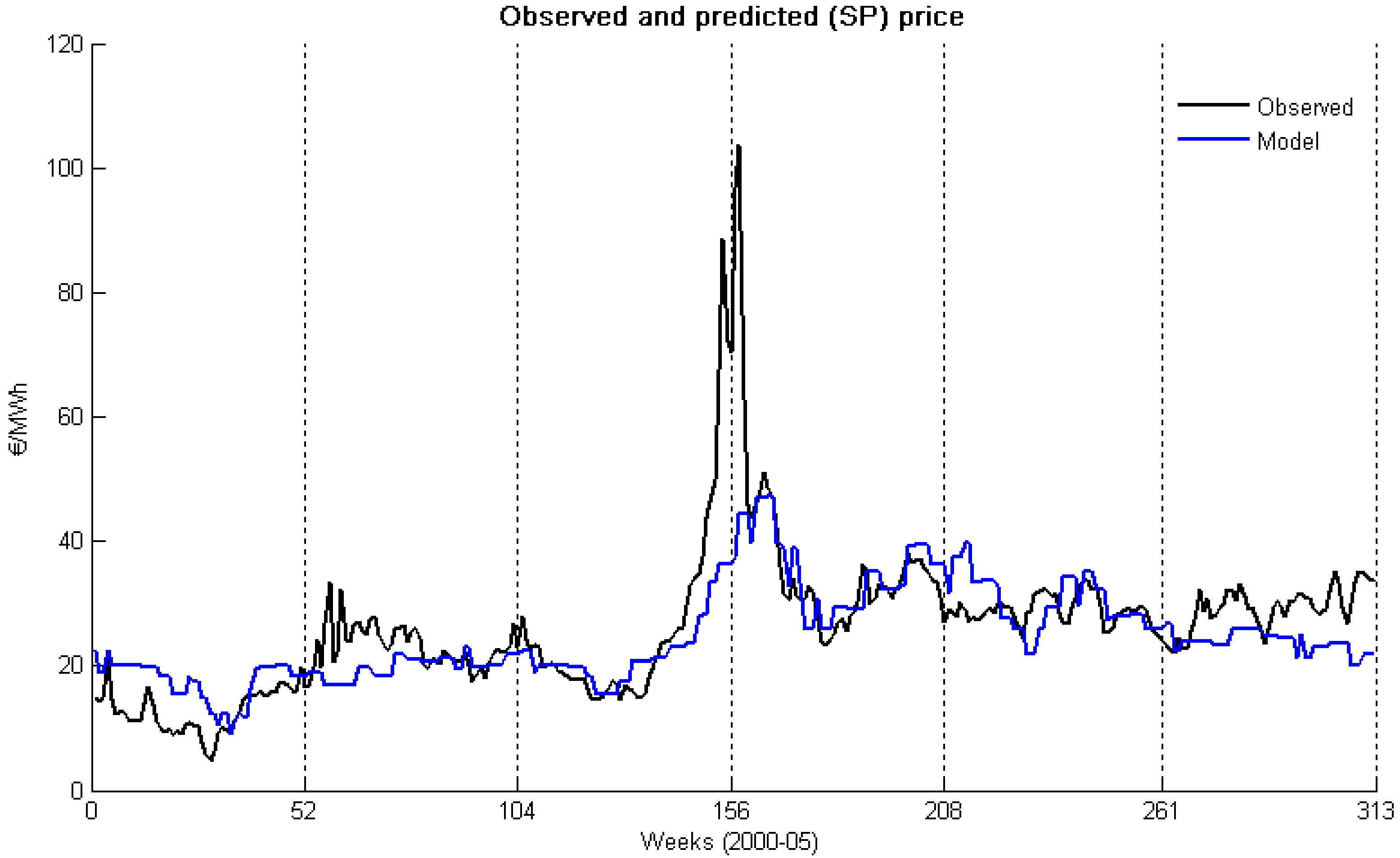
Weekly price distributions:



