FONDAZIONE ENI ENRICO MATTEI

Measuring the potential value of demand response using historical market data

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Agenda

1. Motivation of the study
2. Demand Response
3. Aggregation of DER
4. Market data and volatility measures
5. Empirical analysis
6. Conclusion

Motivation of the study

- EU-DEEP (FP6 project) → "the birth of a EUropean Distributed EnErgy Partnership that will help the large-scale implementation of distributed energy resources in Europe"
- One of the main issues related to the deployment of Distributed Energy Resources (DER), which is the combination of Demand Response (DR) and Distributed Generation (DG), is the ex-ante assessment of their benefits
- One of the main results of Eu Deep is the analysis of three business cases studying the possibilities of aggregation of DER
- The profitability of these solutions depends heavily on markets volatility

Motivation of the study (2)

- We want to infer a general assessment of profitability of DR on the basis of historical market results, but one single value of volatility cannot fully retain DR commercial potential and results are sensitive to the type of index used
- Our goal is to show that through a detailed analysis of volatility and price patterns it is possible to infer more information on the possible most profitable technologies and customers' profiles
- Customers in Demand Response are the providers of an economic good or their flexibility, which can be sold in the market

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Demand Response

- DR is any "*change in electric usage by the end-use customers from their normal consumption patterns in response to change in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*" (US Department of Energy, 2006)
- *Price-based DR* → end-user prices are (more or less) linked to the wholesale price of electricity (Real Time Pricing, Time-of-Use Pricing)
- *Incentive-based DR* → specific contracts designed to favor the availability of DR in particular critical times (more flexible than traditional pricing systems). The economic incentive is usually a combination of *bill savings for enrolling* in the programs with the commitment of reducing load when called, and *penalties for not responding* when the event is called

Economic rationale of DR

- Theory of peak load pricing (Boiteaux, 1949; Steiner, 1957, *QJE*) → prices should be higher during high-demand states providing incentive to efficient use of capacity → TOU prices
- Use of price as an instrument of congestion management and to favor system reliability (Bohn et al., 1984, *RJE*; Kleindorfer and Fernando, 1993, *JRE*) → dynamic pricing
- Without a direct connection between wholesale and retail market prices, serious inefficiency issues may rise, also in relation to market power potential in the wholesale market (Borenstein and Holland, 2005, *RJE*) → DR is the "missing" link

Costs Associated with the Implementation of Demand Response

- Costs incurred by the customer to provide flexibility:

I. Magnitude of the requested reduction (curtailment) or shift in consumption
II. Length of the shift (few minutes to several hours)
III. Time of the day, when the action is required
IV. Season (life is structured differently in different seasons)
V. Frequency of the request (daily, monthly, yearly)
VI. Timing of notice (e.g. one day, one hour, no notice)

- Technological costs

  It is necessary to provide a communication infrastructure to support the exchange of information between customers and the company controlling DR

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Aggregation of DER

- Aggregation is the combined management of several DER units
- The Aggregator is a commercial entity with as a main purpose the optimization of the energy use of several customers
- The customers have installed at their site DR, DG or storage technologies
- Aggregation allows to increase their profitability allowing access to the various electricity markets as the costs of participation for the customers individually are too high
- Studying the characteristics of volatility can help the aggregator to choose the most profitable customers and technologies

Aggregation of DER

- There is no fixed preferred type of volatility as it is function of the interaction between the available technologies and the available customer profiles
- Preferred technologies can vary locally especially as they could be based on RES
- **Actions of the aggregator**:

