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Measuring the Impact of Nuclear Accidents on Energy Policy

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Motivation

- Nuclear renaissance of the past decade (?), with new constructions and improved technologies.
- Questioning the impact of past accidents on reactor construction starts, as well as the possible effect of the Fukushima accident (2011) on future worldwide construction.
- Lack of econometric study in the literature conducted on construction starts and capacities, literature dealt mostly with psychological and political aspects.
- Attempting to close the gap by working with a complete dataset (IAEA).

Related Literature

- The existing econometric studies: (logit) models on construction starts, without testing energy usage as an independent variable.
- I control for the massive change in the size of the power plants over the years by working with the actual capacities in-build, allowing for a different econometric approach.
- Accidents modelled as dummies in the past were running for a uniform number of years or to the end of the the sample period. I allow the accident impact to potentially diminish and stop over time for each country.

Panel Dataset

- Panel Dataset 1965-2009 for 31 countries with civil nuclear power.
- Variables
 - S: Reactor Construction Starts in current year (in MWe)
 - E: Primary Energy Consumption
 - Y: Real GDP
 - infl: Inflation
 - r: Real Interest Rates
 - ENSEC: Energy Security Measure
 - Pooled Accident Dummies (Luc, TMI, Chernobyl) rated INES 5 or higher in the examined period (IAEA)

Accident Dummies

- Accident Dummies:
 - The length of the dummy variable varies pro country. The optimal length was determined by running a model where the impact length of the different accidents was allowed to vary, after controlling for energy consumption, persistence and the other accidents.
 - Choice by AIC criteria, from an array of 30504 models pro country.

The Basic Model

- Dynamic panel with FE (recommended for unbalanced macroeconomic data above $T=30$, cointegration not an option.
- Construction starts—measured in MW(e) capacities.
- Accident Model I: controlling for the lag of the dependent variable, due to the autoregressive nature of the series, for the lag of primary energy consumption, and fixed effects:

$$\text{Log}S_{i,t} = \beta_0 + \beta_1 \log S_{i,t-1} + \beta_2 \log E_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

- The construction starts in a given year in a country are denoted as $S_{i,t}$, energy consumption is denoted as $E_{i,t}$, country fixed assets are denoted with μ_i , and time fixed effects with λ_t . Construction starts were rescaled by adding one MW(e) capacity to each year, to allow the log-transformation

Period Fixed Effects of Accident Model I

Figure: Period Fixed Effects (λ_t) from Accident Model I

The Basic Model

- Accident Model II: Measure the influence of accidents on nuclear power plant construction: TMI, Chernobyl, Lucens, INES 5 or higher & public after 1965.
- Non-public Russian military accidents excluded.
- Estimate the time length of the impact, which may differ from country to country: individual regressions for all countries, allowing for the impacts of the nuclear accidents to last for varying times:

$$\begin{aligned} \text{Log}S_{i,t} = & \beta_0 + \beta_1 \text{log}S_{i,t-1} + \beta_2 \text{log}E_{i,t-1} + \beta_3 \text{LUC}_{1-41} \\ & + \beta_4 \text{TMI}_{1-31} + \beta_5 \text{CHER}_{1-24} + \varepsilon_{i,t} \end{aligned}$$

- Allow the Lucens dummy (LUC) to take on the value of "1" in successive time periods, allowing for differing impact extents. The variable thus takes on a positive value first in 1969, then in 1969 and 1970, and then progressively covers the entire sample period between 1969-2009.
- Similar treatment for the impact of the TMI accident (1979 to 2009) and for Chernobyl (1986 to 2009).
- The optimal impact length of an accident determined taking into account the other accidents, the constructions of the previous year and the energy consumption of the previous year, I ascertain by running the entire array of models, in this case $41 \times 31 \times 24 = 30504$ regressions for each country.

Pooled Accident Impact

- To avoid the ambiguous situation of interpreting the results individually, I construct a pooled variable for each accident dummy, including the optimal impact length for each country, and run the regression in a panel setting once again:

$$\begin{aligned} \text{Log}S_{i,t} = & \beta_0 + \beta_1 \text{log}S_{i,t-1} + \beta_2 \text{log}E_{i,t-1} + \beta_3 \text{LUC}_{i,t} \\ & + \beta_4 \text{TMI}_{i,t} + \beta_5 \text{CHER}_{i,t} + \mu_i + \varepsilon_{i,t} \end{aligned} \quad (3)$$

- The results including a time trend instead of the period fixed effects can be seen in Accident Model III:

$$\begin{aligned} \text{Log}S_{i,t} = & \beta_0 + \beta_1 \text{log}S_{i,t-1} + \beta_2 \text{log}E_{i,t-1} + \beta_3 \text{LUC}_{i,t} \\ & + \beta_4 \text{TMI}_{i,t} + \beta_5 \text{CHER}_{i,t} + \mu_i + \beta_8 t + \varepsilon_{i,t} \end{aligned}$$

