# Title

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August 6, 2020

**Abstract**

This is the abstract.

***Keywords***— time series, IPE, IR

**Work in progress. Please don't cite.**

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# I. Modelling "Steel and Guns" in a Global Setting: Presenting the GVAR Methodology

## I. GVAR: Country-specific Equations and Granger-causality Tests

Global vector auto-regressive models (GVAR) are a special category of vector auto-regressive models (VAR). Following Box-Steffensmeier et al. (2014, 164), define a VAR model as follows,

$$\mathbf{x}_{it} = \boldsymbol{\alpha}_i + \boldsymbol{\Phi}_i \mathbf{x}_{i,t-p} + \mathbf{u}_{it} \tag{1}$$

where $\mathbf{x}_{it}$ is a $k_i \times 1$ vector of endogenous variables which are lagged $p$ times on the right-hand side, and where $E(\mathbf{u}_{it}) = 0$. Now, following Mauro and Pesaran (2013, 14), define a GVAR model with $p$ lags for country $i$ as follows,

$$\mathbf{x}_{it} = \boldsymbol{\alpha}_i + \boldsymbol{\Phi}_i \mathbf{x}_{i,t-p} + \boldsymbol{\Lambda}_{1i} \mathbf{W}_t + \boldsymbol{\Lambda}_{2i} \mathbf{W}_{t-p} + \mathbf{u}_{it} \tag{2}$$

where $\mathbf{x}_{it}$ is a $k_i \times 1$ vector of domestic (i.e. endogenous) variables, $\mathbf{W}_t$ is a $k_i \times 1$ vector of weakly-exogenous foreign variables, and $\mathbf{u}_{it}$ is a serially uncorrelated and cross-sectionally weakly dependent process. As it becomes apparent, the inclusion of foreign variables $\mathbf{W}_t$ in Equation 2 is one of the main characteristics of the GVAR approach, and the main difference with the VAR equation described in Equation 1. In simple, the Global vector autoregressive GVAR model in Equation 2 explains $\mathbf{x}_{i,t}$ as a function of past values $\mathbf{x}_{i,t-p}$ lagged $p$ times, at the same time that it weights these dynamics by weakly-exogenous foreign variables $\mathbf{W}_{t-p}$ (weights which are captured by parameters $\boldsymbol{\Lambda}_{ni}$).

Since we are substantively interested in weather "guns" *cause* "steel" or the other way around, in this paper we estimate country-specific bivariate Granger-causality tests within the GVAR framework.[1] The Granger-causality method was introduced in Granger (1969) and it seeks to investigate if some variable $X$ Granger-causes another variable $Y$, or the other way around. A variable $X$ is said to Granger-cause $Y$ if predictions of $Y$ based on lagged values of $Y$ and lagged values of $X$ perform better than explaining $Y$ just with its own past values. Since Granger-causality

1. We acknowledge that without proper experimentation and randomization there cannot be proper causation. Consequently, and following the Granger methodology, we employ a rather lose definition of "causation" and explore if lagged values of a variable *forecast* another variable.

tests are usually estimated by fitting VAR equations (Equation 1) we now derive the Granger-causality test within the GVAR framework. The substantive advantage of GVAR Granger-causality tests over regular Granger-causality tests is that estimates are weighted by the global economy, situating the domestic dynamics within the global context. More formally, we estimate the following GVAR Granger-causality system for every country $i$ with $p$ lags as follows:

$$\begin{aligned}
\mathbf{x}_{it} &= \boldsymbol{\alpha}_i + \boldsymbol{\Phi}_{1i}\mathbf{y}_{i,t-p} + \boldsymbol{\Phi}_{2i}\mathbf{x}_{i,t-p} + \boldsymbol{\Lambda}_{1i}\mathbf{W}_t + \boldsymbol{\Lambda}_{2i}\mathbf{W}_{t-p} + \boldsymbol{\Lambda}_{3i}\mathbf{W}_t + \boldsymbol{\Lambda}_{4i}\mathbf{W}_{t-p} + \mathbf{u}_{it} \\
\mathbf{y}_{it} &= \boldsymbol{\alpha}_i + \boldsymbol{\Phi}_{1i}\mathbf{x}_{i,t-p} + \boldsymbol{\Phi}_{2i}\mathbf{y}_{i,t-p} + \boldsymbol{\Lambda}_{1i}\mathbf{W}_t + \boldsymbol{\Lambda}_{2i}\mathbf{W}_{t-p} + \boldsymbol{\Lambda}_{3i}\mathbf{W}_t + \boldsymbol{\Lambda}_{4i}\mathbf{W}_{t-p} + \mathbf{u}_{it}
\end{aligned} \tag{3}$$