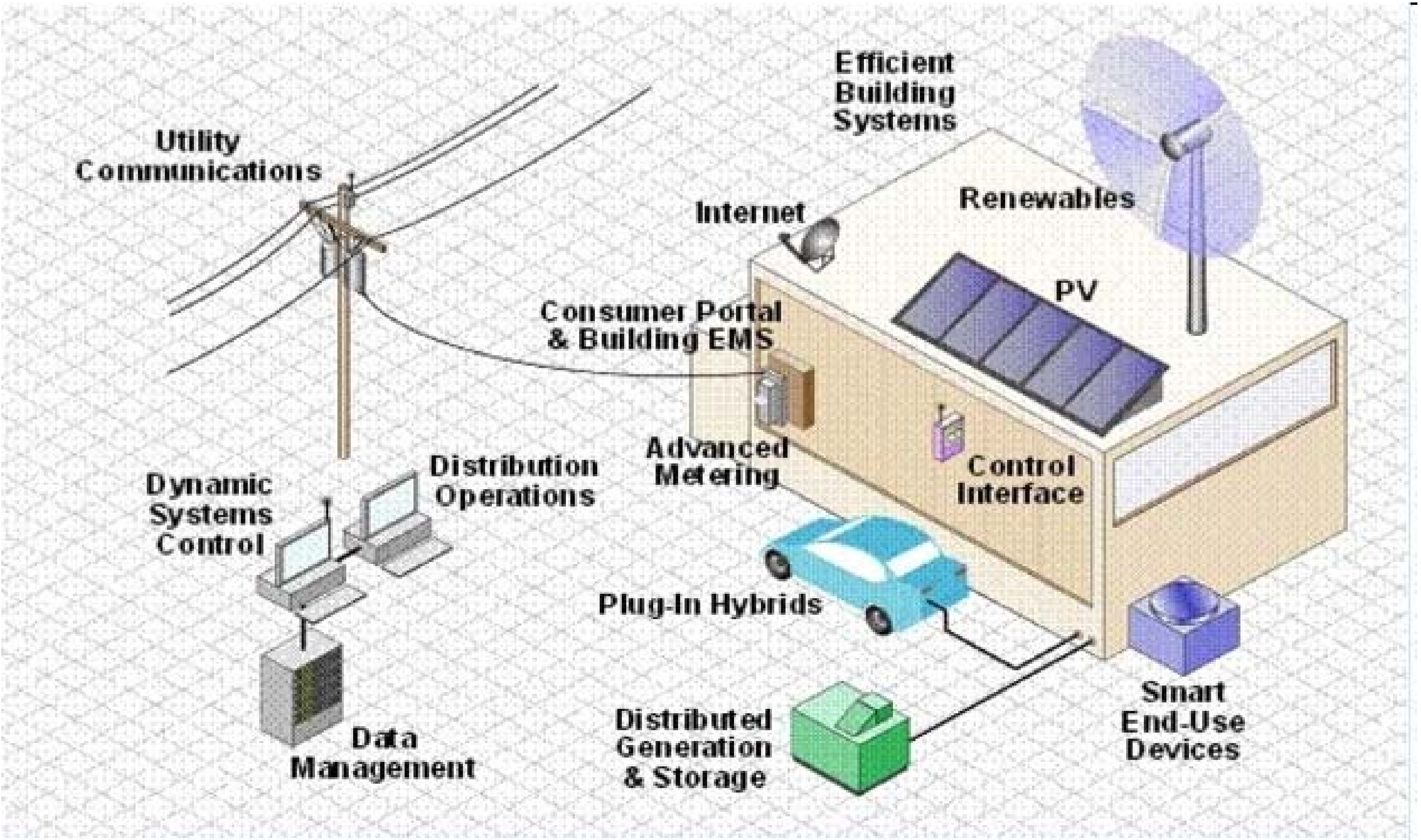
✓ Choice of investments in technologies

✓ Selection of customers with the highest flexibility potential

✓ Continuous management and optimization of the system

- Remark: the control of the Electricity System is not fully decentralized. The aggregator is a sufficiently large entity which can be compared to a medium-large generator.

Aggregation of DER (Local Energy System)



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Duration curves

$$LDC(y_l) = \frac{1}{T}\sum_{h=1}^{T} 1, \forall l_h > y_l$$

$$PDC(y_p) = \frac{1}{T}\sum_{h=1}^{T} 1, \forall p_h > y_p$$

- Describe the (historical) probability of having load (or price) above a certain threshold
- Peak loads and peak prices are certainly associated to higher potential value of DR

Volatility measures

- Historical volatility is the standard deviation of logarithmic returns ($r_{t,h}$) over a time window (T)

$$\sigma_{h,T} = \sqrt{\frac{1}{(N-h)} \sum_{t=1}^{N} (r_{t,h} - \bar{r}_{h,T})^2}$$

h is the temporal distance between the two price observation that are compared

N is the number of observation (e.g. 24 hours in a day)

- Volatility indexes provide essential information to understand the need of short-term DR and the evaluation of DR strategies based on time-shift

Volatility measures

- Daily Velocity with reference to Daily Average (DVDA) is an alternative measure of volatility (Li and Flinn, 2004). The concept of price velocity employs the daily average of price changes to quantify price uncertainty.

$$DVDA = \frac{\left\{ \left(\frac{1}{N-h} \right) \sum_{t=1}^{N} \delta_{t,h} \right\}}{\frac{1}{N} \sum_{t=1}^{N} p_t}$$

$\delta_{t,h}$ is the price variation in absolute value

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What should we look for?

- We look for characteristics of price patterns correlated with:

✓ Economic benefits associated to DR (for example, high price levels and high price volatility)

✓ Cost of providing flexibility by the clients (for example, time of day when DR should occur, seasonality, frequency, predictability)

✓ Possibility of implementation by the aggregator (for example, it may be easier to implement DR during office hours; trading opportunities between day-ahead and balance markets)

- "Interesting events" → when the characteristics of price patterns make it profitable for the aggregator to implement DR

