Determinants of vertical proliferation: a causality analysis of the nuclear weapon states

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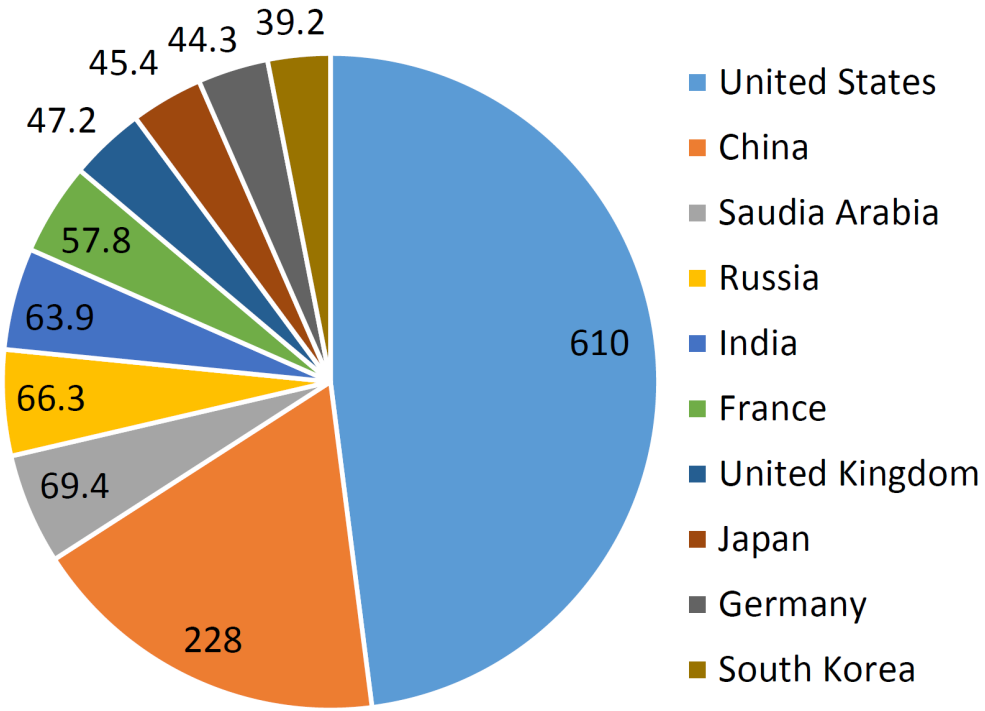
Salzburg, 15 October 2019

Post cold war arms race and nuclear new builds

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



Source: Own depiction based on SIPRI (2018).

- 9/10 use Nuclear Power.
- Saudi Arabia: projected 17 GWe of nuclear capacity by 2040.
- 6/10 are nuclear-weapon states.
- 5 largest nuclear reactor new-build programmes are in major nuclear weapon states (Stirling and Johnstone, 2018).

Nuclear power for military and civilian purposes

Country	Year of Achieving		First Power Reactor
	Weapon	Electric Power	
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.
- Nuclear power capabilities could be translated into nuclear weapons capabilities.

Research questions and hypotheses

Research question:

- How does the civilian use of nuclear energy causally determines vertical proliferation of nuclear warheads in nuclear weapon states?

Hypothesis:

- I hypothesize that the civilian use of nuclear power significantly is causally related to a countries' nuclear warheads arsenal.

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

(Lévêque, 2014)

Agenda

1. Theoretical aspects of proliferation
2. Empirical evidence of proliferation
3. Data and empirical strategy
   - Data/Graphical representation
   - Empirical specification
   - Toda Yamamoto (1995) causality methodology
4. Empirical results
5. Conclusions

Horizontal vs. vertical proliferation

Horizontal proliferation:

- "[...] refers to nation-states or nonstate entities that do not have, but are acquiring, nuclear weapons or developing the capability and materials for producing them" (Sidel and Levy, 2007).
- Spread of nuclear weapons to new states.

Vertical proliferation:

- "[...] refers to nation-states that do possess nuclear weapons and are increasing their stockpiles of these weapons, improving the technical sophistication or reliability of their weapons, or developing new weapons" (Sidel and Levy, 2007).
- Accumulation of nuclear weapons within the nuclear weapon states.

Determinants of nuclear proliferation

1. Determinants of (horizontal) nuclear proliferation:
   - Conceptual framework based on the ordering concepts of opportunity and willingness (Siverson and Starr, 1990; Jo and Gartzke, 2007).

2. Supply-side and demand-side of nuclear proliferation (Kroenig, 2009b):
   - Opportunity: supply-side of proliferation.
   - Willingness: demand-side of proliferation.
   - States may have chosen to develop nuclear weapons but do not succeed when lacking capabilities.
   - Countries with advanced industrial capacities are expected to more easily successful develop and possess nuclear weapons.

Determinants of nuclear proliferation

1. Nuclear opportunity: structural possibilities to manufacture nuclear weapons (macro level factors).
   - Set of technologies (knowledge) to the manufacture of nuclear weapons.
   - Nuclear fissile materials (Highly enriched uranium and plutonium).
   - Economic capacity.
2. Nuclear willingness: domestic and geopolitical conditions which impact the decision to develop nuclear weapons (choice processes that occur on the micro level).
   - Security model (deterring external aggression).
   - Domestic politics model:
     - Civilian nuclear industry.
     - Units in the military.
     - Politicians.
   - Norms model (symbol for modernity).

Empirical evidence of proliferation

Which factors drive the decisions to pursue nuclear weapons production programs and to develop actual nuclear weapons capabilities?

