Nuclear energy consumption, economic growth, and militarization: A multi-country causality analysis

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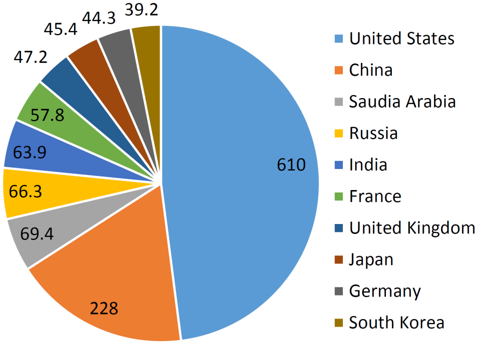
Post cold war arms race and nuclear new builds

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



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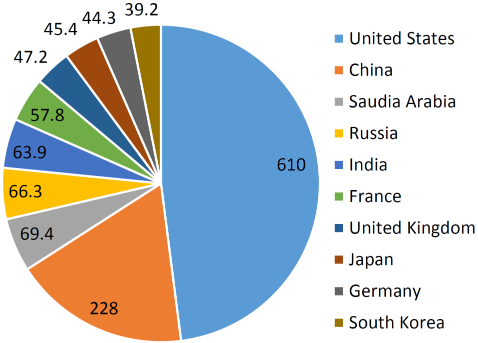

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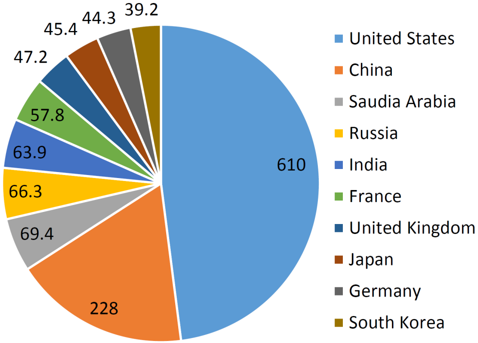

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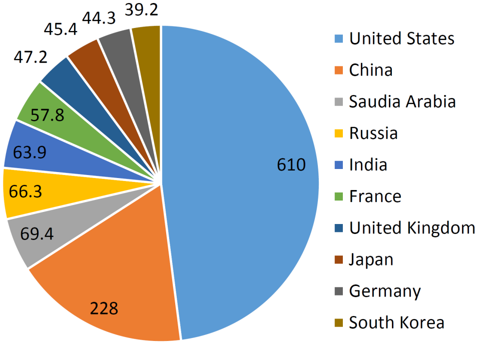

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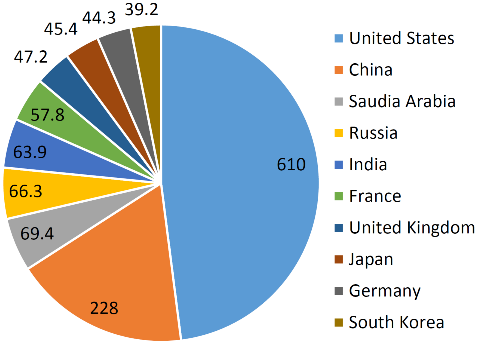

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- Saudi Arabia: projected 17 GWe of nuclear capacity by 2040.
- 6/10 are nuclear-weapon states.
- 5 largest nuclear reactor new-build programmes are in major nuclear weapon states (Stirling and Johnstone, 2018).

Nuclear power for military and civilian purposes

	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	~ 1992[a]	Qinshan 1 (300 MWe)

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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 defense burden impact economic development during the post cold war era?
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- The civilian use of nuclear power significantly is causally related to a countries military apparatus in at least some economies.

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

(Lévêque, 2014)

Agenda

1. Nuclear energy and military complex
2. Empirical literature
3. Data and empirical strategy
   - Data
   - Empirical specification
   - Panel time series estimation
   - Multi-country causality
4. Empirical results
5. Conclusions

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- Development of light water systems for nuclear-propelled submarines by the U.S. Navy (Cowan, 1990).
- During the enrichment process of natural uranium, depleted uranium (DU) can be obtained as a byproduct.
- Military applications of DU: armor breaking projectiles or protective armor for tanks (Bleise et al., 2003; Giannardi and Dominici, 2003).

Related empirical literature

Nuclear energy consumption and economic growth nexus:

- Empirical literature investigating the causal relationship between nuclear energy consumption and economic growth.
- 14 relevant causality papers (either multi-country time series analyses or panel time series studies).
- Mixed empirical evidence (different econometric techniques applied, selection of countries, and time periods (Tsani and Menegaki, 2018)).

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Defense spending and economic growth nexus:

- Dates back to the seminal work by Benoit (1978).
- 17 relevant causality papers (either multi-country time series analyses or panel time series studies).
- Aggregate demand stimulation vs. investment crowding-out.

