The Impact of Nuclear Energy on Electricity Prices

(Natural Resource and Energy Economics)

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October 13, 2023

View our code and data on GitHub!

Our Topic in Context

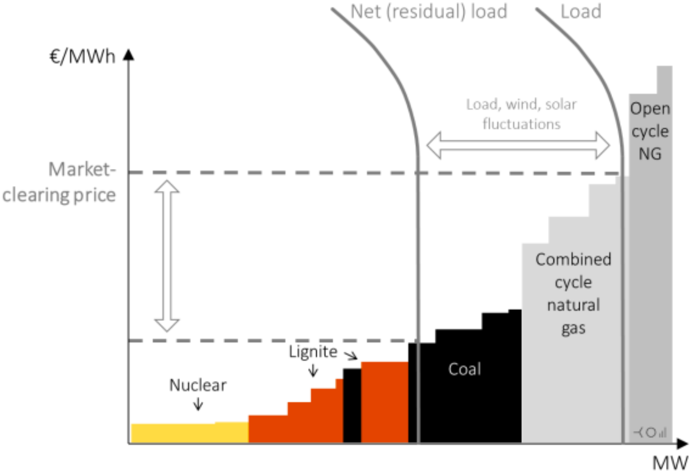
Introduction

We want to shed light on the following research questions:

- Does having a higher percent of nuclear energy **reduce** wholesale electricity **prices** (merit-order effect)?
- Does having a higher percent of nuclear energy **stabilize prices**?

Merit Order Effect

Back



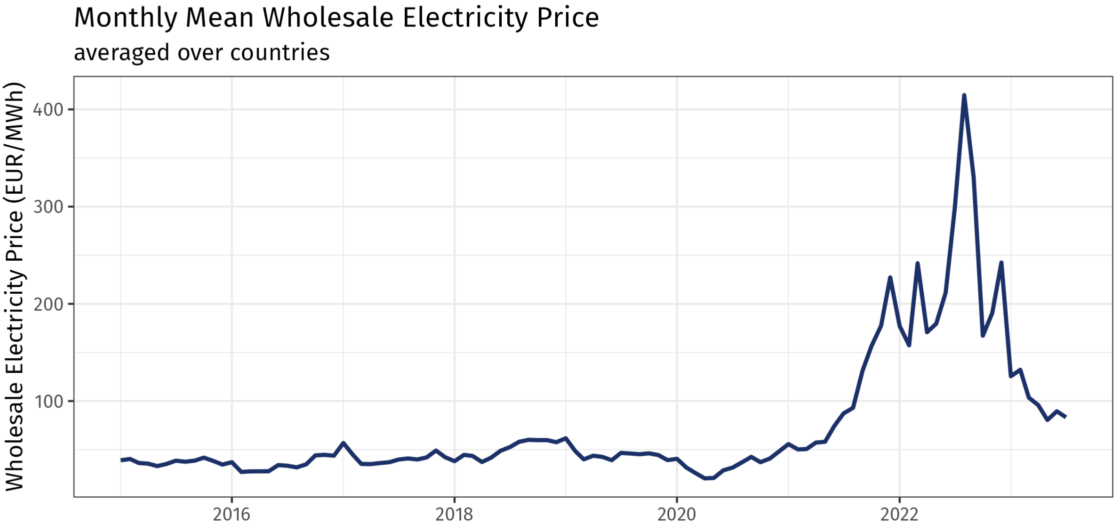
(Hirth, 2022)

Commodity Risk

(Trading Economics, 2023a)

(Trading Economics, 2023b)

Wholesale Electricity Price Development



(EMBER, 2023a)

A brief Overview of the Literature Review

- Nuclear outages increase wholesale electricity prices (Grossi et al., 2017; Nestle, 2012; Rinne, 2019)
- Nuclear energy reduces air pollution and emissions (Freese et al., 2023; Jarvis et al., 2022)
- Evidence of cost escalation of nuclear (Boccard, 2014; Clò, Cataldi, & Zoppoli, 2015; Davis, 2012)
- Deregulation/Privatization improves performance in US (Davis, 2012; Davis & Wolfram, 2012)

Our Contribution: Estimating the impact of nuclear energy on the level and volatility of wholesale electricity prices in Europe

