The relationship between nuclear energy and military expenditures: A panel data analysis

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Research questions

Hypotheses:

- Are military expenditures a significant explanatory factor for the deployment of nuclear electricity production?
- Are military expenditures and nuclear electricity production jointly determined?

"Atomic energy was born of science and warfare [...]"

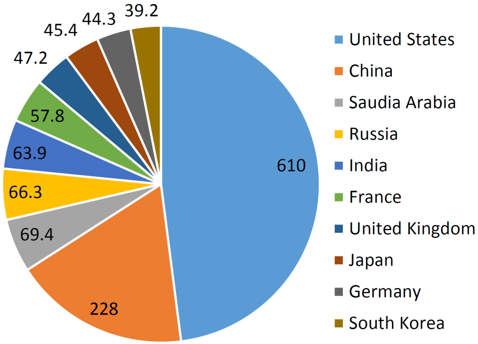
(Lévêque, 2014a)

Agenda

1. Introduction
2. Literature
3. Data and empirical specification
4. Empirical results
5. Preliminary conclusions and research outlook

Introduction

Figure 1: Top 10 states
military expenditure in billion USD (2017)



Source: Own depiction based on SIPRI Military Expenditure Database 2018

- 9/10 use Nuclear Power
- Saudi Arabia: projected 17 GWe of nuclear capacity by 2040
- 6/10 are nuclear-weapon states
- 9/10 have the technical capacity to build nuclear weapons (Fuhrmann and Tkach, 2015)
- world military expenditures reached 1739 billion in 2017, the highest level since the end of the cold war (SIPRI, 2018)

Introduction

	Year of Achieving		
Country	Weapon	Electric Power	First Power Reactor
United States	1945	1957	Shippingport (60 MWe)
Former USSR	1949	1958	Troisk A (100 MWe)
United Kingdom	1952	1956	Calder Hall 1 (50 MWe)
France	1960	1964	Chinon A1 (70 MWe)
China	1964	$\sim$ 1992[a]	Qinshan 1 (300 MWe)

Source: Bodansky (2007)

Economies of scope logic: nuclear power is developed for military and civilian purposes (e.g., electricity, medical services)

- most countries that have nuclear weapons had those weapons well before they had civilian nuclear power
- nucler power has been developed at the intersection of military use and electricity generation

Literature review

Nuclear energy and military complex:

- Acheson-Lilienthal Report (1946): development of atomic energy for civil purposes and for bombs is interchangeable and interdependent
- Lovins and Lovins (1980): inherent link between the military and "civil" branch of nuclear power

Nuclear energy and economic growth:

- relationship between nuclear energy consumption and economic growth (Smyth and Narayan, 2015)
- mixed empirical evidence (time series studies vs. panel data studies)

Military expenditures and economic growth:

- relationship between economic growth and military spending dates back to the seminal work by Benoit (1978)
- aggregate demand stimulation vs. investment crowding-out

Data I: construction of the panel and variables

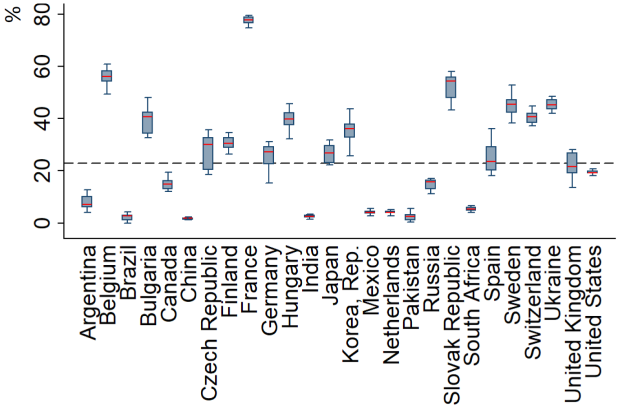
Construction of our panel:

- 33 countries listed in World Development Indicators (WDI) database capable of producing nuclear electricity
- 26 out of 33 (79%) countries which are listed in the WDI database are included for the period 1993 to 2014
- Armenia, Iran, Kazakhstan, Romania, Italy, Lithuania, and Slovenia are excluded
- All-income (26) = high-income (17) + non high-income (9)

Main variables of interest:

