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Militarizing the Climate Crisis: An Analysis of the Short-Run and Long-Run Effects of Militarization on Nations' Carbon Emissions, 1990–2020

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ABSTRACT

Building on scholarship in global political economy, historical sociology, and environmental sociology, as well as emerging streams of research on militarization and climate change, we theorize about and successively investigate the short-run and long-run effects of two far-reaching characteristics of militarization on nations' carbon emissions and the climate crisis in general. We contend that emergent and changing conditions associated with the capital-intensiveness and size of militaries shape path dependencies, which structure short-run and long-run effects on carbon pollution. To test our propositions, we estimate dynamic models of emissions for 104 nations from 1990 to 2020. Overall, the findings confirm our arguments. The short-run and long-run effects of the capital-intensiveness and size of militaries on carbon emissions are positive and nontrivial. Further, their estimated short-run and long-run effects are consistent across three distinct measures of carbon emissions, statistically symmetrical, robust to different modeling techniques, and not sensitive to any nations included in the analysis.

Key words: climate change; militarization; environmental sociology; global political economy; carbon emissions.

The climate crisis is one of the most serious problems facing humanity (Fisher 2024; Mezy 2020; Smith 2017). Sociology's methodological pluralism and emphasis on social structures and institutions, inequality, power, and relationships at multiple scales positions the discipline to greatly increase our shared understanding of the causes, consequences, and solutions to this crisis (Caniglia et al. 2021; Davidson 2022; Dunlap and Brulle 2015; Klinenberg, Araos, and Koslow 2020; Pellow and Brehm 2013). One of the primary areas of research in the sociology of climate change focuses on the anthropogenic drivers of greenhouse gas emissions (Dietz, Shwom, and Whitley 2020; Jorgenson et

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al. 2024; Rosa and Dietz 2012). Anthropogenic drivers, in this context, refer to the social systems, institutions, and human actions causing emissions, and the societal factors shaping and conditioning those actions. Besides helping to solidify the presence and relevance of climate change within environmental sociology and the discipline in general (Jorgenson 2024; Lockie 2022; Stuart 2021), sociological research on anthropogenic drivers and adjacent topics is becoming more influential in interdisciplinary work on climate (Dietz 2017; Longo et al. 2021). This sociological research is also increasingly covered in the climate change syntheses and assessment reports of governmental agencies and international organizations (IPCC 2022; Marino et al. 2023). While anthropogenic drivers are causes of climate change, increasing our knowledge of these factors is also essential for establishing a more holistic understanding of the consequences and especially solutions to the climate crisis (Dietz 2023; Grant, Jorgenson, and Longhofer 2020).

Economic growth and population growth are the most studied drivers, along with forms of inequality, electricity generation, industrial production, and trade networks. Nonetheless, it is crucial to focus on other structural characteristics of societies. In this study, we advance anthropogenic drivers research by focusing on the short-run and long-run effects of militarization, which also answers the longstanding call to bring the military back into the discipline (e.g., Andreski 1968; Giddens 1987; Kentor and Kick 2008). To do so, we draw from scholarly work in historical sociology and global political-economy on militarism and the coercive power of nation-states (Chase-Dunn 1998; Mann 2014; Tilly 1990); the growing literature in environmental sociology and other fields on the environmental impacts of militaries and their activities (Alvarez, Shtob, and Theis 2024; Auerbach 2024; Hooks and Smith 2004; Lengefeld, Hooks, and Smith 2021); and especially the emerging research on how distinct characteristics of militaries shape the carbon emissions of nations throughout the world (Bradford and Stoner 2017; Clark, Jorgenson, and Kentor 2010; Crawford 2022; Jorgenson et al. 2023; Smith and Lengefeld 2020). In particular, and building on these areas of scholarship and research, we theorize how the emerging and evolving conditions associated with the capital-intensiveness and relative size of national militaries shape path dependencies that structure short-run and long-run effects on nations' carbon emissions, and we then empirically evaluate our propositions.