- Singh and Way (2004):
  - Level development, the external threat environment, the lack of great-power security guarantees, and low level of integration in the world determine proliferation.
- Jo and Gartzke (2007):
  - Security concerns and technological capabilities determinane the presence of a nuclear weapons programs.
  - Security concerns, economic capabilities, and domestic politics are the main predictors to explain the possession of nuclear weapons.

Empirical evidence of proliferation

Does nuclear assistance for weapon purpose, sensitive nuclear transfers, peaceful nuclear cooperation, and institutional technical cooperation impact the spread of nuclear weapons?

- Kroenig (2009a): strategic characteristics of nuclear suppliers are key determinants of sensitive nuclear assistance.
- Kroenig (2009b): sensitive nuclear assistance (key materials and technologies) statistically significant impacts nuclear proliferation.
- Fuhrmann (2009): civilian nuclear cooperation increases the likelihood that countries initiate weapons programs and build nuclear bombs.
- Brown and Kaplow (2014): receiving a Technical Cooperation (TC) program administered by the IAEA related to the nuclear fuel cycle increases the likelihood to to seek nuclear weapons.

Empirical evidence of proliferation

Different aspects of proliferation empirically covered:

- Why do nuclear weapon states deploy nuclear warheads abroad (Fuhrmann and Sechser, 2014)?
- Is there a link between the US nuclear arsenal and the spread of nuclear weapons to other countries (Kroenig, 2016)?
- What influences the nuclear force structure within nuclear weapon states (Gartzke et al., 2014)?

Data and empirical strategy

Data:

- Multi-country causality analysis on 7 nuclear weapon states.
- China (1993 - 2018), France (1965 - 2018), India (1998 - 2018), Pakistan (1998 - 2018), Russia (1992 - 2018), UK (1965 - 2018), USA (1965 - 2018).

Empirical strategy:

- Country causality analysis: Toda and Yamamoto (1995) version of the Granger non-causality test.
- Variables which have a different order of integration can be used irrespective of whether the variables of interest are I(0) or I(1).

Variable selection

Dependent variable:

- Nuclear warheads (W): quantities of stockpiled warheads a country possesses in a given year based on the Federation of American Scientists (FAS).

Supply side (opportunity) related factors:

- Nuclear energy consumption (NE) and military expenditure (M) capture a state's underlying nuclear and military capacity.
  - Aggregate indicator for the nuclear industrial capabilities useful for maintaining a nuclear weapons arsenal.
  - Generic indicator to tap the broader capabilities of the civil and military nuclear infrastructure.
  - Nuclear warheads require specific military infrastructure.
  - Military budget to acquire complex control and delivery systems as well as to maintain a nuclear arsenal.

Variable selection

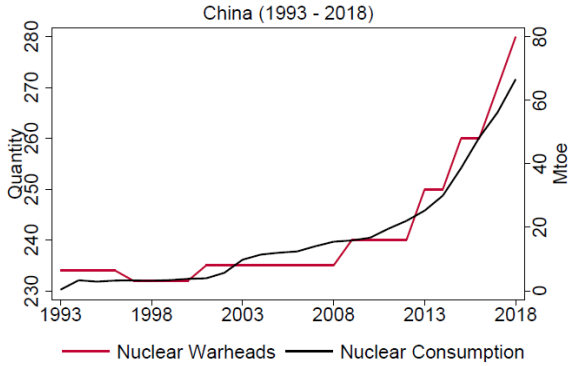
Supply side (opportunity)/demand side (willingness) related factors:

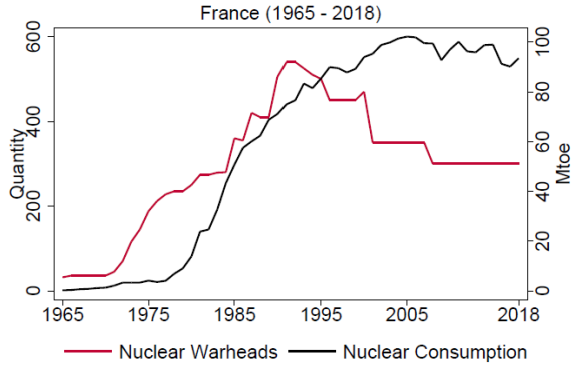
- Trade-openness (T) captures increasing economic capacity and openness.
  - An essential component for sustained economic growth.
  - Outward orientation facilitates the accessibility of advanced technologies (Hart, 1983; Ben-David and Loewy, 1998).
  - Captures the extent of integration into the international community indicating regime/outward orientation.

