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RESEARCH NOTE

A spatiotemporal analysis of NATO member states' defense spending: how much do allies actually free ride?

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Abstract
Concerns over free riding in NATO are widespread. An intuitive approach to analyzing free riding is treating it as a systematic pattern of spatial interdependence between the allies: how does a NATO member's defense spending react to changes in other allies' military expenditures? While recent work has found statistically significant free riding (negative spatial interdependence in the outcomes), it suffers from important limitations. First, this research does not adequately account for temporal dependence. Second, it does not quantify the effect of interest. Accounting directly for temporal dependence provides a meaningfully distinct perspective on the within-alliance dynamics, demonstrating that the spatiotemporal effect of free riding is, in fact, more substantial than its short-run effect, challenging inferences of static spatial models. We discuss the relevant practical and theoretical implications.

Keywords: defense spending; spatial methods; pooled cross-section time series models

1. Introduction

Does belonging to a military alliance induce free riding? More concretely, do NATO members free ride, and, if so, to what extent? The relevance of this latter question, in particular, extends beyond academia. Former US President Trump was perhaps the most explicit and vocal in blaming allies for free riding and in calling for substantially ramping up military spending. Yet he was by no means an exception (Duchin, 1992). Such ally behavior matters not only politically but also militarily and strategically. Crucially, free riding and its extent have implications for the Alliance's deterrence posture in the face of heightened military threats from Russia.

Notwithstanding certain US officials' discourse, there is little consensus on the nature and magnitude of free riding. An intuitive strategy to operationalize free riding is treating it as an endogenous spatial lag (Yesilyurt and Elhorst, 2017; George and Sandler, 2018). That is, it is expected to manifest as a systematic pattern of negative spatial interdependence in the outcomes, whereby an average NATO member decreases its defense spending in response to other allies' increased military expenditures.

The political economy literature on NATO allies' defense spending has made important contributions but still suffers from two important weaknesses. First, it does not systematically account for temporal dynamics; consequently, free riding behavior risks mischaracterization. Omitting autoregressive temporal dependence limits the phenomenon to a short-run perspective alone, although there are good reasons to expect that the full free riding effect manifests gradually over time. Second, the literature does not provide the quantitative magnitude of free riding. Put simply, even if we are convinced by short-run estimates of free riding behavior (i.e. that allies free ride), we do not know the extent to which NATO member states participate in this behavior. There is therefore a huge missed opportunity in the literature to extract pertinent information from the statistical results (King *et al.*, 2000; Drolc *et al.*, 2019). Ultimately, both of these issues hinder our efforts to fully appreciate the inter-ally dynamics in NATO.

By applying the latest methodological insights from the time-series cross-section (TSCS) literature, we show that the short-run effect of free riding in NATO, once we account for temporal dependence, is substantially smaller compared with the effect estimate obtained from one-dimensional spatial models previously outlined in the relevant literature. However, over time, the effect of interest is considerably larger. These findings, together with the estimated magnitude of actual free riding within NATO as well as the display of its dynamics over time, offer novel insights with important implications for policy discussions and academic research.

2. Existing findings

Free riding in alliances is closely related to the concept of public goods. To the extent that security created by alliances is non-excludable and non-rival in consumption, we might expect member states to free ride on other allies' expenditures (Olson and Zeckhauser, 1966; Becker *et al.*, 2024). There are alternative theoretical accounts of examining alliance spending dynamics, such as the bargaining or US pressure perspectives (Fang and Ramsay, 2010; Blankenship, 2020, 2021). Yet the insights based on free riding, implicitly or explicitly derived from the public goods model, remain widely shared in the public and academic discourse.

In empirical research, an intuitive strategy to operationalize free riding is treating it as an endogenous spatial lag (Yesilyurt and Elhorst, 2017; see also Franzese and Hays, 2006). Specifically, when a member state's allies increase their military expenditures, that same country is expected to decrease its own, which makes this dynamic one of negative spatial interdependence in the outcomes. Whether this process is direct (e.g., strategic interaction) or indirect (e.g., indirect spillovers), it is inherent to intergovernmental cooperation (Flores, 2011; Drolc *et al.*, 2019; Cook *et al.*, 2020).

Research on NATO allies' defense spending has seen important methodological improvements. Recently, there have been a few studies that, using spatial econometric techniques, specifically address spatial interdependence among NATO allies' military expenditures (George and Sandler, 2018, 2022; Kim and Sandler, 2024).[1] This research sets itself apart from existing studies on worldwide patterns of military spending, which tend to point to arms race (Goldsmith, 2007; Yesilyurt and Elhorst, 2017).

