Powering Down Nuclear: A Multidimensional Impact Evaluation of the German Case

14th Toulouse Conference on the Economics of Energy and Climate

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7 June 2024

Introduction

Motivations

- **Nuclear phase-out**: cessation of nuclear power for energy production
- **Nuclear concerns**: economic, health, environmental and accidents (1979 Three Mile Island, 1986 Chernobyl, 2011 Fukushima)
- **Many countries**: Belgium, Germany, Italy, South Korea, Spain, Sweden, Switzerland
- **Efficient and fair energy transitions**

Research question

What are the local socio-economic impacts of a large-scale nuclear shutdown?

Literature

Local Socio-economic Impact Assessment and Nuclear Shutdown

- **Local socio-economic impacts of energy transition:** Davis (2011), de Faria *et al.* (2017), Rud *et al.* (2022)
- **US small-scale nuclear closure effects on the electricity market and air pollution**: Davis and Hausman (2016); Severnini (2017)
- **Energy market and air pollution consequences of the German nuclear phase-out**: Traber and Kemfert (2012); Bruninx et al; (2013); Knopf *et al.* (2014); Grossi *et al.* (2017); Jarvis *et al.* (2022)
- **Fukushima accident and local housing values:** Bauer *et al.* (2017), Coulomb and Zylberberg (2021)

Contributions

- **Socio-economic** impact assessment of a **large-scale permanent** nuclear shutdown
- ***Ex-post* quasi-experimental** evaluation techniques and rich **multidisciplinary panel** data
- **Direct and induced local effects** on labour, health and real estate

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Policy Background

Germany is bringing an end to its nuclear age

The last three nuclear reactors in Germany will be gradually switched off on Saturday, as Europe's largest economy has been looking to phase out nuclear power since 2002.

Le Monde
Published on April 15, 2023, at 12:53 pm (Paris) · 2 min read

An activist of environmental organisation Greenpeace poses in front of the capital's landmark Brandenburg Gate in Berlin on April 15, 2023. ODD ANDERSEN / AFP

The 2011 German Atomic Energy Act:

- **Exogenous:** Fukushima accident, widespread anti-nuclear opinion, political setback in State elections
- **Unanticipated:** multiple back and forths in recent nuclear policy
- **Large-scale:** 17 reactors, 22% of total electricity generation

