Measuring the Impact of Nuclear Accidents on Energy Policy

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Outline

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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:

$$LogS_{i,t} = \beta_0 + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t} \qquad (1)$$

- 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

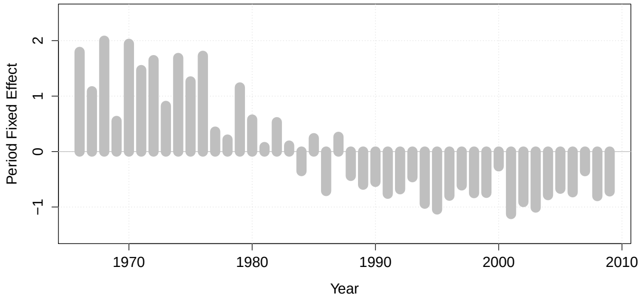

Figure: Period Fixed Effects (λ_t) from Accident Model I

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:

$$\begin{aligned} LogS_{i,t} = \beta_0 + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \beta_3 LUC_{1-41} \\ + \beta_4 TMI_{1-31} + \beta_5 CHER_{1-24} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

The Basic Model

- 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*31*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:

$$\begin{aligned} LogS_{i,t} = \beta_0 + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \beta_3 LUC_{i,t} \\ + \beta_4 TMI_{i,t} + \beta_5 CHER_{i,t} + \mu_i + \varepsilon_{i,t} \end{aligned} \tag{3}$$

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

$$\begin{aligned} LogS_{i,t} = \beta_0 + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \beta_3 LUC_{i,t} \\ + \beta_4 TMI_{i,t} + \beta_5 CHER_{i,t} + \mu_i + \beta_8 t + \varepsilon_{i,t} \end{aligned} \tag{4}$$

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Impact of Nuclear Accidents on Reactor Constructions

Table: Accident Impact on Reactor Construction

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

* 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.

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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.

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Interest Rates and inflation

$$LogS_t = \beta_0 + \beta_1 logS_{t-1} + \beta_2 logE_{t-1} + \beta_3 LUC_t + \beta_4 TMI_t + \beta_5 CHER_t + \beta_6 r_t + \beta_7 infl_t + \varepsilon_t \quad (5)$$

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

	β_0	$logS_{i,t-1}$	$logE_{i,t-1}$	LUC_t	TMI_t	$CHER_t$	$r_{i,t}$	$\pi_{i,t}$	μ_i
United States	4.35	0.22	0.44	-1.14	-7.83	0.07	0.00	0.02	
	(0.42)	(0.05)	(0.55)	(0.00)	(0.00)	(0.42)	(0.98)	(0.59)	
Japan	15.08	-0.25	-2.10	6.06	3.13	5.88	-0.55	-0.24	
	(0.68)	(0.20)	(0.73)	(0.02)	(0.01)	(0.00)	(0.08)	(0.15)	
France	-11.28	-0.15	3.28	-5.87	1.91	-5.74	-0.18	0.26	
	(0.51)	(0.25)	(0.32)	(0.00)	(0.07)	(0.00)	(0.27)	(0.07)	
South-Africa	-6.63	-0.33	2.14	-1.69	-3.16	-3.86	-0.01	0.07	
	(0.31)	(0.25)	(0.29)	(0.26)	(0.26)	(0.26)	(0.70)	(0.26)	
Sweden	60.03	-0.10	-15.60	4.37	7.83	1.28	-0.03	-0.03	
	(0.22)	(0.33)	(0.22)	(0.04)	(0.00)	(0.24)	(0.42)	(0.35)	
Panel sample	2.08	0.48	-0.19	0.01	-0.37	-0.87	-0.01	0.0[illegible]	i[illegible]cl
	(0.43)	(0.00)	(0.72)	(0.99)	(0.51)	(0.02)	(0.07)	(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:

$$LogS_{i,t} = \beta_0 + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \beta_3 LUC_{i,t} + \beta_4 TMI_{i,t} + \beta_5 CHER_{i,t} + \beta_9 logY_{i,t-1} + \mu_i + \varepsilon_{i,t} \quad (6)$$

$$LogS_{i,t} = c + \beta_1 logS_{i,t-1} + \beta_2 logE_{i,t-1} + \beta_3 LUC_{i,t} + \beta_4 TMI_{i,t} + \beta_5 CHER_{i,t} + \beta_{10} \Delta logY_{i,t-1} + \mu_i + \varepsilon_{i,t} \quad (7)$$

Real Income and Economic Growth

Table: Impact of real GDP and Growth on Reactor Construction

	β_0	$logS_{i,t-1}$	$logE_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	$logY_{i,t-1}$	$\Delta logY_{i,t-1}$	μ_i
YM I	5.92	0.36	1.07	0.14	-0.09	-0.89	-0.74		incl
	(0.49)	(0.00)	(0.09)	(0.72)	(0.80)	(0.01)	(0.38)		
YM II	-0.38	0.38		0.12	-0.02	-0.80	0.10		incl
	(0.95)	(0.00)		(0.77)	(0.96)	(0.02)	(0.81)		
gM I	-1.29	0.38	0.48	0.31	-0.02	-0.87		2.24	incl
	(0.34)	(0.00)	(0.12)	(0.52)	(0.96)	(0.01)		(0.21)	
gM II	0.82	0.39		0.13	0.05	-0.69		2.22	incl
	(0.00)	(0.00)		(0.79)	(0.88)	(0.01)		(0.21)	

	β_0	$logS_{i,t-1}$	$\Delta logE_{i,t-1}$	$LUC_{i,t}$	$TMI_{i,t}$	$CHER_{i,t}$	$logY_{i,t-1}$	$\Delta logY_{i,t-1}$	μ_i
egM I	0.83	0.37	1.63	0.18	0.06	-0.69			incl
	(0.00)	(0.00)	(0.15)	(0.65)	(0.87)	(0.01)			
egM II	0.81	0.39	1.13	0.11	0.06	-0.69		1.61	incl
	(0.00)	(0.00)	(0.33)	(0.82)	(0.87)	(0.01)		(0.35)	

* 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, $logY_{i,t-1}$=real income in year t-1, $\Delta logY_{i,t-1}$=economic growth in year t-1, μ_i=country fixed effects. Robust p-values are in parenthesis.

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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.

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Energy Security

Table: Impact of Energy Security on Reactor Construction

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

* 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.

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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.