Descriptive statistics

Statistic	Description	Italy	Belgium	Uk (£)	France	Spain
	Standard descriptive statistics					
$\overline{p}_{YEAR}$	Average price over year 2007	**70,99**	41,78	27,85	40,88	39,35
σ_{YEAR}	Standard deviation	37,02	**54,47**	24,23	49,45	13,19
VI_{YEAR}	Variability index (σ_{YEAR}/ VI_{YEAR})	0,52	**1,30**	0,87	1,21	0,34
Max	Maximum value of price	242,42	**2.500**	639,54	**2.500**	130
$90\%q$	90% quantile (10% observation above this price)	**119,61**	71,00	42,43	69,61	56,50
$95\%q$	95% quantile	**149,78**	95,51	58,55	92,50	66,11
$\overline{\sigma}_{DAY}$	Average value of the daily standard deviation	**31,86**	19,92	14,30	18,15	9,42
$\overline{VI}_{DAY}$	Average value of the variability index computed day by day	**0,44**	0,38	**0,44**	0,36	0,24
$\rho_{LOAD,PRICE}$	Correlation between load and price	**0,81**	0,28	-	-	0,76

Volatility measures

Statistic	Description	Italy	Belgium	Uk	France	Spain
$\overline{\sigma}_{1/2,DAY}$ (UK)	Average value of the daily volatility, computed considering consecutive half-hours			0,176		
$\overline{\sigma}_{1,DAY}$	Average value of the daily volatility, computed considering consecutive hours (lag 1 hour)	0,240	0,262	**0,271**	0,248	0,128
$\overline{\sigma}_{2,DAY}$	Average value of the daily volatility, computed considering a lag of 2 hours	0,391	**0,398**	0,331	0,373	0,208
$\overline{\sigma}_{3,DAY}$	Average value of the daily volatility, computed considering a lag of 3 hours	0,502	**0,510**	0,369	0,470	0,262
$\overline{\sigma}_{4,DAY}$	Average value of the daily volatility, computed considering a lag of 4 hours	0,578	**0,580**	0,404	0,530	0,297
$\overline{\sigma}_{1/2,WORK}$ (UK)	Average value of the daily volatility, computed considering consecutive half-hours, 8am-7pm (or 7am-8pm)			0,221 – 0,224		
$\overline{\sigma}_{1,WORK}$	Average value of the daily volatility during work days, computed considering consecutive hours, 8am-7pm (or 7am-8pm)	0,263 – 0,271	0,150 – 0,198	**0,348 – 0,346**	0,129 – 0,159	0,093 – 0,109
$\overline{\sigma}_{2,WORK}$	Average value of the daily volatility during work days, computed considering a lag of 2 hours, 8am-7pm (or 7am – 8pm)	0,413 – **0,429**	0,235 – 0,291	**0,417** - 0,414	0,201 – 0,237	0,147 – 0,167
$\overline{DVDA}$	Average value of the Daily Velocity Daily Average	**0,171**	0,15	0,148	0,139	0,091
$\overline{DVOA}$	Average value of the Daily Velocity Overall Average	0,176	0,19	0,164	**0,178**	0,091

