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# Climate change will not precipitate peace

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**Abstract**

Gartzke (2012, Journal of Peace Research, 49 (1), 177-192) reports that, over the last 120 years, there has been a statistically significant, negative relationship between the global mean surface air temperature and the world total number of onsets of militarized inter-state disputes. Gartzke argues that global warming would bring peace. Unfortunately, Gartzke largely ignores the non-stationary nature of his observations. Re-analysing Gartzke's data, I find that his regressions are spurious: There is no statistically meaningful relationship between temperature and conflict.

**Key words:** militarized conflict; temperature; cointegration

## Introduction

Peace research is an interdisciplinary field, organized around an issue rather around a set of methods. It is impossible to keep up with the state of the art in the many disciplines and subdisciplines that are relevant to the study of peace and conflict, but one would expect that articles pass muster at basic methodological standards. Unfortunately, an article recently published in this journal (Gartzke 2012) does not pass that test. Under the provocative title "Could climate change precipitate peace?", Erik Gartzke makes a number of errors. Specifically, Gartzke ignores 25 years of cointegration theory. It is not clear how widespread these errors are in the field of peace research.

According to Scopus, only two articles (Chen et al. 1996;Kollias 1996) in the Journal of Peace Research refer to the seminal article by (Engle & Granger 1987); only one article (Smyth & Narayan 2009) refers to cointegration; and only three articles (Lin & Ali 2009;Ocal & Yildirim 2010;Raknerud & Hegre 1997) refer to stationarity. The few references, Gartzke's response to my review comments (I was assigned as a reviewer for his article), and my communication with the journal editors suggests that cointegration theory is not well-known in peace research.

Therefore, section 2 succinctly reviews this crucial part of statistical methodology. Section 3 assesses the methods used by Gartzke. Section 4 offers an alternative analysis of the same data, leading to very different findings. Section 5 concludes.

Although the critique is targeted at Erik Gartzke and his recent article, his work was randomly brought to my attention. As far as I know, my criticism could have been aimed at any number of analysts and articles in peace research.

**Integration**

Consider a time series $X=\{X_0, X_1, ..., X_t , ..., X_T\}$. A series $X$ is said to be stationary, or integrated of order zero, I(0), if its moments do not change over time. Typically, only the first moment is considered, and variance, skewness, kurtosis etc are ignored. Stationarity then requires that the mean of any subset of the sample is equal to the mean of any other subset – or rather that there is no statistically significant difference between the estimates of these means.

A series $X$ is said to non-stationary if it is not stationary. That is not terribly precise. A series $X$ is said to be integrated of order one, I(1), if its first difference, $\Delta X_t=X_t-X_{t-1}$, is stationary. More generally, $X$ is I($n$) if $\Delta^n X_t=\Delta^{n-1}X_t-\Delta^{n-1}X_{t-1}$ is stationary.

Non-stationary variables pose difficulties for regression analysis (Hamilton, 1994). The intuition is as follows. A regression analysis seeks to explain as much as possible of the observed variation in the dependent variable by the variations in the independent variables. The variance of a trending variable is dominated by its trend. If an independent variable has a trend as well, then its variance too is dominated by the trend. More importantly, the trend in any independent variable can explain a large share of the trend in the dependent variable. This implies that, in a regression analysis, the confidence in the parameter estimates is overstated. That is, a regression analysis will find a statistically significant relationship even when there is none. The regression is spurious.

Statisticians have long known about this problem, but it was not until (Engle & Granger, 1987) that a solution was found, a solution that has been justly rewarded with a Nobel Prize. Two I(1) series $X$ and $Y$ are said to be cointegrated if a linear combination $X-\beta Y$ is I(0). Essentially, one regresses $X$ on $Y$, but rather than testing whether $\beta$ is statistically significantly different from zero, one tests whether the residuals are stationary.