Related empirical literature

Defense spending and energy consumption nexus:

- How does an increasing military apparatus affects a countries' energy consumption levels?
- Bildirici (2017): causal relationship between militarization, economic growth, energy consumption, and CO_2 emission for the United States covering the period 1960 - 2013.
  - Unidirectional causality from militarization to CO_2 emissions.
  - Unidirectional causality from energy consumption to CO_2 emissions.
  - Unidirectional causality from militarization to energy consumption.
  - No feedback relationships.

Data and empirical strategy

Data:

- Panel time series estimation and multi-country causality analysis.
- 28 out of 30 (93%) countries which use nuclear power over the period 1996 to 2016 are included.
- Overall panel (28) = OECD (18) + non-OECD (10).
- Armenia, Iran, Italy, Lithuania, and Taiwan not included.

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Empirical strategy:

- Panel time series estimation: Dynamic heterogeneous panel autoregressive distributed-lag (ARDL) approach.
- Multi-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).

Empirical specification

Augmented production function framework:

$$Y_{it} = \beta_{0i} + \beta_{1i} C_{it} + \beta_{2i} L_{it} + \beta_{3i} NE_{it} + \beta_{4i} M_{it} + \epsilon_{it}$$

- Y: GDP billion constant 2010 USD.
- C: Gross capital formation billion constant 2010 USD.
- L: Labor force is in million.
- NE: Nuclear energy consumption (mtoe).
- M: Military expenditure is in the share of GDP.
- All variables are converted into natural logarithms.

Panel time series estimation

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.

VECM representation of the ARDL(p,q) model:

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

- $X_{it} = C_{it}, L_{it}, NE_{it}, M_{it}$ 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 ϕ_i not lower than -2 provides evidence for a long-run relationship (Loayza et al., 2006).

Multi-country causality analysis (trivariate framework)

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.

Trivariate framework which is given in the following VAR system:

$$\begin{bmatrix} Y_t \\ NE_t \\ M_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} + \sum_{j=1}^{k} \begin{bmatrix} \beta_{11j} & \beta_{12j} & \beta_{13j} \\ \beta_{21j} & \beta_{22j} & \beta_{23j} \\ \beta_{31j} & \beta_{32j} & \beta_{33j} \end{bmatrix} \begin{bmatrix} Y_{t-j} \\ NE_{t-j} \\ M_{t-j} \end{bmatrix} + \sum_{j=k+1}^{d_{max}} \begin{bmatrix} \delta_{11j} & \delta_{12j} & \delta_{13j} \\ \delta_{21j} & \delta_{22j} & \delta_{23j} \\ \delta_{31j} & \delta_{32j} & \delta_{33j} \end{bmatrix} \begin{bmatrix} Y_{t-j} \\ NE_{t-j} \\ M_{t-j} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \end{bmatrix}$$

Empirical results I: Panel time series estimation

	Overall	OECD	non-OECD
			long-term
C	0.508^a	0.702^a	0.422^a
	(19.67)	(6.38)	(14.13)
L	0.326^a	-0.886^c	0.0574
	(5.26)	(-1.81)	(0.44)
NE	0.0853^a	0.115^b	0.126^a
	(4.19)	(2.23)	(4.67)
M	0.0443	-0.0312	-0.428^a
	(1.18)	(-0.40)	(-9.83)
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ec	-0.0924^a	-0.0622^a	-0.151^a
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- Increasing military expenditure reduces economic output in the long-term in the non-OECD group.
- Increasing nuclear energy consumption increases economic output in the long-term in both the OECD and non-OECD panel.

Empirical results II: Multi-country causality

Nuclear energy consumption and economic growth			Military expenditure and economic growht			Nuclear energy consumption and military expenditure		
$NE \rightarrow Y$	$Y \rightarrow NE$	$NE \leftrightarrow Y$	$M \rightarrow Y$	$Y \rightarrow M$	$M \leftrightarrow Y$	$NE \rightarrow M$	$M \rightarrow NE$	$NE \leftrightarrow M$
Bulgaria	Finland	Germany	Belgium	Hungary	China	Belgium	China	Brazil
Czechia	Hungary	Mexico	Czechia	Sweden	France	Pakistan	Finland	Germany
India	Netherlands	Romania	Pakistan	Ukraine	Germany	Korea, Rep.	Hungary	Japan
Japan	Pakistan	Russia	Switzerland		Japan		India	Russia
Korea, Rep.	Ukraine	Slovakia	UK		Korea, Rep.		Mexico	Slovakia
Switzerland		Slovenia	US		Mexico		Netherlands	Slovenia
		South Africa			Russia		Romania	Spain
		Spain			Slovenia		Ukraine	UK
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Notes: $\rightarrow$ and $\leftrightarrow$ indicate unidirectional and bidirectional causality, respectively Superscripts a, b, and c represent significance at 1%, 5%, and 10%.