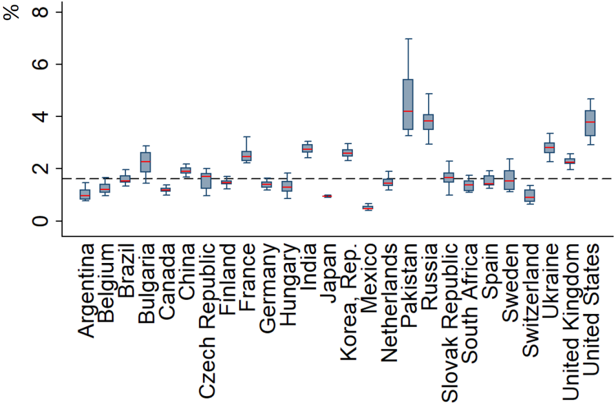
- electricity production from nuclear sources (% of total)
- military expenditures (% of GDP)
- selection of variables determines country and time dimension

Nuclear electricity production (% of total) (1993 - 2014):



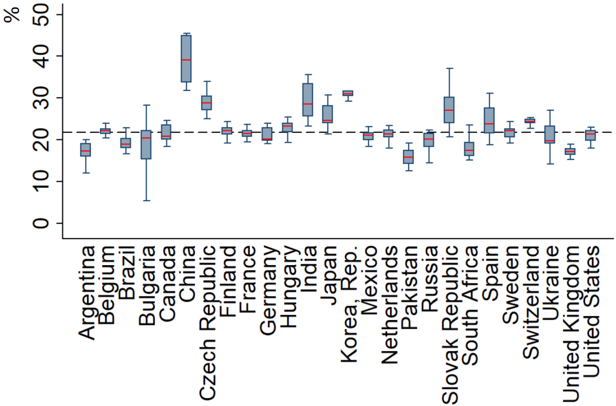
- reflects the importance of nuclear power in the overall energy mix
- four reactors in both Slovak Republic and Hungary account for almost 50% to the total of electricity porduction

Military expenditures (% of GDP) (1993 - 2014):



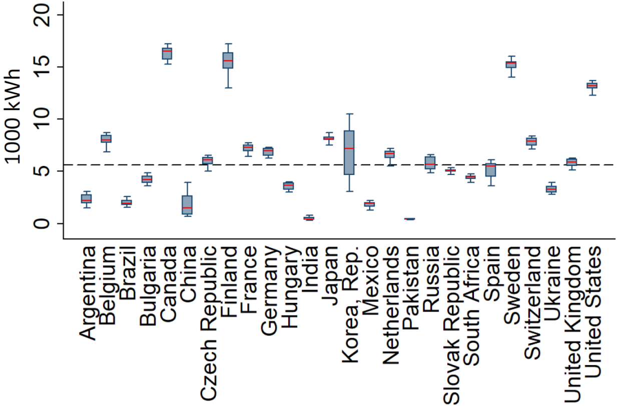
- countries maintaining nuclear power for electricity generation also have a large military sector
- domestic nuclear supply chain is needed to provide for nuclear Navy requirements (e.g. Moniz 2011; Energy Futures Initiative 2017)

Gross fixed capital formation (% of GDP) (1993 - 2014):



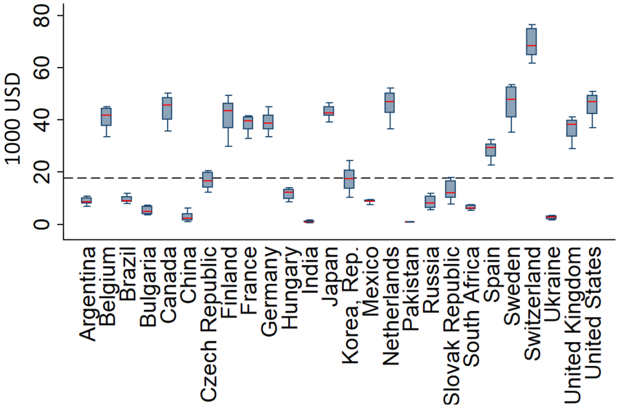
- nuclear power is considered to have the highest construction costs of all the generating technologies (e.g. Rothwell 2016; Davis 2012; D'haeseleer 2013)
- escalation of capital costs has observed regularly (e.g. Joskow (1982); Rangel/Lévêque (2015); Schneider, et al. (2016))

Electric power cons. (kWh per capita) (1993 - 2014):