While non-stationarity complicates statistical analyses, it provides additional insight into causality. There are three rules:

- An I($n+m$) series cannot solely cause an I($n$) series for any $m>0$. For example, a trending variable cannot cause a stationary variable; if it would, the stationary variable would have been trending.
- An I($n-m$) series cannot solely cause an I($n$) series for any $m>0$. For example, a stationary variable cannot explain the trend in a trending variable; if it would, the trending variable would have been stationary.
- Two I($n+m$) series can jointly cause an I($n$) series only if the two series are cointegrated of order $m$. Two trending variables can cause a stationary variable only if the trends cancel one another.

Armed with these insights, let us reconsider the analysis of (Gartzke 2012).

**Gartzke's analysis**

(Gartzke, 2012) builds a regression model of the onset of militarized inter-state disputes for the last 150 years or so. His main explanatory variables are the annual mean temperature, democracy, per capita energy consumption (an indicator for development according to the author), membership of intergovernmental organizations, the number of people, and the number of countries. All variables are aggregated cq averaged to the global level.

Figure 1 shows that the explanatory variables all trend upwards, as does the dependent variable. Table I confirms this: All variables are I(2) according to the Augmented Dickey-Fuller test. The Dickey-Fuller test works as follows. As simple AR(1) is defined as:

(1) $X_t = \rho X_{t-1} + u_t$

$X$ would be non-stationary, or rather I(1), if $\rho$=1. In order to test this, rewrite:

(2) $\Delta X_t = X_t - X_{t-1} = (\rho - 1)X_{t-1} + u_t = \delta X_{t-1} + u_t$

and test for $\delta$=0. The test is generalized by including a constant (which corresponds to a linear trend) and time trend (which corresponds to an accelerated trend), and the statistical properties are improved by adding further lags:

(3) $\Delta X_t = \alpha + \beta t + \sum_{l=1}^{L} \gamma_l \Delta X_{t-l} + \delta X_{t-1} + u_t$

In Table I, we set $L$=5 and tested down.

Table I also reports the results of the KPSS test. This follows the same set-up, but instead of testing whether the parameters are statistically significantly different from zero, it tests whether the model performs significantly worse if the parameter $\delta$ is omitted using a Lagrange multiplier test.

The KPSS test is more conservative than the ADF test. Most variables are I(1) rather than I(2). Nonetheless, there is severe risk of spurious regression in this data set.

Figure 2 shows the residuals of the 8 equations in Gartzke's Table G.I. The residuals appear to be trending. This is confirmed by Table II. According to the ADF test, the residuals are I(1) without exception. The KPSS test agrees, the residuals are all I(1), except for model 3 where the null hypothesis of stationary is rejected at the 10% level but not at the 5% level.

That is, the residuals of these regression models violate the assumptions that underpin the statistical analysis. Therefore, the results of Table G.I are invalid.

Gartzke acknowledges this. In his Table G.III, he shows the results of additional regressions, in which the independent variables were made stationary by differencing and logging. Gartzke does not formally test the transformed variables for stationarity. The dependent variable is non-stationary too, but was not transformed.[1] Table G.III does not offer a solution to the statistical problems of Table G.I.

**Gartzke's data reinterpreted**

Table I shows the results of testing for cointegration between conflict on the one hand and each of the ten explanatory variables on the other hand. Cointegration tests are straightforward. You regress $X$ on $Y$, and test the

[1] Of course, transforming the right-hand side of an equation but not the left-hand side means that a different hypothesis is tested.

residuals for stationarity as above. Nine of the ten explanatory variables cointegrate with conflict. The sole exception is temperature squared. This is ironic as Gartzke puts this variable centre stage. It may come as a surprise that temperature squared does not cointegrate whereas temperature does. It should be noted, though, that temperature is measured in deviation from the 1961-90 average. Because global warming has been more or less steady, the temperature record starts negative and ends positive. Temperature squared starts positive, goes to zero, and turns positive again. See Figure 1. The 1961-90 climate normal is, of course, arbitrary; and the squared temperature is meaningless as a result. Strictly, people in the first half of the 20th century would fight more (or less) because of warming in the second half. I therefore cast temperature squared aside.