Our Topic in Context

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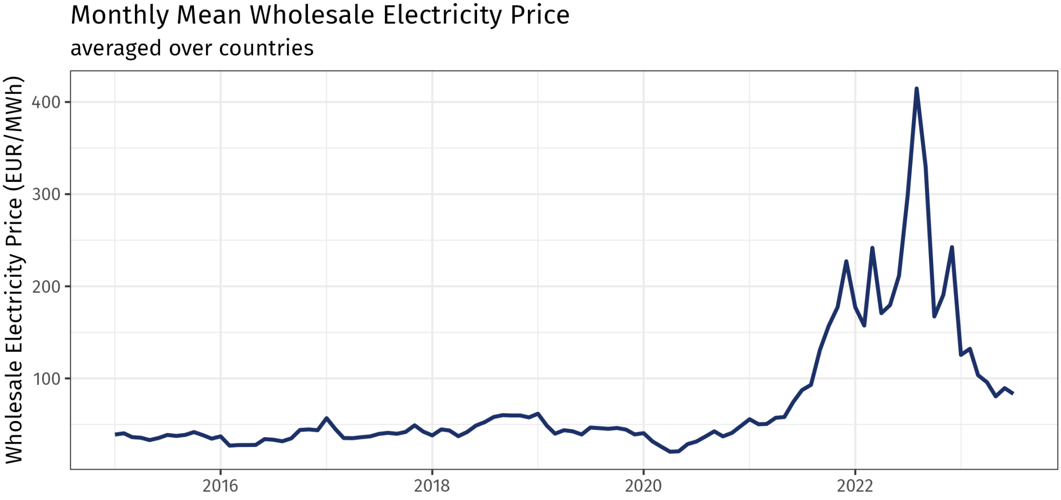
Data Definitions and Sources

We use data from the following sources:

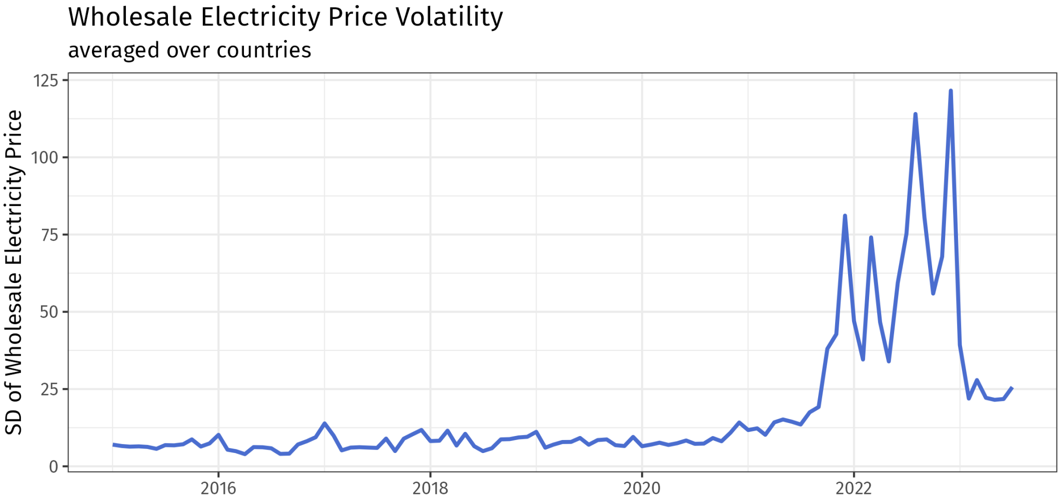
- Monthly **wholesale electricity prices** by country
  - from ENTSO-E, compiled by EMBER (2023a)
- Share of **nuclear energy** in energy generation, as well as monthly energy **generation** and **demand** by country
  - from ENTSO-E, compiled by EMBER (2023b)
- Monthly **natural gas prices** by country
  - Sourced from HEPI (2023)
- Monthly **temperature** data by country
  - Sourced from Copernicus (2023), aggregated on a country level using geodata from Eurostat (2023c)

Wholesale Electricity Price Development



(EMBER, 2023a)