In our case, the vector $\mathbf{x}_{it}$ contains country-year levels of "military personnel," while vector $\mathbf{y}_{it}$ contains country-year levels of "iron and steel production." Both variables were systematized by the Correlates of War Project, particularly, the National Material Capabilities dataset (Singer, Bremer, and Stuckey 1972).[2] The dataset covers all countries in the world between 1816-2012.

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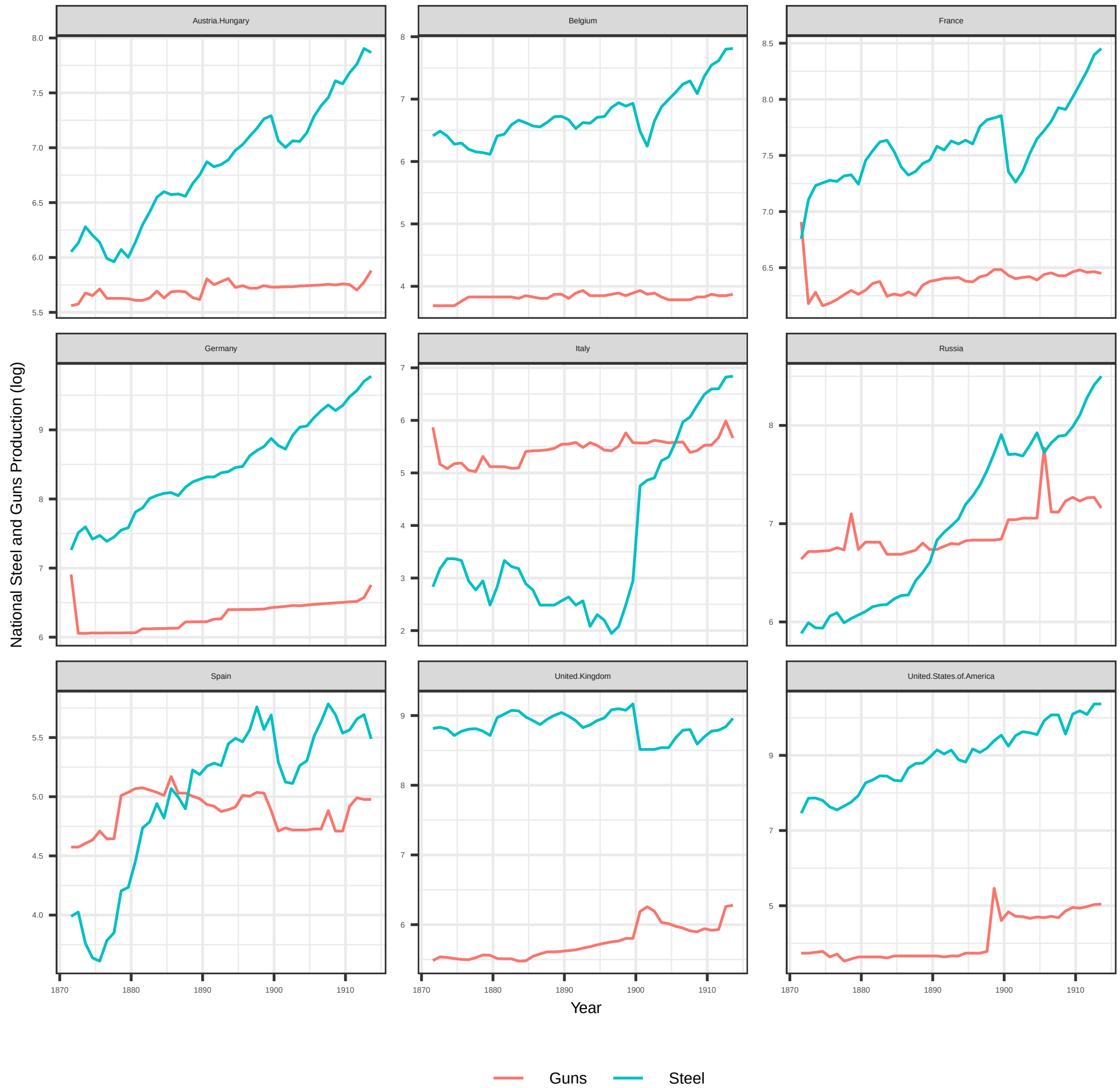