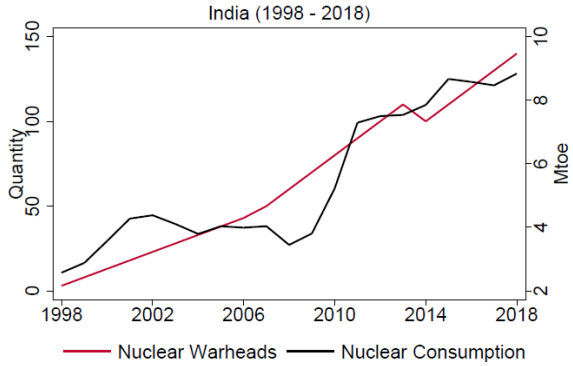
Summary statistics

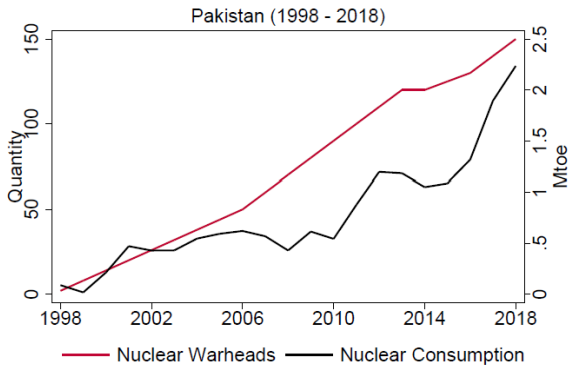
	W		NE		M		T	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
China (1993 - 2018)	241.31	12.74	17.21	17.59	1.90	0.13	44.48	10.01
France (1965 - 2018)	298.85	144.60	58.48	40.48	3.24	0.84	45.79	10.31
India (1998 - 2018)	65.10	43.52	5.47	2.20	2.65	0.19	41.02	10.48
Pakistan (1998 - 2018)	72.81	47.67	0.78	0.56	3.84	0.56	31.41	3.02
Russia (1992 - 2018)	10,105.22	6,570.69	33.94	7.40	3.78	0.59	55.87	12.94
UK (1965 - 2018)	319.17	100.21	13.53	5.36	3.44	1.26	50.68	6.25
USA (1965 - 2018)	16,652.41	9,358.41	117.68	70.35	4.93	1.59	20.25	6.14

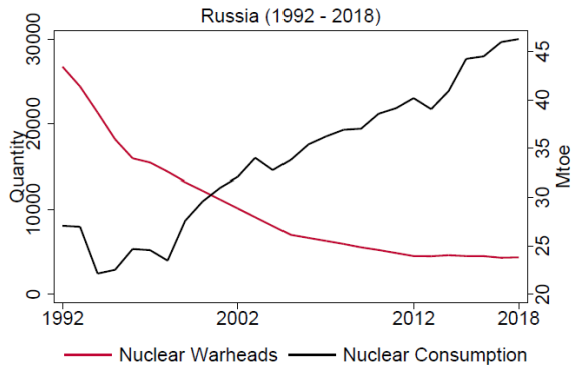
Graphical representation

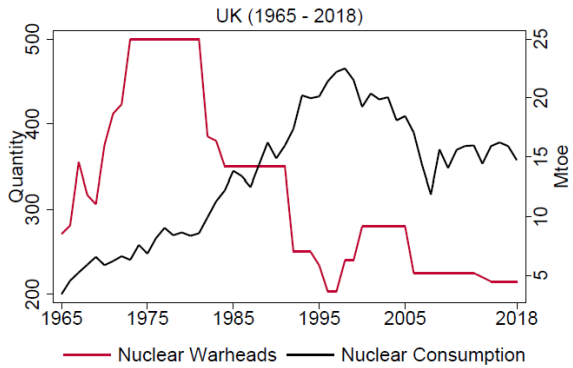


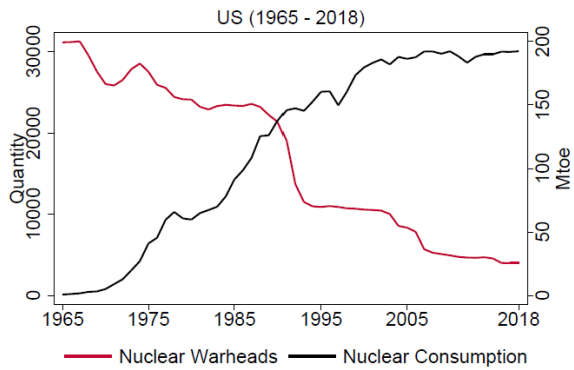












Empirical specification

Continous variable framework consisting of supply side (opportunity) and demand side (willingness) related factors:

$$W_{it} = \beta_{0i} + \beta_{1i} NE_{it} + \beta_{2i} M_{it} + \beta_{3i} T_{it} + \epsilon_{it}$$

- W: Nuclear warheads quantities of stockpiled warheads.
- NE: Nuclear energy consumption (mtoe).
- M: Military expenditure (share of GDP).
- T: Trade-openness (share of GDP).
- All variables are converted into natural logarithms.

Country causality analysis

Toda and Yamamoto (1995) procedure:

- Applicable to variables involved in the system that may be integrated or cointegrated of an arbitrary order.
- Reduces the risks of incorrectly identify the order of integration of the time series (Mavrotas and Kelly, 2001) to minimize pre-test biases (Soytas and Sari, 2006).
- Basic idea: artificially augment the optimum lag length k of a VAR by the maximal order of integration d_{max} of the variables to include an additional lag.
  - Identity the maximal order of integration d_{max} with unit root tests such as Dickey-Fuller (1979), Phillips-Perron (1988), and Kwiatkowski et al. (1992).
  - Utilize information criteria to identify the optimum lag length k for each of the VARs in a given country.
  - Estimate a $(k + d_{max})$th-order VAR for every country and ignore the last lagged d_{max} when inferring causality using modified Wald tests.

Country causality analysis

Toda and Yamamoto (1995) procedure:

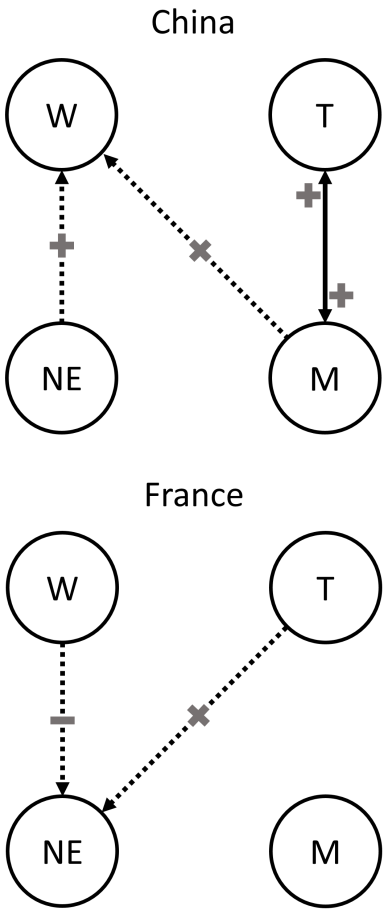
- Modified Wald test to test the significance of the parameters in a vector autoregression (VAR) model to identify the causal relations.
- Augment the optimum lag length k by the maximal order of integration d_{max} of the variables to include an additional lag.
- In the estimated $(k + d_{max})$th-order VAR the coefficients of the last lagged d_{max} vectors are ignored when inferring the causality.