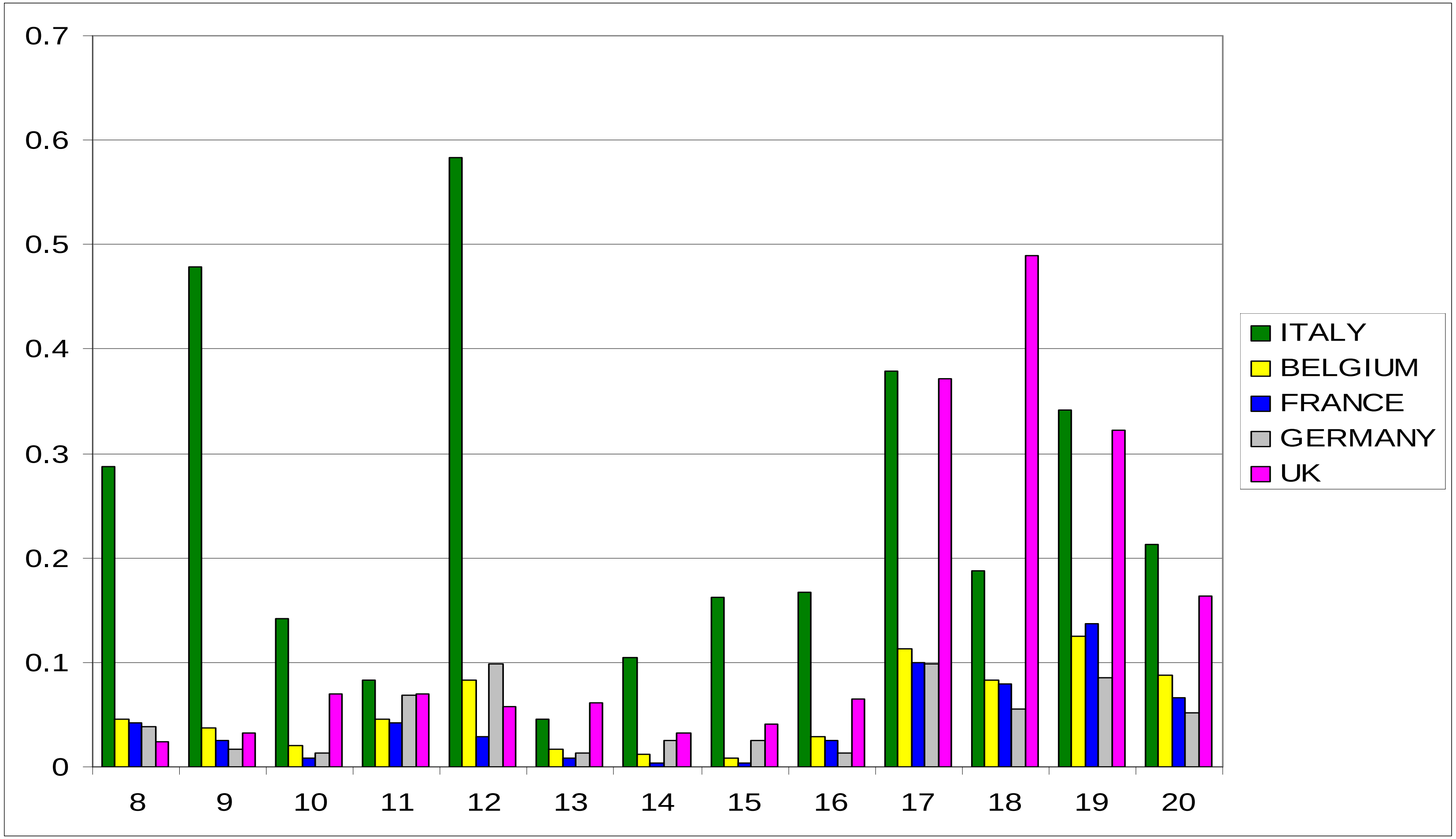
Volatility and DR

- The costs for consumers to implement DR depend on the length of the shift in consumption (How long) ➔ volatility indexes are computed considering different lags
- Possibility to implement DR (When) ➔ volatility index filtered to consider only working hours
- Volatility “ranks” of markets depend heavily on the index used ➔ this means that different DR characteristics are preferred in different markets

Volatility and seasonality (Germany)

	2007-2009	Winter (Nov-Jan)	Other months	Difference
Volatility (lag 1 hour)	0.260 (0.009)	0.361 (0.024)	0.230 (0.008)	0.131 *** (0.020)
Volatility (lag 2 hours)	0.381 (0.010)	0.493 (0.027)	0.348 (0.009)	0.145 *** (0.023)
Volatility working hours (lag 1 hour)	0.164 (0.006)	0.241 (0.022)	0.143 (0.003)	0.098 *** (0.013)
Volatility working hours (lag 2 hour)	0.228 (0.006)	0.316 (0.020)	0.204 (0.004)	0.112 *** (0.013)

