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Yi Wan, Martin Densing :: Paul Scherrer Institute, Switzerland

Nonlinear Inverse Demand Curves in Electricity Market Modeling

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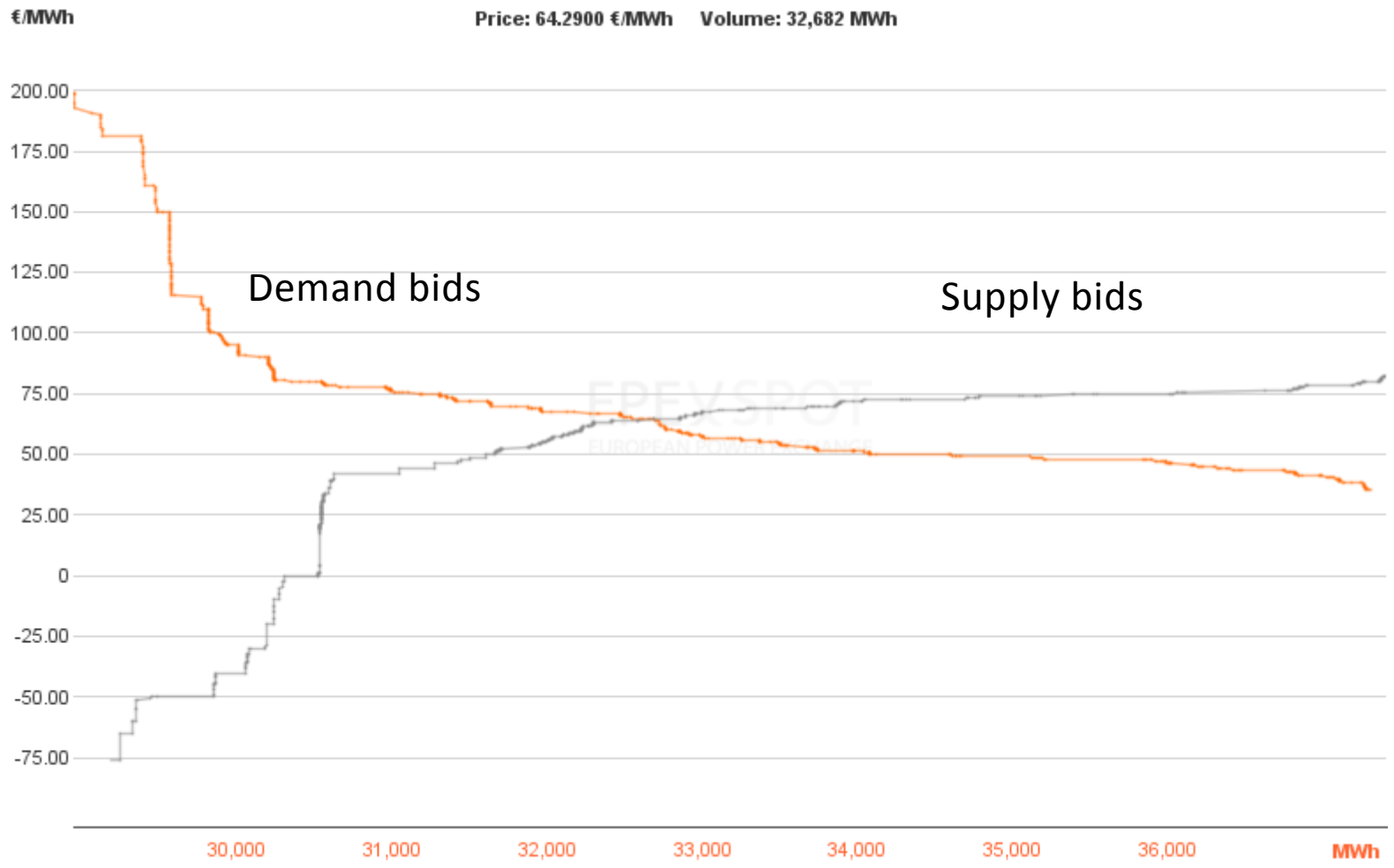
Motivations
Estimating Inverse Demand Function



**EPEX SPOT SE: Aggregated Curves*, www.epexspot.com/en/market-data/dayaheadauction/curve/auction-aggregated-curve/2018-09-18/DE/10.

