# Lecture 7: Electricity markets

## with special focus on the Nordic market

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# Illustration

- demand is $D = 3$
- two producers $i = 1, 2$
- firm 1 cost structure: $c_1 = \{(0, 1), (1, 2), (2, 3), (2.5, 4)\}$
- firm 2 cost structure: $c_2 = \{(0, 1), (1, 2), (2.5, 3)\}$

Market

- firms make bids to produce:
  $b = \{(p_1, 1), (p_2, 2), (p_3, 3), (p_4, 4)\}$
- given bids $b_1$ and $b_2$, supply $S$ can be defined as the lowest price needed to procure quantity $q$.
- for example, If firms bid their costs, supply curve is $S = \{(0, 2), (1, 4), (2, 5), (2.5, 7)\}$
- What is the equilibrium price?

# What does the illustration tell about electricity markets?

1. Demand is inelastic
   - Consumers are not active in the market
   - Demand becomes before the supply
2. Small number of producers
   - Firm 1 above could raise profits by withholding capacity. How exactly?
3. Producers have capacity constraints
   - What if $D > 7$?
4. There is an auction design for clearing the market
   - Uniform price in the illustration
   - Alternative: firms are paid according to their bids
5. Environmental regulation has an impact on costs
   - The impact is different across firms, depending on their technologies
   - The dispatch order of firms will change
   - New firms may enter the market with different costs

# Illustration in practice

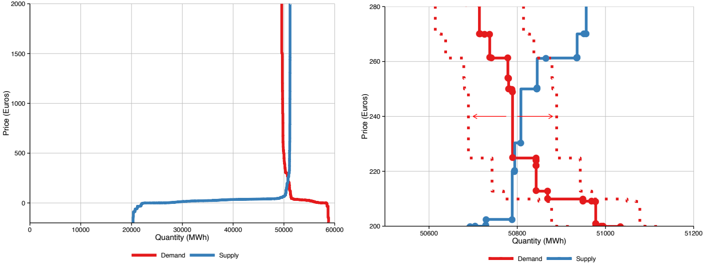



Figure: Supply and demand aggregate bid curve example for production and consumption between 17:00 and 17:59 on 2 February 2012. Nordpool Spot.

# The Nordic Electricty Market

- Among the first deregulated electricity markets. In contrast with many other markets: a cross-border market.
    - Many important wholesale market with somewhat differing market rules: England-Wales, PJM, ERCOT, California, New Zealand,
- Market place: Nord Pool Spot
    - Owned and run by Nordic system operators
    - Norway started 1991, Sweden joined 1996, Finland 1998, and Finally East Denmark 2000. Estonia (2010), Lithuania (2012).
    - Day-ahead market: participants submit bid and ask schedules for each hour of the next day. Using these the market is cleared. If not physically possible, then different price areas are formed ("zonal pricing")

# Nordic Market Area

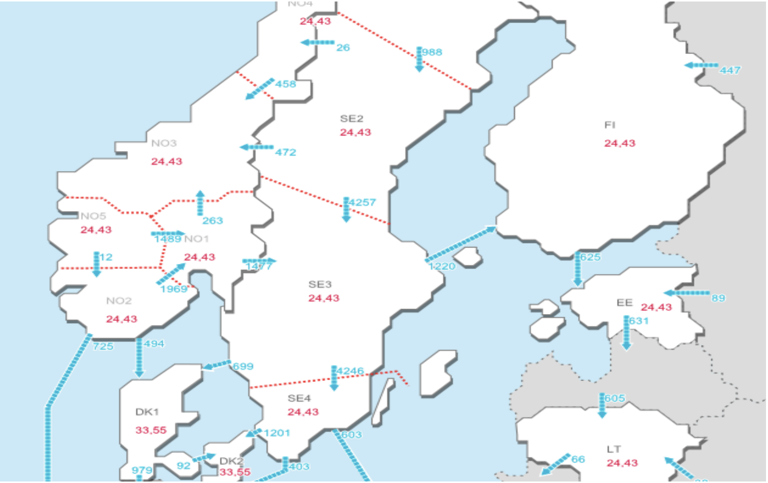



Figure: The Nordic market. April 26 prices (€/MWh) in the price zones (24 h averages). Power flows between the regions in MW. Source: Statnett, the Norwegian TSO (April 26, 2015).