The core takeaway from this research on NATO is negative and statistically significant spatial interdependence arising from the outcomes of other units, that is, defense spending of other allies. While the implied substantive interpretation is that free riding is prevalent and substantial, this interpretation suffers from two significant limitations. First, temporal dependence is omitted. Second, a substantively meaningful estimate of the free riding effect is not provided.

3. The need to directly adjust for spatiotemporal dependence

The vast majority of research based on TSCS data considers either the temporal dimension or the spatial one as a source of dependence. As noted by Cook *et al.* (2023, 59), only a meager percentage of such articles in top political science journals have been concerned with "model[ing] *both* temporal and spatial dependence directly."

Fixed effects (FE) have often been used to adjust for the underspecified dimension, that is, to correct for either within-country or within-period correlation (Cook *et al.*, 2023; see also Kropko and Kubinec, 2020). However, by incorporating FE, one imposes a specific structure of

[1]See also a similar analysis on EU member states' military expenditures (George and Sandler, 2021).

correlation (time-invariant spatial clustering in the case of unit FE, or homogenous period-based shocks in the case of time FE); other solutions to deal with spatial correlation, including regional or regional-period indicators (Cook *et al.*, 2023), or the method of panel-corrected standard errors (Beck and Katz, 1995), do not resolve the distinctive challenges of two-dimensional data analysis either. More generally, the very logic of correcting standard errors prevents us from any theoretical insight into how space and time interact to define the outcome of interest.

Compared to pre-defined structures, endogenous spatial interdependence implies autoregressive patterns. This means that units influence other units in a diminishing manner, thus allowing this influence to manifest as more diffuse, without it being constrained, for instance, to a pre-defined region (Cook *et al.*, 2023). Another important aspect associated with the diffuse character of spatial interdependence in the outcomes is global spillovers, as units affect other units beyond their (direct) neighbors (Yesilyurt and Elhorst, 2017). Yet the potential of spatial interdependence remains underestimated if temporal dependence is overlooked.

Inadequate attention to modeling the spatial and temporal dimensions jointly leads to biased estimates of the dependence parameters (notably, overestimation of the included parameter if the other is omitted), the covariates' coefficients, and their effects (Elhorst, 2001; Cook *et al.*, 2023). Lately, therefore, there has been a notable methodological shift aimed at directly modeling space and time in applied research (Cook *et al.*, 2023), refining some previous work (e.g., Elhorst, 2001). This shift is no longer solely reliant on an empirical perspective (Yesilyurt and Elhorst, 2017), but is backed by theoretical insights and analytical evidence.

Beyond the relevant methodological concerns, researchers are also interested in providing a substantive interpretation of the phenomenon of interest. Yet the lack of attention to spatio-temporal dependence undermines this endeavor, as it increases the risk that the researcher might not accurately identify the precise mechanism driving the observed data, which is both spatially and temporally correlated (Cook *et al.*, 2023). Even if the researcher is only interested in accurately modeling contemporaneous spatial interdependence, neglecting the temporal dimension is likely to result in a biased coefficient of the spatial parameter, as well as inaccurate covariates' estimates, thus impairing the validity of inferences and the theoretical scope of the analysis.

There are strong reasons to expect that military spending, like other forms of budgetary expenditures, has considerable persistence over time (Cantekin *et al.*, 2023). While certain authors have incorporated such "habit persistence" in their analysis of worldwide defense expenditures, including within a spatial setup (Yesilyurt and Elhorst, 2017; see also Goldsmith, 2007), this consideration has not systematically featured the defense economics literature (Flores, 2011; Skogstad, 2016; Kofroň and Stauber, 2024). Importantly, it has been overlooked in spatial analysis of free riding in NATO (George and Sandler, 2018, 2021; Kim and Sandler, 2024). An equally significant area of advancement in defense economics is the estimation of the full free-riding effect, which, to the best of our knowledge, has not been estimated in the literature so far.