Motivations
Improving Electricity Market Modeling

Traditional approach: linear inverse demand curve

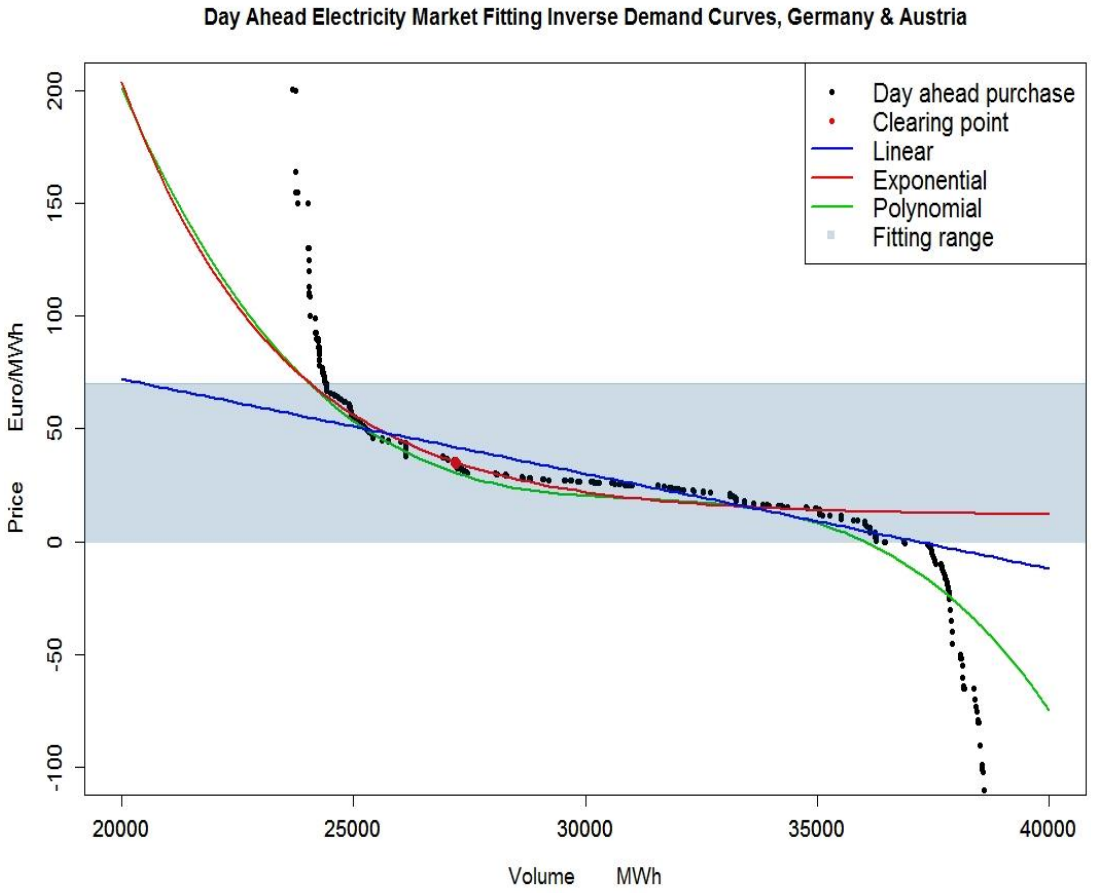
- Easily numerically solvable
- Previously: lack of empirical market data

- New computational tools
- Data transparency measures

New approach: Nonlinear demand curves

Nonlinear Demand Curve Fitting

- Curves fitted with least-square method for each hour
  - Linear, Cubic-polynomial and Exponential



Average mean squared error (MSE) of fitting for standardized hourly day-ahead market data of Germany & Austria, 2006-2015

Curve	MSE
Linear	0.1258
Exponential	0.0618
Polynomial	0.0421

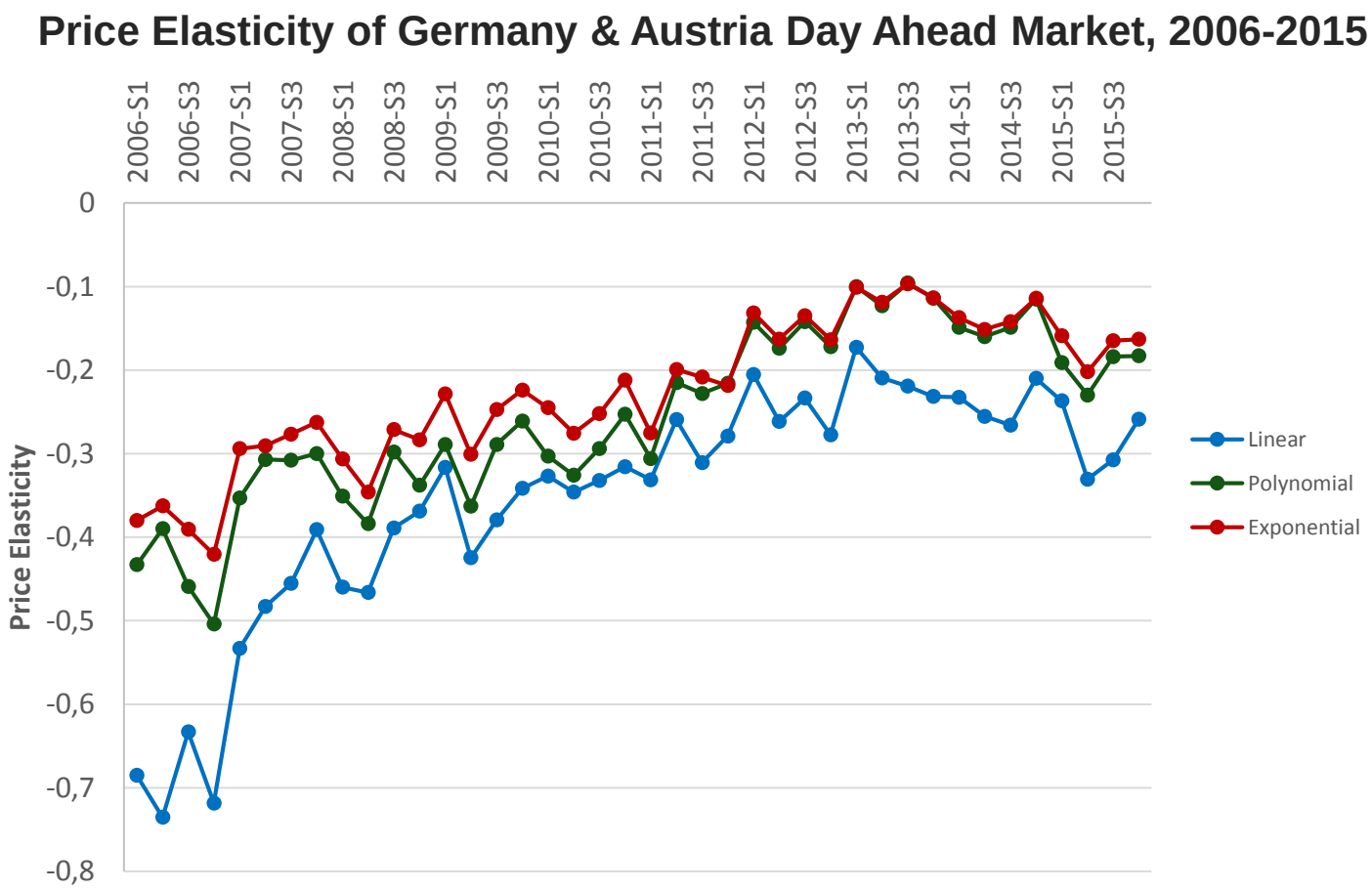
- Polynomial format fits the market data best