**Figure 1: National Steel and Guns Production (log), 1871-1913.**
**Note**: *Variables are "milper" and "irst." Both were obtained from Singer, Bremer, and Stuckey (1972).*

Also, the vector of foreign variables is the single variable "dyadic trade" which measures bilateral trade flows between two countries. This variable was constructed by the same project but in the Trade dataset (Barbieri, Keshk, and Pollins 2009; Barbieri and Keshk 2016)[3] and was used to construct the weight matrix $\mathbf{W}$. The matrix is a square matrix which has all $K$ countries in both its columns and rows with zeros as diagonal elements. The matrix represents bilateral trade among two countries measured by the *flow1* and the *flow2* variables. The former measures imports from a country (*importer1*) to another country (*importer2*), and the latter measures the reverse dyad, i.e. imports from *importer2* to *importer1*. More formally, $\mathbf{W}$ contains $t$ sub-matrices (one sub-matrix per year) with dimensions $k \times k$ for a total of $\mathbf{K}$ countries such that,

$$\mathbf{W}_t = \begin{array}{cc} & \begin{array}{ccccc} \mathbf{i}_1 & \mathbf{i}_2 & \mathbf{i}_3 & \dots & \mathbf{i}_K \end{array} \\ \begin{array}{c} \mathbf{i}_1 \\ \mathbf{i}_2 \\ \mathbf{i}_3 \\ \vdots \\ \mathbf{i}_K \end{array} & \begin{bmatrix} 0 & f_{21} & f_{31} & \dots & i_{K1} \\ f_{12} & 0 & f_{32} & \dots & i_{K2} \\ f_{13} & f_{23} & 0 & \dots & i_{K3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{1K} & f_{2K} & f_{3K} & \dots & i_{KK} \end{bmatrix} \end{array}$$

Every $W_t$ matrix weights all $K$ country-specific Granger regressions described in Equation 3. Every $K$ system is weighted by the other $K-1$ countries. And as Equation 3 shows, the GVAR methodology also considers $p$ lags of the $\mathbf{W}$ matrix. Following the literature on Granger-causality tests we focus our attention model-specific f-tests (one per country) which tests if all variables in the model are jointly significant. Then null is that there is no Granger causality.

## II. Results

Figure 2 shows country-specific p-values of the Granger-causality f-tests obtained when fitting Equation 3 (detailed results shown in Table A1, Table A2 and Table A3). The plot shows that during the $1871-1913$ period, in 44% of the countries, steel Granger-caused guns. This percentage changes to 38%, and to 33% for the hegemonic countries during the $1955-2012$ period. In other words, in 45.5% of the instances, guns Granger-caused steel for the $1955-2012$ period. These results strongly suggest that the guns-steel "causal" relationship reverses during the late 20th century.