# Nordic Market

- Agents: consumers, retailers, producers, transmission system operator (TSO)
- TSO is responsible for the transmission grid
  - In short term: the trades should be physically feasible
  - In long run: investments to develop the grid
- Consumers
  - consumer needs a contract for electricity. These contracts can be bought from the retail market. Typically longer-term contracts. The retail market is open for competition.
  - The retailer in turn needs contract with the supplier. Such contracts can be bought from the wholesale market. Typically day-ahead market

# Descriptives of the Nordic Market

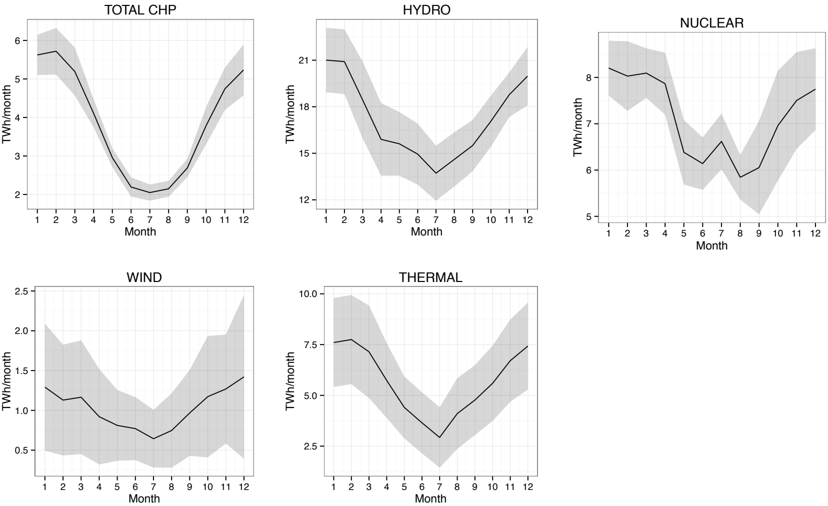
- Electricity is traded hour by hour: lots of data!
- Aggregation to weekly or even monthly level allows better understanding of the fundamentals
  - Demand has a seasonal pattern
  - Hydro resources have also seasonal dynamics
  - Cost shifters such as input prices change not from hour to hour but over longer time periods
- Below I describe the Nordic market at the monthly level using data from years 2001-2014. The data and the code for analysis can be downloaded from *here*. There is also a paper in the folder, providing references for the data sources.

# Generation by technology (annual)

$$\underbrace{DEMAND}_{\text{from consumers}} = \underbrace{HYDRO + THERMAL}_{\text{price sensitive}} + \underbrace{WIND + CHP + NUCLEAR}_{\text{price insensitive}}$$

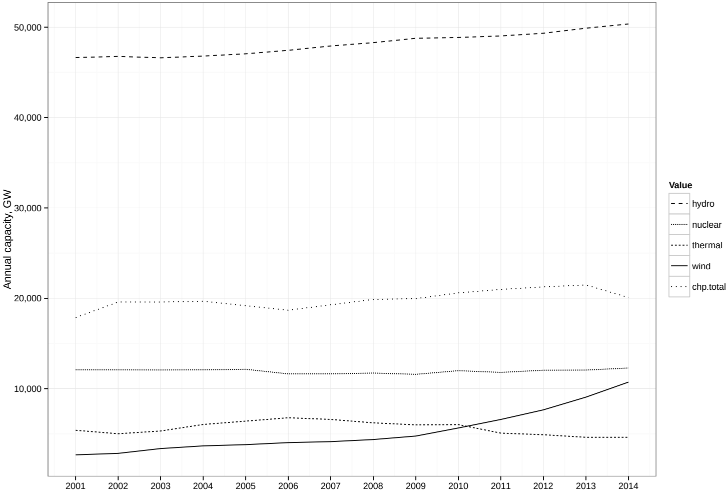
| | HYDRO | THERMAL | CHP | WIND | NUCLEAR |
|---|---|---|---|---|---|
| DEN | 0 | 20.8 | 7.2 | 10.4 | 0 |
| FIN | 13.1 | 37.4 | 14.6 | 0.6 | 22.1 |
| NOR | 126.7 | 0 | 2.4 | 1.6 | 0 |
| SWE | 66 | 14.1 | 7.6 | 7.6 | 63.3 |
| Total | 205.8 | 72.3 | 31.8 | 20.2 | 85.4 |

Table: Annual generation in TWh/year by technology in the Nordic market. Average value in period 2001-2014, except for wind 2010-2014.