Four variable framework which is given in the following VAR system:

$$\begin{bmatrix} W_t \\ NE_t \\ M_t \\ T_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \sum_{j=1}^{k} \begin{bmatrix} \beta_{11j} & \beta_{12j} & \beta_{13j} & \beta_{14j} \\ \beta_{21j} & \beta_{22j} & \beta_{23j} & \beta_{24j} \\ \beta_{31j} & \beta_{32j} & \beta_{33j} & \beta_{34j} \\ \beta_{41j} & \beta_{42j} & \beta_{43j} & \beta_{44j} \end{bmatrix} \begin{bmatrix} W_{t-j} \\ NE_{t-j} \\ M_{t-j} \\ T_{t-j} \end{bmatrix}$$

$$+ \sum_{j=k+1}^{d_{max}} \begin{bmatrix} \delta_{11j} & \delta_{12j} & \delta_{13j} & \delta_{14j} \\ \delta_{21j} & \delta_{22j} & \delta_{23j} & \delta_{24j} \\ \delta_{31j} & \delta_{32j} & \delta_{33j} & \delta_{34j} \\ \delta_{41j} & \delta_{42j} & \delta_{43j} & \delta_{44j} \end{bmatrix} \begin{bmatrix} W_{t-j} \\ NE_{t-j} \\ M_{t-j} \\ T_{t-j} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \\ \epsilon_{4t} \end{bmatrix},$$

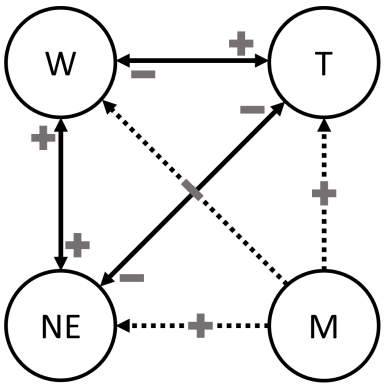
Empirical results China and France:



- Positive unidirectional causality from both *NE* and *M* to *W*.
- Negative unidirectional causality from *W* to *NE*.

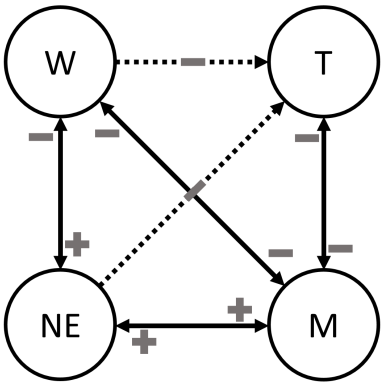
Empirical results India and Pakistan:

India



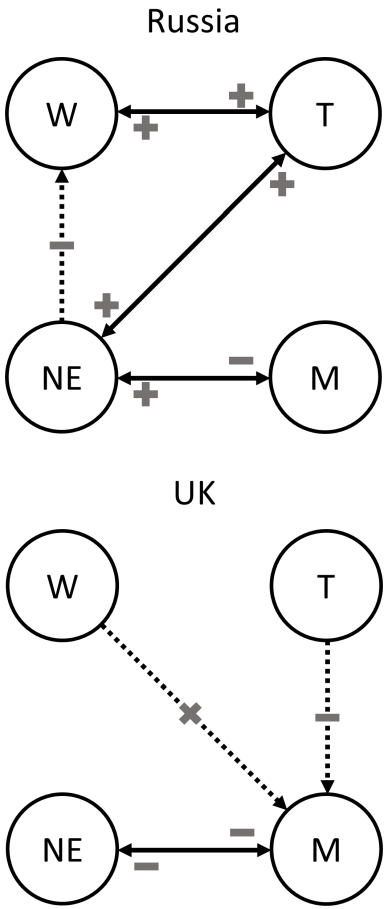
- Negative unidirectional causality from M to W.
- Bidirectional causality between W and NE as well as T.

Pakistan



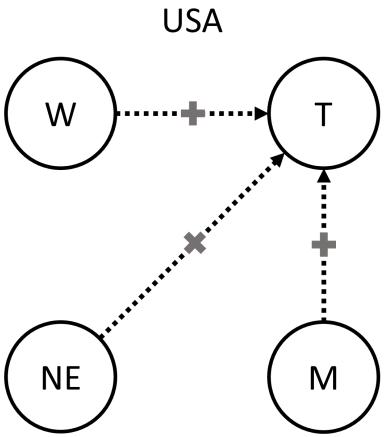
- Negative unidirectional causality from W to T.
- Bidirectional causality between the W and NE as well as M.

Empirical results Russia and UK:



- Negative unidirectional causality from NE to W.
- Bidirectional causality between W and T.
- Positive unidirectional causality from W to M.

Empirical results USA:



- Positive unidirectional causality from W to T.