Table I shows that there are multiple cointegrated variables. The direction of causality is not clear. One can well imagine that conflict affects development, democracy, membership of international organizations, the number of people, and the number of countries. Conflict also affects energy use and, through aerosol emissions, the temperature. In a case like this, a Vector Error Correction Model (VECM) is appropriate (Engle & Granger, 1987; Johansen, 1988). Equation (3) gives the basic specification, but $X$ should be reinterpreted as a vector.

There are 10 variables in the VECM and thus a risk of overspecification. I used two strategies to reduce the dimensionality of the model. Firstly, I omitted the variable that was least significant in the VECM, and repeated this until all variables were significant (Hendry, 1995). I kept conflict and temperature regardless of their significance. Membership of international organizations, membership squared, and population were included. Secondly, I followed the same stepwise general-to-specific specification search but now in an OLS with conflict as the dependent variable. Democracy, development, development squared and membership of international organizations remained.

Figure 3 shows the key results from the VECM: The impulse-response function of conflict to temperature. An impulse-response function gives the reaction of one variable to a temporary shock to another variable. Figure 3 shows four variants. The full VECM was estimated with one and five annual lags, and the two reduced VECM were estimated with one lag.

In three of the four cases shown in Figure 3, there is no significant response of conflict to a transient change in the temperature. By construction, there is then no significant response to a permanent temperature change either. There is a statistically significant response if variables are removed on the basis of their significance in an OLS regression. This in itself is inappropriate. The impulse-response function is peculiar: A *temporary* change in temperature has a *permanent* effect on conflict. This is because (in all four variants of the VECM) there is a unit root in conflict: shocks accumulate. However, it is implausible that there would be more or less conflicts now and forever just because it is warm or cold now. In sum, there is no statistically significant effect of temperature on conflict in three out of four cases, and in the fourth case the effect is significant but suspect.

These findings should not surprise us. Previous research (Tol & Wagner, 2010) has shown that, although temperature may have affected conflict in the temperate zone in the distant past, there is no such evidence for recent times. In Africa, rainfall may have an effect on conflict (Hendrix

& Salehyan, 2012; Raleigh & Kniveton, 2012; Theisen, 2012), but not temperature.

## Discussion and conclusion

Gartzke (2012) claims empirical support for a causal relationship between temperature and conflict, and concludes that a warmer world would be more peaceful. However, Gartzke's data are trending, and his analysis does not properly take account of that. A re-analysis of Gartzke's data reveals that his regression is spurious. There is no statistically significant relationship between the global mean surface air temperature and the world total number of onsets of militarized international disputes. Climate change will not precipitate peace.

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Table I. Stationarity test results for variables.

| Variable | ADF | KPSS | Cointegrated? |
|---|---|---|---|
| Conflict | I(2) | I(1) | |
| Temperature | I(2) | I(1) | Yes |
| Temp^2 | I(2) | I(1) | No |
| Democracy | I(2) | I(1) | Yes |
| Dem^2 | I(2) | I(1) | Yes |
| Development | I(2) | I(1) | Yes |
| Dev^2 | I(2) | I(1) | Yes |
| Intergovernmental organizations | I(2) | I(1) | Yes |
| IGO^2 | I(2) | First difference trend stationary | Yes |
| Population | I(2) | I(2) | Yes |
| Countries | I(2) | I(2) | Yes |

Table II. Stationarity test results for residuals.

| Variable | ADF | KPSS |
| --- | --- | --- |
| Number of countries, number of people, temperature | I(1) | I(1) |
| + temperature squared | I(1) | I(1) |
| + democracy | I(1) | I(0) |
| + democracy squared | I(1) | I(1) |
| + development | I(1) | I(1) |
| + development squared | I(1) | I(1) |
| + membership of intergovernmental organizations | I(1) | I(1) |
| + membership squared | I(1) | I(1) |

Figure 1. Variables used in the analysis, rescaled to lie between 0 and 1.