To test our arguments, we estimate dynamic models of carbon emissions for an unbalanced panel dataset of 104 nations from 1990 to 2020 as well as for a sample restricted to nations with no missing data. Similar to prior sociological research on other drivers (e.g., Longhofer and Jorgenson 2017; Thombs 2018; Vesia, Mahutga, and Khánh Hà Buì 2023), we use three different measures of national carbon emissions as dependent variables, each of which has unique properties and substantive implications related to mitigation, efficiency, and equity: total emissions, emissions per unit of GDP, and per capita emissions. In the analysis, we focus on the short-run and long-run effects of military expenditures per soldier and military participation rate, two measures that capture the far-reaching yet distinct capital-intensive and relative size characteristics of national militaries (Carlton-Ford et al. 2019; Clark et al. 2010; Jorgenson, Clark, and Kentor 2010; Jorgenson et al. 2023; Kentor, Jorgenson, and Kick 2012). We also assess whether their short-run and long-run effects are asymmetrical, meaning that positive and negative changes in expenditures per soldier or participation rate differentially affect national emissions (Thombs, Huang, and Fitzgerald 2022; York and Light 2017). Modeling for potential asymmetry in their effects is important on climate mitigation and overall solutions grounds (Huang and Jorgenson 2018; York 2012). Finally, we conduct robustness checks to determine whether the results are consistent across different model estimation techniques, and we assess if the analysis is sensitive to the inclusion of any of the nations in the overall dataset.

The findings are consistent with our arguments. The short-run and long-run effects of military expenditures per soldier and military participation rate on all three carbon emission outcomes are positive and nontrivial for both the complete unbalanced dataset and the dataset restricted to nations with no missing data. Further, their estimated short-run and long-run effects are statistically symmetrical, robust to different modeling techniques, and not sensitive to any outlier nations included in the analysis. We now turn to the literature review, where we summarize the prior areas of research and scholarship that inform our approach and facilitate our research questions.

MILITARIZATION AND THE CLIMATE CRISIS

Foundational scholarship in historical sociology and global political economy highlights that nation-states utilize their coercive power to secure and maintain access to natural resources throughout the world (e.g., Chase-Dunn 1998; Engels 1968; Magdoff 1978; Mann 2014; Marx 1976; McNeill 1982; Tilly 1990; Weber 1978). Coercive power, in this geopolitical context, commonly refers to nations' military power (Kentor 2000; Pape 1996; Tilly 1990; Turner 2013). In the contemporary era, access to fossil fuels and other resources are the lifeblood of carbon-intensive production and economic growth for nations and corporations (Clark and York 2005; El Tinay 2024; Grant et al. 2020; Jorgenson and Clark 2009, 2012; Lynch and Long 2022; Podobnik 2006; Rieger 2024; Vesia et al. 2023). International stability benefits corporations and the broad economic interests of nation-states, as it allows for more consistency and reliability in the flow of energy, other raw materials, and produced commodities through extraction, production, and trade networks (Chase-Dunn, Kawano, and Brewer 2000; Kentor, Clark, and Jorgenson 2023; Martin 1977). The coercive power of national militaries plays a prominent role in maintaining such stability, both domestically and internationally (Cooley, Nexon, and Ward 2019; Gerace 2004; Heo and Ye 2019; Hirst 2001). Such observations from global political economy and historical sociology suggest that militarization, as a form of coercive power, will lead to notable increases in nations' carbon emissions.

A significant body of research in the environmental social sciences examines the relationship between militarization and the environment. War has both short-term and long-term environmental consequences. Scorched earth operations, which include the use of nuclear, biological, chemical, and depleted uranium weapons, kill flora and fauna. They also result in a toxic legacy, as chemical compounds remain in ecosystems, circulating within the food web (Auerbach 2024; Brauer 2009; Commoner 1971; Frey 2013; Levy and Sidel 2007; Mitchell 2020; Rice 2015, 2023; Sills 2014; Wilcox 2011; Zierler 2011). The environmental impacts of war in the contemporary era continually evolve, as emerging technologies shape the precision and scale of destruction. For the more capital-intensive and technologically sophisticated militaries, this manifests in forms of "risk-transfer militarism" (Shaw 2002, 2005), which minimizes casualties for their soldiers, decreases loss of machinery, and shields their homeland's citizens, while inflicting damage and suffering on human and nonhuman populations, the built environment, and the overall natural environment of distant locations (Hooks, Lengefeld, and Smith 2021; Lengefeld, Hooks, and Smith 2021).