Conclusion

- Implications for "new" nuclear powers China, India, and Pakistan:
  - The presence of bidirectional causality between nuclear warhead stockpiles and nuclear energy consumption in India and Pakistan and the existence of positive significant causality from nuclear warhead stockpiles to nuclear energy consumption in China empirically reveals a potential nuclear lock-in induced by or simultaneously affected by nuclear warhead stockpiles.
  - This also suggests a strong autarkic (civil) nuclear technology base utilizable for maintaining and increasing military applications particularly in form of nuclear warheads.
- The neglected military dimension of nuclear power can impede a nuclear phase out particularly in nuclear weapon states.
- Research outlook:
  - Strengthen the interpretation of the various causality relationships.

Thank you.

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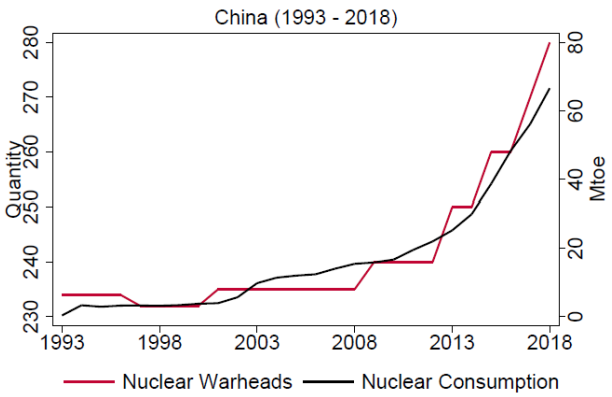
Toda and Yamamoto (1995) Granger non-causality test

1. Results from the augmented Dickey-Fuller (1979), Phillips-Perron (1988), and Kwiatkowski et al. (1992) unit root tests:
   - The maximal order of integration d_{max} has been identified as one except for Russia and USA
   - In Russia (USA), the series on W (NE) is integrated of order 2.
2. Utilize the Schwarz's Bayesian information criterion (SBIC) to identify the optimum lag length k for each of the VARs in a given country.
   - China (2 lags), India (1 lag), France (2 lags), Pakistan (2 lags), Russia (3 lags), UK (2 lags), and USA (2 lags).
3. Diagnostic tests: If necessary, increase lag length k to remove autocorrelation in residuals and to whiten disturbances of the VAR models or adjust lag length k to achieve stability of the VAR models.
   - For 5 out of 7 VARs I was able to remove the autocorrelation in the residuals, for 6 out of 7 VARs I achieved stability, and for 3 out of 7 VARs the disturbances are normally distributed.

China


China (1993 - 2018)
Quantity
230
240
250
260
270
280
Mtoe
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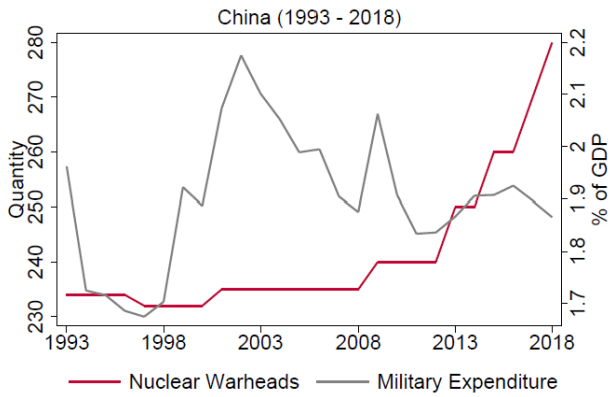
20
40
60
80
1993
1998
2003
2008
2013
2018
Nuclear Warheads
Nuclear Consumption


China (1993 - 2018)
Quantity
230
240
250
260
270
280
% of GDP
1.7
1.8
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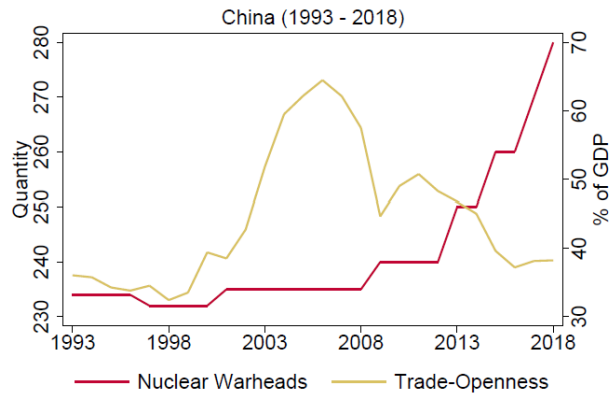
2018
Nuclear Warheads
Military Expenditure


China (1993 - 2018)
Quantity
230
240
250
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% of GDP
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1993
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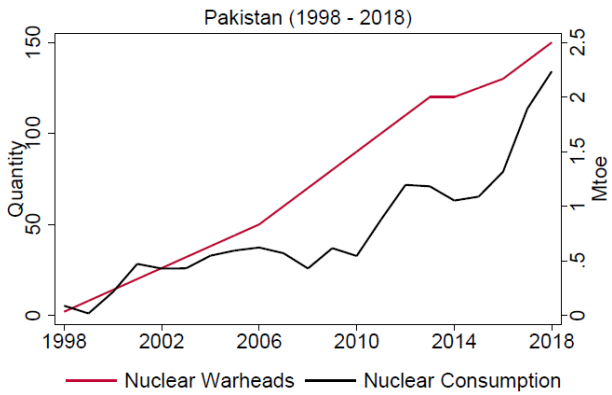
2003
2008
2013
2018
Nuclear Warheads
Trade-Openness