Exhaustible resource within a year

Storable good across the years


Observed and predicted (SP) reservoir level
x 10^4
GWh
Observed
Model
0
52
104
156
208
261
313
Observed and predicted (SP) hydro output
GWh
Observed
Model
Weeks (2000-05)

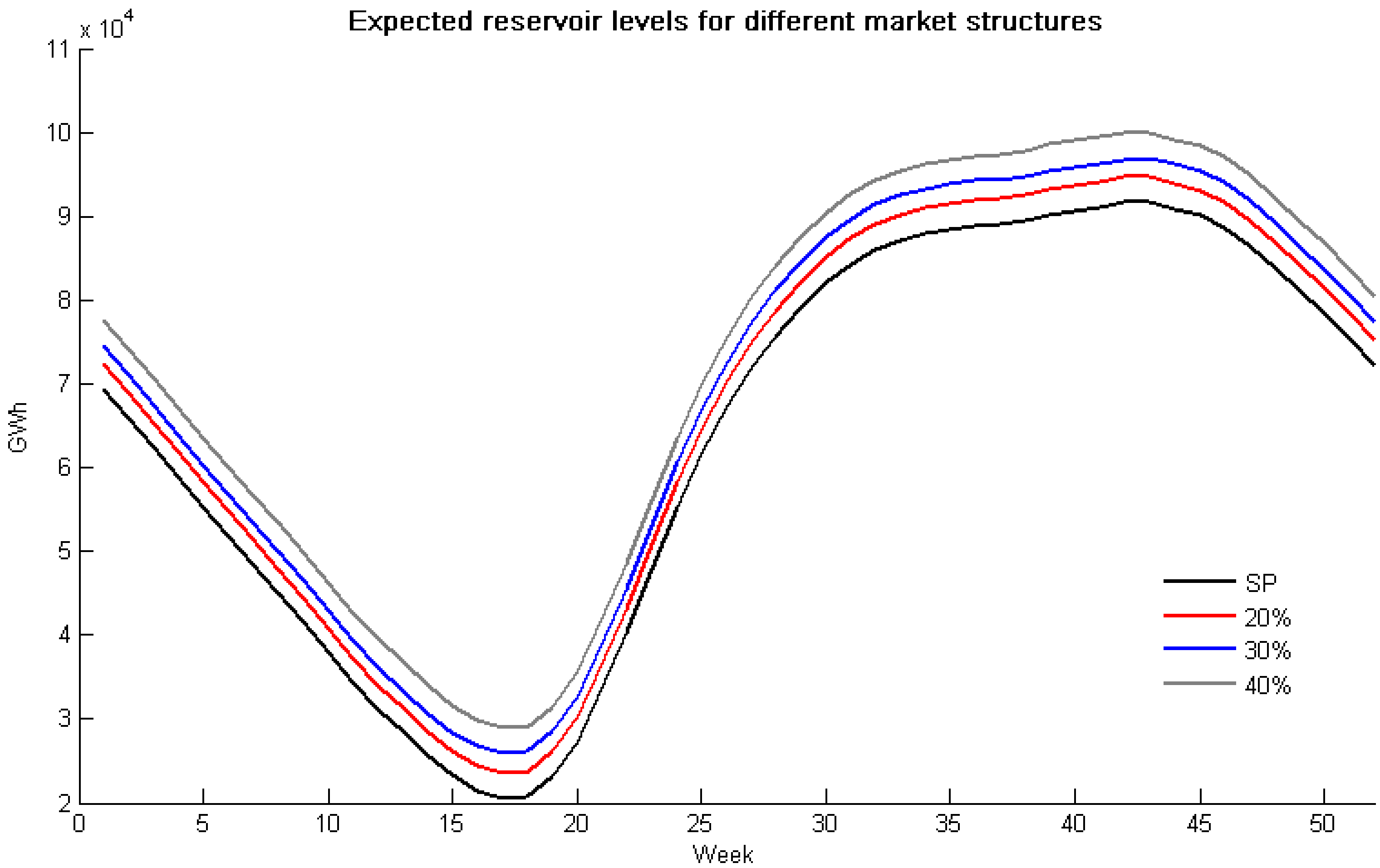

Observed and predicted (SP) price
€/MWh
0
20
40
60
80
100
120
0
52
104
156
208
261
313
Weeks (2000-05)
Observed
Model