Beyond war, however, the structure, operations, and technologies of national militaries have significant environmental impacts, influencing fossil fuel consumption and greenhouse gas emissions, ground-level air and water pollution, biodiversity loss, the production of dangerous munitions, and well-documented patterns of environmental injustice (Alvarez 2016; Bradford and Stoner 2014, 2017; Clark et al. 2010; Crawford 2022; Hooks and Smith 2004, 2005; Jorgenson and Clark 2016; Jorgenson, Clark, and Kentor 2010; Lawrence et al. 2015; Payne and Swed 2024; Smith and Lengefeld 2020). To advance scholarship regarding how these characteristics of militaries influence carbon emissions and climate change, we suggest that it is necessary to consider the historical development of militarization. Here we focus on how the emerging and evolving conditions associated with the capital-intensiveness and relative size of militaries shape path dependencies that create short-run and long-run effects on the environment in general, and carbon emissions and the climate crisis in particular.

According to C. Wright Mills (1956), the position and prominence of the military in society changed following the Second World War. Within the United States, top military leaders increasingly joined the most powerful individuals in the federal government and corporate world in making major policy decisions with national and international consequences. This ascendency arose due to the global threat presented by the creation of atomic/nuclear weapons, the conception of war and preparation for war as normal political affairs, and the increasing geopolitical competition between nations as part of the Cold War. These changes contributed to an expanding military budget and military contracts for the private sector that produce high-tech weaponry and equipment, resulting in a "permanent war economy." In other words, these developments helped facilitate an arms race between nations, arms trading among nations, and military security/defense agreements among allies (Elveren 2019; Hossein-Zadeh 2006; Lens 1970; Mayer 1991; O'Connor 1973). They also drive ongoing technological advances, expansion in infrastructure, and growth of personnel for militaries (Auerbach and Clark 2024; Kentor et al. 2012).

Treadmill of destruction theory, within environmental sociology, emphasizes that national militaries generate a powerful growth dynamic supported by expanding budgets, fostering the creation of high-tech land vehicles, planes, boats, weapons, and communications systems (Clark and Jorgenson 2012; Custers 2010; Hooks 1994; Hooks and Smith 2004, 2005; Smith, Hooks, and Lengefeld 2024; Soeters 2018; Willis 2017). New equipment is meant to advance performance and improve execution of desired tasks, such as increasing the speed of travel, which enhances strike capacity and the ability to move troops, weaponry, and other equipment further in less time. These developments make the militaries more capital-intensive and thus more fossil fuel consumptive (Collins 1981; Shaw 1988).

Non-nuclear aircraft carriers consume approximately 6,000 gallons of fuel per hour; F-35A, F-16, and F-15 fighter planes often burn 1,500 to 1,600 gallons of fuel per hour; and military helicopters require nearly five gallons to travel a mile (Clark and Jorgenson 2012; Levy and Sidel 2007; Sanders 2009). It is estimated that 70 percent of fuel used by national militaries is associated with flying fighter jets and that newer planes are even more fuel intensive (Akkerman et al. 2022). These forms of military equipment are used for the constant training of personnel in preparation for war. The climate implications are profound, given the amount of fossil fuels consumed consistently by the vast fleets of carbon-inefficient machinery (Clark et al. 2010; Crawford 2022; Jorgenson, Clark, and Givens 2012).