Gist of the paper

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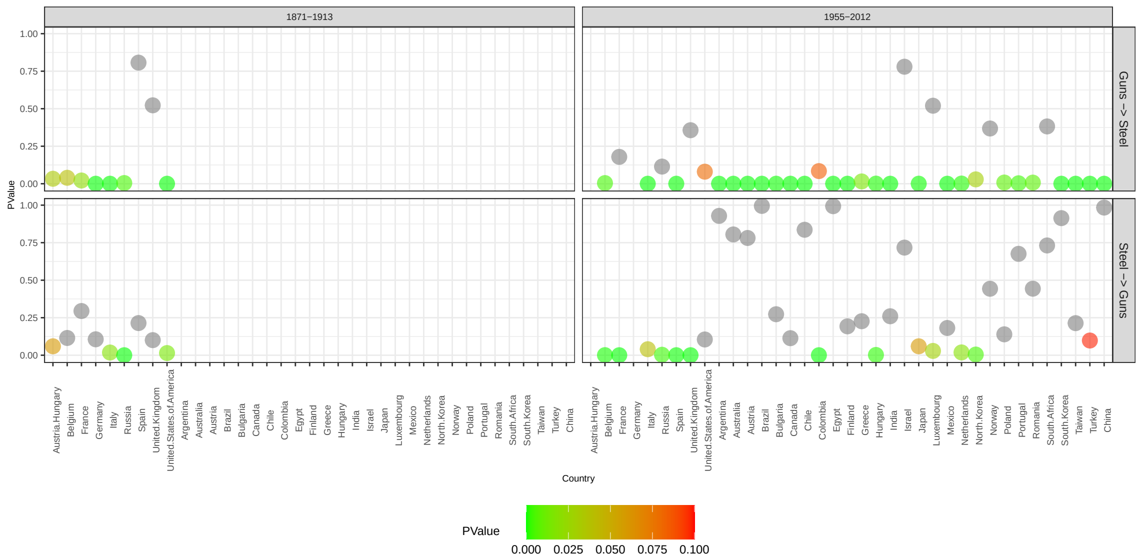


**Figure 2: P-Values of the Country-specific Granger-causality F-Tests, 1871-2012.**
**Note***: Plot shows country-specific p-values of the Granger-causality f-tests obtained when fitting Equation 3 (detailed results shown in Table A1, Table A2 and Table A3). The plot shows that during the 1871-1913 period, in 44% of the countries, steel Granger-caused guns. This porcentage changes to 38% and to 33% for the hegemonic countries during the 1955-2012 period.*

