An Optimization Approach for the Design of Time-of-Use Rates

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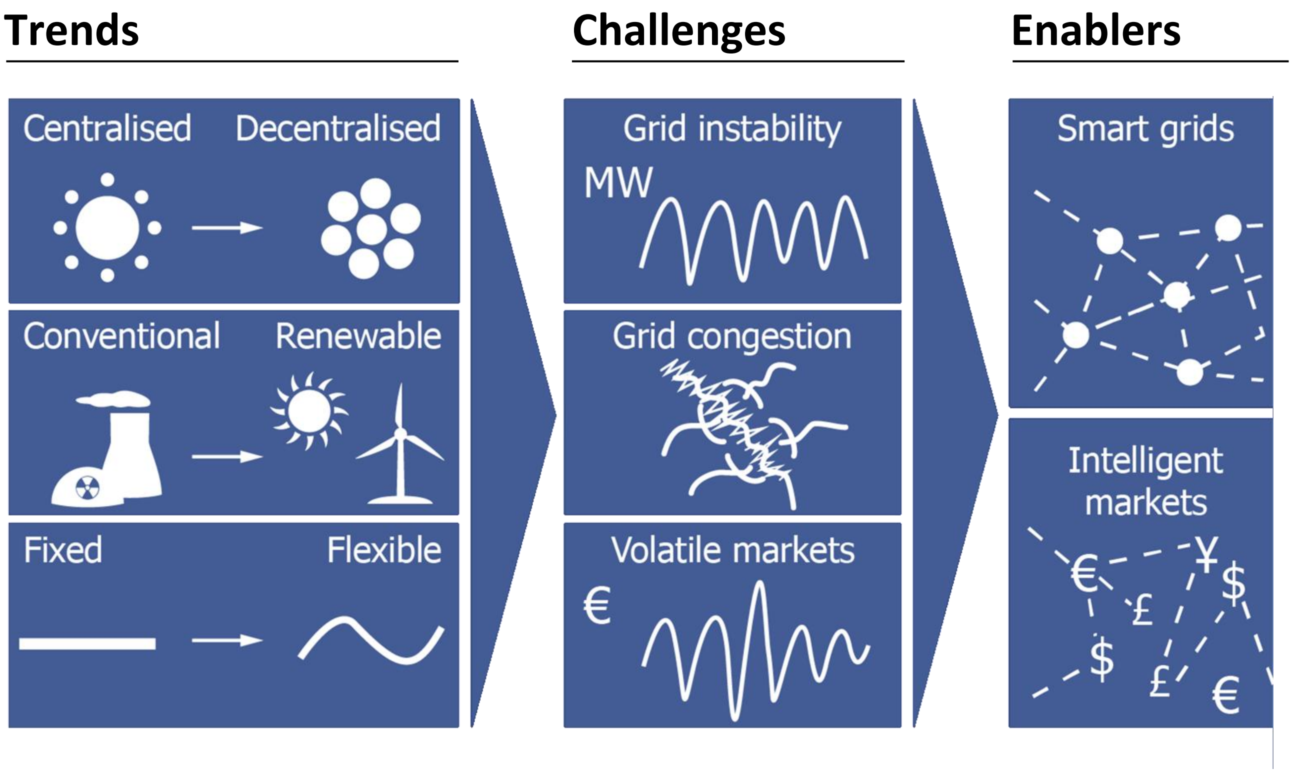
Agenda

Market design and load flexibility are key components to cope with current power system challenges