Interesting for **causal interpretation**

Figure 1: The German Nuclear Phase-Out

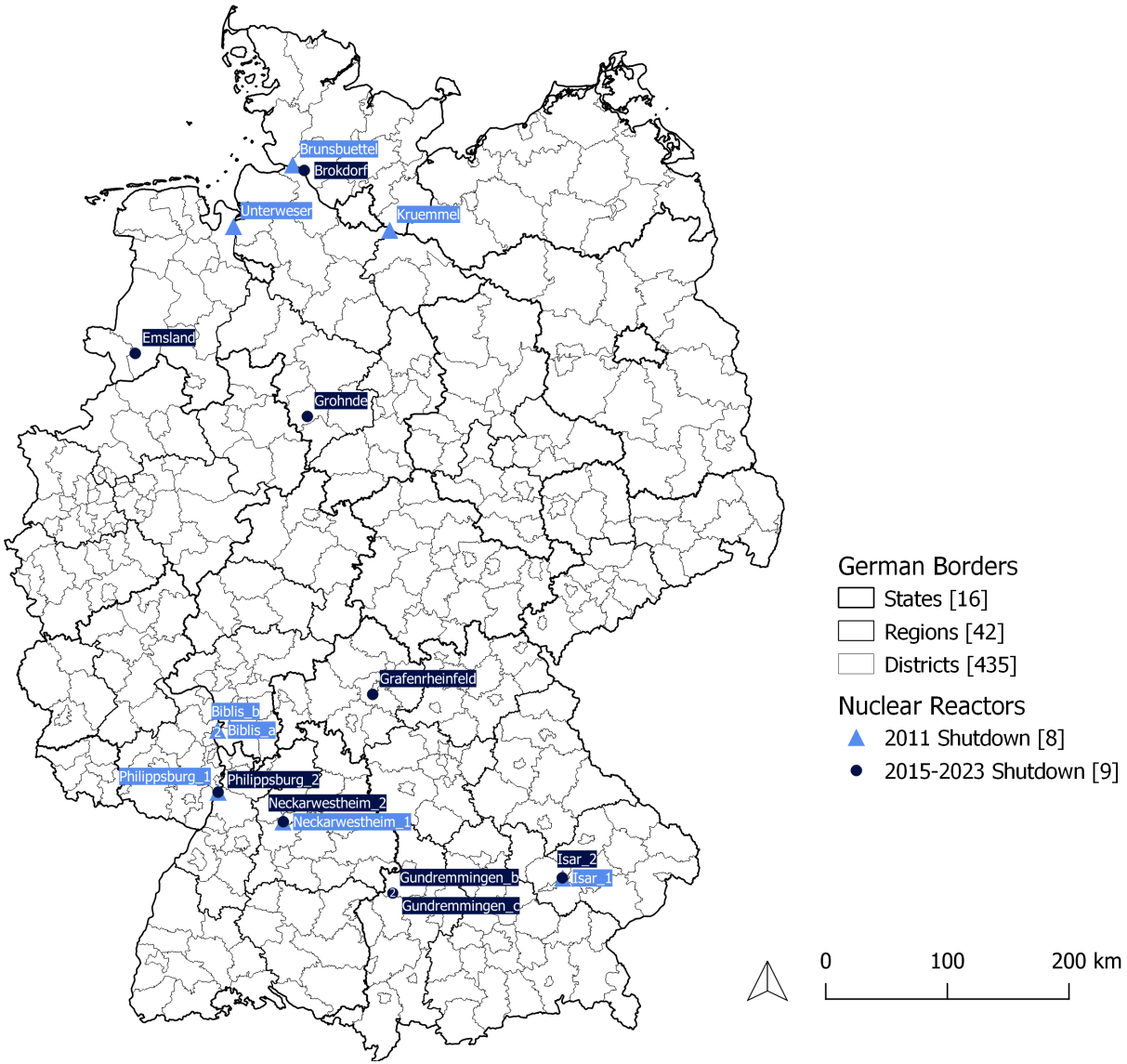


Figure 2: Annual German Electricity Generation by Source (billion kWh)