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Japan	Pakistan	Russia	Switzerland		Japan		India	Russia
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- No pattern emerges: the dynamic relationships between nuclear energy consumption, economic growth, and militarization cannot be generalized across nuclear power producing countries.

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- Nuclear energy consumption positively causes economic growth in Bulgaria, Czech Republic, and South Korea.
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- Bidirectional causal relationship between nuclear energy consumption and economic growth in the majority of countries.

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Conclusion

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- Reducing nuclear energy consumption might detrimentally affect output in Bulgaria, Czech Republic, and South Korea since nuclear energy consumption positively and significantly causes economic growth (nuclear electricity production share exceeds 20% in all three countries (PRIS, 2019)).

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- Potential nuclear lock-in induced by or simultaneously affected militarization: the neglected military dimension of nuclear power then can impede a nuclear phase out particularly in nuclear weapon states.

Thank you.

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Conclusion

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- Increasing nuclear energy consumption on averages increases economic output in the long-term.
- The dynamic relationships between nuclear energy consumption, economic growth, and militarization cannot be generalized.
- Bidirectional causal relationship in the majority of countries.

References I

- Bildirici, M.E., (2017). The causal link among militarization, economic growth, CO2 emission, and energy consumption. Environmental Science and Pollution Research, 24(5): 4625 - 4636.
- Benoit, E., (1978). Growth and defense in developing countries. Economic development and cultural change, 26(2): 271 - 280.
- Bleise, A., Danesi, P.R. and Burkart, W., (2003). Properties, use and health effects of depleted uranium (DU): a general overview. Journal of environmental radioactivity, 64(2-3): 93 - 112.
- Bodansky, D., (2007). Nuclear energy: principles, practices, and prospects. Springer Science & Business Media.
- Cowan, R., (1990). Nuclear power reactors: a study in technological lock-in. The journal of economic history, 50(3): 541 - 567.
- Deutch, J.M., (1992). The new nuclear threat. Foreign Affairs, 71(4): 120 - 134.

References II

- Dritsakis, N., (2004). Defense spending and economic growth: an empirical investigation for Greece and Turkey. Journal of Policy Modeling, 26(2):249 - 264.
- Hausman, J.A., (1978). Specification tests in econometrics. Econometrica: Journal of the econometric society 46(6): 1251 - 1271.
- Lévêque, F., (2014). The Economics and Uncertainties of Nuclear Power. Cambridge, UK: Cambridge University Press.
- Fuhrmann, M., (2009). Taking a walk on the supply side: The determinants of civilian nuclear cooperation. Journal of Conflict Resolution, 53(2): 181 - 208.
- Giannardi, C. and Dominici, D., (2003). Military use of depleted uranium: assessment of prolonged population exposure. Journal of environmental radioactivity, 64(2-3): 227 - 236.
- Kollias, C., Manolas, G. and Paleologou, S.M., (2004). Defence expenditure and economic growth in the European Union: a causality analysis. Journal of Policy Modeling, 26(5): 553 - 569.

References III

- Loayza, N.V. and Ranciere, R., (2006). Financial development, financial fragility, and growth. Journal of Money, Credit and Banking 38(4): 1051 - 1076.
- Moscone, F. and Tosetti, E., (2009). A review and comparison of tests of cross-section independence in panels. Journal of Economic Surveys 23(3):528 - 561.
- Pesaran, M.H., (2007). A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics, 22 (2), pp. 265 - 312.
- Pesaran, M.H. and Smith, R., (1995). Estimating long-run relationships from dynamic heterogeneous panels. Journal of econometrics 68(1): 79 - 113.
- Pesaran, M.H., Shin, Y. and Smith, R.P., (1999). Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association 94(446): 621 - 634.
- PRIS, (2019). PRIS - Power Reactor Information System, `https://pris.iaea.org/PRIS/home.aspx`, access date: 14th May 2019.

References IV

- Schneider, M., Froggatt, A., Thomas, S., Hazemann, J., Katsuta, T., Stirling, A., Wealer, B., Johnstone, P., Ramana, M.V., von Hirschhausen, C., Stienne, A., (2018). The World Nuclear Industry Status Report 2018. A Mycle Schneider Consulting Project, Paris, London, September 2018.
- Stockholm International Peace Research Institute (SIPRI), (2017). Trends in World Military Expenditure, 2017. SIPRI Fact Sheet, Stockholm, Sweden.
- Stirling, A. and Johnstone, P., (2018). A Global Picture of Industrial Interdependencies Between Civil and Nuclear Infrastructures. SPRU-Science and Technology Policy Research, Working Paper Series SWPS 2018-13 (August), University of Sussex, United Kingdom.
- Toda, H.Y. and Yamamoto, T., (1995). Statistical inference in vector autoregression with possibly integrated processes. Journal of econometrics, 66(1-2): 225 - 250.
- Tsani, S. and Menegaki, A.N., (2018). The Energy-Growth Nexus (EGN) Checklist for Authors. In The Economics and Econometrics of the Energy-Growth Nexus. Academic Press, London, United Kingdom: 347 - 376.