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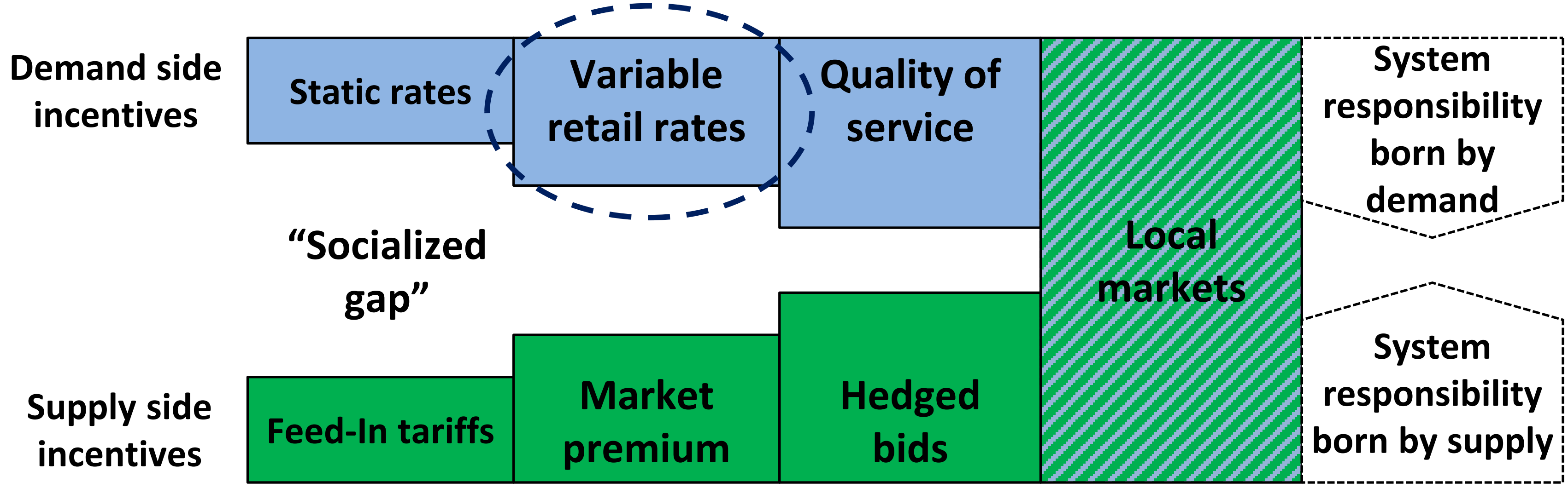
Intelligent markets are obtained from the composition of incentives



⇨ **Today's focus: An optimization approach for the design of variable retail electricity rates**

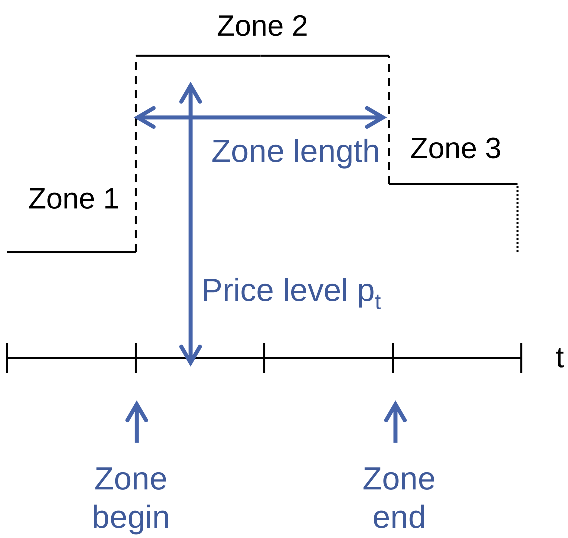
Variable rates are efficient but need to account for the „human dimension“

- Wholesale prices reflect diversity, dynamics and uncertainty of power system [Keles et al. 2012]
- Variable retail rates offer a means to expose demand side to price risk [Schweppe et al. 1988]
- Two notions of rate variability:
  - Rate granularity (# time zones)
  - Rate dynamics (update interval)
- Limited acceptance of too complex rate designs [Goett et al. 2000, Gerpott and Paukert 2012]:
  - Preference for fewer rate zones (low granularity)
  - Preference for static rates (no/ low rate dynamics)
- Load automation increases acceptance [Dütschke and Paetz 2013]

Time-of-use rates can moderate rate complexity to ensure efficiency while retaining customer acceptance

Research on time-of-use rates has explored only limited design options

Rate Structure



	Rate zones	Zone length	Dynamics
Oren et al. (1987)	Variable	Exogenous	Static
Reiss and White (2005)	2 / 5	Exogenous	Static
Celebi and Fuller (2007)	3	Exogenous	Static
Ahlert and van Dinther (2009)	Variable	Symmetrical	Static

Rate zone length, varying number of time zones and dynamics as potential design options