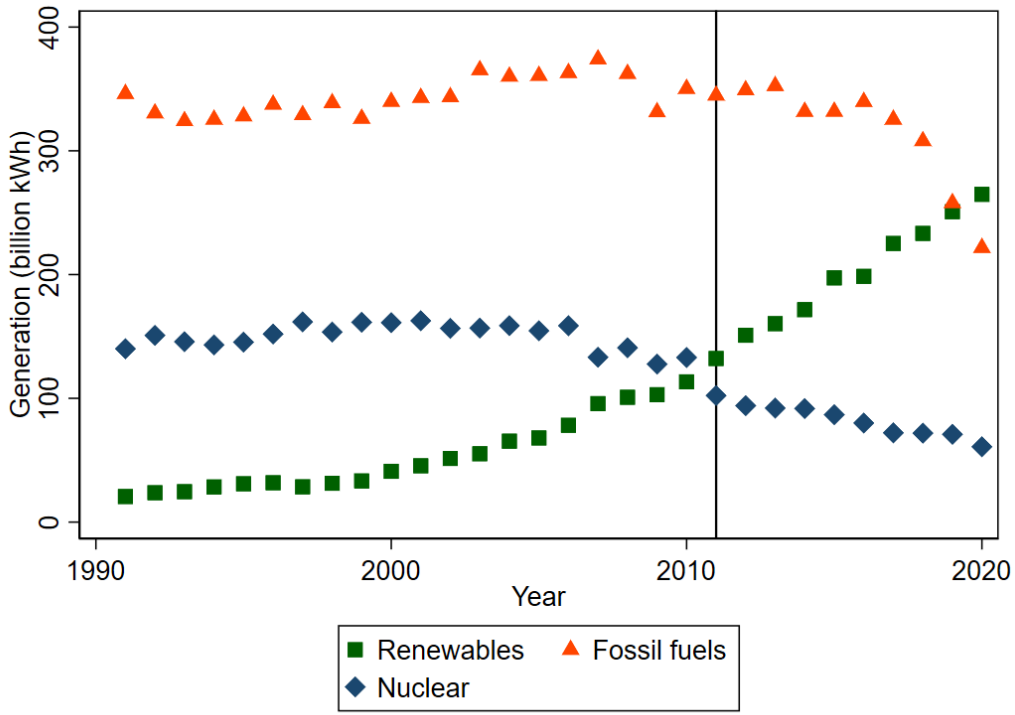


Table 1: Annual German Electricity Generation by Source (% of total generation)

Year	Renewables	Fossil fuels	Nuclear	Total
2010	19.00%	58.70%	22.30%	100.00%
2012	25.41%	58.75%	15.84%	100.00%

Source: Data from the EIA

Data and Empirical Strategy

Data

Health, housing and labour market outcomes:

German Socio-Economic Panel (GSOEP)

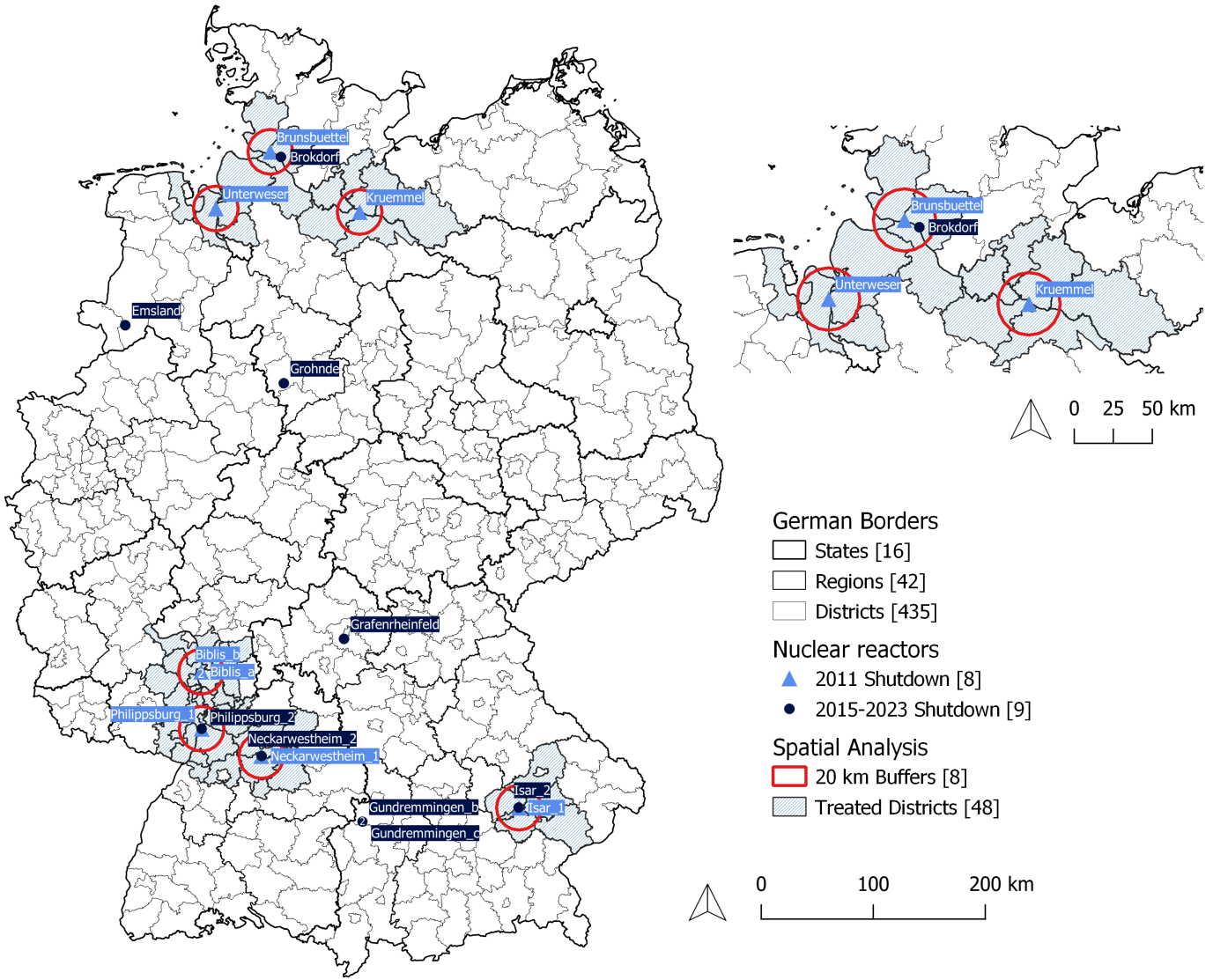
- 30,000 individuals
- district localisation
- 2006-2014
- annual data