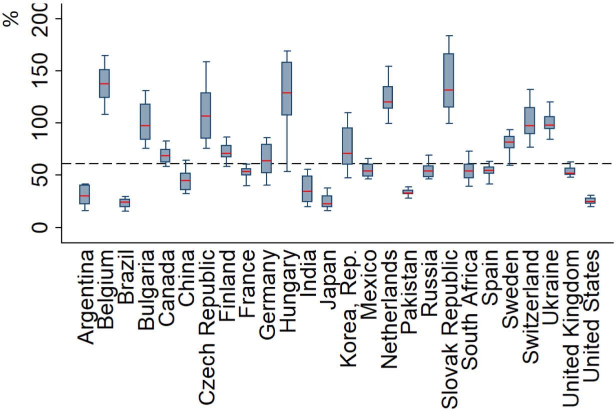
- electricity demand tends to increase globally as new major economies develop
- we control for a countries overall electricity demand as an indicator of the size of economy and level of development

GDP per capita (constant 2010 USD) (1993 - 2014):



- the level of economic development shapes peoples attitude towards highly controversially discussed generating technologies such as nuclear power
- empirical literature is analysing the relationship between nuclear energy consumption and economic growth (Smyth and Narayan, 2015)

Trade-openness (% of GDP) (1993 - 2014):



- enebales countries to import key components to facilitate the operation of nuclear power plants (Lévêque, 2014b)
- expands economic activities thus stimulating the volume of domestic production which results in increasing energy demand (Shahbaz et al., 2014)

Empirical specification

Model 1: $N_{it} = \alpha_{0i} + \alpha_{1i} M_{it} + \alpha_{2i} C_{it} + \alpha_{3i} E_{it} + \epsilon_{it}$

Model 2: $N_{it} = \beta_{0i} + \beta_{1i} M_{it} + \beta_{2i} C_{it} + \beta_{3i} E_{it} + \beta_{4i} Y_{it} + \epsilon_{it}$

Model 3: $N_{it} = \lambda_{0i} + \lambda_{1i} M_{it} + \lambda_{2i} C_{it} + \lambda_{3i} E_{it} + \lambda_{4i} T_{it} + \epsilon_{it}$

- N: electricity production from nuclear sources (share in total electricity production)
- M: military expenditures (percentage of GDP)
- C: gross fixed capital formation (percentage of GDP)
- E: electric power consumption (kWh per capita)
- Y: GDP per capita (constant 2010 USD)
- T: trade-openness (% of GDP)

Panel causality test

- if lagged values of x significantly predict present values of y in an error correction model from lagged values of x as well as y, then x is said to Granger cause y (Granger, 1969).

Dumitrescu and Hurlin (2012) panel non-causality test

- the following bivariate model can be used to test whether x causes y

$$y_{i,t} = \alpha_{0i} + \sum_{k=1}^{K} \beta_{ik} y_{i,t-k} + \sum_{k=1}^{K} \gamma_{ik} x_{i,t-k} + \epsilon_{it}$$

- $H_0 : \gamma_{i1} = ...\gamma_{iK} = 0$ (absence of causality for all countries)
- $H_1 : \gamma_{i1} \neq 0$ and $H_1 : \gamma_{i1} = 0$ (causality for some countries but not necessarily for all)

Estimated coefficients

	All-income			High-income			Non high-income		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
	long-run coefficients								
M	0.128^a	0.0736^c	0.237^a	0.135^a	-0.395^a	-0.754^a	0.538^a	2.049^a	0.578^a
	(3.99)	(1.74)	(4.49)	(3.64)	(-5.44)	(-5.65)	(7.84)	(3.68)	(6.32)
C	-0.164^b	0.142^b	-0.128^b	-0.305^a	-0.462^b	-0.134	-0.0954^b	0.0680	-0.105^b
	(-2.20)	(2.10)	(-2.05)	(-3.11)	(-2.40)	(-0.60)	(-2.35)	(0.11)	(-2.32)
E	0.342^a	0.953^a	0.308^a	0.574^a	0.614^a	2.115^a	0.279^a	3.375^a	0.255^a
	(7.39)	(10.43)	(6.82)	(5.25)	(3.52)	(5.86)	(5.82)	(3.95)	(4.79)
Y		-0.756^a			-1.740^a			-3.398^a	
		(-6.70)			(-6.84)			(-3.98)	
T			0.123^b			-1.992^a			0.124
			(2.03)			(-7.58)			(1.18)

Notes: Nuclear electricity production is the dependent variable; M1, M2, and M3 indicates specification 1 to 3, respectively.