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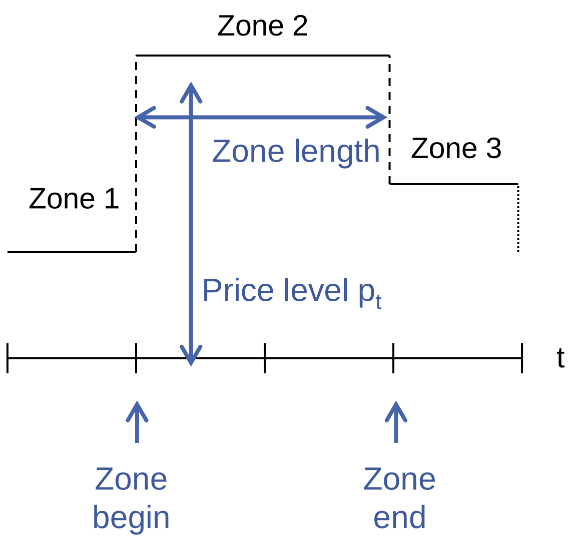
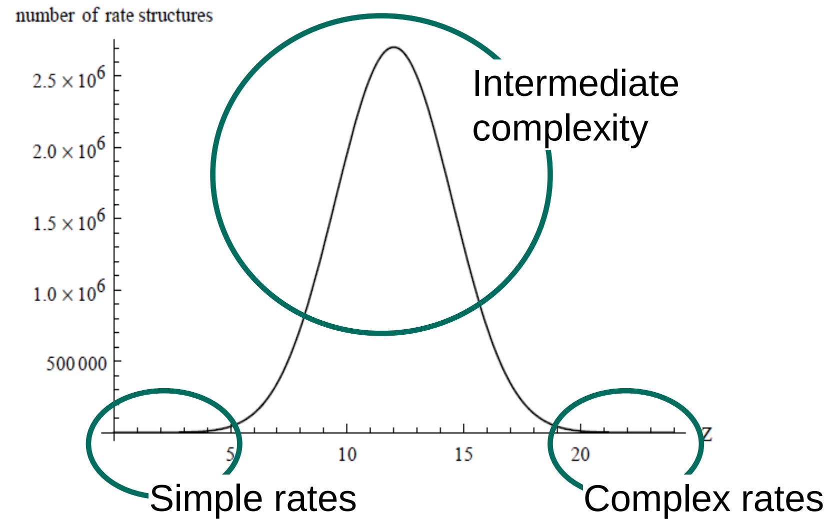
Designing customized time-of-use rates is computationally complex

Rate Structure



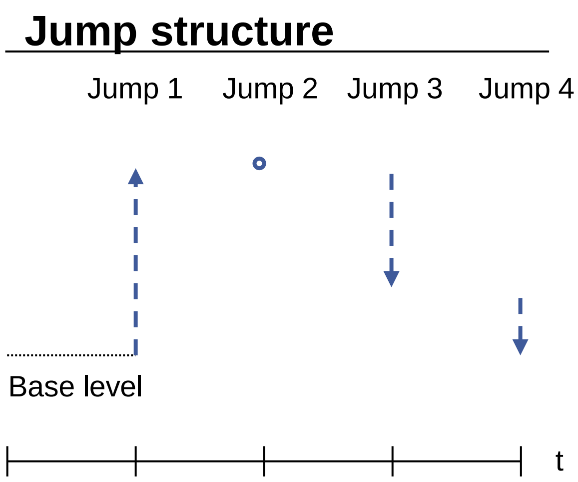
Combinatorial complexity



- Multitude of design options for rates with intermediate complexity
- Dynamic updating of rates and segment-specific rates necessitate determination of many individual rate designs

Need for efficient rate design approach

A mixed-integer optimization model for the time-of-use rate design problem



Decision variables

- Hourly price level [implicit]: $p_t \in R$
- Jump indicator [explicit]: $j_t^{+/-} \in \{0,1\}$
- Jump magnitude [explicit]: $\Delta_t^{+/-} \in R^+$

Objective function

Minimize hourly absolute deviation from wholesale costs: $\min_{\mathbf{p}} \sum_{t \in \mathrm{T}} |p_t - c_t|$

Constraints $\forall t \in \{1,..,T\}$:

- Rate structure: $p_t = p_{t-1} + \Delta_t^+ - \Delta_t^-$
- Jump structure: $\Delta_t^{+/-} \leq j_t^{+/-} \cdot \xi$
- Granularity: $\sum_{t=1}^{T} j_t^+ + j_t^- \leq Z$

Optimal rate structure can be determined by solver

Optimization program facilitates a rich set of other design constraints

- *“Freeze times”*

$$\Delta_t = 0 \;\forall t \in F$$

- *Price spread limitations*

$$p_i - p_j < \eta \;\forall i \neq j$$

- *Price ceilings*

$$p_t < \bar{p} \;\forall t$$

- *Jump magnitude limitations*

$$\Delta_t < \bar{\Delta} \;\forall t$$

- *Average price targets*

$$\sum_{t \in T} p_t \leq P$$

- …

Facilitates the impact evaluation of different marketing and regulatory requirements

