Bayesian Panel VAR models for forecasting electricity prices in Europe

Thesis - M.Sc. Data Science & Economics

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UNIVERSITÀ DEGLI STUDI DI MILANO

- Introduction
- Data Structure
- Model Description
- Empirical Results
- Conclusions

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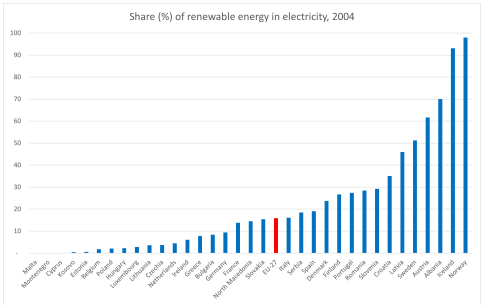
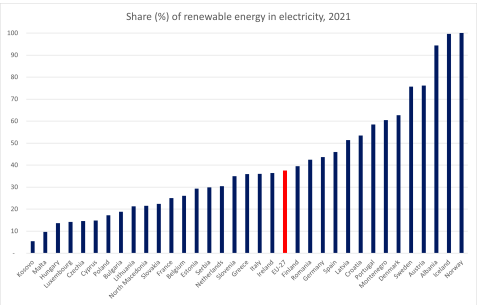
Renewable Energy penetration in electricity

1 Introduction





Source: Eurostat

Research questions

- How does RES affect electricity prices?
- Do RES generation provide information to forecast electricity prices?
- How interconnected are European electricity markets?

Methodology

1 Introduction

- Bayesian Panel Vector Autoregressive modeling approach
- Panel composed of nine countries: BE, DK, FI, FR, DE, IT, NL, ES, PT
- Daily data from January 1-2020 up to September 30-2023
  1. Daily electricity price (EUR/MWh) per country
  2. Day-ahead forecasts for solar, wind, and total system load (MW) per country
  3. Daily international prices for oil, coal, gas and CO2

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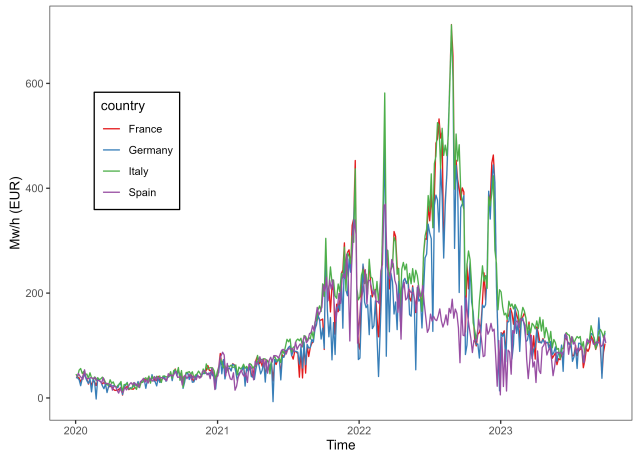
2 Data Structure

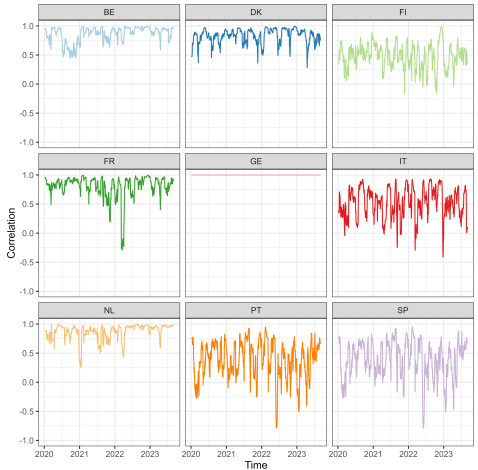
Electricity prices, largest economies

2 Data Structure



Correlation coefficients on electricity prices - Germany

2 Data Structure



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Panel VAR Models

3 Model Description

A panel VAR for unit i is described as (Dieppe et al., 2016):

$$
\begin{aligned}
y_{it} &= \sum_{i=1}^{N} \sum_{j=1}^{p} A_{ij,t}^{k} y_{j,t-k} + C_{i,t} x_t + \varepsilon_{it} \\
&= A_{i1,t}^{1} y_{1,t-1} + \cdots + A_{i1,t}^{p} y_{1,t-p} \\
&+ A_{i2,t}^{1} y_{2,t-1} + \cdots + A_{i2,t}^{p} y_{2,t-p} \\
&+ \ldots \\
&+ A_{iN,t}^{1} y_{N,t-1} + \ldots + A_{iN,t}^{p} y_{N,t-p} \\
&+ C_{i,t} x_t + \varepsilon_{it}
\end{aligned}
\tag{1}
$$