Military expenditures are, in part, used to advance research and development of advanced technologies. As they are designed, constructed, and produced, the vehicles and weaponry, such as fighter jets, take years to materialize. Once they are produced, they are deployed for long periods of time, whether used in training, exercises, or conflict, and they require continual maintenance. This novel technology helps set the standard for warfare, which spurs innovation by other nations or the purchasing of new equipment via arms sales. At the same time, additional military expenditures support research and development of the next generation of fighter jets, other vehicles and weaponry, and related equipment. As Charles H. Anderson (1976:76–77) argues, military spending fosters ongoing growth and expansion as “there is never enough military power or sophisticated enough military hardware.” We suggest that this path dependency generates nontrivial short-run and long-run effects of capital-intensive militarization on nations’ carbon emissions.

A similar pattern is evident in the relative size of militaries. Larger militaries are generally more spatially dispersed (Kentor et al. 2012). In other words, their footprint is greater, as they require more land for their operations. This includes both domestic and international lands. For example, in the 1960s, the United States had 375 major military bases throughout the world, whereas by 2020, there were at least 800 international bases, alongside over 900 domestic bases (Johnson 2004; Jorgenson et al. 2023; Sanders 2009; Turse 2015; Vine 2015). These built environments require constant supplies and maintenance of basic necessities, electricity and electrical systems, fossil fuels, and other resources. A global network of bases is staffed by soldiers and support personnel, and equipped with advanced weapons, transportation, and communication systems. These structural and organizational conditions tied to the relative size of militaries necessitates stockpiling as well as the direct and indirect consumption of fossil fuels to ensure regular operations (Belcher, Bigger, et al. 2020; Belcher, Neimark, and Bigger 2020; Lawrence et al. 2015; USDOD 2020).

Some research suggests that as militaries become more capital-intensive, with a growing emphasis on high-tech weaponry systems and motivated by the never-ending arms race, it can dampen the need to recruit more soldiers (e.g., Kentor et al. 2012; Kentor and Kick 2008). Nevertheless, if a military is relatively larger, additional fossil fuels and other resources are consumed to maintain its overall infrastructure, troop size, array of vehicles, and weapons systems (Jorgenson et al. 2010). Military size locks in resource consumption, including the burning of fossil fuels, given contracts with the defense industry and other sectors that specify a set number of years of service (Jorgenson et al. 2023; Smith et al. 2024). Therefore, and more broadly, we argue that the relative size of militaries also has short-term and long-term effects on nations’ carbon emissions.

Many of the world’s militaries recognize climate change as a “threat multiplier” presenting additional challenges to national security and global stability (Burnett and Mach 2021; Machlis and Hanson 2008; Marzec 2016; USDOD 2010). Concerns regarding geopolitical relations and energy security have prompted some nations to explore avenues to "green" their militaries by expanding the use of renewable energies and improving fossil fuel efficiencies (Bigger and Neimark 2017; Condliffe 2017; Durant 2007; Light 2014; Samaras, Nuttall, and Bazilian 2019; USDOD 2020). Nevertheless, the size and capital intensiveness of national militaries create real challenges for transitioning to renewable energy and other decarbonization efforts (Crawford 2022). Additionally, nations with larger and more capital-intensive militaries are much slower to ratify international climate agreements (Givens 2014). Others indicate that military spending diverts necessary monetary resources away from society's effectively addressing climate change (Akkerman et al. 2022). For these reasons as well, many scholars argue that the world's national militaries are not sustainable and contribute directly and indirectly to the climate crisis (e.g., Belcher et al. 2020; Clark et al. 2010; Crawford 2022).