**EPEX SPOT* bid curve data, hour 01,04.02.2015

Change of Demand Curve Elasticity Over Time for Germany & Austria

$$\text{Elasticity} = \frac{\partial Q}{\partial P} \cdot \frac{P}{Q}$$

- Nonlinear curves give lower price elasticity estimation

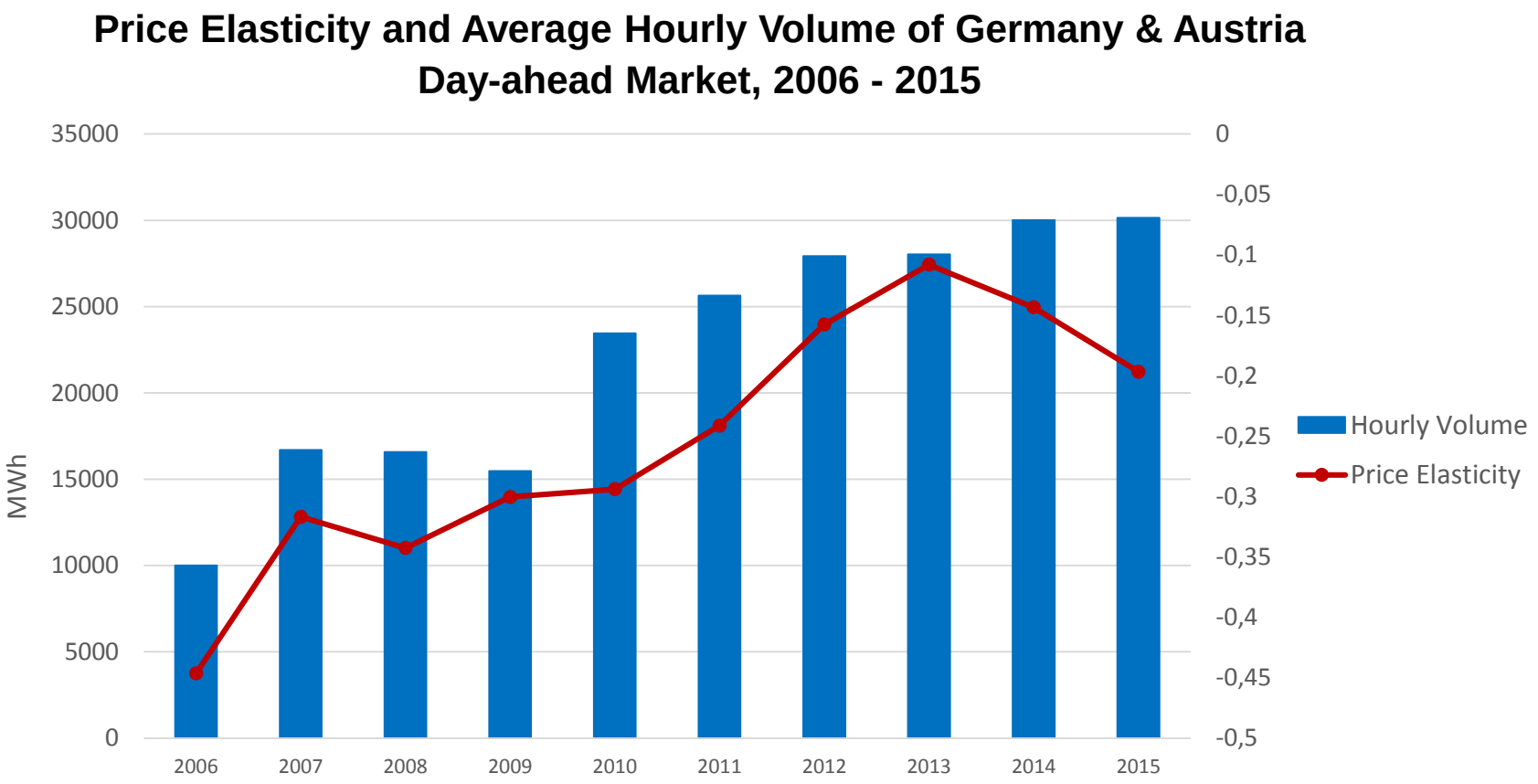


*Bönte, Werner, et al. "Price elasticity of demand in the EPEX spot market for electricity—New empirical evidence." *Economics Letters* 135 (2015): 5-8.
*Knaut, Andreas, and Simon Paulus. *Hourly price elasticity pattern of electricity demand in the German day-ahead market*. No. 16/07. EWI Working Paper, 2016.