“Interesting” events

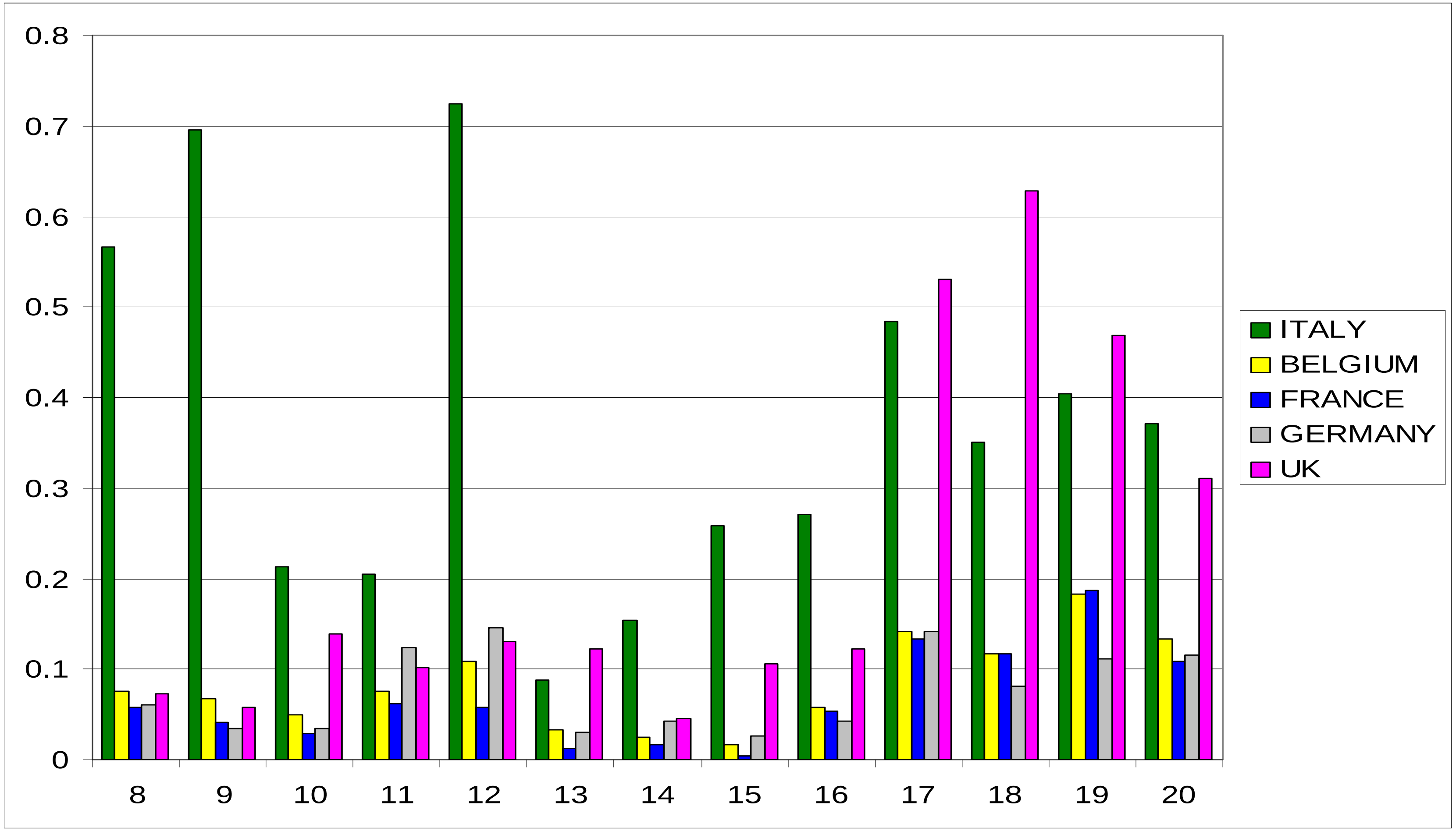


Frequency of price differentials above an arbitrary threshold of 30 Euros, by time of day

Comments

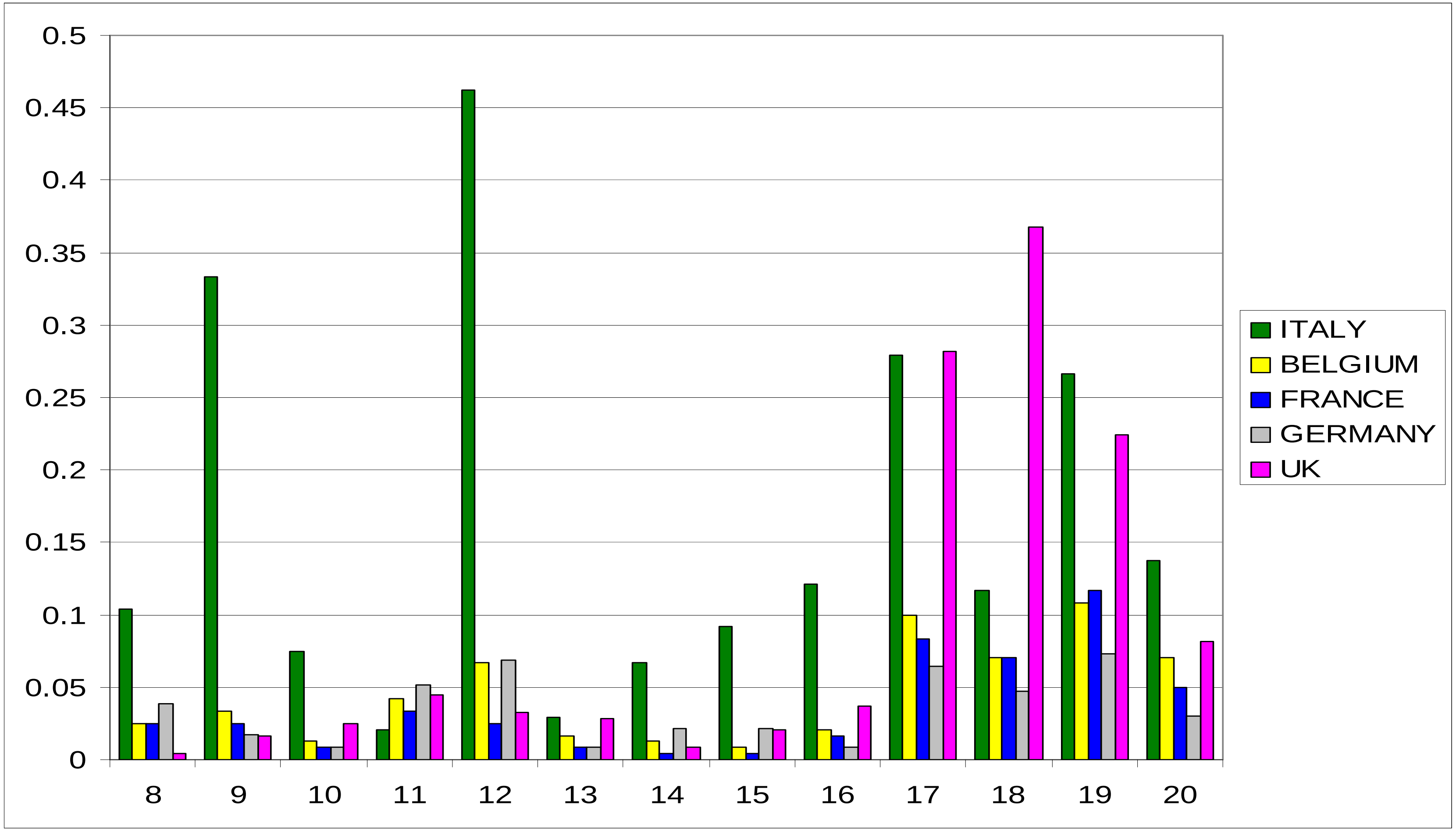
- The threshold of 30 Euros is arbitrary, sensitivity analysis is needed (also the analysis can extend to lag higher than one hour)
- It represents a realistic cost to implement DR
- As technologies are exploited jointly it is not useful to express a value per technology
- The figure helps to understand the "frequency" of events and also the "time of day" when they occur
- Italy and Uk register the higher number of events, rather concentrated in few hours of the day (predictability); Belgium, France has fewer and less predictable events.
- This can be seen also from comparing descriptive statistics of price differentials (Italy vs Belgium in the example)