Dumitrescu and Hurlin (2012) panel causality test results

All-income		High-income		Non high-income	
unidirectional	bidirectional	unidirectional	bidirectional	unidirectional	bidirectional
$M \rightarrow E$ $M \rightarrow Y$ $M \rightarrow T$ $C \rightarrow N$	$N \leftrightarrow M$ $C \leftrightarrow E$	$M \rightarrow N$ $M \rightarrow Y$ $M \rightarrow T$ $C \rightarrow N$ $C \rightarrow E$ $T \rightarrow Y$	-	$M \rightarrow T$ $C \rightarrow T$ $E \rightarrow C$ $E \rightarrow T$ $Y \rightarrow T$	$N \leftrightarrow M$

Notes: $\rightarrow$ and $\leftrightarrow$ indicate unidirectional and bidirectional short-run causality, respectively.

- bidirectional causality between military expenditures and nuclear electricity production in all- and the non-high income panels
- unidirectional causality runs from military expenditures to nuclear electricity production in the high-income panel

Preliminary conclusion

- military expenditures tend to impact nuclear electricity production positve in magnitude
- military expenditures and nuclear electricity production are jointly determined in both the all- and non high-income panels
- results tend to be driven by the non high-income panel (Bulgaria, Brazil, China, India, Mexico, Pakistan, Russia, South Africa, Ukraine)
- Energy Futures Initiative (2017): domestic civil nuclear sector necessary for the military sector to
  - provide the experts and expertise
  - provide for nuclear Navy requirements
  - develop small reactors which power domestic bases and operational units abroad
- race of militarization increases energy consumption (Bildirici, 2017)
- linkages between the civilian use of nuclear power and the military sector in general might impede a nuclear phase out

Research outlook

"One of the surprising features of modern economic growth is that economies with abundant natural resources have tended to grow less rapidly than natural-resource-scarce economies."

(Sachs and Warner, 1995)

The nuclear resource curse:

- the link between abundant and cheap nuclear power, and the economic development conditions of countries attempting to use this to "go nuclear", i.e. to enter the sector
- big nuclear vendor countries, mainly China, Russia, and the U.S. provide nuclear power plants to newbies at very favorable conditions
- working hypothesis: the availability of abundant and cheap nuclear power capacities, the resource, incites many emerging and poor countries to go nuclear, but is likely to turn into a resource curse not only in economic, but also in longer-term development perspectives

Thank you.

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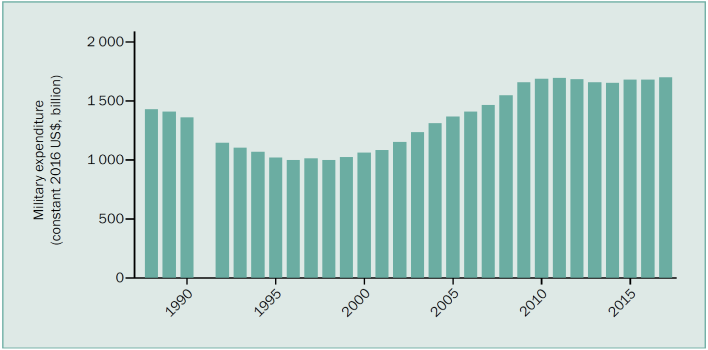
Back up: List of countries

High-income panel (17): Belgium, Slovak Republic, Hungary, Netherlands, Czech Republic, Switzerland, Sweden, Finland, Korea, Rep., Canada, Germany, Spain, France, United Kingdom, Argentina, United States, and Japan.

Upper middle-income (6): Bulgaria, Mexico, Russian Federation, South Africa, China, and Brazil.

Lower middle-income (3): Ukraine, India, and Pakistan.

Back up: Global military expenditures 2017



Source: SIPRI Fact Sheet: Trends in world military expenditres 2018

- increase from 1097bn in 1993 to 1642bn in 2014 (+50%)

Back up: Summary statistics

	All-income (n=26)				High-income (n=17)				Non high-income (n=9)			
	P_{50}	cv	m	sd	P_{50}	cv	m	sd	P_{50}	cv	m	sd
N	22.86	78	25.47	19.89	29.70	58	32.11	18.50	4.26	124	12.94	16.04
M	1.62	53	1.93	1.02	1.45	45	1.69	0.76	2.29	53	2.39	1.27
C	21.81	25	22.80	5.66	22.32	19	23.01	4.32	20.43	34	22.40	7.58
E	5,619.33	70	6,297.76	4,399.10	7,143.76	51	8,208.68	4,164.65	2,388.76	67	2,688.24	1,795.74
Y	17,721.94	79	24,388.29	19,324.65	38,529.42	47	34,593.34	16,240.13	5,448.89	67	5,112.09	3,445.78
T	60.84	54	70.62	38.11	70.36	51	78.69	40.46	50.39	50	55.37	27.44