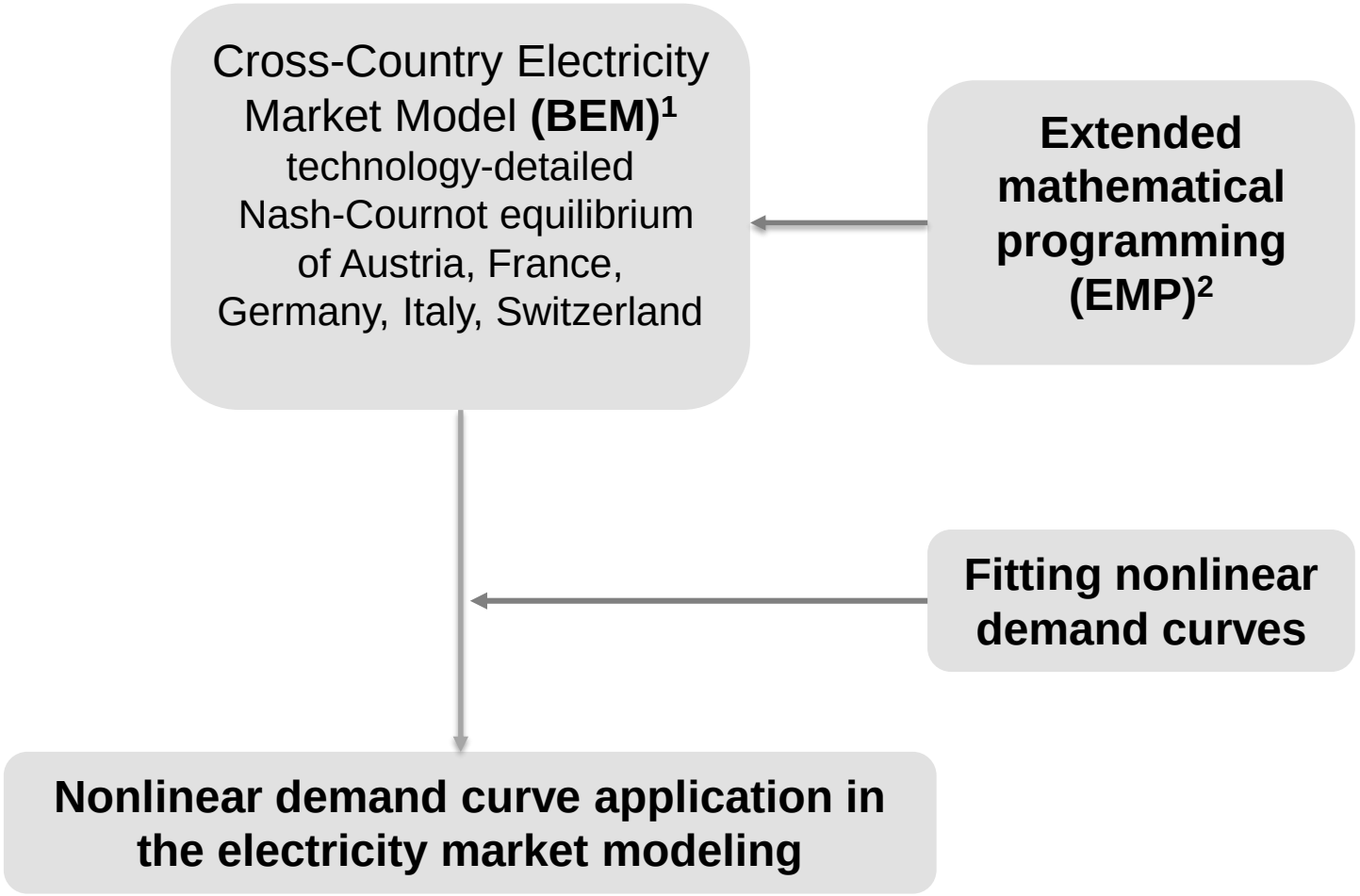
Change Demand Curve Elasticity Over Time for Germany & Austria

Elasticity = $\frac{\partial Q}{\partial P} \cdot \frac{P}{Q}$

- 2008: Financial crisis, not fully liberalized electricity market
- 2010: Institutional change, renewable supply expand
- 2013: Matured players, informative market, improved price forecast