A non-competitive market structure

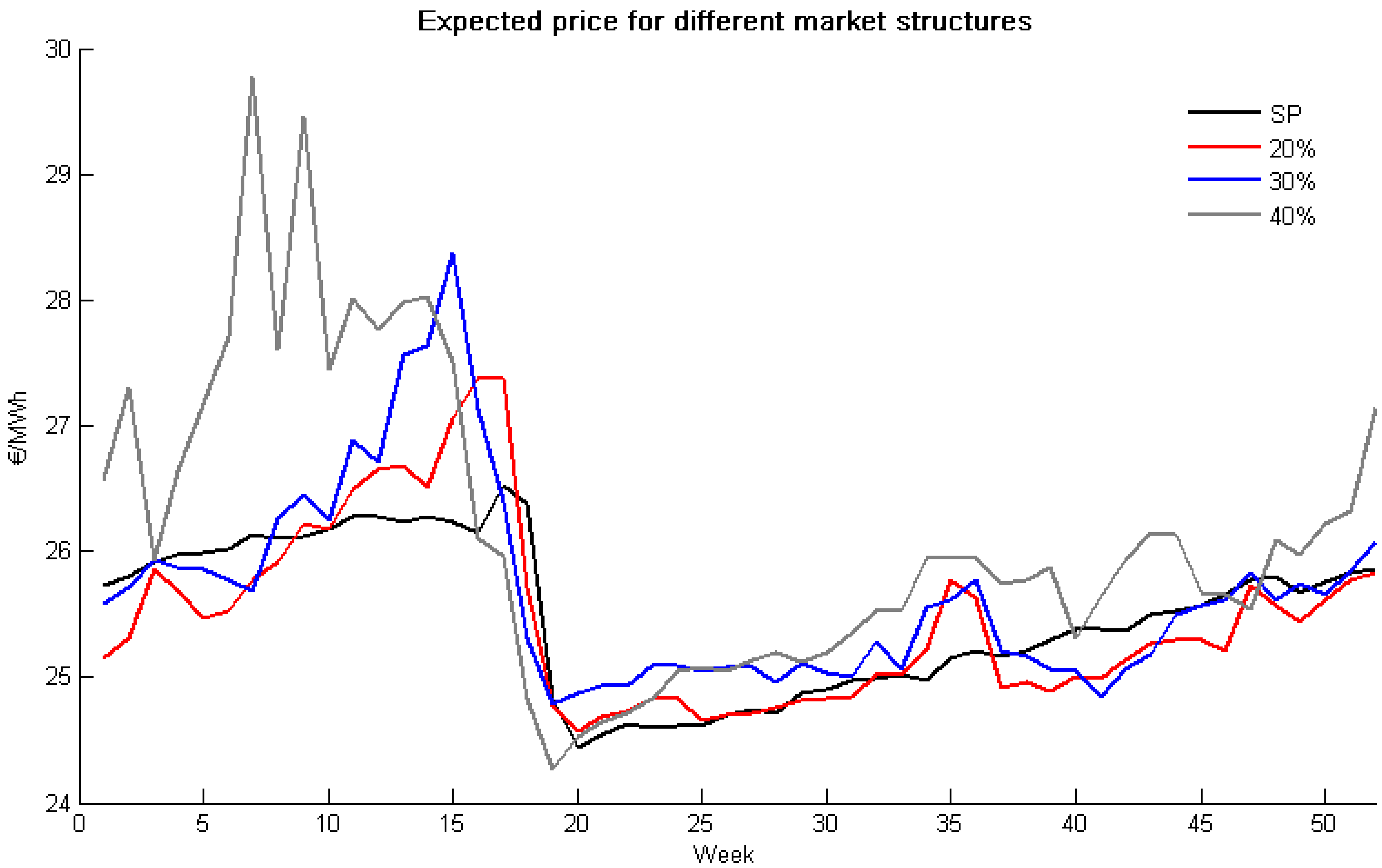
- Hydro resource shared between a strategic agent and a group of price-taking small firms
- Storage capacity, production capacity and inflow divided according to a single parameter (10%, 20%, 30%...)
- Which capacity share fits the data best?
  - GMM approach