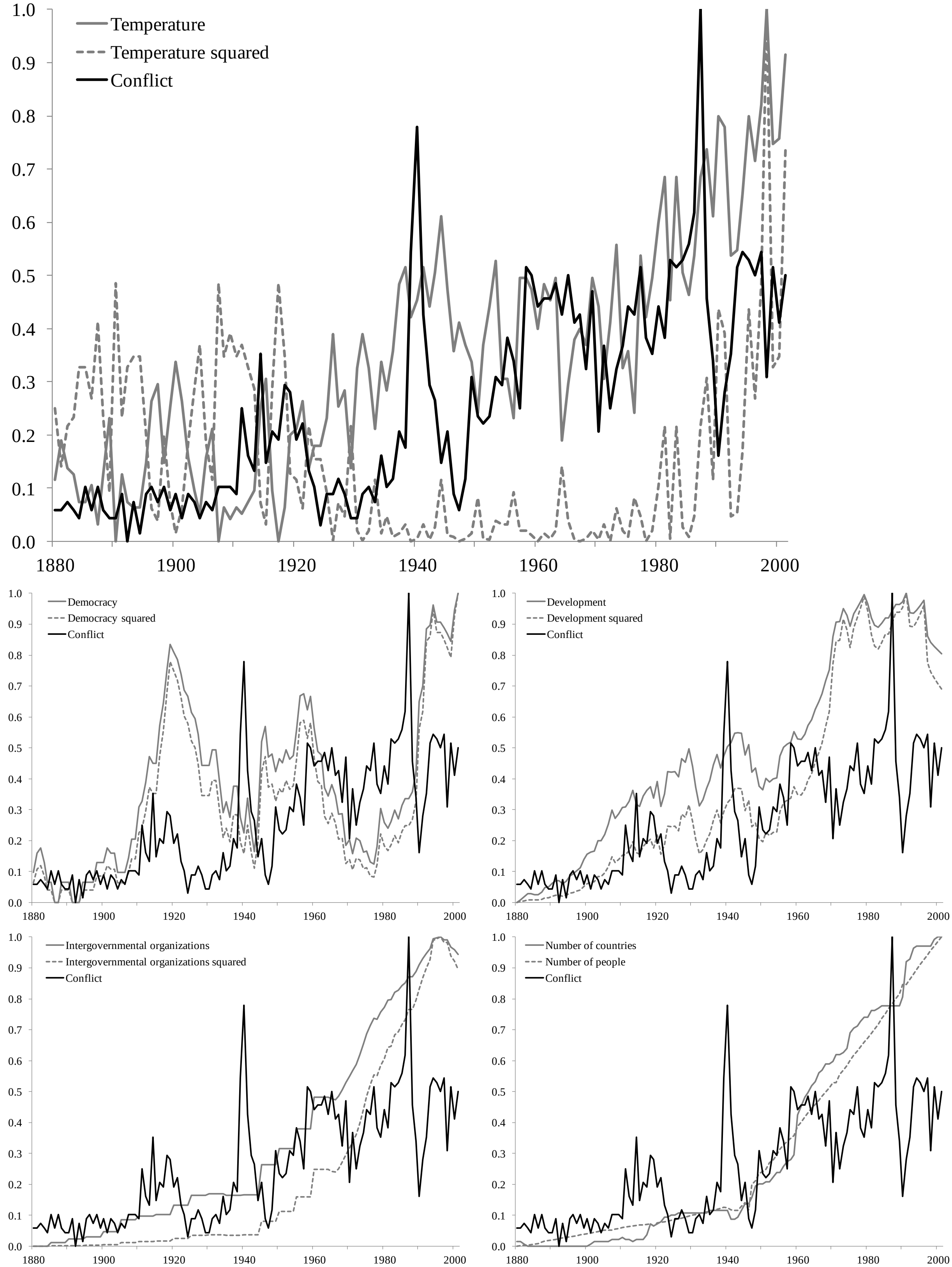


Figure 2. The number of onsets of militarized international disputes ("conflict"), the average residual of the 8 estimated regression models ("residual") and the 67% confidence interval of the average residual (bars).