Numerical Implementation

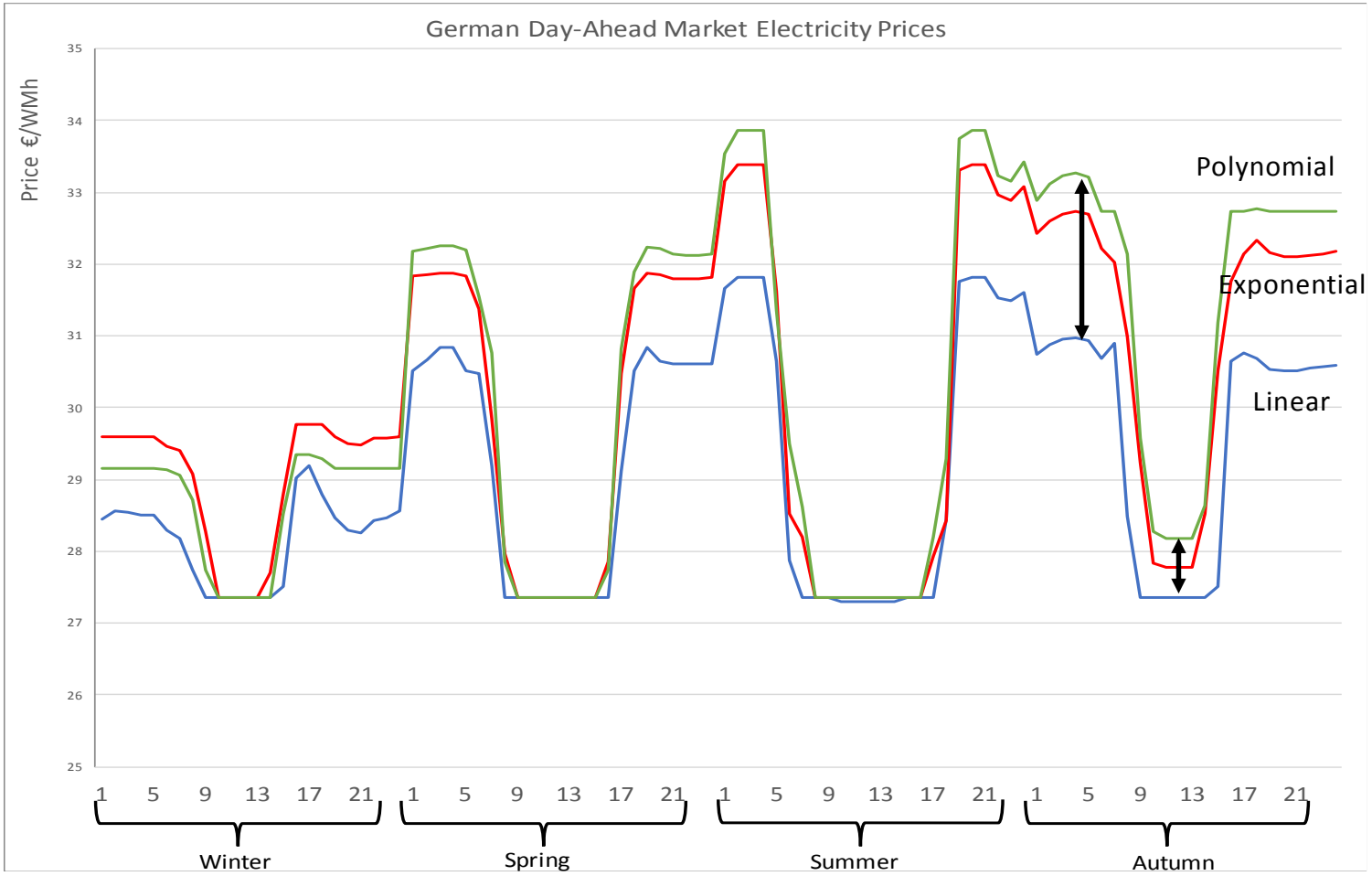


[1]Panos, Evangelos, and Martin Densing. "The future developments of the electricity prices in view of the implementation of the Paris Agreements: will the current trends prevail, or a reversal is ahead?." *Energy Economics*(2019).

[2]Kim, Youngdae, and Michael C. Ferris. "Solving equilibrium problems using extended mathematical programming." *Mathematical Programming Computation* (2019).