Key features of the market power model

- Timing each week:
  1. Agents observe the state
  2. The large firm chooses output
  3. The small firms choose output
  4. Thermal sector produces the residual demand
- The equilibrium actions are solved using backward induction within each period
- The solution of the competitive agents' problem using a fixed point procedure
  - Curse of dimensionality


Expected reservoir levels for different market structures
x 10^4
11
10
9
8
7
6
5
4
3
2
GWh
0
5
10
15
20
25
30
35
40
45
50
Week
SP
20%
30%
40%

HSE


Expected price for different market structures
€/MWh
30
29
28
27
26
25
24
0
5
10
15
20
25
30
35
40
45
50
Week
SP
20%
30%
40%

Estimation

- Three moment restrictions: prices, reservoirs, outputs
- Sample mean of the prediction error:

$$g_T(\alpha) = \frac{1}{T}\sum_{t=1}^{T} m_t(\alpha) - x_t.$$

- Statistic to be minimized

$$H_T(\alpha) = g_T(\alpha) \cdot W g_T(\alpha)$$

The best match: 30 per cent model

Values of the test statistic under different market structures

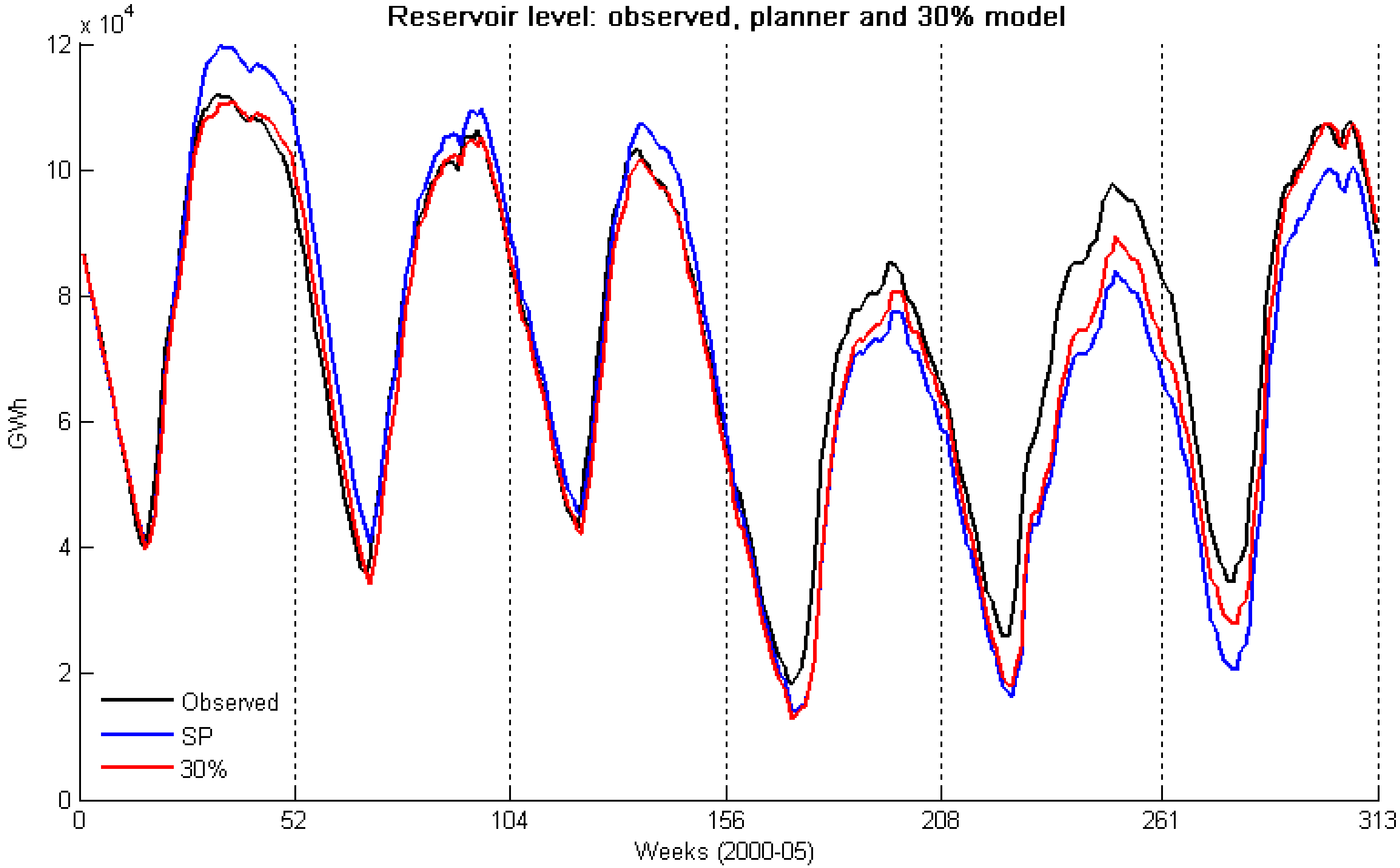
Weeks	SP		15		20		25		30		40		50	
1	1.21	-	1.00	-	0.82	-	0.68	-	**0.55**	-	0.66	-	0.91	-
4	1.20	-	0.98	-	0.80	-	0.66	-	**0.53**	-	0.64	-	0.89	-
13	1.14	28.0	0.93	21.5	0.75	16.4	0.61	12.2	**0.48**	**8.2**	0.57	15.9	0.78	21.1
26	1.06	9.5	0.84	7.3	0.67	5.8	0.53	4.3	**0.40**	**3.2**	0.47	5.9	0.56	10.4
52	0.94	5.8	0.73	4.2	0.58	3.3	0.46	2.4	**0.35**	**1.7**	0.37	3.4	0.48	4.3