4. Empirics

We directly model both the spatial and temporal dimensions in our analysis of 27 NATO allies' defense expenditures.[2] We adjust for temporal dependence through the lagged dependent variable (LDV). Relative to the previous work, we update the data on defense spending measured as total spending (in millions, constant 2020 USD) up to 2021 (SIPRI, 2022). We generally follow an empirical strategy motivated by George and Sandler's (2018, 2022) work. Our covariates thus include GDP measured in absolute value (constant 2015 USD; World Bank, 2022a) and population (World Bank, 2022b). We use the logarithmic transformations of these covariates as well as of the dependent variable and adjust our models for country FE. While adjusting for unobserved

[2]We exclude Iceland, Montenegro, and North Macedonia.

time-invariant influences, country FE also account for fixed patterns of spatial clustering in the outcome (Cook *et al.*, 2023), including permanent threats.

Following George and Sandler (2018), we look at several time periods – from 1975 to 2021, from 1991 to 2021, and from 1999 to 2021 –, to test whether there were differences in free riding across these periods. Furthermore, our models include time trends (up to the cubic polynomial), which effectively capture non-linear patterns over time (Carter and Signorino, 2010), including those of defense spending (Blankenship, 2020).

Our empirical strategy is based on the spatial autocorrelation (SAC) model and the (spatial) maximum likelihood estimator. Recent methodological literature has identified multisource models as an improved empirical specification strategy (Cook *et al.*, 2020, 2023). As a reminder, SAC models mitigate the risk that the observed spatial dependence in the outcomes is actually driven by spatial effects in the residuals, a common concern in spatial analysis given the known issue that different spatial sources tend to introduce to data-generating processes similar empirical patterns (Cook *et al.*, 2020).

Furthermore, we use a non-row standardized weights matrix representing inverse distances (in hundreds of kilometers) between the capital cities. The relevance of this matrix rests on the notion that geographically closer allies may be expected to assist militarily in the case of a conventional conflict (George and Sandler, 2018). Moreover, closer allies are expected to face similar threats and develop similar defense capabilities, thus making a given country benefit more from its ally-neighbors' military spending. Besides, weight matrices derived from physical distances provide an advantage in terms of exogeneity.

We find that, compared to one-dimensional spatial models (Table 2 in the Supplementary Material[3]), once we account for temporal autoregressive dynamics (Table 3), our models improve considerably in terms of model fit (e.g., log likelihood improves by a factor of almost 2 to 2.5 for the different time periods). The estimated spatial-lag parameter (ρ) is negative and significant, which corresponds to the results derived from the static spatial models and thus suggests free riding. Importantly, however, the spatiotemporal models (Table 3) offer a meaningfully distinct understanding relative to the exclusively spatial perspective previously established in the NATO free riding literature. They reveal that the impact of other allies' military expenditures on a given member state's defense spending extends beyond a single period and, instead, unfolds over time, ultimately proving to be substantially larger than its contemporaneous effect.

While estimated spatial parameters can offer much valuable information, they are not directly interpretable (LeSage and Pace, 2009; Whitten *et al.*, 2019). Based on the operationalization of our variables, interpreting free riding makes sense if we try to answer the following question: what is the expected effect of 1 percent positive shock in all allies' military expenditures, except for a given country, on that country's defense spending for one period and all the periods? Alternatively, what is the average effect of a shock in an ally's military spending on another ally's defense expenditure, again, for one and all the periods?

In the case of a positive shock in defense spending of all allies, except for a specific country, the static models suffer from an inflation bias. More concretely, they indicate a contemporaneous spatial free riding effect, which is much greater than the short-run effect derived from the spatio-temporal models. It is greater by a factor of around three across the periods (e.g., −0.046 percent vs. −0.016 during the 1975–2021 period[4]). The expected effects of an increase in a single ally's military expenditure are similarly inflated in the static models.[5] We also observe that other covariates' coefficient-estimates turn out to be substantially smaller when we account for temporal dependence.

[3]All tables appear in the Supplementary Material.

[4]See Tables 2 and 3.

[5]The scalar results are not reported.