Empirical Strategy

Natural Experiment

- **Difference-in-Differences:** compare changes in outcomes before and after the phase-out, between treated and control districts
- **Panel event study:** outcome persistence
- **Heterogeneous analysis:** direct and induced local effects
- **Treated:** districts near a nuclear pp closed in 2011
- **Controls:** districts further away from the nuclear pp

Figure 3: Spatial Analysis of the German Nuclear Phase-Out



Difference-in-Differences

$$Y_{idt} = \alpha + \beta(Treated_d \times Post_t) + \theta C_{it} + \rho_t + \mu_i + \gamma_d + \varepsilon_{idt}$$

	Employment status, hours worked, wage
Y_{idt}	Life and health satisfaction, health status
	Rental income
$Treated_d$	Dummy for treated districts (near a nuclear pp closed in 2011)
$Post_t$	Dummy for years after the phase-out
C_{it}	Age, age^2, female, education, marital status, children
ρ_t	Year FE
μ_i	Individual FE
γ_d	District FE
ε_{idt}	Error term

Results

Table 2: Labour Outcomes by District

	Employment Status	Employment Level	Annual Work Hours	Secondary Employment	Self Employment	Annual Labour Earnings	Annual Wage Main Job	Household Public Transfers
Post*Treatment	0.012	-0.007	31.966**	0.010	0.019**	722.447*	571.332*	-643.932***
	(0.010)	(0.010)	(16.255)	(0.011)	(0.009)	(408.146)	(337.916)	(197.654)
Individual Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	148176	80751	130484	147109	147109	130484	129041	71083
R^2	0.8030	0.7397	0.8544	0.4260	0.5477	0.8373	0.8977	0.7080
Adjusted R^2	0.7414	0.6528	0.8104	0.2465	0.4063	0.7881	0.8668	0.5963

Constant included, Individual controls: age^2, years of education, number of children and couple status

Cluster-robust standard errors by districts in parentheses

Years 2006 to 2013, 2011 excluded

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Health Outcomes by District

	Life Satisfaction	Health Satisfaction	Self-Rated Health	Doctor Visits	Hospital Nights
Post*Treatment	-0.142***	-0.115*	-0.047*	-0.623	-0.170
	(0.043)	(0.061)	(0.024)	(0.414)	(0.136)
Individual Controls	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Observations	145992	146135	148375	128492	128978
R^2	0.6599	0.6897	0.7057	0.5165	0.3733
Adjusted R^2	0.5551	0.5942	0.6135	0.3701	0.1842

Constant included, Individual controls: age^2, years of education, number of children and couple status

Cluster-robust standard errors by districts in parentheses

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Conclusion

Labour and health outcomes:

- **Positive "direct" effect** of the phase-out on energy workers

  Nuclear plant dismantling and electricity market adjustments

- **Negative "induced" effect** on other local economic activities

  Adaptive behaviours to economic uncertainty and concerns for the district's future dynamism