Notes: P_{50} is the median, cv the coefficient of variation, m the arithmetic mean, and sd the standard deviation. The coefficient of variation is defined as the standard deviation divided by mean. It is presented as a percentage and is a measure for the relative dispersion of the variables. The data obtained from the World Development Indicators (WDI) database from The World Bank (last updated 26 July 2018).

Back up: Multicollinearity test

	All-income		High-income		Non high-income	
Explanatory variables	VIF	Mean VIF	VIF	Mean VIF	VIF	Mean VIF
M	1.36		1.16		2.22	
C	1.02		1.14		1.07	
E	5.59	3.00	2.62	1.74	8.74	4.59
Y	5.78		2.63		8.23	
T	1.26		1.12		2.70	

Values of the variance inflation factor (VIF) for the explanatory variables in any income group are all below 10, which is a commonly used rule of thumb (Montgomery et al., 2001).

Back up: Cross-section dependence test results

		Variables in levels					
		N	M	C	E	Y	T
All income	abs (corr)	0.39	0.52	0.46	0.63	0.90	0.67
	CD statistic	1.23	27.43^a	4.90^a	42.20^a	76.02^a	43.74^a
		(0.22)	(0.00)	(0.00)	(0.00)	(0.00))	(0.00))
High income	abs (corr)	0.39	0.61	0.49	0.66	0.92	0.77
	CD statistic	3.50^a	25.43^a	7.55^a	30.64^a	50.49^a	38.77^a
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Non high income	abs (corr)	0.42	0.36	0.36	0.66	0.91	0.48
	CD statistic	6.31^a	3.35^a	6.40^a	17.99^a	25.48^a	5.89^a
		(0.00)	(0.00)	(0.00)	(0.14)	(0.00)	(0.00)

Notes: P-values are in brackets; superscripts a, b, and c represent significance at 1%, 5%, and 10%, respectively; all variables in natural logarithms.

Back up: Panel unit root test

	All-income		High-income		Non high-income	
	No Trend	Trend	No Trend	Trend	No Trend	Trend
N	-2.117^c	-3.356^a	-2.647^a	-2.854^a	-2.975^a	-4.276^a
M	-2.144^c	-2.227	-1.884	2.221	-2.744^a	-2.721^c
C	-1.455	-2.216	-1.615	-2.009	-2.373^b	-1.793
E	-2.018	-2.614^c	-2.322^a	-3.775^a	-2.601^a	-2.055
Y	-2.184^b	-2.014	-1.521	-1.618	-3.554^a	-2.657
T	-1.976	-1.985	-1.809	-2.160	-2.397^b	-2.205
ΔN	-5.063^a	-5.015^a	-5.138^a	-5.280^a	-5.331^a	-5.023^a
ΔM	-4.070^a	-4.172^a	-4.131^a	-4.067^a	-4.559^a	-4.835^a
ΔC	-3.745^a	-3.776^a	-3.521^a	-3.684^a	-3.127^a	-4.078^a
ΔE	-4.269^a	-4.603^a	-5.049^a	-5.039^a	-3.174^a	-4.174^a
ΔY	-2.689^a	-2.646^b	-2.805^a	-2.745^b	-3.340^a	-3.299^a
ΔT	-3.522^a	-3.568^a	-3.507^a	-3.430^a	-3.752^a	-3.772^a

Notes: P-values are in brackets; superscripts a, b, and c represent significance at 1%, 5%, and 10%, respectively; critical values are from Pesaran (2007).