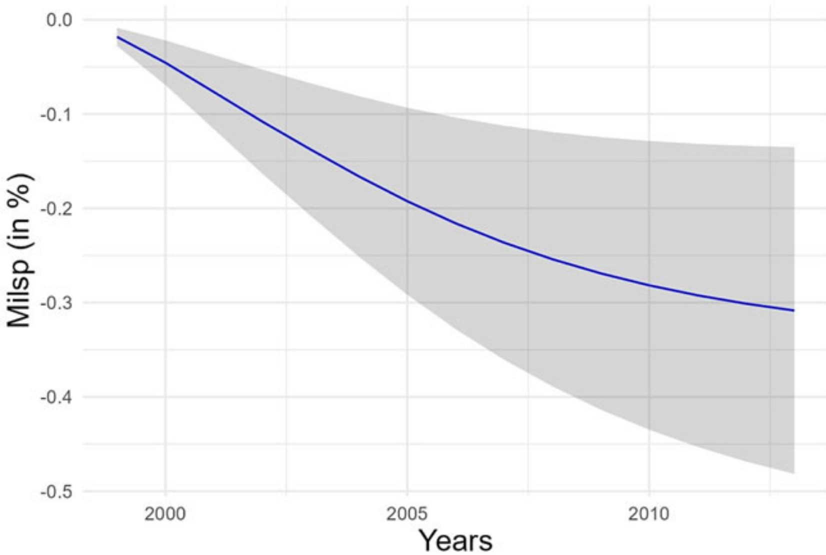

Figure 1. The average cumulative spatiotemporal (dynamic) effect of a permanent positive shock in defense spending of a member state's allies over a 15-year period.

Notes: The average effect was derived using the spatial model results obtained based on the 1999–2021 data and considering the allies that were members of NATO in 1999. Confidence intervals of 95 percent were obtained after running 1000 simulations.

To provide quantitative estimates, absent the LDV, we derive the average effect of free riding from the off-diagonal elements of a full $N \times N$ effects matrix taking the form of the contemporaneous spatial multiplier, $d\mathbf{y} = (\mathbf{I} - \rho\mathbf{W})^{-1}$ (e.g., Franzese and Hays, 2006; Elhorst and Vega, 2013). In other words, our focus is on the average indirect effect across NATO allies, supposing that the allies' defense spending could have endured a positive shock of one unit. In the LDV models, the average spatiotemporal (dynamic) effect is derived from the spatiotemporal multiplier, $d\mathbf{Y} = (\mathbf{I} - \varphi\mathbf{L} - \rho\mathbf{W})^{-1}$.[6] Based on this derivation strategy, Figures 1 and 2 plot the cumulative response-path estimates of interest during a specified period.[7] The average spatiotemporal effect of free riding (Figure 1), over time, simply accumulates the period-based averages, across NATO countries, of all the indirect effects incurred by an individual ally. For a single country's effect (Figure 2), the response-path dynamic illustrates the accumulated period-based averages, each time calculated across NATO allies, of the mean indirect effects attributable to individual countries.

In the spatiotemporal scenario, the effect of a permanent positive shock in allies' defense spending reverberates not only across space but also time. Specifically, Figure 1 illustrates the average cumulative spatiotemporal effect, over 15 years, for a NATO member state considering a shock of a 1 percent in defense spending of all its allies. Figure 2 illustrates the average spatiotemporal effect, assuming an increase in defense spending of a single ally.

The spatiotemporal free riding effects end up larger than suggested by the static models. The results are generally similar across the different time periods. A permanent positive shock of 1 percent in NATO members' defense spending, except for a given ally, may be expected to

[6]The dimensions of which are those of a given unbalanced panel.

[7]To determine the uncertainty intervals, we, first, created multivariate normal draws for both the spatial lag and the LDV, utilizing the variance-covariance matrix derived from our estimated parameters. Leveraging these drawn estimates, we subsequently generated effect matrices from which were derived (multiple) simulated cumulative indirect effects for each NATO ally, as well as were calculated their corresponding (period-based) standard errors, thereby establishing the bounds of uncertainty. The reported effects and their bounds represent the averaged outcomes across NATO member states.

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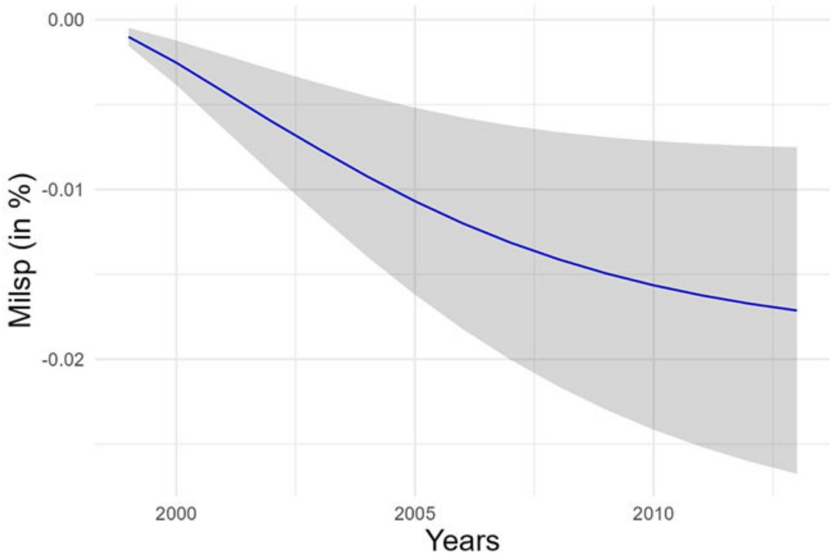