Pakistan


Pakistan (1998 - 2018)
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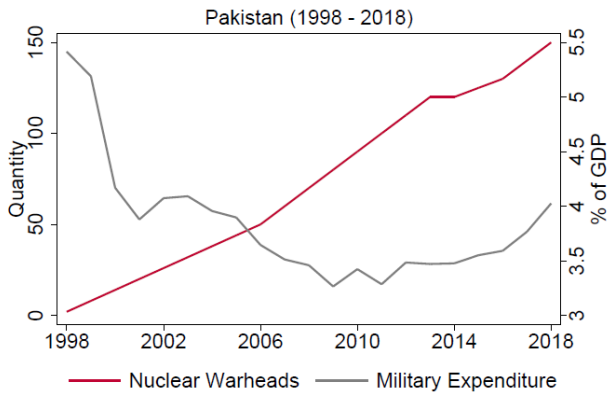
Nuclear Warheads
Nuclear Consumption


Pakistan (1998 - 2018)
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% of GDP
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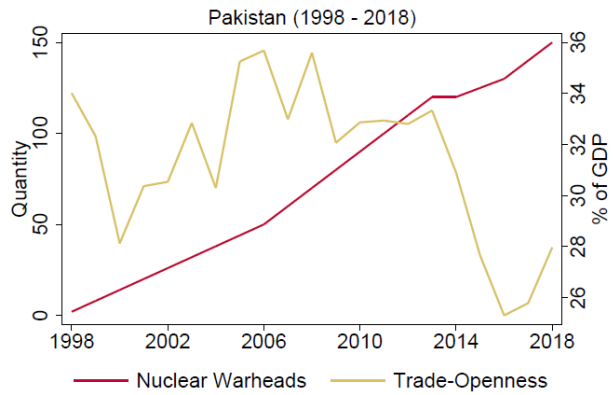
Nuclear Warheads
Military Expenditure


Pakistan (1998 - 2018)
Quantity
0
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100
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1998
2002
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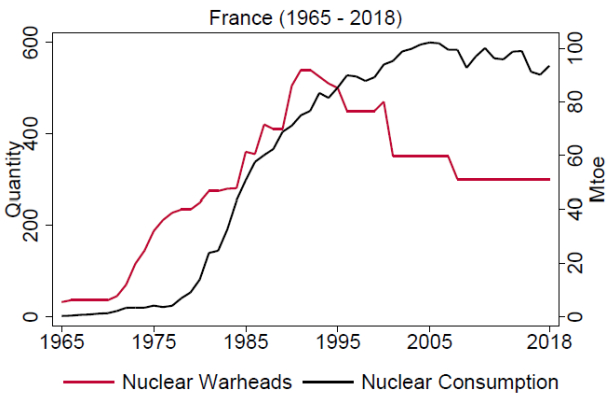
2018
% of GDP
26
28
30
32
34
36
Nuclear Warheads
Trade-Openness

France


France (1965 - 2018)
Quantity
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200
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1965
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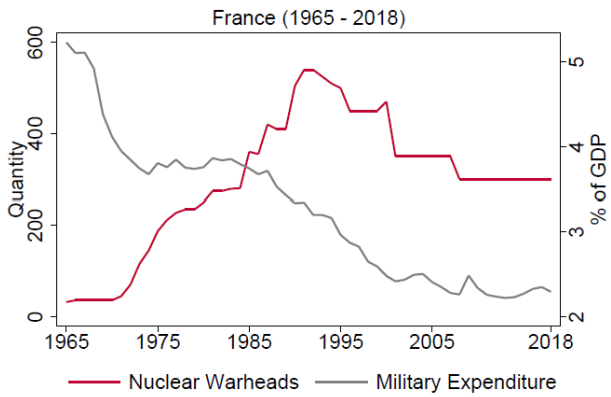
2018
Nuclear Warheads
Nuclear Consumption


France (1965 - 2018)
Quantity
0
200
400
600
% of GDP
2
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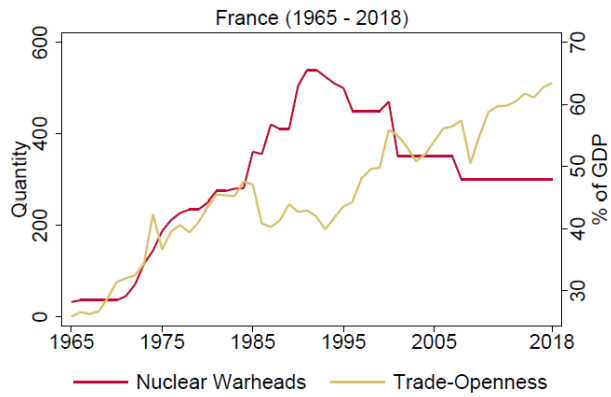
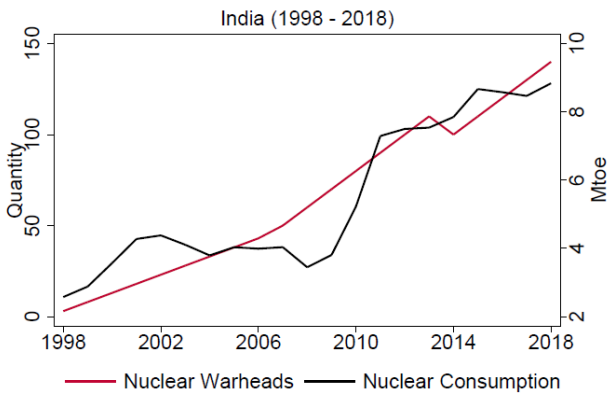
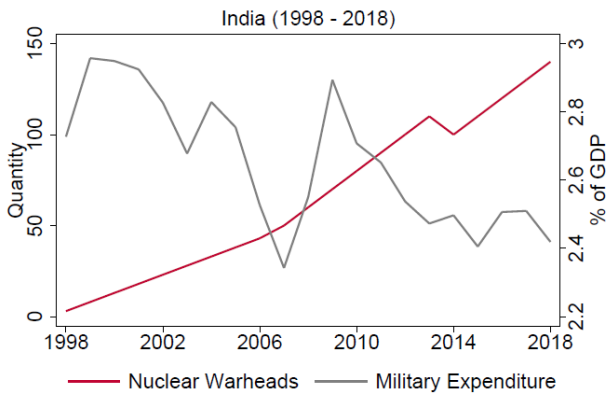
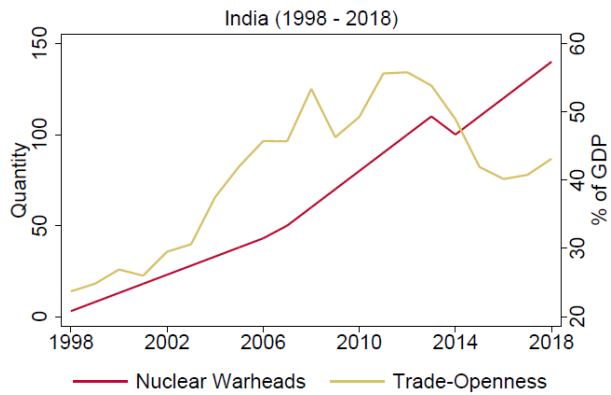
1965
1975
1985
1995
2005
2018
Nuclear Warheads
Military Expenditure