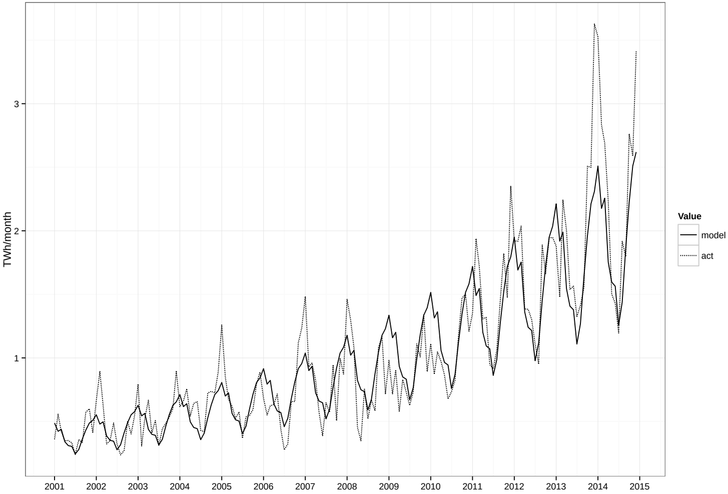

Mean monthly supplies by source in TWh and +/- st. dev. bands in 2001-2014 in the Nordic market area.

# Capacity development (installed)




The Figure depicts the development of the installed capacity in the Nordic countries in period 2001-2014 (measured at the beginning of the year).

# Wind generation development



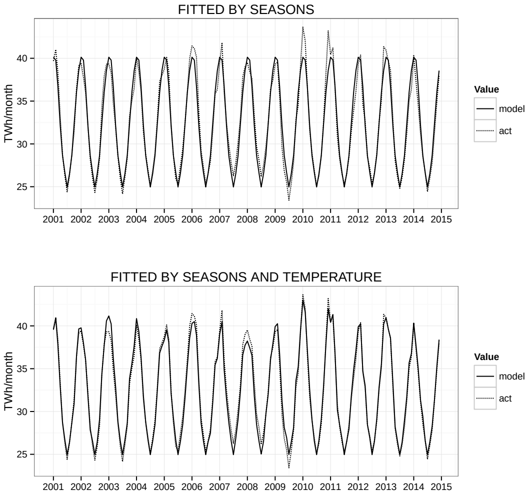

The figure shows the historical mean monthly wind output and the fitted wind output from a regression of wind on month dummies and time trend. Units are in TWh/month. Data from years 2001-2014.

# Seasonal demand

| | (1) | (2) |
|---|---|---|
| Temperature | | 0.63 (0.04)*** |
| Jan | 44.89 (0.41)*** | 32.51 (0.82)*** |
| Feb | 44.61 (0.51)*** | 32.17 (0.83)*** |
| Mar | 41.12 (0.51)*** | 30.78 (0.71)*** |
| Apr | 35.62 (0.31)*** | 29.30 (0.51)*** |
| May | 31.16 (0.22)*** | 29.24 (0.24)*** |
| Jun | 28.47 (0.25)*** | 28.32 (0.26)*** |
| Jul | 26.68 (0.23)*** | 26.67 (0.23)*** |
| Aug | 28.33 (0.21)*** | 28.22 (0.19)*** |
| Sep | 30.95 (0.21)*** | 29.18 (0.21)*** |
| Oct | 35.54 (0.31)*** | 29.44 (0.42)*** |
| Nov | 40.04 (0.44)*** | 31.11 (0.60)*** |
| Dec | 43.03 (0.65)*** | 31.58 (0.73)*** |
| $R^2$ | 0.95 | 0.98 |
| Adjusted $R^2$ | 0.95 | 0.98 |
| Observations | 168 | 168 |
| *Note:* | *p<0.1; **p<0.05; ***p<0.01 | |

The table reports total demand $D_t$ (measured in TWh) regressed on: seasons (column 1); seasons and temperatures (column 2). The temperature measured in Nordic heating degree days. Robust standard errors in parentheses.The seasonal quantities are directly informative about the mean aggregate demand per month in TWh. When the temperature decreases by one degree Celsius, the demand increases by .63 TWh/month. With $R^2 = .98$, the Nordic climatic conditions explain almost all of the variation in the seasonal demand.