Figure 2. The average cumulative spatiotemporal (dynamic) effect of a permanent positive shock in defense spending of a single ally over a 15-year period.
Notes: The average effect was derived using the spatial model results obtained based on the 1999–2021 data and considering the allies that were members of NATO in 1999. Confidence intervals of 95 percent were obtained after running 1000 simulations.

lead, over 15 years, to a cumulative decrease of 0.21 to 0.31 percent (depending on the time period considered) in that ally's own military expenditure.[8] The long-run stable-state (LRSS) responses are even more significant in magnitude.[9]

Finally, we ran several additional models to check the robustness of our results (Table 4). To guard against the possibility that the US might be driving NATO allies' defense budgets, we tested whether the results stand once the US is dropped from the sample. Furthermore, we tested a matrix that gives special importance to US spending (the US being treated as the closest ally by assigning to the US the same distance-based weight as the one attributed to the actual closest ally). Besides, we included Russian spending, as well as the interaction term between Russian spending and geographical proximity to Russia as additional covariates to better capture the threat environment. Finally, we incorporated host-nation support (HNS) for US military presence in host countries as a proxy for US pressure.[10] None of these variations affect the robustness of our main findings.

5. Conclusion

In this research note, we suggest two principal contributions. First, we present the first study on free riding in NATO that models directly both temporal and spatial dependence. Second, we quantify the estimated effect of free riding within the alliance. Based on the state-of-the-art methodological knowledge in TSCS analysis, we argue that accurate derivation of (negative) spatial interdependence between allies' defense spending, which is used in the literature as a measure for free riding, cannot be modeled appropriately if temporal dependence is present but unaccounted for.

[8]More detailed results are not reported.
[9]See Table 3. The responses were calculated based on the following formula: $d\mathbf{Y} = (\mathbf{I} - \varphi\mathbf{I} - \rho\mathbf{W})^{-1}$ (e.g., Cook *et al.*, 2023: 71).
[10]The data on HNS, measured in percent of GDP, come from Blankenship (2021).

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We empirically show that the inclusion of the LDV substantially reduces the spatial-lag parameter, although it does not render the lag insignificant. We therefore corroborate the finding of the earlier research that free riding exists within NATO. Yet, at the same time, we show that the short-run effect in the spatiotemporal models is markedly smaller than the one derived from one-dimensional spatial models. More importantly still, in the long run, the spatial effect is substantially more profound. These represent meaningfully different versions of the phenomenon in terms of their dynamics, thereby affecting our inference.

These findings have a few important implications. On the policy (or practical) level, they suggest that some of the concerns over free riding may have been justified, as the phenomenon appears to manifest itself in a more significant manner than previously thought (with the caveat that endogenous spatial interdependence is only one, albeit important, way to capture free riding). Our evidence suggests that additional efforts are necessary to mitigate free riding in NATO, especially given the alliance's extended membership, as well as the actual need to increase NATO defense spending in the context of support for Ukraine and Russia's aggression more generally. Our analysis also points to the complexity of free riding, which is not limited to short-run annual dynamics but unfolds over a longer time period. This underscores the need for allies' strategic commitment.

One implication for researchers is that scholarship investigating free riding in NATO and other alliances or, more generally, modeling interdependence in military expenditures needs to also directly model the temporal dependence, at least as a sensitivity check. In fact, this implication has a broader bearing – while the use of TSCS analysis has grown very substantially in social science, only a minority of studies address both time and spatial dependence directly (Cook *et al*., 2023).

Finally, the bias stemming from the neglect of temporal dependence is not limited to the overestimation of spatial dependence. Covariates' coefficient-estimates will also suffer from bias, while the effects of interest will be estimated inaccurately, including by omitting their meaningfully diverse dynamics. All this speaks directly to the researcher's efforts of uncovering the true data-generating process of any given phenomenon and therefore provides an indispensable basis for future research motivated by TSCS data.

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