Back up: Estimated coefficients

	All-income			High-income			Non high-income		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
				long-run coefficients					
M	0.128[a]	0.0736[c]	0.237[a]	0.135[a]	-0.395[a]	-0.754[a]	0.538[a]	2.049[a]	0.578[a]
	(3.99)	(1.74)	(4.49)	(3.64)	(-5.44)	(-5.65)	(7.84)	(3.68)	(6.32)
C	-0.164[b]	0.142[b]	-0.128[b]	-0.305[a]	-0.462[b]	-0.134	-0.0954[b]	0.0680	-0.105[b]
	(-2.20)	(2.10)	(-2.05)	(-3.11)	(-2.40)	(-0.60)	(-2.35)	(0.11)	(-2.32)
E	0.342[a]	0.953[a]	0.308[a]	0.574[a]	0.614[a]	2.115[a]	0.279[a]	3.375[a]	0.255[a]
	(7.39)	(10.43)	(6.82)	(5.25)	(3.52)	(5.86)	(5.82)	(3.95)	(4.79)
Y		-0.756[a]			-1.740[a]			-3.398[a]	
		(-6.70)			(-6.84)			(-3.98)	
T			0.123[b]			-1.992[a]			0.124
			(2.03)			(-7.58)			(1.18)
				ECM					
ECM	-0.303[a]	-0.287[a]	-0.304[a]	-0.256[a]	-0.238[a]	-0.126[b]	-0.420[a]	-0.158	-0.416[a]
	(-4.66)	(-3.66)	(-4.62)	(-2.97)	(-2.79)	(-2.10)	(-3.79)	(-1.51)	(-3.80)
DM	0.320	0.592	0.735	0.775	1.22	1.322	-0.618	-0.601	-0.373
	(0.57)	(0.79)	(0.81)	(1.00)	(1.15)	(0.98)	(-0.90)	(-0.80)	(-0.70)
DC	-0.417	-0.691	-0.489	0.0170	-0.0477	-0.0834	-1.220	-1.716	-1.129
	(-1.14)	(-1.10)	(-1.29)	(0.11)	(-0.34)	(-0.35)	(-1.20)	(-0.95)	(-1.07)
DE	0.397	-0.130	0.494	0.156	0.099	-0.0318	0.729	-0.225	0.834
	(0.83)	(-0.23)	(0.93)	(0.23)	(0.15)	(-0.04)	(1.40)	(-0.20)	(1.30)
DY		1.116			0.924[c]			1.761	
		(0.76)			(1.73)			(0.40)	
DT			-0.0683			0.185			-0.344
			(-0.38)			(0.97)			(-0.92)
$Const.$	0.0404	0.388[c]	-0.0768	-0.229[b]	4.224[a]	-0.910[b]	-0.123	0.359[b]	-0.250
	(0.35)	(1.83)	(-0.65)	(-2.12)	(2.74)	(-2.14)	(-0.51)	(2.24)	(-1.04)

Back up: Empirical strategy

1. detect contemporaneous correlation among countries after controlling for individual characteristics (i.e. global shocks, local interactions)
2. test for unit roots in the presence of cross-section dependence from a single common factor
3. dynamic heterogeneous panel autoregressive distributed-lag (ARDL) approach
4. heterogeneous panel causality test

Back up: Cross-section dependence test

- contemporaneous correlation among countries that is left over after controlling for individual characteristics (Moscone and Tosetti, 2009)
- first-generation panel methods assume cross-sectional independence

Pesaran (2004) CD test is robust to the presence of

- nonstationary processes,
- parameter heterogeneity or structural breaks,
- ... and perfoms well in small samples.

Back up: Second-generation panel unit root test

- using nonstationary variables can lead to apparently significant regression results although the data is unrelated

Pesaran (2007) CIPS panel unit root test

- Cross-sectionally augmented Im-Pesaran-Shin (2003) (IPS) test

$$\Delta y_{it} = \delta_i^{'} d_t + \rho_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{J} d_{ij} \Delta \overline{y}_{t-j} + \sum_{j=1}^{J} \beta_{ij} \Delta y_{i,t-j} + \epsilon_{it}$$

- $H_0 : \rho_i = 0$ is tested against $H_1 : \rho_i < 0$ and $H_1 : \rho_i = 0$

Back up: Panel ARDL approach

- estimation of the long-run effect of military expenditures on nuclear electricity production
- identification of short- and long-term dynamics of relevant explanatory factors for nuclear electricity production

ARDL(p,q) model

- variables which have a different order of integration can be used irrespective whether the variables of interest are I(0) or I(1)
- inclusion of lags for the dependent and independent variables reduces problems resulting from endogeneity

Back up: Panel ARDL approach

VECM representation of the ARDL(p,q) model

$$\Delta N_{it} = \beta_{0i} + \phi_i(N_{i,t-1} - \theta_i X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta N_{i,t-1} + \sum_{j=0}^{q-1} \delta_{ij}^{*} \Delta X_{i,t-j} + \epsilon_{it},$$