No evidence for real-estate outcomes

Future work

- **Matching:** propensity score
- **Additional robustness checks:** phase-out intensity
- **Real-estate outcomes:** RWI-GEO-RED(X) datasets
- **Mechanisms:** fossil fuel power plant
- **Gradual closure:** anticipation effect
- **Indirect national effect:** *via* electricity price increase

Panel Event Study

$$Y_{idt} = \alpha + \sum_{n=2}^{5} \beta_n (Treated_d \times Lag_n) + \sum_{k=1}^{3} \delta_k (Treated_d \times Lead_k)$$
$$+ \theta C_{it} + \rho_t + \mu_i + \gamma_d + \varepsilon_{idt}$$

	Employment status, hours worked, wage
Y_{idt}	Life and health satisfaction, health status
	Rental income
$Treated_d$	Dummy for treated districts (near a 2011-closed nuclear pp)
$Post_t$	Dummy for years after the phase-out
$Lag_n, Lead_k$	Binaries for number of years away from phase-out
C_{it}	Age, age^2, female, education, marital status, children
ρ_t	Year FE
μ_i	Individual FE
γ_d	District FE
ε_{idt}	Error term

Heterogeneous Analysis

$$Y_{idt} = \alpha + \eta Sector_{it} + \beta(Treated_d \times Post_t) + \nu(Sector_{it} \times Post_t) + \lambda(Sector_{it} \times Treated_d) + \sigma(Sector_{it} \times Treated_d \times Post_t) + \theta C_{it} + \rho_t + \mu_i + \gamma_d + \varepsilon_{idt}$$

	Employment status, hours worked, wage
Y_{idt}	Life and health satisfaction, health status
	Rental income
$Treated_d$	Dummy for treated districts (near a nuclear pp closed in 2011)
$Post_t$	Dummy for years after the phase-out
$Sector_{it}$	Vector of 10 sectors
C_{it}	Age, age^2, female, education, marital status, children
ρ_t	Year FE
μ_i	Individual FE
γ_d	District FE
ε_{idt}	Error term