In summary, we argue that the emergent and changing conditions associated with the capital-intensiveness and relative size of militaries shape path dependencies, which structure short-run and long-run effects on nations' carbon pollution. These propositions are grounded in scholarship in global political economy and historical sociology regarding militarization as coercive power (e.g., Chase-Dunn 1998; Mann 2014; Tilly 1990; Weber 1978), and the assertions of the theory of treadmill of destruction regarding the growth dynamics of militaries (e.g., Clark and Jorgenson 2012; Hooks and Smith 2004, 2005). We suggest the focus on both the short-run and long-run effects of militarization on national carbon emissions and the climate crisis in general is a noteworthy and necessary advance for the growing body of macro-comparative research in this tradition (e.g., Bradford and Stoner 2017; Jorgenson et al. 2023; Smith et al. 2024; Smith and Lengefeld 2020). Therefore, in the analysis below, we assess the effects of the capital intensiveness and the relative size of militaries on nations' carbon emissions, where we expect to observe notable short-run and long-run effects of both militarization characteristics. Consistent with much past research, we use military expenditures per soldier to measure the capital intensiveness of national militaries, and military participation rate to measure their relative size. We also assess if their short-run and long-run effects are asymmetrical, as doing so is important for climate mitigation efforts and for other substantive and methodological reasons. Finally, we conduct various robustness checks and sensitivity analyses, all of which yield consistent findings.

DATA AND METHODS

We maximize the use of available data. The overall panel dataset consists of 2,683 annual observations for 104 nations (27.5 mean, 11 minimum, and 30 maximum annual observations per nation) for 1990 to 2020. Due to modest amounts of missing data for different measures, the samples vary across the estimated models, depending on which variables are included. The year 1990 is the earliest, and 2020 is the most recent year, in which some of the primary independent variables are currently available. We also estimate and report models where we restrict the dataset to nations with no missing data, which consists of perfectly balanced panels of 30 annual observations for 58 nations, and we conduct sensitivity analyses where we estimate models while systematically excluding, one at a time, each of the 104 nations in the overall dataset. Table A1 in the online appendix lists the nations in the overall dataset and flags those that are among the 58 nations with no missing data. All analyzed data are publicly available, and the overall dataset will be posted on the lead author's lab website.

Dependent Variables

Consistent with past sociological research (e.g., Longhofer and Jorgenson 2017; Jorgenson and Clark 2012; Thombs 2018; Vesia et al. 2023), we use three dependent variables for this study: total CO_2 emissions, CO_2 emissions per unit of GDP, and CO_2 emissions per capita. We gather these data from the World Bank (2024), and they include territorial (i.e., production-based) emissions from the burning of fossil fuels and the manufacture of cement. Total emissions are measured in kilotonnes (kt), emissions per unit of GDP are measured in kilograms per 2015 US$ of GDP, and per capita emissions are measured in metric tonnes per person. Each of these measures has distinct characteristics and substantive significance, and using all three allows for far-reaching analyses of the effects of militarization on nations' emissions and the climate crises in general. Total emissions focus on overall volume and capture the extent to which nations contribute to the accumulation of emissions in the atmosphere, while emissions per unit of GDP is a common measure of carbon efficiency, and emissions per capita is often used as a measure of international inequality in emissions.

Primary Independent Variables

Following a well-established tradition in cross-national research on the effects of militarization, the primary independent variables for this study are military expenditures per soldier (MEPS) and military participation rate (MPR) (e.g., Carlton-Ford et al. 2019; Clark et al. 2010; Givens 2014; Jorgenson and Clark 2009; Jorgenson et al. 2010, 2023; Kentor 2000; Kentor et al. 2012). MEPS quantifies the capital intensiveness of nations' militaries, and MPR measures the relative size of nations' militaries. For the overall dataset, they are weakly correlated at -.113 in their original metrics and.011 in logarithmic form. Therefore, they capture far-reaching yet distinct characteristics of militarization.

MEPS is calculated by dividing total military expenditures by total armed forces personnel. To calculate MEPS, we use total military expenditures, measured in constant 2022 U.S. dollars, which we obtain from Stockholm International Peace Research Institute's online Military Expenditure Database (SIPRI 2024). These data include expenditures on personnel, operations and maintenance, procurement, military research and development, military infrastructure spending (including military bases), and military aid (in the military expenditure of the donor country). They exclude civil defense and current expenditures on previous military activities, demobilization, conversion, and weapon destruction. The total armed forces personnel data consist of active-duty military personnel, including paramilitary forces if the training, organization, equipment, and control suggest they may be used to support or replace regular military forces. MPR is measured as armed forces personnel as a percent of total labor force. We obtain the total armed forces personnel and MPR data from the World Bank (2024).