Agenda

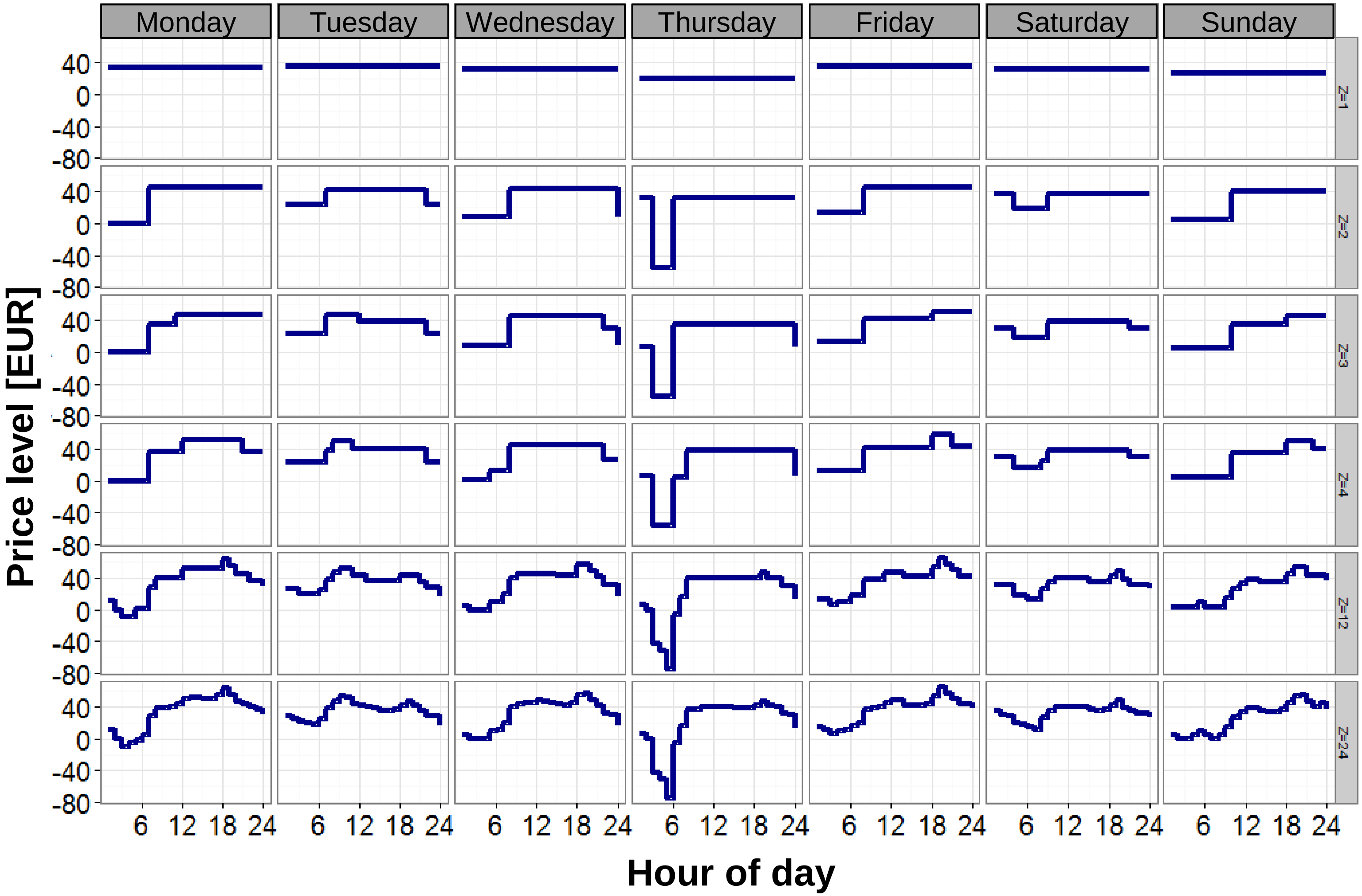
1 Introduction

2 Optimization Model

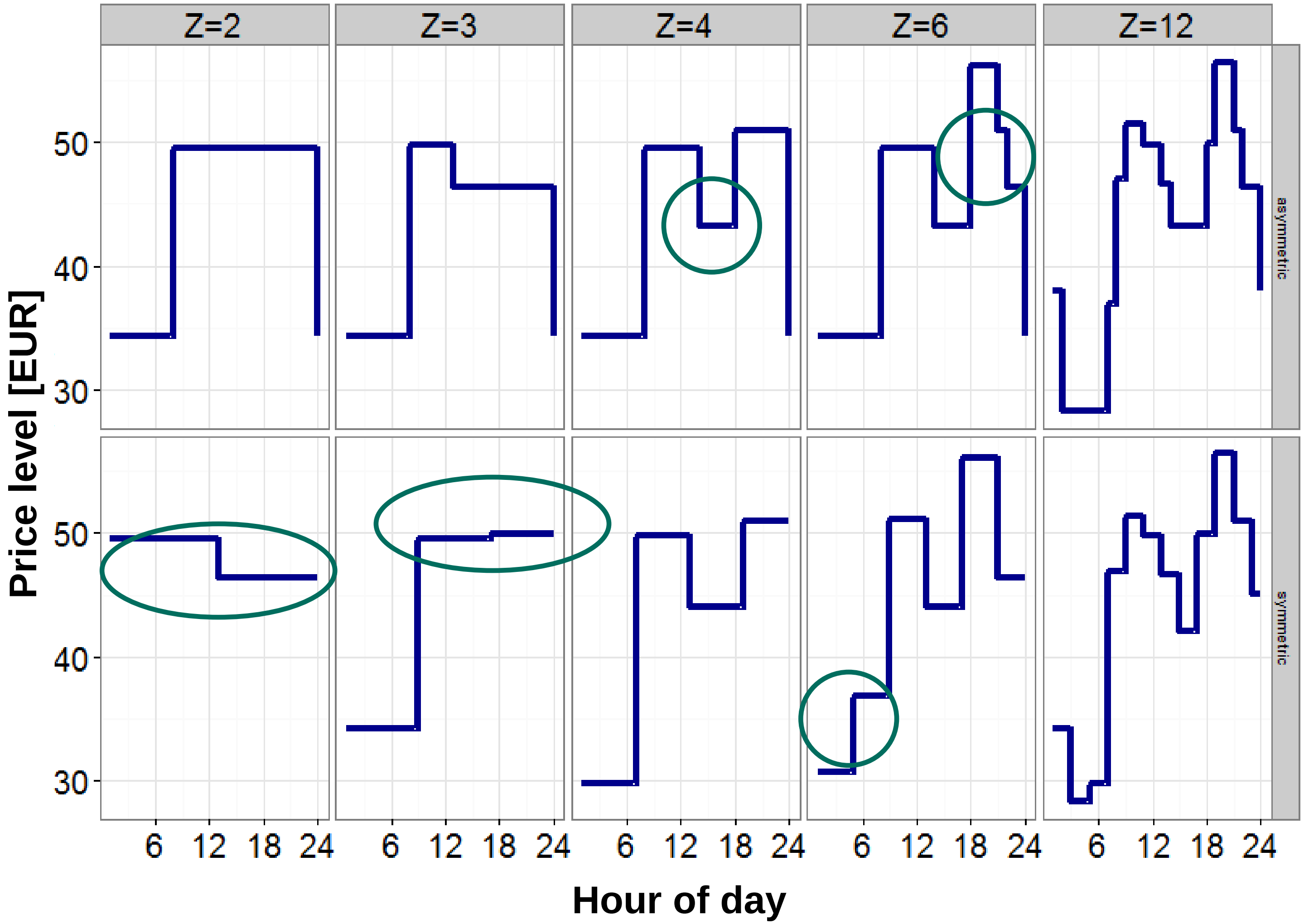
3 Rate Design Results

4 Summary and Outlook

Various design results for different granularity levels and daily updating



Rate length symmetry limits rate design potential for low granularity levels



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Rate design is driven by data availability and provides an input for price strategy

Data collection

- Load, cost and elasticity measures are crucial inputs for rate optimization
- Sensor infrastructure and data processing need to meet requirements

Individual rate design

- MIP optimization provides scalable way for determining optimal rate designs
- Facilitation of various design criteria

Pricing strategy

- Advanced electricity pricing as a means to establish the notion of energy services
- Utilize rates of inter-mediate complexity to transfer system risk to customers

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