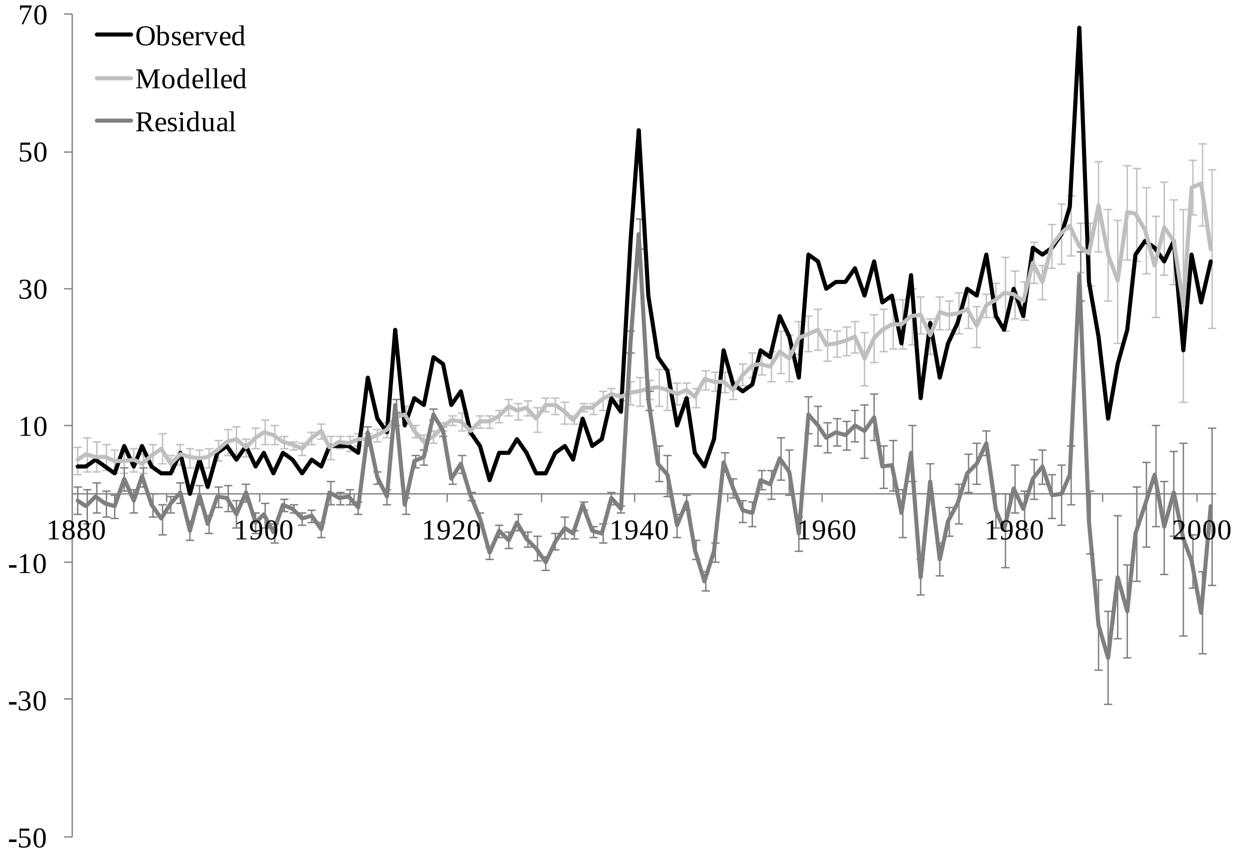
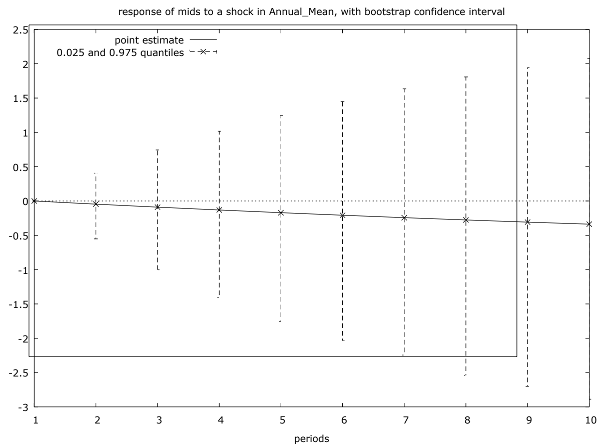
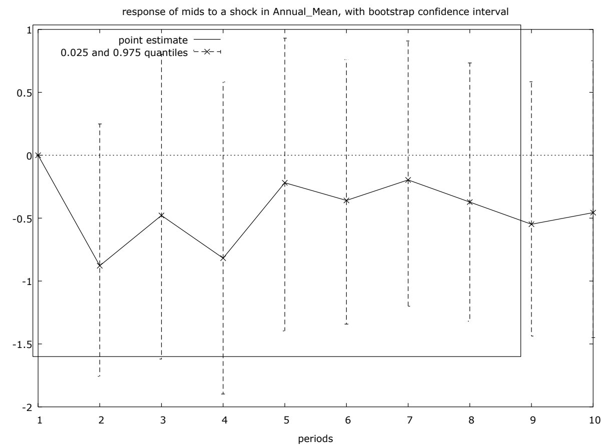