“Interesting” events



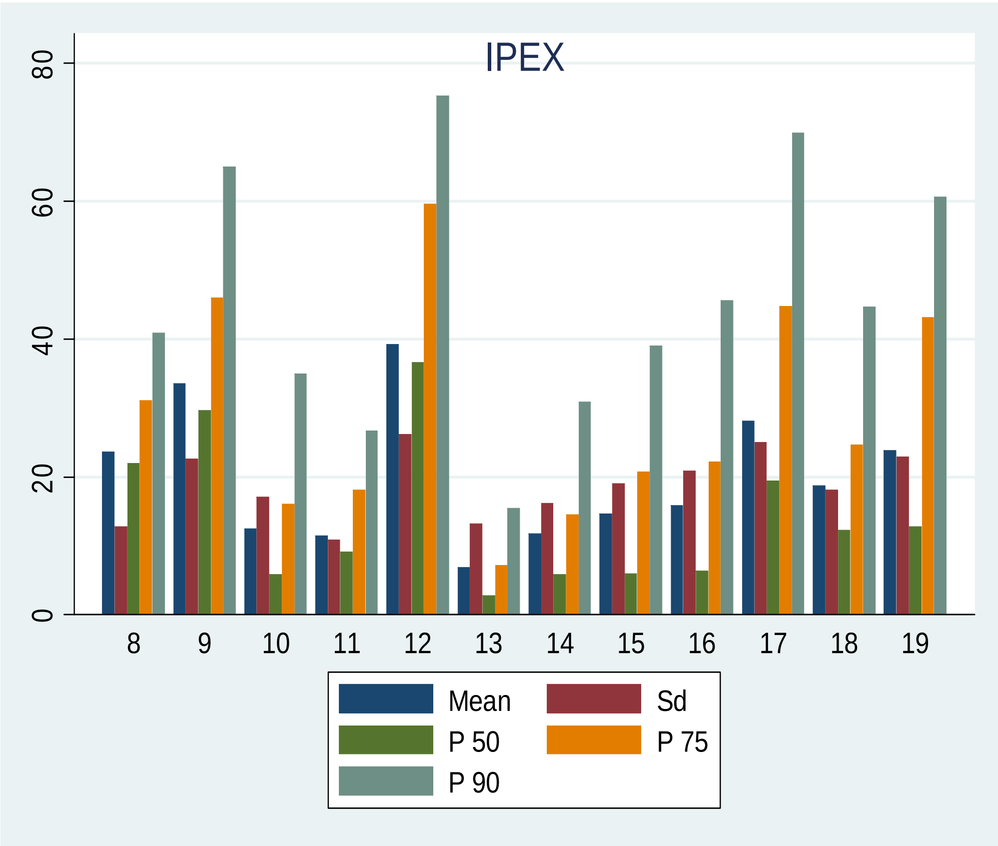
Frequency of price differentials above an arbitrary threshold of 20 Euros, by time of day