with:

$$y_{i,t} = \underbrace{\begin{pmatrix} y_{i1,t} \\ y_{i2,t} \\ \vdots \\ y_{in,t} \end{pmatrix}}_{nx1}, A^k_{ij,t} = \underbrace{\begin{pmatrix} a^k_{ij,11,t} & a^k_{ij,12,t} & \cdots & a^k_{ij,1n,t} \\ a^k_{ij,21,t} & a^k_{ij,22,t} & \cdots & a^k_{ij,2n,t} \\ \vdots & \vdots & \ddots & \vdots \\ a^k_{ij,n1,t} & a^k_{ij,n2,t} & \cdots & a^k_{ij,nn,t} \end{pmatrix}}_{nxn},$$

$$C_{it} = \underbrace{\begin{pmatrix} c_{i1,1t} & c_{i1,2t} & \cdots & c_{i1,mt} \\ c_{i2,1t} & c_{i2,2t} & \cdots & c_{i2,mt} \\ \vdots & \vdots & \ddots & \vdots \\ c_{in,1t} & c_{in,2t} & \cdots & c_{in,mt} \end{pmatrix}}_{nxm}, x_t = \underbrace{\begin{pmatrix} x_{1,t} \\ x_{2,t} \\ \vdots \\ x_{m,t} \end{pmatrix}}_{mx1}, \epsilon_{i,t} = \underbrace{\begin{pmatrix} \varepsilon_{i1,t} \\ \varepsilon_{i2,t} \\ \vdots \\ \varepsilon_{in,t} \end{pmatrix}}_{n \times 1} \sim \mathcal{N}(0, \Sigma_{ii,t}).$$

Panel VAR models

3 Model Description

The unrestricted panel VAR described is likely to be over-parametrized (Koop and Korobilis, 2019), involving $p \times (N \times n)^2$ unknown autoregressive parameters and $\frac{N \times n \times (N \times n + 1)}{2}$ error covariance terms.

Panel VAR models - Structural Factor approach

3 Model Description

Therefore the Structural Factor approach developed in Ciccarelli and Canova, 2006, and Canova and Ciccarelli, 2013 is used to produce a restricted version of the general panel VAR. The priors of the model are:

$$\pi(\theta|\theta_0, \Theta_0) \propto \left(-\tfrac{1}{2}(\theta-\theta_0)'\Theta_0^{-1}(\theta-\theta_0)\right).$$

$$\pi(\tilde{\Sigma}) \propto |\tilde{\Sigma}|^{-Nn+1/2}.$$

$$\pi(\sigma) \propto \sigma^{-\frac{\alpha 0}{2}-1} \exp\left(\frac{-\delta_0}{2\sigma}\right).$$

Modelling strategy

3 Model Description

The models tested are:

- Model 1 (Panel BVAR): electricity prices + dummies.
- Model 2 (Panel BVAR + RES): electricity prices + RES generation + dummies.
- Model 3 (Panel BVARX): electricity prices + RES generation + exogenous energy + dummies.

Coefficients were estimated for the in-sample period (Jan 1-2020 to Dec 31-2021) and then a daily rolling-window forecast is produced for the out-sample period (Jan 1-2022 to Sep 30-2023).

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4 Empirical Results

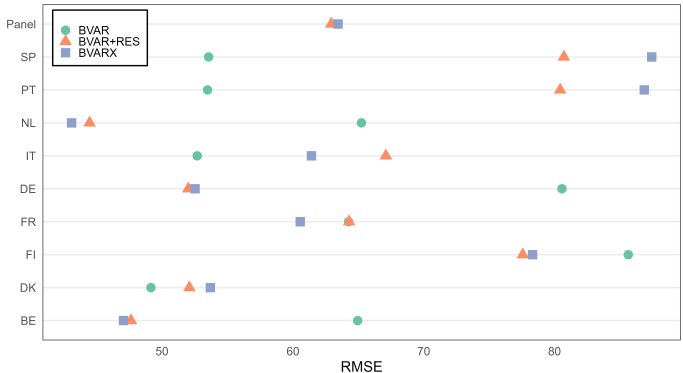
Out-of-sample forecasts

How is the forecast performance evaluated?