France (1965 - 2018)
Quantity
0
200
400
600
% of GDP
30
40
50
60
70
1965
1975
1985
1995
2005
2018
Nuclear Warheads
Trade-Openness

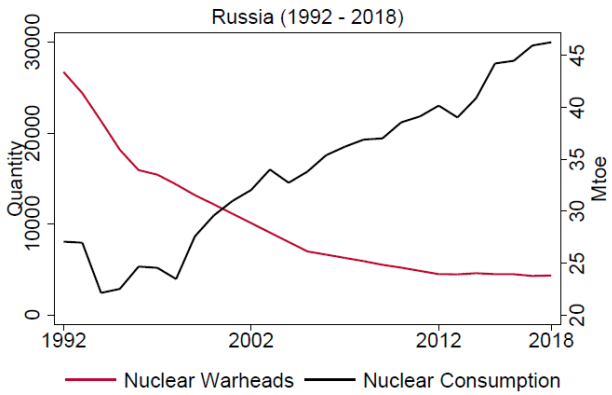
India

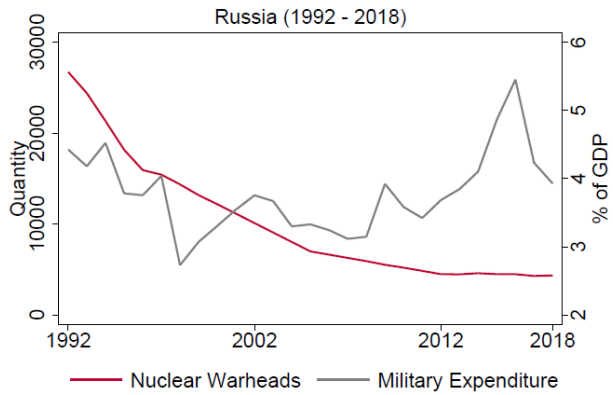

India (1998 - 2018)
Quantity
Mtoe
0
50
100
150
2
4
6
8
10
1998
2002
2006
2010
2014
2018
Nuclear Warheads
Nuclear Consumption

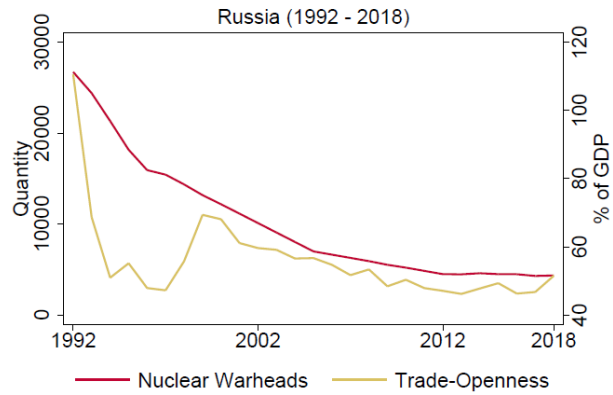

India (1998 - 2018)
Quantity
% of GDP
0
50
100
150
2.2
2.4
2.6
2.8
3
1998
2002
2006
2010
2014
2018
Nuclear Warheads
Military Expenditure


India (1998 - 2018)
Quantity
% of GDP
0
50
100
150
20
30
40
50
60
1998
2002
2006
2010
2014
2018
Nuclear Warheads
Trade-Openness

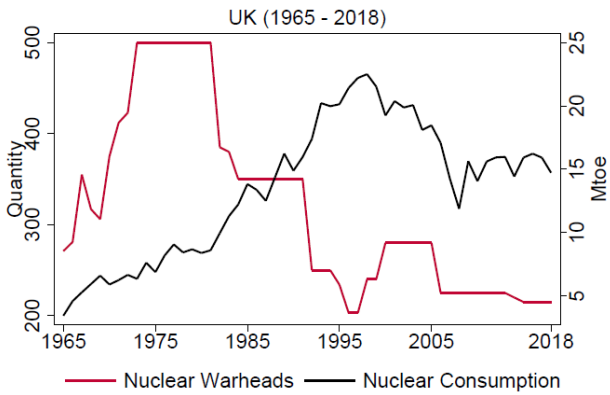
Russia

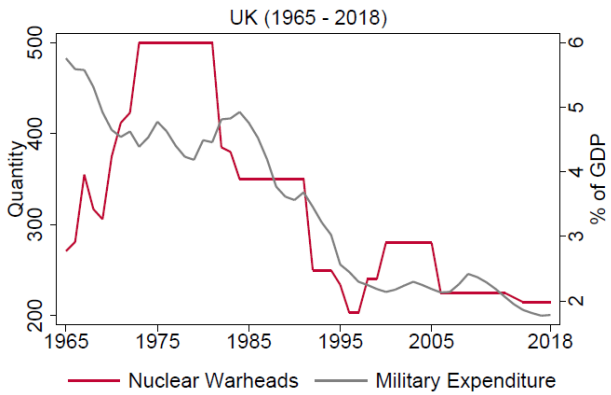

Russia (1992 - 2018)
Quantity
0
10000
20000
30000
Mtoe
20
25
30
35
40
45
1992
2002
2012
2018
Nuclear Warheads
Nuclear Consumption