# Seasonal demand



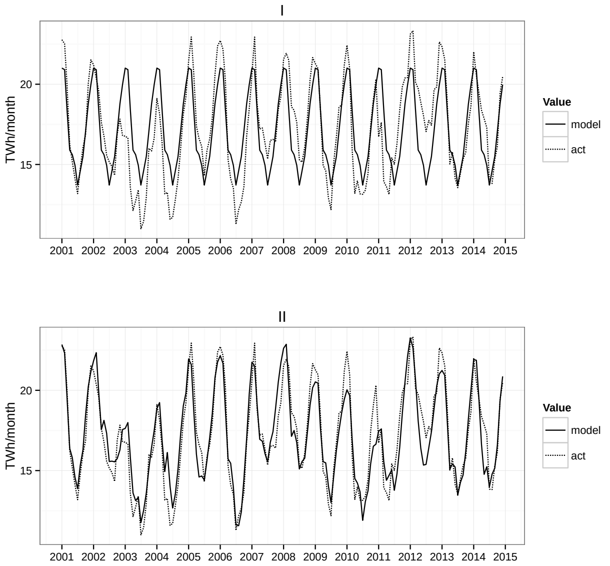

Actual (dotted lines) and the estimated TOTAL DEMAND (solid lines) (TWh/month) in years 2001-2014. Upper panel: actual and fitted values from TOTAL DEMAND regressed on seasons (column 1 of the Table). Lower panel: actual and fitted values from TOTAL DEMAND regressed on seasons and temperature (column 2 of the Table)

# The power of simple regression analysis: explaining generation patterns of hydro

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Inflow | | $-0.001$ | $0.06^{***}$ | $0.05^{**}$ |
| Reservoir | | $0.15^{***}$ | $0.16^{***}$ | $0.16^{***}$ |
| Demand $d_t$ | | | $0.50^{***}$ | $0.51^{***}$ |
| Trend | | | | $0.10^{***}$ |
| Month FE | YES | YES | YES | YES |
| $R^2$ | 0.63 | 0.86 | 0.91 | 0.92 |
| Adjusted $R^2$ | 0.6 | 0.84 | 0.9 | 0.91 |
| Observations | 168 | 168 | 168 | 168 |
| *Note:* | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 | | | |

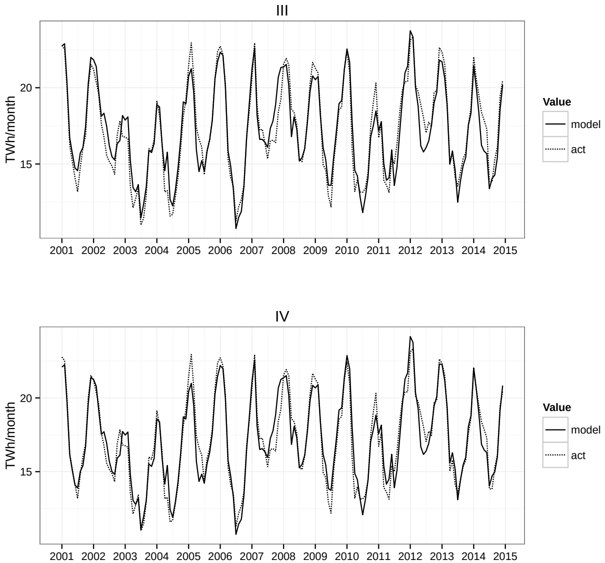
Notes: Linear regression of the hydro output on the following variables. Column (1): seasonal dummies. Column (2): seasonal dummies + inflow + reservoir. Column (3): seasonal dummies + inflow + reservoir + residual demand. Column (4): seasonal dummies + inflow + reservoir+residual demand+trend. Units: inflow, reservoir, demand, and production is measured Terawatt hours. Variables ”demand” and ”reservoir” expressed as deviations from seasonal mean values. Robust standard errors for estimates in column 4: inflow 0.02, reservoir 0.01, demand 0.04, and trend 0.01.

# Fitted and actual hydro generation




Estimation results from Table. Solid lines = fitted values, dotted lines=actual. Hydro policies estimated on four sets of explanatory variables (TWh/month) in years 2001-2014. I: seasons. II: seasons+inflow+reservoir.

# Fitted and actual hydro generation




Estimation results from the Table. Solid lines = fitted values, dotted lines=actual. Hydro policies estimated on four sets of explanatory variables (TWh/month) in years 2001-2014. III: seasons+inflow+reservoir+trend. IV: seasons+inflow+reservoir+trend+demand.

# The same exercise for the thermal power generation:

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Inflow | | $-0.10^{***}$ | $-0.06^{***}$ | $-0.04^{**}$ |
| Reservoir | | $-0.12^{***}$ | $-0.11^{***}$ | $-0.11^{***}$ |
| Demand $d_t$ | | | $0.33^{***}$ | $0.32^{***}$ |
| Trend | | | | $-0.14^{***}$ |
| Month FE | YES | YES | YES | YES |
| $R^2$ | 0.44 | 0.79 | 0.82 | 0.88 |
| Adjusted $R^2$ | 0.4 | 0.77 | 0.81 | 0.87 |
| Observations | 168 | 168 | 168 | 168 |
| *Note:* | | | $^{*}$p$<$0.1; $^{**}$p$<$0.05; $^{***}$p$<$0.01 | |

Notes: Linear regression of the thermal output on the following variables. Column (1): seasonal dummies. Column (2): seasonal dummies + inflow + reservoir. Column (3): seasonal dummies + inflow + reservoir + trend. Column (4): seasonal dummies + inflow + reservoir+trend+temperature. Units: inflow, reservoir, demand, and production is measured Terawatt hours. Variables ”demand” and ”reservoir” expressed as deviations from seasonal mean values. Robust standard errors for estimates in column 4: inflow 0.02, reservoir 0.008, demand NA, and trend 0.015.