Results

Figure 4: Event Study Estimates - Labour Outcomes by District

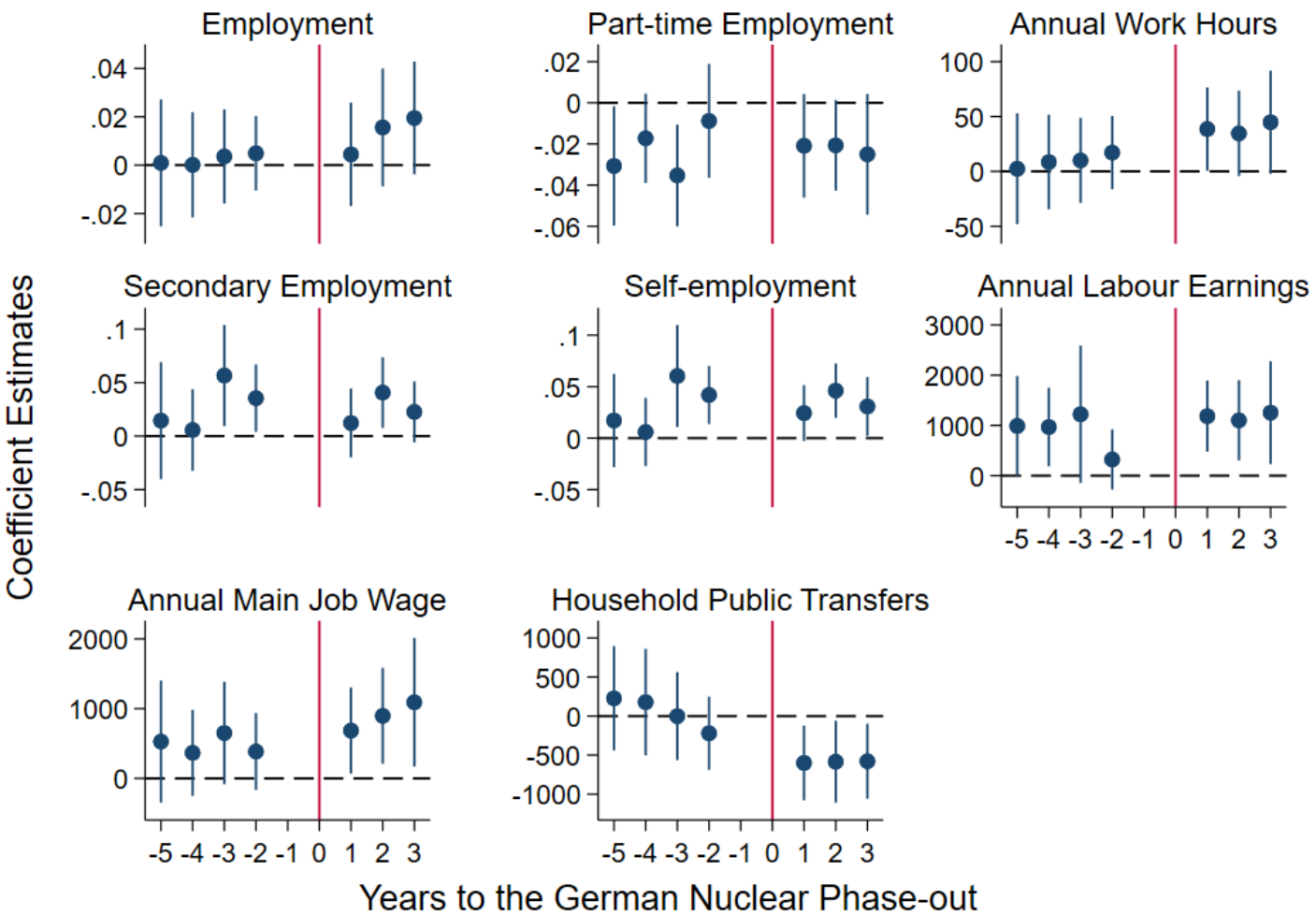

Table 4: Labour Outcomes by District - Heterogeneous Impacts

	Employment Status	Employment Level	Annual Work Hours	Secondary Employment	Self Employment	Annual Labour Earnings	Annual Wage Main Job	Household Public Transfers
Post*Treatment	0.011	-0.007	29.250*	0.010	0.019**	680.216*	541.734	-649.402***
	(0.010)	(0.010)	(16.358)	(0.011)	(0.009)	(404.583)	(344.964)	(199.426)
Energy*Post*Treatment	-0.013	0.017	295.731**	-0.049	-0.025	3936.431	2876.238	220.513
	(0.035)	(0.045)	(144.095)	(0.088)	(0.083)	(3958.984)	(3314.556)	(1207.886)
Individual Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	148176	80751	130484	147109	147109	130484	129041	71083
R^2	0.8033	0.7397	0.8545	0.4260	0.5477	0.8374	0.8978	0.7080
Adjusted R^2	0.7417	0.6529	0.8105	0.2465	0.4063	0.7882	0.8669	0.5964

Individual controls: age^2, years of education, number of children and couple status

Constant, Energy, Energy*Post, Energy*Treatment included

Cluster-robust standard errors by districts in parentheses

Years 2006 to 2013, 2011 excluded

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Health Outcomes by District - Heterogeneous Impacts

	Life Satisfaction	Health Satisfaction	Self-rated Health	Doctor Visits	Hospital Nights
Post*Treatment	-0.143***	-0.116*	-0.049**	-0.609	-0.161
	(0.043)	(0.060)	(0.025)	(0.421)	(0.137)
Energy*Post*Treatment	0.174	0.206	0.279	-4.565	-1.560
	(0.261)	(0.402)	(0.175)	(5.203)	(1.492)
Individual Controls	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Observations	145992	146135	148375	128492	128978
R^2	0.6599	0.6897	0.7057	0.5165	0.3734
Adjusted R^2	0.5551	0.5942	0.6135	0.3701	0.1842