Impact of Nuclear Accidents on Reactor Constructions

Table: Accident Impact on Reactor Construction

	β_0	$\log S_{i,t-1}$	$\log E_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	@t	μ_i	λ_t
Acc.M.I	-4.99 (0.00)	0.31 (0.00)	1.30 (0.00)					incl	incl
Acc. M.II	-0.74 (0.59)	0.37 (0.00)	0.37 (0.25)	0.34 (0.35)	-0.02 (0.96)	-0.82 (0.01)		incl	not incl
Acc. M.III	-3.18 (0.02)	0.31 (0.00)	1.23 (0.00)	-0.04 (0.91)	-0.15 (0.67)	-0.54 (0.06)	-0.05 (0.00)	incl	not incl

* S_{t-1} =construction starts in year t-1, E_{t-1} =primary energy consumption in year t-1, $LUC_{i,t}$ = Lucens accident impact, $TMI_{i,t}$ =Three Mile Island Accident Impact, $CHER_{i,t}$ =Chernobyl accident impact, μ_i =country fixed effects, λ_t =period fixed effects. Robust p-values are in parenthesis.

Pooled Accident Impact

- Trend and Chernobyl dummy: negative and significant → of all the examined accidents only Chernobyl had a lasting and negative consequence on worldwide nuclear power plant construction.
- Length of the impact?
 - Negative Chernobyl effect stops for China (1995), India (1999), and South Korea (2005) after a time span of nine-nineteen years.
 - No effect found on Japan. → Literature: Japan and Korea were building at a substantial rate when others were not. Reasons?
- Impact of energy dependence, physical constraints on pipeline transmission, national energy security question.

Real Interest Rates and Inflation

- Sociological, historical and political environment of nuclear energy must be considered along.
- Where data available, test of the joint impacts of inflation and real interest rates on new power plant construction. → A full time series: United States & South Africa (1965-2009), partial series: France (1965-2004), Sweden (1970-2005), and Japan (1971-2009).
 - Individual regression : the coefficients of both the real interest rate and the inflation variables usu. negative as expected, but non-significant.
 - A panel regression : non-significant coefficients with coefficient values around zero.
- No evidence for claim in literature regarding the impact of inflation and real interest rates.

Interest Rates and inflation

$$\begin{aligned} \log S_t = & \beta_0 + \beta_1 \log S_{t-1} + \beta_2 \log E_{t-1} + \beta_3 LUC_t \\ & + \beta_4 TMI_t + \beta_5 CHER_t + \beta_6 r_t + \beta_7 \text{infl}_t + \varepsilon_t \end{aligned} \quad (5)$$

Table: Impact of Inflation and Real Interest Rate on Reactor Construction

	β_0	$\log S_{i,t-1}$	$\log E_{i,t-1}$	LUC_t	TMI_t	$CHER_t$	$r_{i,t}$	$\pi_{i,t}$	μ_i
United States	4.35 (0.42)	0.22 (0.05)	0.44 (0.55)	-1.14 (0.00)	-7.83 (0.00)	0.07 (0.42)	0.00 (0.98)	0.02 (0.59)	
Japan	15.08 (0.68)	-0.25 (0.20)	-2.10 (0.73)	6.06 (0.02)	3.13 (0.01)	5.88 (0.00)	-0.55 (0.08)	-0.24 (0.15)	
France	-11.28 (0.51)	-0.15 (0.25)	3.28 (0.32)	-5.87 (0.00)	1.91 (0.07)	-5.74 (0.00)	-0.18 (0.27)	0.26 (0.07)	
South-Africa	-6.63 (0.31)	-0.33 (0.25)	2.14 (0.29)	-1.69 (0.26)	-3.16 (0.26)	-3.86 (0.26)	-0.01 (0.70)	0.07 (0.26)	
Sweden	60.03 (0.22)	-0.10 (0.33)	-15.60 (0.22)	4.37 (0.04)	7.83 (0.00)	1.28 (0.24)	-0.03 (0.42)	-0.03 (0.35)	
Panel sample	2.08 (0.43)	0.48 (0.00)	-0.19 (0.72)	0.01 (0.99)	-0.37 (0.51)	-0.87 (0.02)	-0.01 (0.07)	0.00 (0.10)	

* S_{t-1} = construction starts in year t-1, E_{t-1} = primary energy consumption in year t-1, LUC_t = Lucens accident impact, TMI_t = Three Mile Island Accident Impact, $CHER_t$ = Chernobyl accident impact, $r_{i,t}$ = real interest rate, $\pi_{i,t}$ = inflation rate, μ_i = country fixed effects. Robust p-values are in parenthesis.