- Point measure: Root Mean Square Error (RMSE)
- Density measure: Continuous Ranking Probability Score (CRPS)
- Diebold and Mariano test
- Model Confidence Set

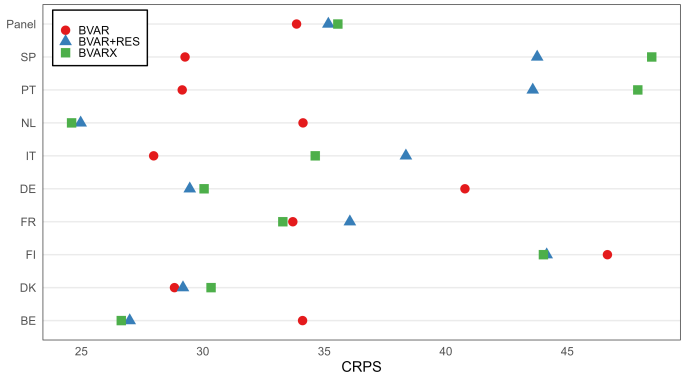
Out-sample forecasts - RMSE

4 Empirical Results



Out-sample forecasts - CRPS

4 Empirical Results



Out-sample forecasts - Model Confidence Set

4 Empirical Results

Unit	RMSE		CRPS	
	MCS	p-value	MCS	p-value
Belgium	M2, M3	0.506	M2, M3	0.766
Denmark	M1, M2, M3	0.469	M1, M2, M3	0.247
Finland	M1, M2, M3	0.275	M1, M2, M3	0.591
France	M1, M2, M3	0.540	M1, M2, M3	0.153
Germany	M2, M3	0.204	M2, M3	0.425
Italy	M1, M3	0.422	M1, M3	0.095*
Netherlands	M2, M3	0.509	M2, M3	0.583
Portugal	M1	0.005***	M1	0.009***
Spain	M1	0.012**	M1	0.009***

Confidence levels: * < 10%, ** < 5%, *** < 1%.

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5 Conclusions

Conclusions and further improvements

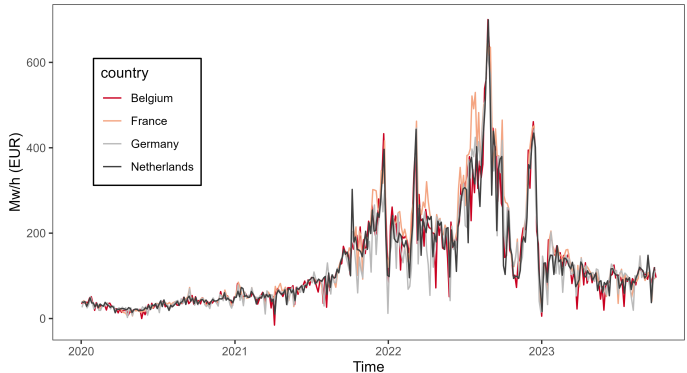
5 Conclusions

- We forecasted daily electricity prices using a Bayesian Panel VAR approach for nine countries in Europe, through three different models, including RES generation forecasts and international fuels and CO_2 prices.
- BE, FI, DE, NL showed improvements both in RMSE and CRPS when including RES variables. Nevertheless, RES models are not statistically better than BVAR model
- PT and ES have a statistically significant Model Confidence Set (M1), while the rest of countries did not

Thanks!

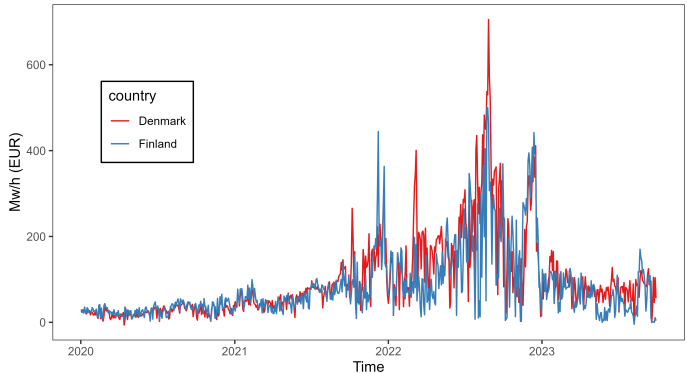
Electricity prices

6 Appendix



Electricity prices

6 Appendix



Electricity prices

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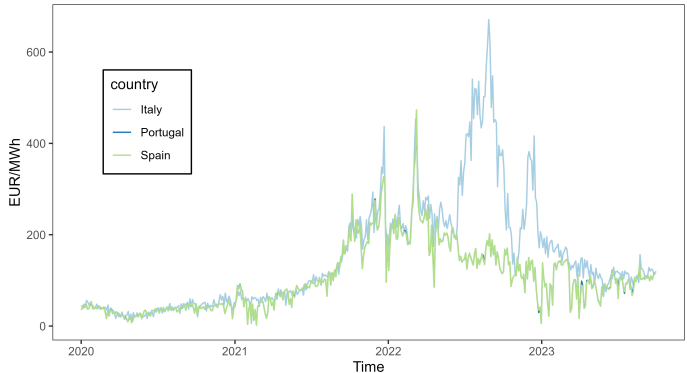