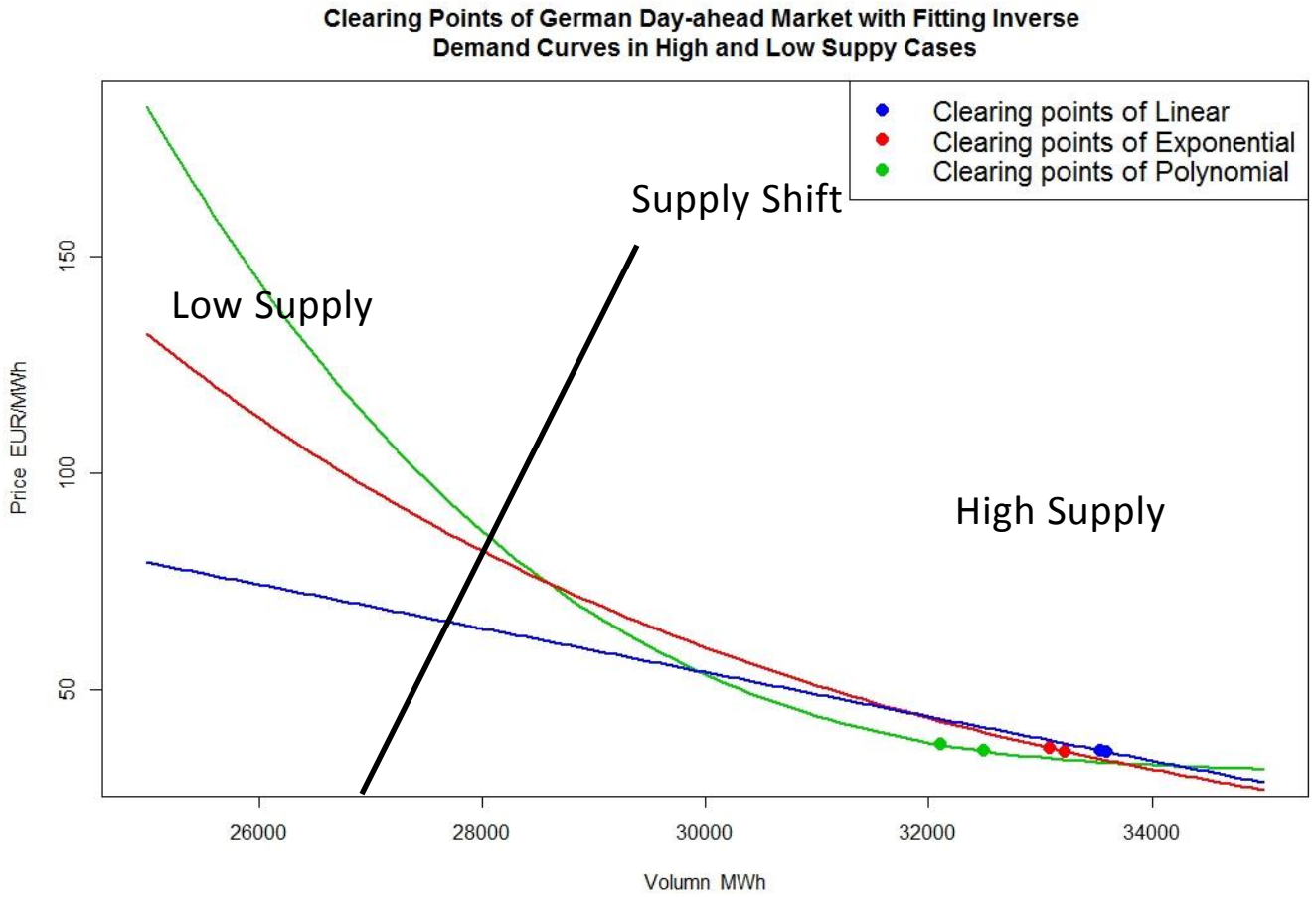
Impacts of the Nonlinear Inverse Demand Curves on Electricity Market Modeling

- When renewable generation increases, the clearing price gap between different demand curves decreases.



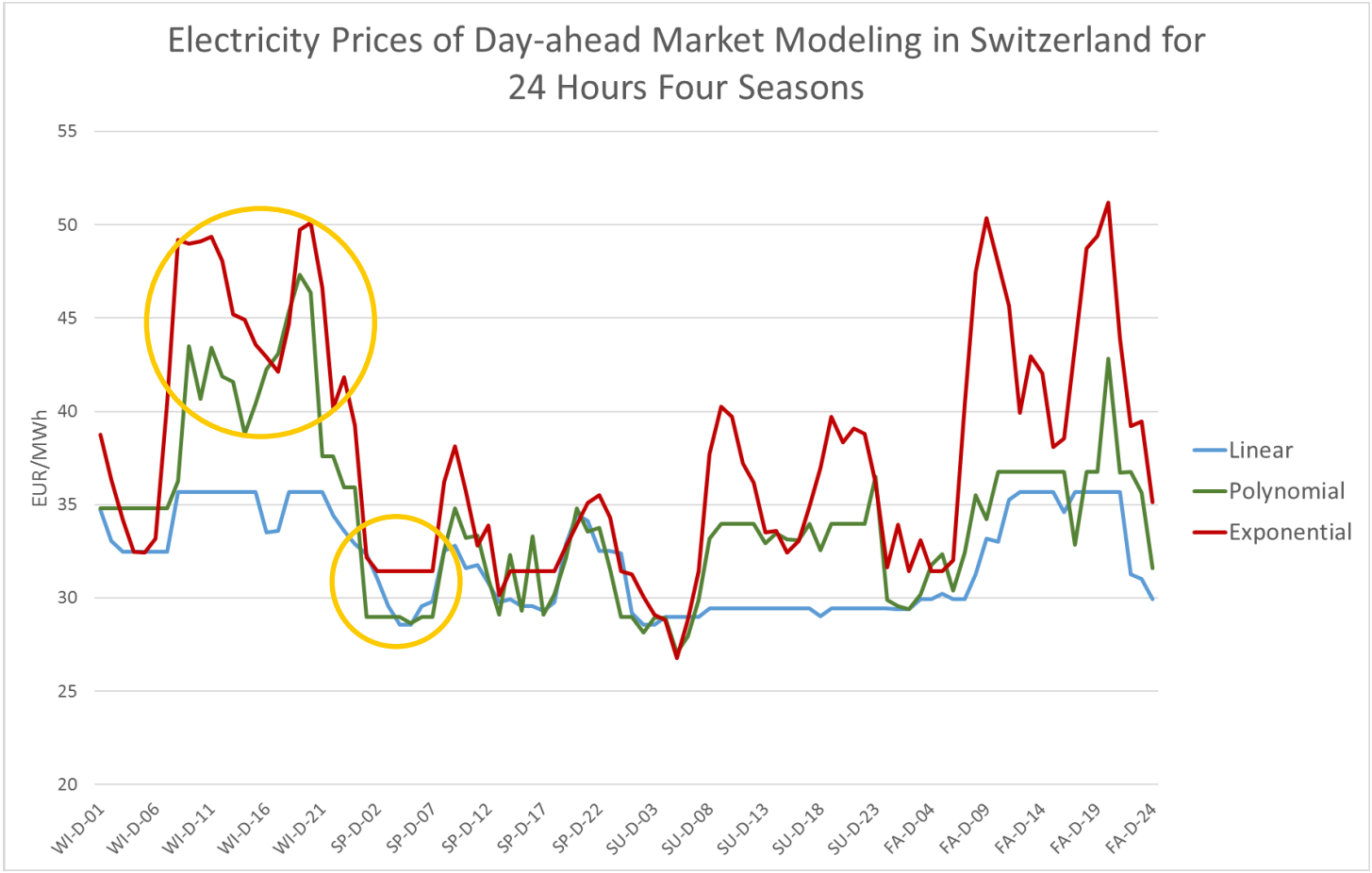
Impacts of the Nonlinear Inverse Demand Curves on Electricity Market Modeling