Back up: List of countries

OECD countries (18): Belgium, Canada, Czech Republic, Finland, France Germany, Hungary, Japan, Korea, Rep., Mexico, Netherlands, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and United States.

Non-OECD countries (10): Argentina, Brazil, Bulgaria, China, India, Pakistan, Romania, Russian Federation, South Africa, and Ukraine.

Empirical strategy: Panel time series estimation

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

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.

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 $H_1 : \rho_i = 0$

Panel ARDL approach

- estimation of long-term effects of explanatory variables on economic growth
- identification of short- and long-term dynamics of relevant explanatory factors of economic growth

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

$$Y_{it} = \beta_{0i} + \sum_{j=1}^{p} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q_1} \delta_{1ij} C_{i,t-j} + \sum_{j=0}^{q_2} \delta_{2ij} L_{i,t-j} + \sum_{j=0}^{q_3} \delta_{3ij} NE_{i,t-j} + \sum_{j=0}^{q_4} \delta_{4ij} M_{i,t-j} + \epsilon_{it}.$$

Panel ARDL approach

VECM representation of the ARDL(p,q) model

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

- $X_{it} = C_{it}, L_{it}, NE_{it}, M_{it}$ 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)

First-order ARDL model

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

- common lag structure makes short-run parameters comparable across panels

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

Empirical results: Panel time series estimation

Peasaran (2004) CD test:

- all series are highly dependent across all income groups

Pesaran (2007) panel unit root test:

- results differ between panels
- panel unit root for the series on L and M exists in any panel.
- panel unit root for the series on GDP (C) in the OECD panel (non-OECD) panel.
- N is 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

Peasaran (2004) CD test:

Table 4: Results of Pesaran (2004) CD tests

		Variables in levels				
		Y	C	L	NE	M
Overall	abs (corr)	0.94	0.62	0.89	0.42	0.49
	CD statistic	83.92^a	48.89^a	41.86^a	10.74^a	24.68^a
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
OECD	abs (corr)	0.96	0.62	0.89	0.38	0.49
	CD statistic	54.33^a	30.01^a	40.38^a	4.04^a	16.17^a
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Non OECD	abs (corr)	0.94	0.64	0.91	0.50	0.47
	CD statistic	28.92^a	19.46^a	2.83^a	8.67^a	10.86^a
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

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

Pesaran (2007) panel unit root test:

Table 5: Results of Pesaran (2007) panel unit root tests

	Overall		OECD		Non OECD	
	No Trend	Trend	No Trend	Trend	No Trend	Trend
Y	-2.392[a]	-2.635[c]	-1.717	-2.379	-1.866	-1.554
C	-2.314[a]	-2.758[b]	-2.06	-2.533	-3.388[a]	-3.692[a]
L	-1.381	-1.641	-1.265	-1.893	-1.315	-1.503
NE	-2.225[b]	-2.893[a]	-2.234[b]	-3.33[a]	-2.181[c]	-2.954[b]
M	-1.798	-1.83	-1.532	-1.664	-2.125[c]	-2.324
ΔY	-2.634[a]	-2.56	-2.89[a]	-2.754[b]	-3.046[a]	-3.064[b]
ΔC	-3.741[a]	-3.721[a]	-3.634[a]	-3.696[a]	-4.062[a]	-4.000[a]
ΔL	-3.671[a]	-4.229[a]	-3.641[a]	-4.169[a]	-3.409[a]	-4.057[a]
ΔNE	-4.485[a]	-4.62[a]	-4.762[a]	-5.011[a]	-4.365[a]	-4.404[a]
ΔM	-3.738[a]	-3.904[a]	-3.883[a]	-4.137[a]	-4.036[a]	-4.352[a]

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

Empirical strategy: Toda and Yamamoto (1995) Granger non-causality test

1. The results from the augmented Dickey-Fuller (1979), Phillips-Perron (1988), and Kwiatkowski et al. (1992) unit root tests indicate that all the series are I(1). The maximal order of integration d_{max} thus has been identified as one.
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. Overall, the lag length k varies per country starting from one but not exceeding three.
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 28 out of 28 VARs I was able to remove the autocorrelation in the residuals, for 24 out of 28 VARs I achieved stability, and for 20 out of 28 VARs the disturbances are normally distributed.
4. 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.