Day-ahead solar generation

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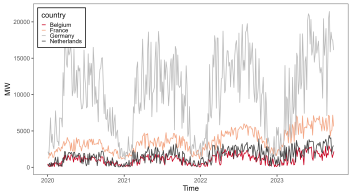
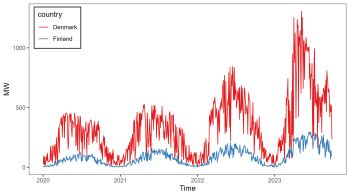
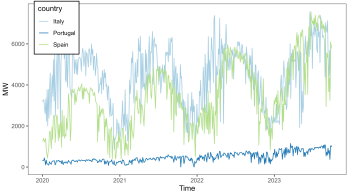


(c) BE, FR, DE, NL



(d) DK, FI



(e) IT, PT, SP

Day-ahead wind generation

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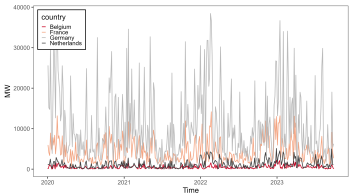
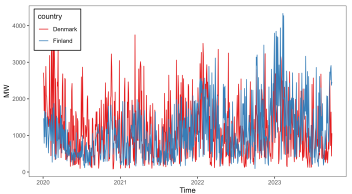
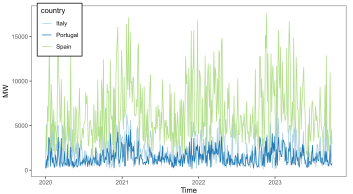


(f) BE, FR, DE, NL



(g) DK, FI



(h) IT, PT, SP

Day-ahead total system load

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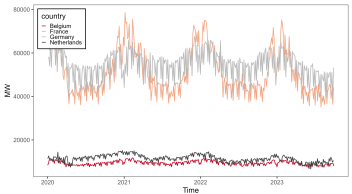
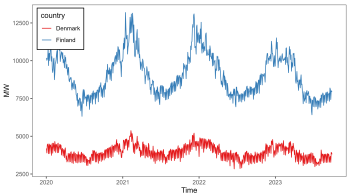
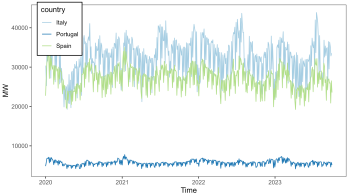


(i) BE, FR, DE, NL



(j) DK, FI



(k) IT, PT, SP

International fuels and CO2 prices

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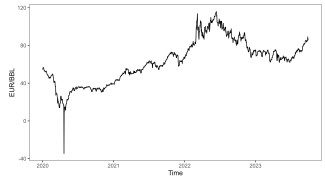
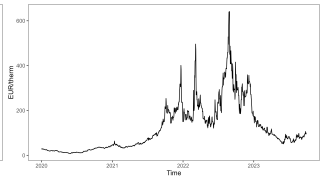
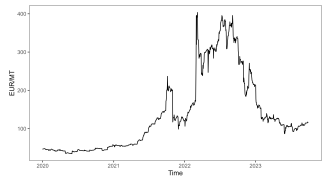


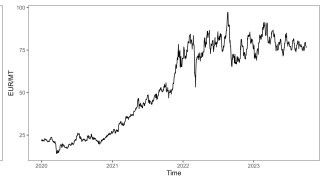
(l) Oil



(m) Gas



(n) Coal



(o) CO2

Out-of-sample forecasts - Diebold and Mariano test

6 Appendix

Unit	BVAR RES		BVAR X	
	RMSE	CRPS	RMSE	CRPS
Belgium	0.384	0.409	0.396	0.422
Denmark	0.492	0.504	0.506	0.516
Finland	0.469	0.483	0.471	0.484
France	0.496	0.525	0.465	0.496
Germany	0.394	0.405	0.411	0.420
Italy	0.572	0.589	0.525	0.556
Netherlands	0.372	0.395	0.382	0.403
Portugal	0.586	0.597	0.609	0.610
Spain	0.587	0.596	0.612	0.612