Additional Independent Variables

The reported models include a variety of additional independent variables common in prior research on the human drivers of national carbon emissions (e.g. Jorgenson et al. 2024; Rosa and Dietz 2012). Each model includes gross domestic product (GDP) per capita (measured in constant 2015 U.S. dollars), and all models of total emissions and emissions per unit of GDP include total population, which counts all residents, regardless of legal status or citizenship. We estimate models of each outcome that also include adult dependency ratio, urban population as a percent of the total population, and trade as percent of GDP.[1] We obtain all these data from the World Bank (2024). Since we estimate dynamic models (see description below), the lagged dependent variable is included in each model as well.

Table A2 in the online appendix provides descriptive statistics for the substantive variables included in the study.

Model Estimation Techniques

All models are estimated using Stata (version 18). Consistent with much prior research on the anthropogenic drivers of CO_2 emissions, all nonbinary variables are transformed into logarithmic form. This means the models estimate elasticity coefficients where the coefficient for the independent variable is the estimated net percentage change in the dependent variable associated with a one percent increase in the independent variable. The primary reported models are estimated with the *xtreg fe* command, which uses the within estimator to account for country-level fixed effects, and temporal fixed effects are estimated with year-specific dummy variables (Allison 2009).

All estimated models are dynamic, meaning they include the lagged dependent variable as a control. Panel data are often autoregressive, meaning the data tend to be correlated over time, and excluding the lag of the dependent variable from the model will result in omitted variable bias if the outcome variable is truly a function of their past value (Pickup 2015). Including the lagged dependent variable also allows for the estimation of both short-run and long-run effects of independent variables. The

[1] The age dependency ratio is the ratio of older dependents, people older than 64, to the working-age population—those aged 15–64 (World Bank 2024).

equation for Model 2 in Tables 1 through 3 (the model of each outcome that includes all independent variables) is as follows:

$$CO_2\ Emissions_{i,t} = \lambda_1 CO_2\ Emissions_{i,t-1} + \beta_1\ Military\ Expenditures\ Per\ Soldier_{i,t}$$
$$+\beta_2\ Military\ Particpation\ Rate_{i,t} + \beta_3\ GDP\ Per\ Capita_{i,t}$$
$$+\beta_4\ Total\ Population_{i,t} + \beta_5\ Adult\ Dependency\ Ratio_{i,t}$$
$$+\beta_6\ Urban\ Population + \beta_7\ Trade\ as\ \%\ GDP_{i,t} + \alpha_i + u_t + \varepsilon_{i,t}.$$

$CO_2\ Emissions_{i,t}$ denotes the dependent variable (total CO_2 emissions, CO_2 emissions per unit of GDP, or CO_2 emissions per capita), α_i refers to the nation-specific fixed effects, u_t refers to the year-specific fixed effects, and $\varepsilon_{i,t}$ refers to the error term. The short-run estimated effects are β_1 - β_7, and the long-run effects are estimated by dividing each short-run estimate by 1- λ_1 (De Boef and Keele 2008). *Total Population*$_{i,t}$ is excluded from all models of CO_2 emissions per capita. The long-run effects are calculated using the community-contributed *lreff* command in Stata (Thombs 2022a), which serves as a wrapper for the *nlcom* command that computes standard errors using the delta method. The short-run estimates correspond to the immediate change in emissions, while the long-run effects estimate the total change in emissions over time.