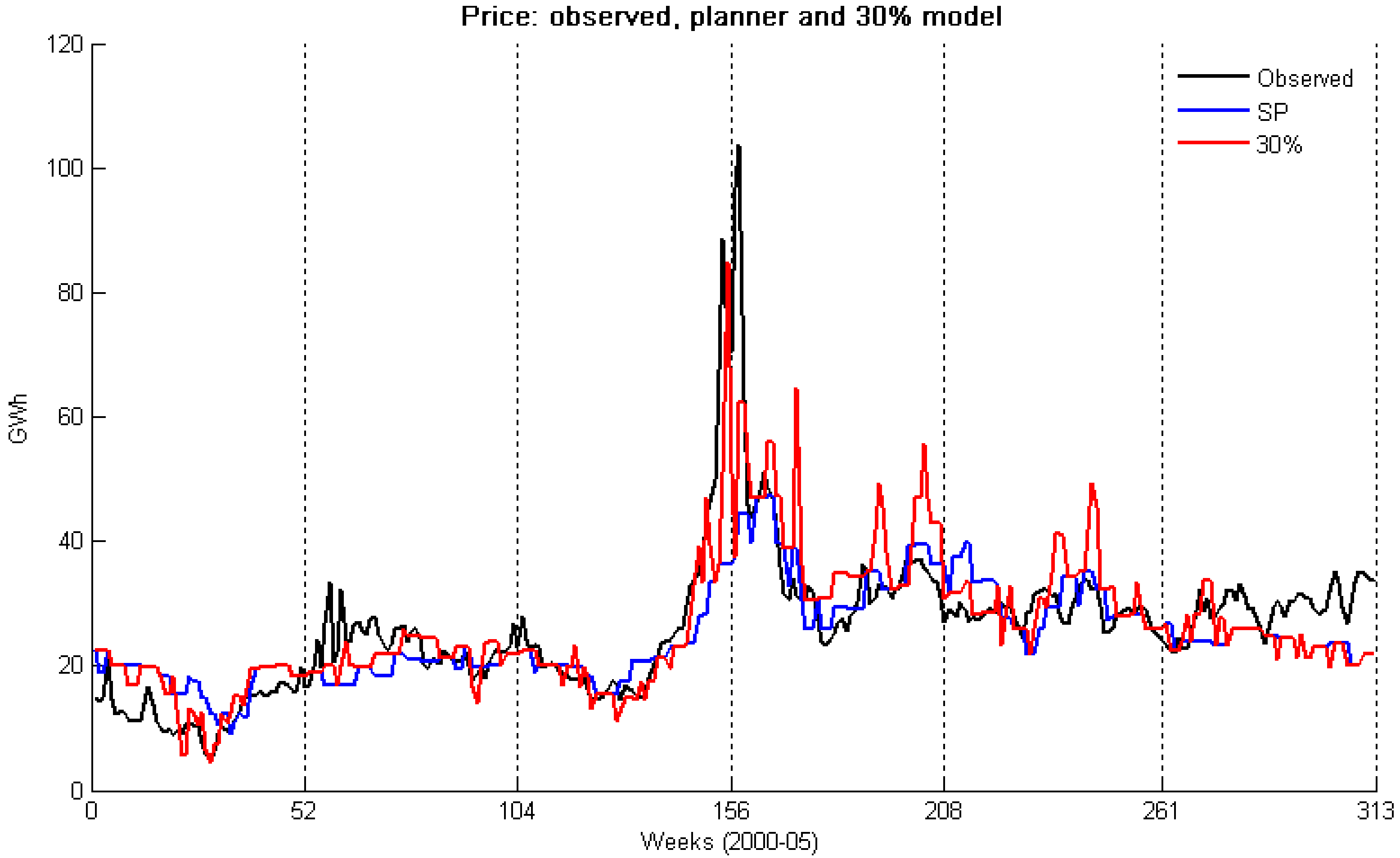
Annual moments

quartely moments

1st stage GMM

2nd stage GMM


Reservoir level: observed, planner and 30% model
x 10^4
12
10
8
6
4
2
0
GWh
0
52
104
156
208
261
313
Weeks (2000-05)
Observed
SP
30%


Price: observed, planner and 30% model
120
100
80
60
40
20
0
GWh
0
52
104
156
208
261
313
Weeks (2000-05)
Observed
SP
30%

Statistics on price and cost (2000-05)

	Observed	SP	20%	30%	40%	50%
Mean price (€/MWh)	26.3	24.9	25.2	26.4	28.0	31.0
Standard deviation	11.9	7.5	8.3	10.6	16.6	28.7
Skewness	2.5	0.9	0.9	1.4	2.3	5.4
Total cost (bn.€)	9.3	8.7	8.8	9.2	9.8	10.9
Welfare loss (bn.€)	0.64	0	0.14	0.57	1.16	2.26

HSE

Concluding remarks

- Long-run simulations imply small welfare losses from market power
- Market power manifested in exceptional situations such as 2002-03
- Several robustness checks in progress
  - Unobserved constraints