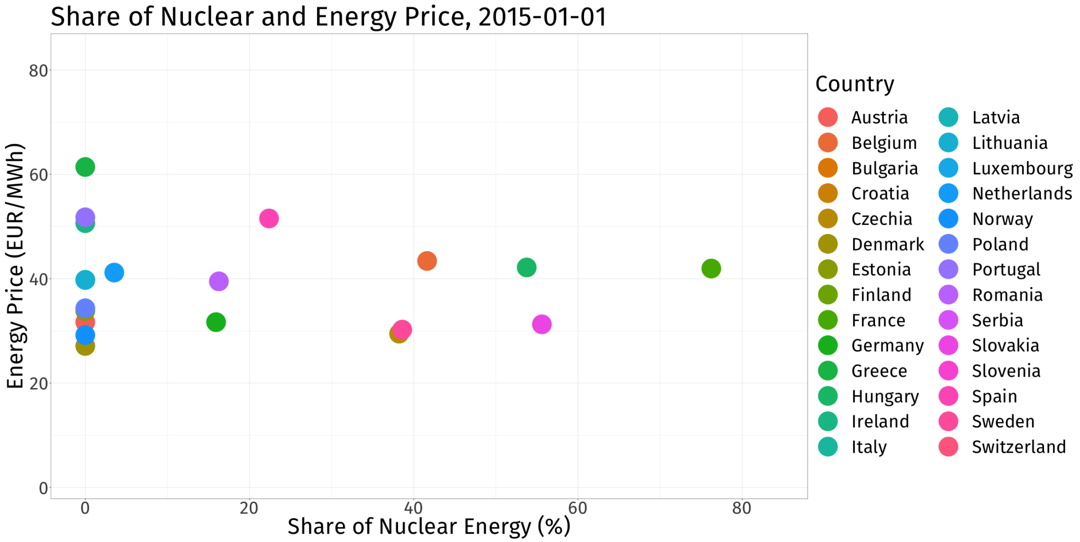
Wholesale Electricity Price Volatility Development



(EMBER, 2023a)

A Fancy Scatter Plot

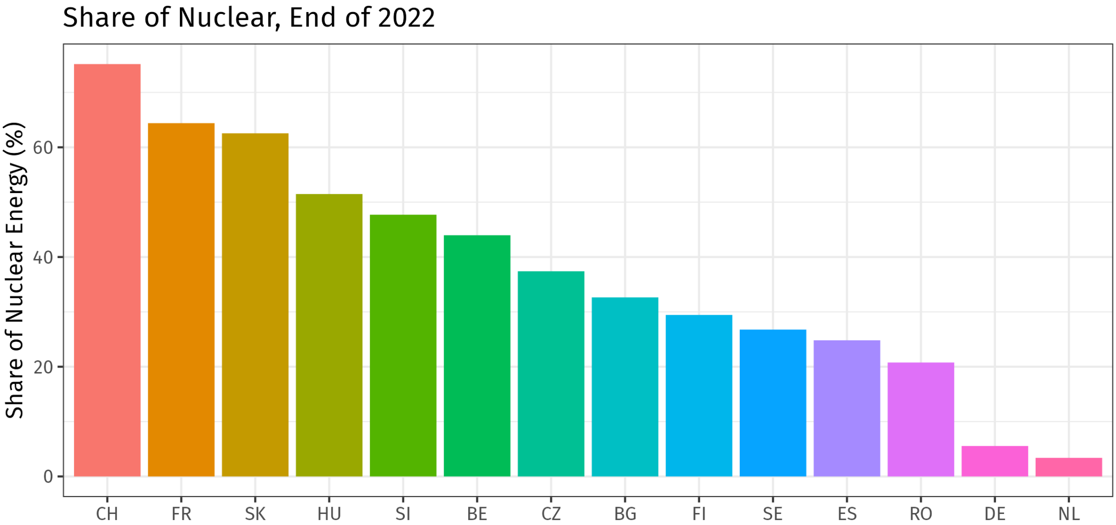
View the animation online instead



(EMBER, 2023a, 2023b)

Who Uses Most Nuclear?

▸ View an animated version online



(EMBER, 2023b)

Empirical Framework

- We follow Ballester and Furió (2015), Tselika (2022), and Cevik and Ninomiya (2022)
- We exploit variation in nuclear electricity generation shares in European Countries over 2015-2022
- Monthly Panel Data for 25 countries

"Panel data models should be preferred over time-series to explore electricity prices." (Tselika, 2022)

Empirical Strategy

We estimate the impact of nuclear energy in a panel regression framework.

$$
\begin{aligned}
log(ElectricityPrices_{i,t}) = & Country_i + Time_t + \boldsymbol{\beta_1 ShareNuclear_{i,t}} + \beta_2 Demand_{i,t} + \beta_3 Temperature_{i,t} \\
& + \beta_4 Temperature^2_{i,t} + \beta_5 log(GasPrices_{i,t}) + \varepsilon_{i,t}
\end{aligned}
$$

where i denotes the country and t denotes the month.