Figure 3. Impulse-response functions of the onset of military conflict to annual mean temperature.

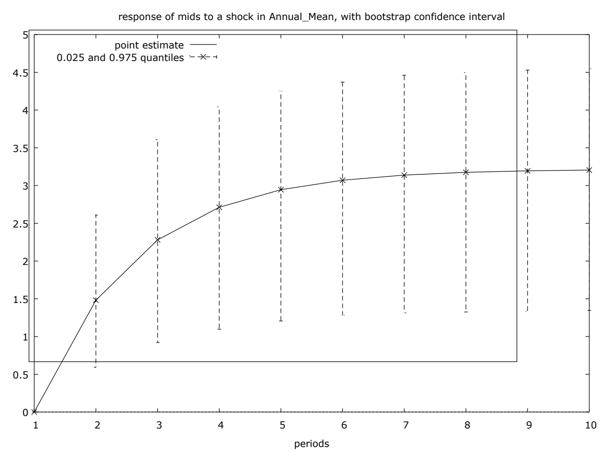
Full model



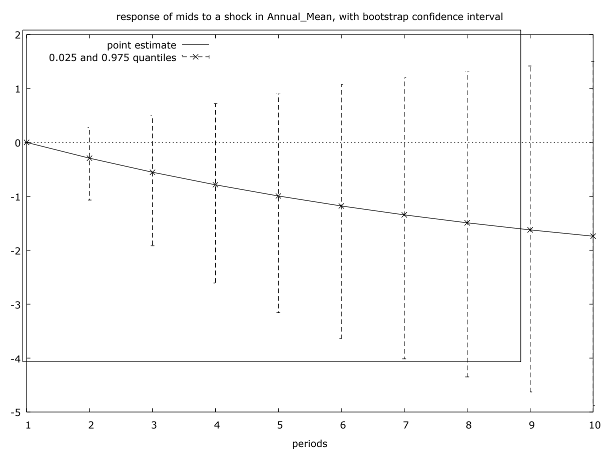

Full model, 5 lags




Reduced model, OLS




Reduced model, VECM

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