- The increasing renewable generation shifts the supply curve right.



Impacts of the Nonlinear Inverse Demand Curves on Electricity Market Modeling

- Nonlinear inverse demand curves are more sensitive in the low supply and high demand case



Impacts of the Nonlinear Demand Curves on Electricity Market Modeling

Lerner Index is defined by:

$$\mathrm{L} = \frac{P - MC}{P}$$

- Lerner Index to assess the market competition level
- Higher Lerner Index indicates lower market competition
- Electricity market with nonlinear demand curve less competitive

Lerner Index of the German day-ahead market prices under three fitting inverse demand functions (price deviation parameter* θ=0.1, 0.2)

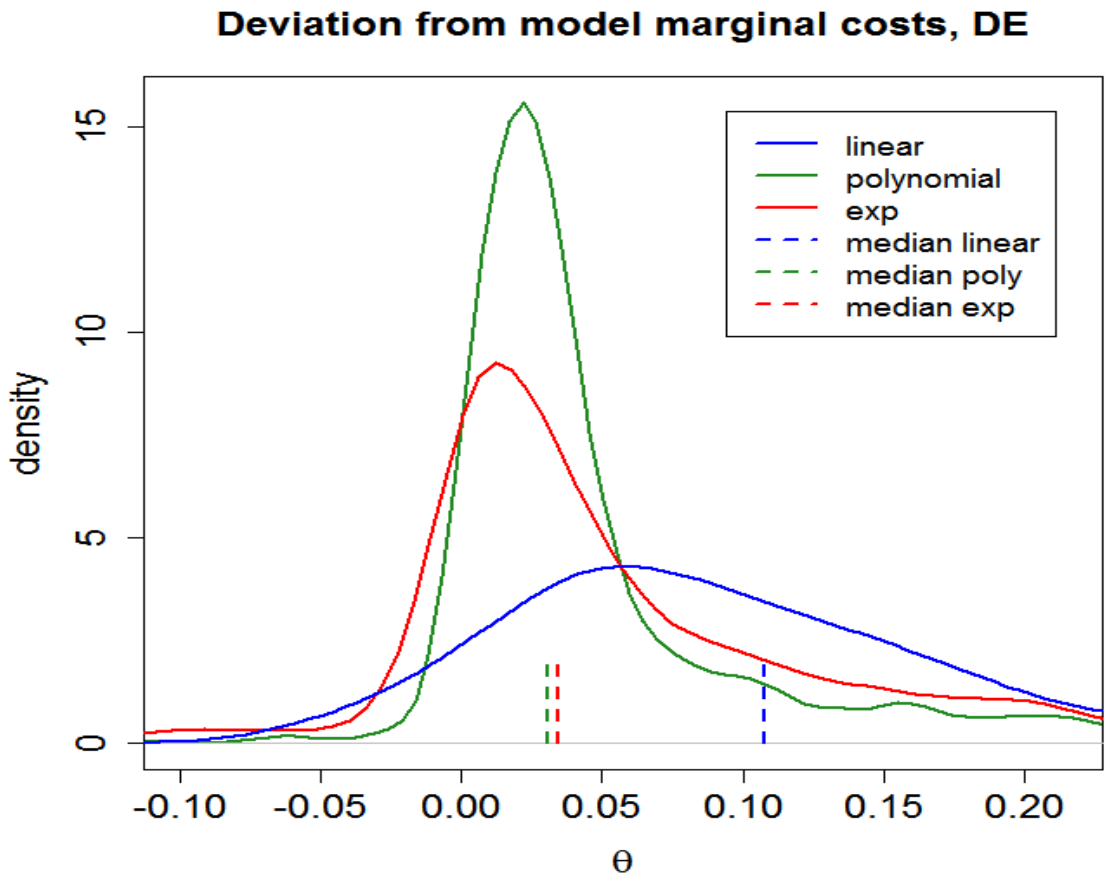
Curve name	**Lerner Index (θ=0.1)**	**Lerner Index (θ=0.2)**
Linear	0.285	0.433
Exponential	0.456	0.734
Polynomial	0.743	0.922