- $X_{it} = M_{it}, C_{it}, E_{it}, Y_{it}, T_{it}$ is the set of explanatory variables
- Δ denotes the first difference operator
- j is the number of lags
- ϕ_i is the error correction or speed of adjustment term
- a negative coefficient on the error-correction term not lower than -2 provides evidence for a long-run relationship and stability of the model (Loayza et al., 2006)

Back up: First-order ARDL model

Model 1:

$$\Delta N_{it} = \phi_i(N_{i,t-1} - \theta_{0i} - \theta_{1i}M_{it} - \theta_{2i}C_{it} - \theta_{3i}E_{it})$$
$$+\delta_{11i}\Delta M_{it} + \delta_{21i}\Delta C_{it} + \delta_{31i}\Delta E_{it} + \epsilon_{it}$$

Model 2:

$$\Delta N_{it} = \phi_i(N_{i,t-1} - \theta_{0i} - \theta_{1i}M_{it} - \theta_{2i}C_{it} - \theta_{3i}E_{it} - \theta_{4i}Y_{it})$$
$$+\delta_{11i}\Delta M_{it} + \delta_{21i}\Delta C_{it} + \delta_{31i}\Delta E_{it} + \delta_{41i}\Delta Y_{it} + \epsilon_{it}$$

Model 3:

$$\Delta N_{it} = \phi_i(N_{i,t-1} - \theta_{0i} - \theta_{1i}M_{it} - \theta_{2i}C_{it} - \theta_{3i}E_{it} - \theta_{4i}T_{it})$$
$$+\delta_{11i}\Delta M_{it} + \delta_{21i}\Delta C_{it} + \delta_{31i}\Delta E_{it} + \delta_{41i}\Delta T_{it} + \epsilon_{it}$$

- number of lags j are determined using information criteria (SBIC)
- common lag structure makes short-run parameters comparable across panels

Back up: MG and PMG estimation techniques

Mean Group estimation (Pesaran and Smith, 1995)

- allows the country specific intercepts, the short- and long-run dynamics, and the error variances to differ across countries
- does not impose any homogeneity restrictions on the parameters for the cross-section members

Pooled Mean Group estimation (Pesaran et al., 1999)

- intrecepts, short-run coefficients, and error variance are determined cross-section specific
- the long-run parameters are constrained to be equal across the groups

Which estimator to choose?

- the test of difference in these models is performed using the Hausman (1987) specification test

Back up: Panel causality test

- if lagged values of x significantly predict present values of y in an error correction model from lagged values of x as well as y, then x is said to Granger cause y (Granger, 1969).

Dumitrescu and Hurlin (2012) panel non-causality test

- the following bivariate model can be used to test wheter x causes y

$$y_{i,t} = \alpha_{0i} + \sum_{k=1}^{K} \beta_{ik} y_{i,t-k} + \sum_{k=1}^{K} \gamma_{ik} x_{i,t-k} + \epsilon_{it}$$

- $H_0 : \gamma_{i1} = ...\gamma_{iK} = 0$ (absence of causality for all countries)
- $H_1 : \gamma_{i1} \neq 0$ and $H_1 : \gamma_{i1} = 0$ (causality for some countries but not necessarily for all)

Back up: Empirical results I

Peasaran (2004) CD test:

- all series are highly dependent across all income groups

Pesaran (2007) panel unit root test:

- results differ between panels
- strong evidence that a panel unit root for the series on C, E, and T exists
- N, M, and Y are stationary in levels (I(0)), all variables are stationary in their first difference I(1)

Implications

- first generation panel data methods are inappropriate
- mixed order of intergration justifies panel ARDL apporach

Back up: Related empirical literature

Nuclear energy and economic growth:

- relationship between nuclear energy consumption and economic growth (e.g. Yoo and Jung (2005); Yoo and Ku (2009); Payne and Tayler (2010); Menyah and Wolde-Rufael (2010); Wolde-Rufael (2010); Wolde-Rufael and Menyah (2010), Apergis and Payne (2010); Apergis et al. (2010); Lee and Chiu (2011))
- mixed empirical evidence (time series studies vs. panel data studies)

Military expenditures and economic growth:

- relationship between economic growth and military spending dates back to the seminal work by Benoit (1978)
- aggregate demand stimulation vs. investment crowding-out