We estimate the same regression with $log(Variance(ElectricityPrices_{i,t}))$ as a measure of volatility.

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(I) The Effect of Nuclear on Electricity Prices

Dependent Variables:	log(price)	log(variance)
Model:	(1)	(2)
Variables		
share_nuclear	0.0009	-0.0104
	(0.0028)	(0.0069)
temperature	-0.0090**	0.0074
	(0.0036)	(0.0162)
temperature square	0.0003**	-0.0004
	(0.0001)	(0.0009)
demand	0.0122***	0.0187*
	(0.0027)	(0.0098)
log(nat_gas)	0.0851	0.1455
	(0.0704)	(0.1658)
Fixed-effects		
Country	Yes	Yes
Date	Yes	Yes
Fit statistics		
Observations	2,199	2,199
R^2	0.94935	0.88520
Within R^2	0.02900	0.00956

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

A Very Different Picture Compared to Renewables

This profile is starkly different from what we see for renewable energy. Multiple studies (Ballester & Furió, 2015; Clò, Alessandra, & Pietro, 2015; Ketterer, 2014; Woo et al., 2011) show that an increase in market share of renewables causes:

- Decrease in day-ahead electricity prices
- Increase in volatility

using different data sets and estimation methods. This is in accordance with the idea that renewables during peak production crowd the market enough to even cause overgeneration and a price reduction. Following the methodology of Cevik and Ninomiya (2022) we find:

(II) The Merit Order Effect of Renewables

Dependent Variables:	log(price)	log(variance)	log(price)	log(variance)
Model:	(1)	(2)	(3)	(4)
Variables				
share_renewables	-0.0047***	0.0113*	-0.0049***	0.0107*
	(0.0007)	(0.0060)	(0.0007)	(0.0062)
temperature	-0.0046	-0.0031	-0.0044	-0.0025
	(0.0050)	(0.0130)	(0.0051)	(0.0129)
temperature square	0.0001	-0.0001	0.0001	-9.76×10^{-5}
	(0.0002)	(0.0007)	(0.0002)	(0.0007)
demand	0.0116***	0.0203**	0.0115***	0.0201**
	(0.0030)	(0.0094)	(0.0030)	(0.0094)
log(nat_gas)	0.1023	0.1082	0.1022	0.1081
	(0.0676)	(0.1442)	(0.0677)	(0.1453)
share_nuclear			-0.0015	-0.0050
			(0.0026)	(0.0079)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Date	Yes	Yes	Yes	Yes
Fit statistics				
Observations	2,199	2,199	2,199	2,199
R^2	0.95248	0.88741	0.95255	0.88753
Within R^2	0.08893	0.02858	0.09037	0.02965

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Differential Effects during the Energy Crisis?

To investigate if a higher share of nuclear had an effect on electricity prices during the energy crisis we estimate the following specification:

$$\begin{aligned}
\log(ElectricityPrices_{i,t}) = & Country_i + \beta_1 ShareNuclear_{i,t} + \beta_2 EnergyCrisis_{i,t} \\
& + \boldsymbol{\delta_1 EnergyCrisis_t * ShareNuclear_{i,t}} \\
& + \beta_3 Demand_{i,t} \\
& + \beta_4 Temperature_{i,t} \\
& + \beta_5 Temperature^2_{i,t} \\
& + \beta_6 log(GasPrices_{i,t}) + \varepsilon_{i,t}
\end{aligned}$$

where $EnergyCrisis_t$ denotes a dummy variable, turning one starting from September 2021

Differential Effects during the Energy Crisis

Dependent Variables:	log(price)	log(variance)	log(price)	log(variance)
Model:	(1)	(2)	(3)	(4)
Variables				
share_nuclear	-0.003	-0.02**	0.0004	-0.01
	(0.004)	(0.010)	(0.003)	(0.007)
temperature	-0.02***	-0.04***	-0.009**	0.007
	(0.004)	(0.01)	(0.004)	(0.02)
temperature square	0.001***	0.002	0.0003**	-0.0004
	(0.0002)	(0.0009)	(0.0001)	(0.0009)
demand	0.02***	0.03**	0.01***	0.02*
	(0.006)	(0.01)	(0.003)	(0.010)
log(nat_gas)	0.35***	0.55**	0.11	0.15
	(0.09)	(0.20)	(0.07)	(0.17)
energycrisis	1.4***	3.7***		
	(0.06)	(0.11)		
energy_crisis*share_nuclear	0.004***	0.003	0.003**	0.0005
	(0.001)	(0.002)	(0.001)	(0.002)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Date			Yes	Yes
Fit statistics				
Observations	2,199	2,199	2,199	2,199
R^2	0.79316	0.75638	0.95063	0.88521
Within R^2	0.78229	0.73991	0.05347	0.00960

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Differential Effects with Demand?