Table 1. Coefficients for the Regression of Total CO_2 Emissions

	Model 1	**Model 2**	**Model 3**
Military Expenditures Per Soldier	.027***	.024*	.023*
	(.008)	(.009)	(.009)
Military Participation Rate	.036**	.035**	.030**
	(.011)	(.012)	(.010)
GDP Per Capita	.185***	.194***	.096***
	(.033)	(.037)	(.026)
Total Population	.343***	.372***	.142*
	(.062)	(.066)	(.057)
Adult Dependency Ratio		-.070*	
		(.032)	
Urban Population		.147*	
		(.068)	
Trade as % GDP		.022	
		(.015)	
Lagged Emissions	.815***	.780***	.902***
	(.028)	(.033)	(.023)
Long-Run Effects for	.147***	.107*	.233*
Military Expenditures Per Soldier	(.043)	(.042)	(.103)
Long-Run Effects for	.195**	.161*	.308*
Military Participation Rate	(.072)	(.065)	(.128)
R-squared Overall	.990	.992	.997
Cross-Sectional Dependence: CD	.62	-.09	-1.43
Cross-Sectional Dependence: CDw	.43	.78	-.04
N / Number of Nations	2863 / 104	2737 / 102	1740 / 58
Min / Mean / Max Obs Per Nation	11 / 27.5 / 30	10 / 26.8 / 30	30 / 30 / 30

Notes: Models estimated with xtreg fe in Stata 18; non-binary variables are in logarithmic form; ***p < 0.001 **p<.01 *p<.05 (two-tailed); clustered robust standard errors in parentheses; models include country-specific fixed effects derived from the within estimator and unreported year-specific intercepts; long-run effects estimated with user-generated lreff command in Stata; CD refers to Pesaran test for weak cross-sectional dependence; CDw refers to Juodis & Reese weighted CD test.

Using the community-contributed *xtcd2* command in Stata (Ditzen 2018, 2021), we report two cross-sectional dependence test statistics of the residuals for each model in Tables 1 through 3: the test by Pesaran (2015, 2021), labeled as CD, and the weighted CD test developed by Juodis and Resse (2022), labeled as CDw.[2] As a set of robustness checks, we use the community-contributed *xtivdfreg* command in Stata to estimate and report models of all three outcomes with the instrumental-variable estimation approach with common factors (Norkutė et al. 2021; Thombs 2022b). We describe this model estimation technique in greater detail towards the end of the Results section, where we report the robustness checks.

For the asymmetrical analysis reported in Tables 4 and 5, we follow the standard approach to modeling asymmetry by including the positive and negative partial sums of MEPS and MPR in the models (Shin,Yu, and Greenwood-Nimmo 2014; Thombs 2022c; Thombs et al. 2022). $x_{i,t}$ is decomposed as $x_{i,t} = x_{i,0} + x_{i,t}^{+} + x_{i,t}^{-}$, where $x_{i,t}^{+}$ and $x_{i,t}^{-}$ are partial sums around a threshold of zero:

$$x_{i,t}^{+} = \sum_{j=1}^{t} \Delta x_{i,t}^{+} = \sum_{j=1}^{t} \max(\Delta x_{i,t}^{+}, 0)$$

$$x_{i,t}^{-} = \sum_{j=1}^{t} \Delta x_{i,t}^{-} = \sum_{j=1}^{t} \max(\Delta x_{i,t}^{-}, 0)$$

In other words, two series are generated that estimate the running totals of the positive ($x_{i,t}^{+}$) and negative ($x_{i,t}^{-}$) changes in $x_{i,t}$. A Wald test is then used to test whether the coefficients of the two sums are equal. If they are statistically different then there is evidence of asymmetry. The partial sums are generated in Stata 18 using the community-contributed *xtasysum* command (Thombs 2022d). All Stata code used to estimate the reported models will be posted on the lead author's lab website.

RESULTS

Short-Run and Long-Run Effects of MEPS and MPR

The estimated models for total CO_2 emissions are reported in Table 1. Model 1 is for the full dataset, which is unbalanced, and includes 2,863 total observations on 104 nations. In addition to estimating the short-run and long-run effects of MEPS and MPR, the model also controls for GDP per capita, total population, and lagged emissions, as well as the country-specific and year-specific fixed effects. Model 2 is also for the full unbalanced panel dataset, and includes adult dependency ratio, urban population, and trade as % GDP as additional controls. Due to missing data, the additional control variables lead to a modest reduction in the overall sample to 2,737 total observations on 102 nations. Model 3 is for the dataset reduced to the 58 nations with no missing data and is thus perfectly balanced and includes 1,740 total observations and consists of the same predictors as Model 1. All cross-sectional dependence test statistics of the residuals (CD and CDw) are not statistically significant, suggesting that there is no strong cross-sectional dependence, and the reported models are unlikely biased or inconsistent in this way (Juodis and Reese 2022; Pesaran 2015).