Real Income and Economic Growth

- Fixing the basic model (Accident Model II), I have tested if including real income or economic growth changes my results significantly:

$$\begin{aligned} \text{Log}S_{i,t} = & \beta_0 + \beta_1 \text{log}S_{i,t-1} + \beta_2 \text{log}E_{i,t-1} + \beta_3 \text{LUC}_{i,t} \\ & + \beta_4 \text{TMI}_{i,t} + \beta_5 \text{CHER}_{i,t} + \beta_9 \text{log}Y_{i,t-1} + \mu_i + \varepsilon_{i,t} \end{aligned} \quad (6)$$

$$\begin{aligned} \text{Log}S_{i,t} = & c + \beta_1 \text{log}S_{i,t-1} + \beta_2 \text{log}E_{i,t-1} + \beta_3 \text{LUC}_{i,t} \\ & + \beta_4 \text{TMI}_{i,t} + \beta_5 \text{CHER}_{i,t} + \beta_{10} \Delta \text{log}Y_{i,t-1} + \mu_i + \varepsilon_{i,t} \end{aligned} \quad (7)$$

Real Income and Economic Growth

Table: Impact of real GDP and Growth on Reactor Construction

	β_0	$\log S_{i,t-1}$	$\log E_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	$\log Y_{i,t-1}$	$\Delta \log Y_{i,t-1}$	μ_i
YM I	5.92 (0.49)	0.36 (0.00)	1.07 (0.09)	0.14 (0.72)	-0.09 (0.80)	-0.89 (0.01)	-0.74 (0.38)		incl
YM II	-0.38 (0.95)	0.38 (0.00)		0.12 (0.77)	-0.02 (0.96)	-0.80 (0.02)	0.10 (0.81)		incl
gM I	-1.29 (0.34)	0.38 (0.00)	0.48 (0.12)	0.31 (0.52)	-0.02 (0.96)	-0.87 (0.01)		2.24 (0.21)	incl
gM II	0.82 (0.00)	0.39 (0.00)		0.13 (0.79)	0.05 (0.88)	-0.69 (0.01)		2.22 (0.21)	incl
	β_0	$\log S_{i,t-1}$	$\Delta \log E_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	$\log Y_{i,t-1}$	$\Delta \log Y_{i,t-1}$	μ_i
egM I	0.83 (0.00)	0.37 (0.00)	1.63 (0.15)	0.18 (0.65)	0.06 (0.87)	-0.69 (0.01)			incl
egM II	0.81 (0.00)	0.39 (0.00)	1.13 (0.33)	0.11 (0.82)	0.06 (0.87)	-0.69 (0.01)		1.61 (0.35)	incl

* S_{t-1} = construction starts in year t-1, E_{t-1} = primary energy consumption in year t-1, $LUC_{i,t}$ = Liferisk accident impact, $TMI_{i,t}$ = Three Mile Island Accident Impact, $CHER_{i,t}$ = Chernobyl accident impact, $\log Y_{i,t-1}$ = real income in year t-1, $\Delta \log Y_{i,t-1}$ = economic growth in year t-1, μ_i = country fixed effects. Robust p-values are in parentheses.

Real Income and Economic Growth

- The test of the natural log of gross domestic product:
 - in the absence of primary energy consumption insignificant results.
 - in the presence of the energy consumption variable negative significant correlation. Reason?
- A panel regression of economic growth or energy consumption growth on reactor constructions: insignificant results, with or without (E).
- The earlier results about the lock-in effect and the impact of accidents remain robust.

Energy Security

Table: Impact of Energy Security on Reactor Construction

	β_0	$\log S_{i,t-1}$	$\log E_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	$ENSEC_{i,t-1}$	@t	μ_i
ES I	0.53 (0.77)	0.34 (0.00)	0.01 (0.98)	0.13 (0.79)	-0.09 (0.81)	-0.79 (0.01)	-0.90 (0.06)		incl
ES II	-2.05 (0.23)	0.29 (0.00)	0.95 (0.02)	-0.29 (0.55)	-0.23 (0.53)	-0.51 (0.08)	-0.53 (0.23)	-0.06 (0.00)	incl

* S_{t-1} = construction starts in year t-1, E_{t-1} = primary energy consumption in year t-1, $LUC_{i,t}$ = Lucens accident impact, $TMI_{i,t}$ = Three Mile Island Accident Impact, $CHER_{i,t}$ = Chernobyl accident impact, $ENSEC_{i,t-1}$ = energy security measure in year t-1, @t = time trend, μ_i = country fixed effects. Robust p-values are in parenthesis.

Energy Security

- While the coefficient of energy security variable is significant and negative:
 - Energy dependency (insecurity) contributes to nuclear power plant construction.
 - Yet the impact of accidents or the magnitude of their coefficients is robust, as is lock-in effect.
 - Oil prices.
- Results support the view that nuclear power plant construction worldwide has been mostly driven besides the increasing energy demand, by historical circumstances, by the lock-in effect, as well as by energy security considerations.

Conclusion

Potential impact of nuclear accidents on reactor construction:

- Accident impact may, but need not wear off after 10 to 30 years, depending on other factors.
- Fukushima is likely to have a significant negative effect on new construction in Japan, while existing plants are likely to continue operating.
- The Fukushima impact may vary according to location.
- Where the major forces encouraging nuclear expansion, such as energy consumption growth, energy security concerns are coupled with government programs and plant ownership, expansion is likely to continue.
- New builds will be more negatively impacted in countries without these factors, or where nuclear energy faces free market conditions.