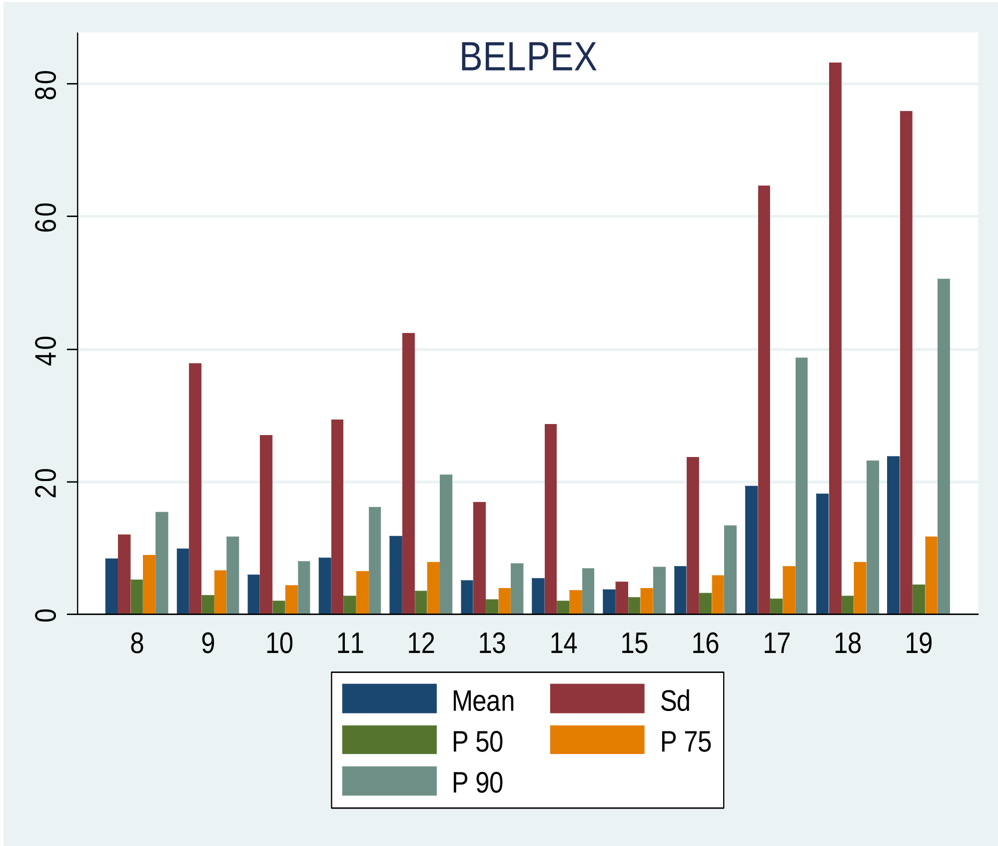
“Interesting” events



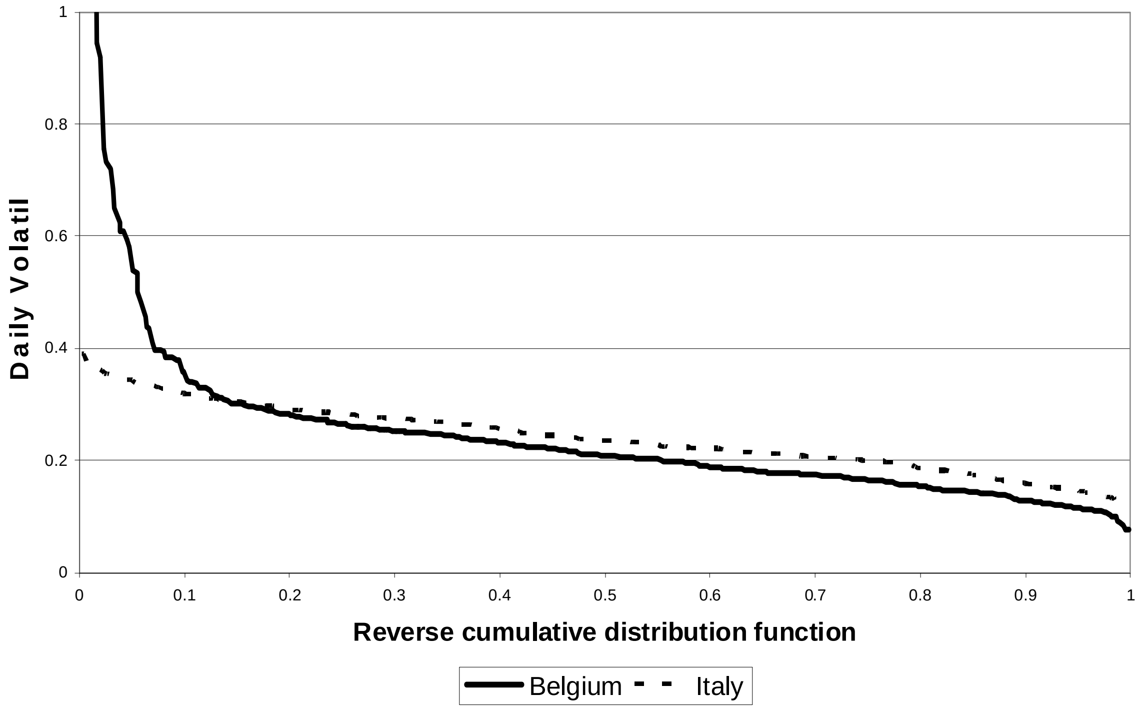
Frequency of price differentials above an arbitrary threshold of 40 Euros, by time of day

Italy vs. Belgium





Daily volatility distribution (Italy vs. Belgium)



- Italy presents characteristics of a country with a certain regularity in daily volatility, instead Belgium has sporadic events. In terms of customers then Italy would favor customers with frequent availability, a characteristic not necessary in Belgium, which instead could be an interesting case for customers, which could accept few curtailments per year with very low probability of overriding.