A small market distortion has a bigger impact on the market with nonlinear

* Conjectural Variation: $P(d) + \mathrm{d} \cdot \theta \frac{\partial P(d)}{\partial d} - C = 0$

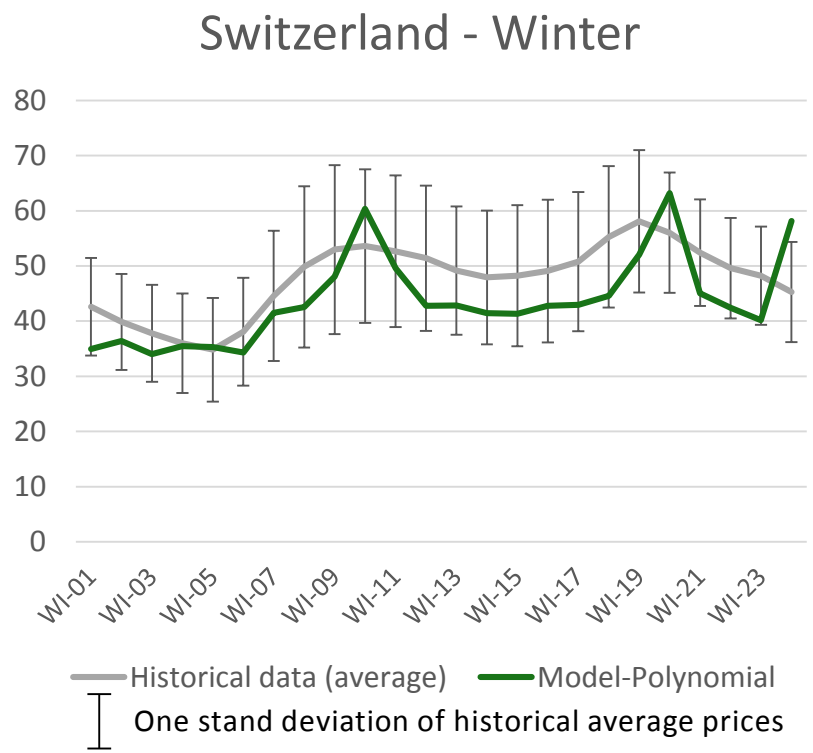
Impacts of the Nonlinear Demand Curves on Electricity Market Modeling

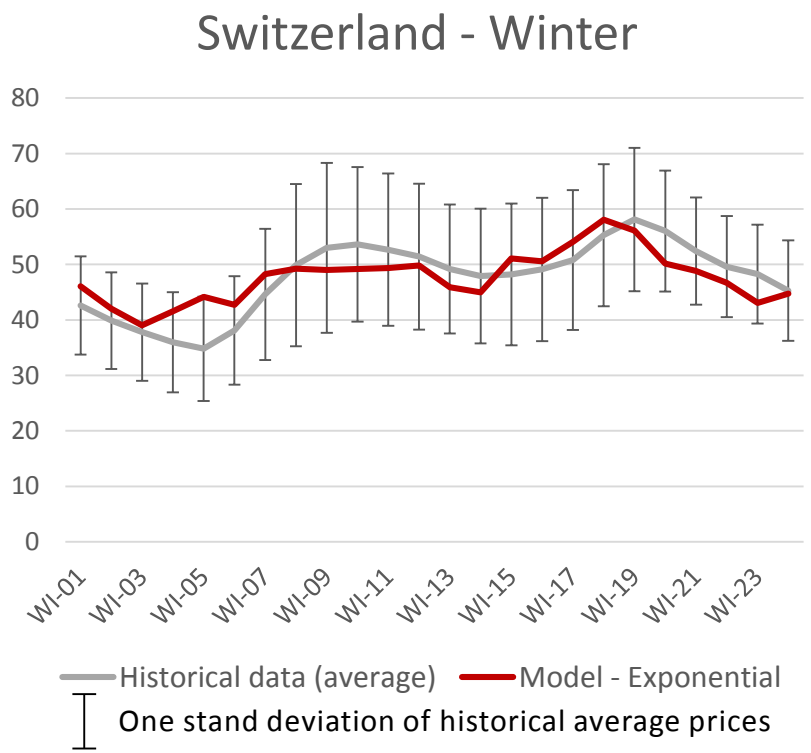
- Price deviation between market price and marginal cost is less when implementing nonlinear demand curves



Comparison with Historical Prices

- With estimated Θ, modeling results is close to the historical real market prices





- Θ scaled by 60%

Conclusions

- Polynomial demand curves perform best in fitting the day-ahead market data compared with Linear and Exponential ones.
- Nonlinear fitting inverse demand curves suggest lower elasticity estimations.
- Nonlinear inverse demand curves can be implemented to improve the electricity market modeling when market supply is low.
- Better explanation for large price deviations between market prices and marginal cost-based prices, even under the assumption of small market distortions.

Thank you very much for your attention

Yi Wan
yi.wan@psi.ch

Martin Densing
martin.densing@psi.ch

Energy Economics Group, Paul Scherrer Institute (PSI)