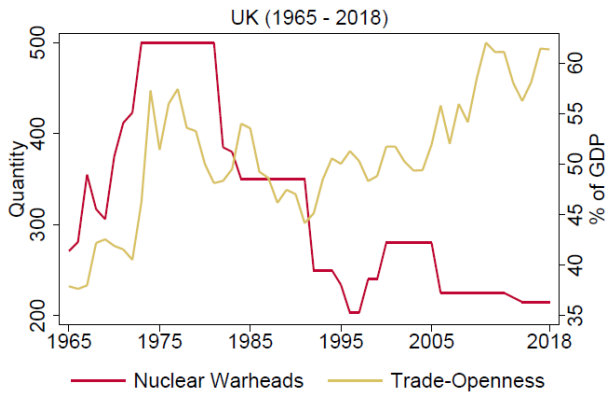

Russia (1992 - 2018)
Quantity
0
10000
20000
30000
% of GDP
2
3
4
5
6
1992
2002
2012
2018
Nuclear Warheads
Military Expenditure


Russia (1992 - 2018)
Quantity
0
10000
20000
30000
% of GDP
40
60
80
100
120
1992
2002
2012
2018
Nuclear Warheads
Trade-Openness

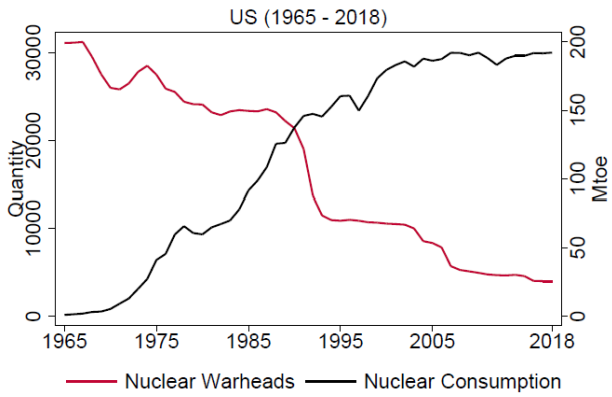
UK

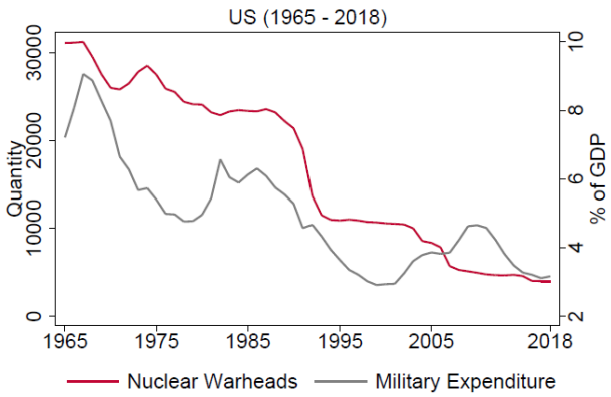

UK (1965 - 2018)
Quantity
200
300
400
500
1965
1975
1985
1995
2005
2018
Mtoe
5
10
15
20
25
Nuclear Warheads
Nuclear Consumption

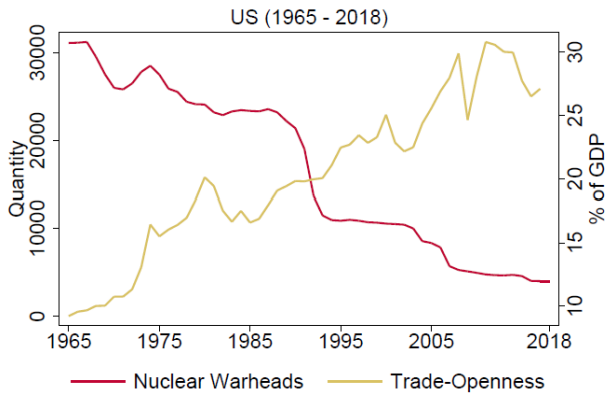

UK (1965 - 2018)
Quantity
200
300
400
500
1965
1975
1985
1995
2005
2018
% of GDP
2
3
4
5
6
Nuclear Warheads
Military Expenditure


UK (1965 - 2018)
Quantity
200
300
400
500
1965
1975
1985
1995
2005
2018
% of GDP
35
40
45
50
55
60
Nuclear Warheads
Trade-Openness

US


US (1965 - 2018)
Quantity
0
10000
20000
30000
Mtoe
0
50
100
150
200
1965
1975
1985
1995
2005
2018
Nuclear Warheads
Nuclear Consumption


US (1965 - 2018)
Quantity
0
10000
20000
30000
% of GDP
2
4
6
8
10
1965
1975
1985
1995
2005
2018
Nuclear Warheads
Military Expenditure


US (1965 - 2018)
Quantity
0
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20000
30000
% of GDP
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2018
Nuclear Warheads
Trade-Openness