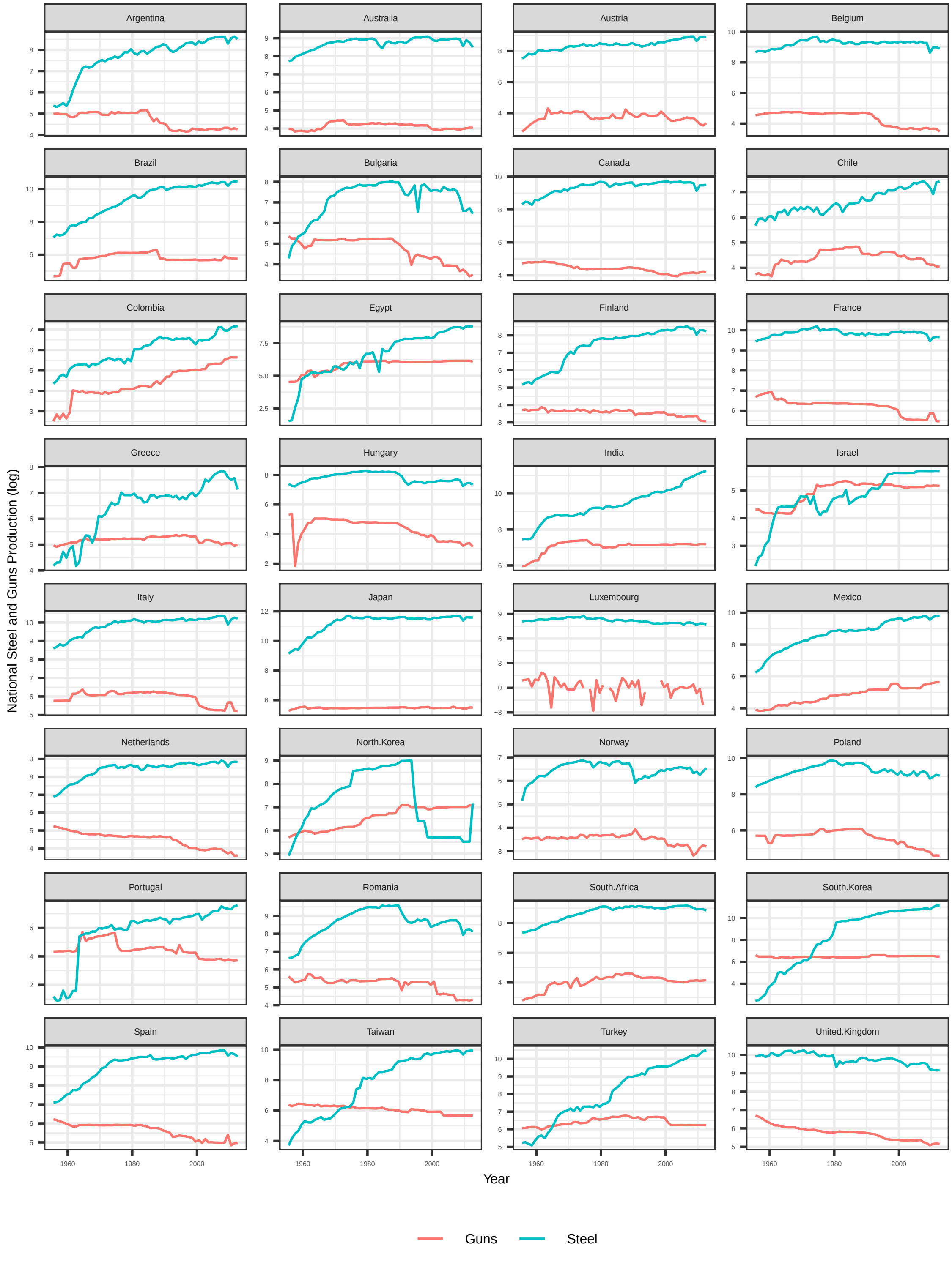




**Figure 3: National Steel and Guns Production (log), 1955-2012.**
**Note**: *Variables are "milper" and "irst." Both were obtained from Singer, Bremer, and Stuckey (1972).*

## References


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**Word count**: 915

# II. Appendix

## I. Appendix

**Table A1:** *Bivariate Gobal Granger Causality Tests of the World Political Economy,* 1871-1913

| | Granger Relationship | F-Test | P-Value | DF | Adjusted R-sq | Lags |
|---|---|---|---|---|---|---|
| Austria-Hungary | steel → guns | 2.16 | 0.06 | 8,31 | 0.192 | 1 |
| | guns → steel | 2.48 | 0.03 | 8,31 | 0.233 | |
| Belgium | steel → guns | 1.781 | 0.11 | 16,19 | 0.263 | 5 |
| | guns → steel | 2.339 | 0.04 | 16,19 | 0.38 | |
| France | steel → guns | 1.27 | 0.29 | 8,31 | 0.052 | 1 |
| | guns → steel | 2.72 | 0.02 | 8,31 | 0.261 | |
| Germany | steel → guns | 1.844 | 0.11 | 8,31 | 0.148 | 1 |
| | guns → steel | 7.891 | 0 | 8,31 | 0.586 | |
| Italy | steel → guns | 2.777 | 0.02 | 16,19 | 0.448 | 5 |
| | guns → steel | 6.801 | 0 | 16,19 | 0.726 | |
| Russia | steel → guns | 8.725 | 0 | 16,19 | 0.779 | 5 |
| | guns → steel | 3.595 | 0 | 16,19 | 0.543 | |
| Spain | steel → guns | 1.454 | 0.21 | 8,31 | 0.085 | 1 |
| | guns → steel | 0.554 | 0.81 | 8,31 | -0.101 | |
| United Kingdom | steel → guns | 1.85 | 0.1 | 16,19 | 0.28 | 5 |
| | guns → steel | 0.966 | 0.52 | 16,19 | -0.016 | |
| United States | steel → guns | 2.942 | 0.01 | 8,31 | 0.285 | 1 |
| | guns → steel | 8.608 | 0 | 8,31 | 0.609 | |

Table shows country-specific Granger-causality F-tests. Last column shows number of domestic lags used per every country-specific Granger model. Number of lags for endogenous variables = 2. Number of lags for foreign variables = 2. Max number of lags for estimating the country-specific VAR model = 5. Information criteria for optimal lag length = AIC. Deterministic variables: Trend and constant.