# Thermal power generation: regression result depicted

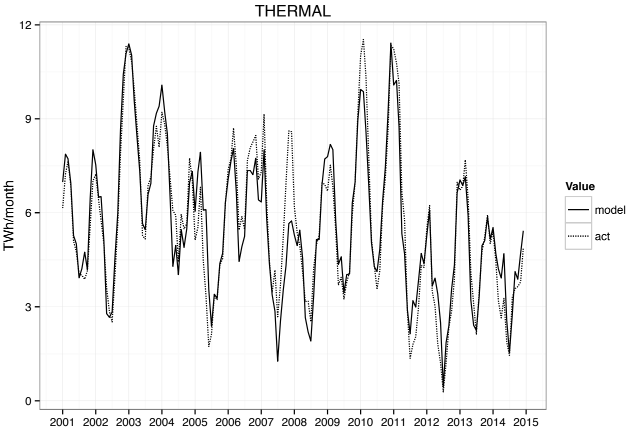



Figure: Explaining thermal power generation

# Prices: a simple regression analysis

Let $q_t^{TH}$ denote thermal power quantity at time $t$, coming from the regression just explained. We regress (the log of) the spot price $p_t$ on (log of) of the index of marginal costs $mc_t$ and on quantity $q_t^{TH}$:

$$\ln p_t = \alpha_0 + \alpha_1 \ln mc_t + \alpha_2 q_t^{TH} + \epsilon_t. \tag{1}$$

Marginal cost is calculated as follows:

$$mc = \frac{COAL.PRICE + EUETS \times .341}{.36}$$

where EUETS is the emissions trading price (European Energy Exchange AG). Coal emission rate is 0.341 $gCO2/kWh$ (Statistics Finland), and the average power efficiency of condensing power plants is assumed to be 36 % (Statistics Finland). COAL.PRICE is from HWWI Coal Eurozone price index at Thompson Reuters Datastream.

| | |
|---|---|
| log(mc) | 0.41 (0.03)*** |
| Thermal | 0.10 (0.01)*** |
| Constant | 1.52 (0.13)*** |
| Observations | 168 |
| $R^2$ | 0.70 |
| Adjusted $R^2$ | 0.70 |

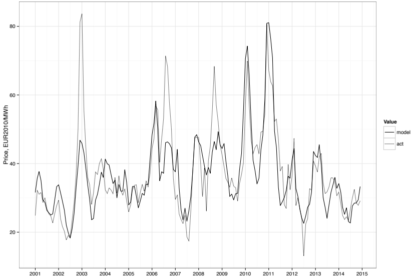
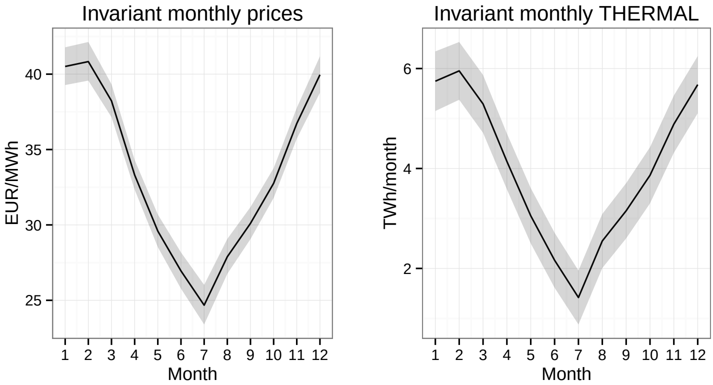



Figure: The table reports the estimates of the coefficients of the thermal supply. Standard errors are reported in parentheses. The coefficient on Thermal reported per TWh of output. All data: monthly observations in years 2001-2014.

# The results predict the following average behavior:




The expected monthly mean prices (in 2010 Euros/MWh) and monthly meanTHERMAL outputs (GWh/month), and their respective 95 confidence intervals. THERMAL output is from the regression above, using historical mean values for the explanatory variables. The confidence interval for outputs follows from that regression directly. The mean invariant price is the price implied by the output from THERMAL policy, using the estimated supply curve. The confidence interval for prices is obtained by applying the supply estimates at the confidence bounds for the policy estimates.