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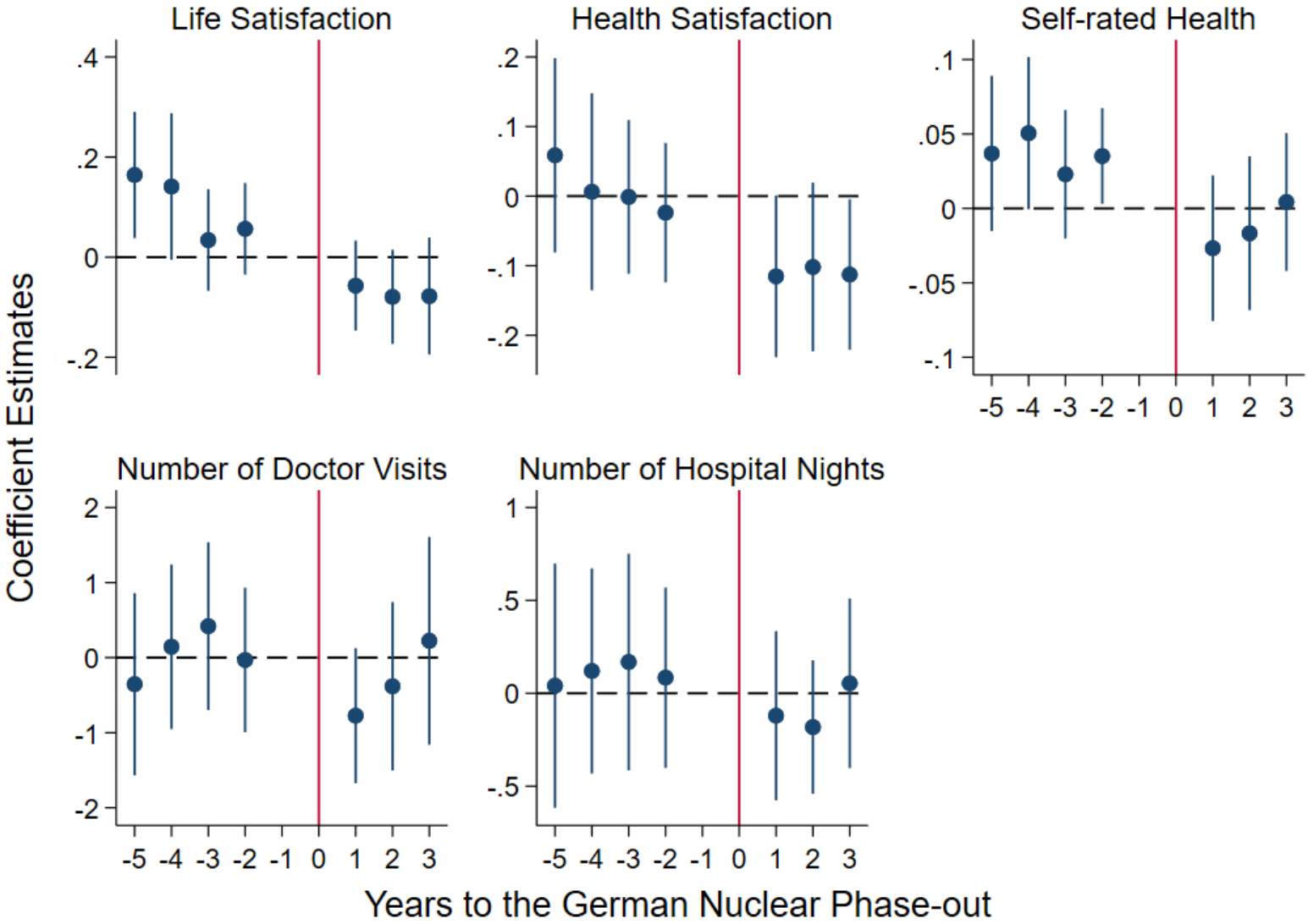

Figure 6: German Nuclear Phase-out and Newly-Commissioned Fossil Fuels Power Plants