**Table A2:** *Bivariate Gobal Granger Causality Tests of the World Political Economy,* 1955-2012 *(A)*

| | Granger Relationship | F-Test | P-Value | DF | Adjusted R-sq | Lags |
|---|---|---|---|---|---|---|
| Argentina | steel → guns | 0.422 | 0.93 | 10,44 | -0.12 | 1 |
| Argentina | guns → steel | 7.765 | 0 | 10,44 | 0.556 | |
| Australia | steel → guns | 0.629 | 0.8 | 12,41 | -0.092 | 2 |
| Australia | guns → steel | 5.618 | 0 | 12,41 | 0.511 | |
| Austria | steel → guns | 0.656 | 0.78 | 12,41 | -0.084 | 2 |
| Austria | guns → steel | 7.305 | 0 | 12,41 | 0.588 | |
| Belgium | steel → guns | 3.842 | 0 | 12,41 | 0.392 | 2 |
| Belgium | guns → steel | 3.001 | 0 | 12,41 | 0.312 | |
| Brazil | steel → guns | 0.237 | 0.99 | 12,41 | -0.209 | 2 |
| Brazil | guns → steel | 9.498 | 0 | 12,41 | 0.658 | |
| Bulgaria | steel → guns | 1.269 | 0.27 | 12,41 | 0.057 | 2 |
| Bulgaria | guns → steel | 4.286 | 0 | 12,41 | 0.427 | |
| Canada | steel → guns | 1.69 | 0.11 | 10,44 | 0.113 | 1 |
| Canada | guns → steel | 5.055 | 0 | 10,44 | 0.429 | |
| Chile | steel → guns | 0.561 | 0.84 | 10,44 | -0.088 | 1 |
| Chile | guns → steel | 7.313 | 0 | 10,44 | 0.539 | |
| Colombia | steel → guns | 4.855 | 0 | 18,32 | 0.581 | 5 |
| Colombia | guns → steel | 1.737 | 0.08 | 18,32 | 0.21 | |
| Egypt | steel → guns | 0.219 | 0.99 | 10,44 | -0.169 | 1 |
| Egypt | guns → steel | 5.471 | 0 | 10,44 | 0.453 | |
| Finland | steel → guns | 1.428 | 0.19 | 12,41 | 0.088 | 2 |
| Finland | guns → steel | 5.041 | 0 | 12,41 | 0.478 | |
| France | steel → guns | 8.235 | 0 | 16,35 | 0.694 | 4 |
| France | guns → steel | 1.442 | 0.18 | 16,35 | 0.122 | |
| Greece | steel → guns | 1.344 | 0.23 | 18,32 | 0.11 | 5 |
| Greece | guns → steel | 2.39 | 0.02 | 18,32 | 0.334 | |
| Hungary | steel → guns | 3.363 | 0 | 12,41 | 0.349 | 2 |
| Hungary | guns → steel | 3.711 | 0 | 12,41 | 0.38 | |
| India | steel → guns | 1.287 | 0.26 | 14,38 | 0.072 | 3 |
| India | guns → steel | 6.048 | 0 | 14,38 | 0.576 | |
| Israel | steel → guns | 0.702 | 0.72 | 10,44 | -0.058 | 1 |
| Israel | guns → steel | 0.63 | 0.78 | 10,44 | -0.073 | |
| Italy | steel → guns | 2.151 | 0.04 | 10,44 | 0.176 | 1 |
| Italy | guns → steel | 11.365 | 0 | 10,44 | 0.657 | |
| Japan | steel → guns | 1.876 | 0.06 | 16,35 | 0.216 | 4 |
| Japan | guns → steel | 4.079 | 0 | 16,35 | 0.491 | |
| Luxembourg | steel → guns | 2.296 | 0.03 | 10,44 | 0.194 | 1 |
| Luxembourg | guns → steel | 0.925 | 0.52 | 10,44 | -0.014 | |
| Mexico | steel → guns | 1.436 | 0.18 | 16,35 | 0.12 | 4 |
| Mexico | guns → steel | 8.525 | 0 | 16,35 | 0.702 | |
| Netherlands | steel → guns | 2.483 | 0.02 | 10,44 | 0.216 | 1 |
| Netherlands | guns → steel | 3.73 | 0 | 10,44 | 0.336 | |
| North Korea | steel → guns | 2.875 | 0 | 18,32 | 0.403 | 5 |
| North Korea | guns → steel | 2.143 | 0.03 | 18,32 | 0.292 | |
| Norway | steel → guns | 1.02 | 0.44 | 10,44 | 0.004 | 1 |
| Norway | guns → steel | 1.122 | 0.37 | 10,44 | 0.022 | |
| Poland | steel → guns | 1.57 | 0.14 | 12,41 | 0.114 | 2 |
| Poland | guns → steel | 2.745 | 0.01 | 12,41 | 0.283 | |
| Portugal | steel → guns | 0.749 | 0.68 | 10,44 | -0.049 | 1 |
| Portugal | guns → steel | 3.265 | 0 | 10,44 | 0.296 | |
| Romania | steel → guns | 1.019 | 0.44 | 10,44 | 0.004 | 1 |
| Romania | guns → steel | 2.878 | 0.01 | 10,44 | 0.258 | |
| South Africa | steel → guns | 0.686 | 0.73 | 10,44 | -0.062 | 1 |
| South Africa | guns → steel | 1.102 | 0.38 | 10,44 | 0.019 | |
| South Korea | steel → guns | 0.448 | 0.91 | 10,44 | -0.114 | 1 |
| South Korea | guns → steel | 9.019 | 0 | 10,44 | 0.598 | |
| Spain | steel → guns | 4.66 | 0 | 10,44 | 0.404 | 1 |
| Spain | guns → steel | 4.92 | 0 | 10,44 | 0.421 | |
| Taiwan | steel → guns | 1.382 | 0.21 | 12,41 | 0.08 | 2 |
| Taiwan | guns → steel | 5.667 | 0 | 12,41 | 0.514 | |
| Turkey | steel → guns | 1.696 | 0.1 | 14,38 | 0.158 | 3 |
| Turkey | guns → steel | 25.426 | 0 | 14,38 | 0.868 | |
| United Kingdom | steel → guns | 9.085 | 0 | 10,44 | 0.6 | 1 |
| United Kingdom | guns → steel | 1.139 | 0.36 | 10,44 | 0.025 | |