To investigate if a higher share of nuclear had an effect on electricity prices based on demand we estimate the following specification:

$$\begin{aligned} log(ElectricityPrices_{i,t}) = & Country_i + \beta_1 ShareNuclear_{i,t} + \beta_2 Demand_{i,t} \\ & + \boldsymbol{\delta_1 Demand_t * ShareNuclear_{i,t}} \\ & + \beta_3 Temperature_{i,t} \\ & + \beta_4 Temperature_{i,t}^2 \\ & + \beta_5 log(GasPrices_{i,t}) + \varepsilon_{i,t} \end{aligned}$$

We estimate the same regression with $log(Variance(ElectricityPrices_{i,t}))$ as the dependent variable.

(IV) Differential Impact in Higher Demand Periods

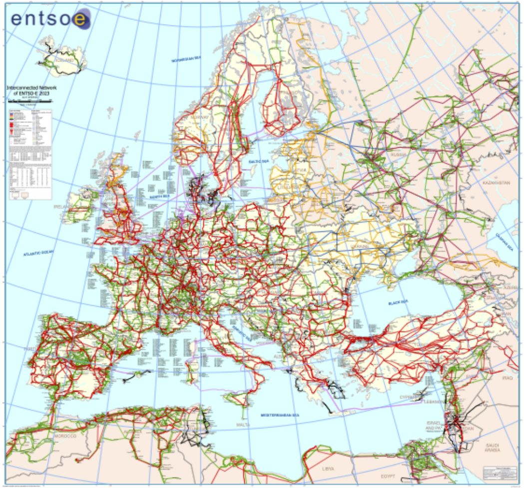
Dependent Variables:	log(price)	log(variance)
Model:	(1)	(2)
Variables		
Demand*ShareNuclear	-4.17×10^{-5}	-0.0007**
	(0.0001)	(0.0003)
share_nuclear	0.0012	-0.0056
	(0.0028)	(0.0059)
demand	0.0147*	0.0619***
	(0.0086)	(0.0176)
temperature	-0.0088**	0.0095
	(0.0037)	(0.0163)
temperature square	0.0002*	-0.0005
	(0.0001)	(0.0009)
log(nat_gas)	0.0851	0.1444
	(0.0704)	(0.1695)
Fixed-effects		
Country	Yes	Yes
Date	Yes	Yes
Fit statistics		
Observations	2,199	2,199
R^2	0.94936	0.88567
Within R^2	0.02920	0.01357

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Why is There no Merit Order Effect for Nuclear?

- Nuclear reactors produce energy at lower marginal cost compared to most other technologies, but the fixed costs of firing up a nuclear power plant are high. Therefore, nuclear is used to provide base-load electricity and is seldom the technology that sets the price (Davis & Wolfram, 2012).
- Variability in total output of electricity from renewable sources could potentially explain why they have Merit Order effects whereas nuclear does not. Merit Order effect
- Has there been room for producers of nuclear energy to exert market power during price discovery? What will happen in the future if the capacity of renewable energy continues to increase? See e.g. Fabra et al. (2006); Rassenti et al. (2003) and Vickrey (1961).

Interconnected Markets



(ENTSO-E, 2023)

- Spillover Effects due to integration of EU energy grid.
- Higher prices in neighboring markets create incentives to export electricity.
- Why do we see an effect for renewables? We leave this as a question for future research.

Limitations and Paths for Further Research

Data Limitatons

- Data only available monthly
- Additional control variables of interest sparsely available

Endogeneity

- Simultaneity?
- Does the energy price have an effect on the share of nuclear power?

Different Identification Strategy

- Quasi-experimental evidence to estimate causal effect (Diff-in-Diff, Synthetic Control, etc.)
- Possibility of conducting a high-frequency analysis

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Applying a model structure popular in studies relating to renewables, we discuss the impact of nuclear energy share in the energy market mix on prices and find no evidence of a direct effect and limited stabilization effects during periods of high demand. We argue that given the limitations of our approach,

- We find no evidence that Nuclear reduces wholesale electricity prices
- On the contrary, nuclear is associated with higher prices during the Energy Crisis
- Slightly lower volatility when demand is higher

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