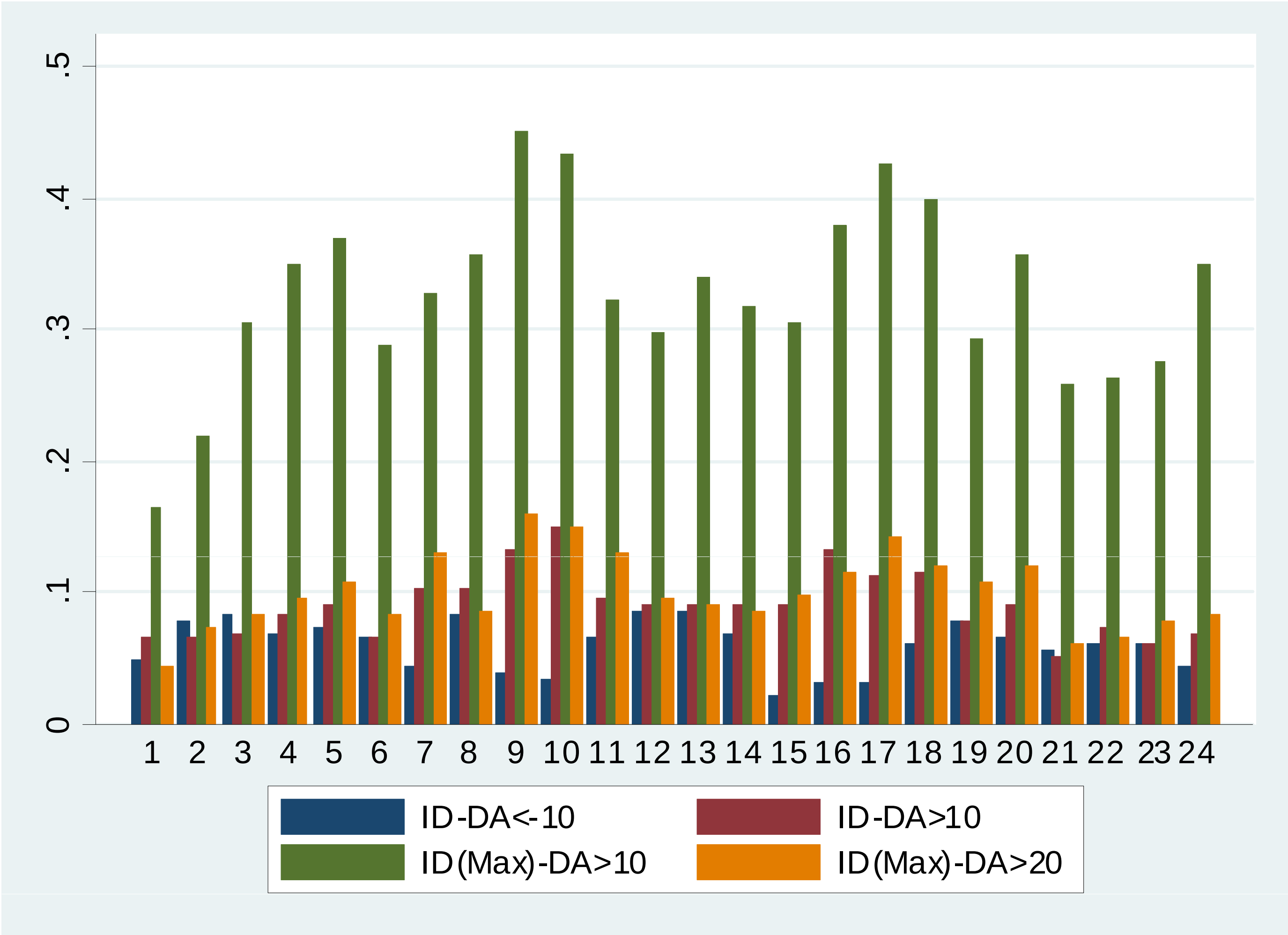
Analysis of the Intraday market

- Case study for Germany
- Intraday market ➔ pay-as-bid auction (day ahead is a uniform marginal price auction)
- We suppose that an aggregator (retailer) can trade his forward position acquired in the day ahead and ask his customers to reduce their consumption
- We analyze the difference in price realization of the day ahead (unique) price with
  - the average price in the intraday market
  - the maximum price in the intraday market

Descriptive statistics

Price differential (Intraday price – Day Ahead Price)		
	Intraday Average	Intraday Maximum
Mean	-0.31	7.37
Std. Dev.	12.32	40.23
Percentiles 1%	-28.67	-18.67
5%	-15.45	-9.07
10%	-10.97	-5.76
25%	-5.50	-0.24
50%	-0.55	5.07
75%	4.82	11.95
90%	11.11	20.42
95%	15.97	28.40
99%	30.66	55.09

Interesting events



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Conclusion and future research

- Simple volatility analysis cannot fully retain DR commercial potential
- Different features of the market can be interesting for the deployment of different types of DR and technologies
- Future research should extend to the Ancillary Services Markets (last minutes reserves used by TSOs) and should also investigate the connections across different markets

THANK YOU!

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