Table shows country-specific Granger-causality F-tests. Last column shows number of domestic lags used per every country-specific Granger model. Number of lags for endogenous variables = 3. Number of lags for foreign variables = 3. Max number of lags for estimating the country-specific VAR model = 5. Information criteria for optimal lag length = AIC. Deterministic variables: Trend.

**Table A3:** *Bivariate Gobal Granger Causality Tests of the World Political Economy,* 1955-2012 *(B)*

| | Granger Relationship | F-Test | P-Value | DF | Adjusted R-sq | Lags |
|---|---|---|---|---|---|---|
| China | steel → guns | 0.252 | 0.98 | 9,45 | -0.142 | 2 |
| | guns → steel | 83.191 | 0 | 9,45 | 0.932 | |
| Russia | steel → guns | 3.663 | 0 | 7,48 | 0.253 | 1 |
| | guns → steel | 1.775 | 0.11 | 7,48 | 0.09 | |
| United States | steel → guns | 1.821 | 0.1 | 7,48 | 0.095 | 1 |
| | guns → steel | 1.961 | 0.08 | 7,48 | 0.109 | |

Table shows country-specific Granger-causality F-tests. Last column shows number of domestic lags used per every country-specific Granger model. Number of lags for endogenous variables = 2. Number of lags for foreign variables = 2. Max number of lags for estimating the country-specific VAR model = 5. Information criteria for optimal lag length = AIC. Deterministic variables: NA.