Across all three models, the short-run effects of both MEPS and MPR on total emissions are positive and statistically significant. For Model 1, the point estimate for MEPS is .027, meaning that a 1 percent increase in MEPS leads to a .027 percent increase in total CO_2 emissions. The point estimate for the short-run effect of MEPS is .024 in Model 2 and .023 in Model 3. For MPR, the point estimate in Model 1 is .036, meaning that a 1 percent increase in MPR leads to a .036 percent increase in total emissions. The point estimate for the short-run effect of MPR is .035 in Model 2 and .030 in Model 3. Turning briefly to the controls, the short-run effects of GDP per capita and total population are positive and statistically significant across all models, and lagged emissions has a consistently positive and statistically significant effect on total emissions. For Model 2, the short-run effect of adult dependency

[2] Cross-sectional dependence in the error term occurs if dependence between cross-sectional units in a regression is not accounted for. Cross-sectional dependence in the error term can lead to omitted variable bias or endogeneity and therefore to inconsistent estimates (Pesaran 2006; Sarafidis and Wansbeek 2012).

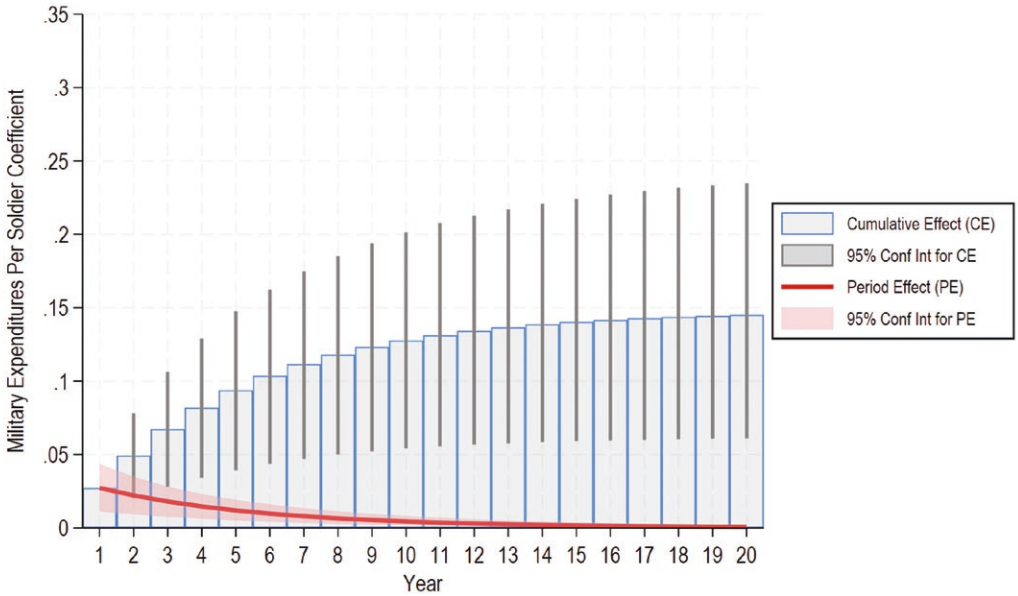

Figure 1: Long-Run Effect of Military Expenditures Per Soldier on Total CO_2 Emissions. Notes: Based on Model 1, Table 1; 95% Conf Int = 95% confidence intervals; 18.3% of cumulative effect in year 1; 63.2% of cumulative effect by year 5; 86.1% of cumulative effect by year 10; 94.5% of cumulative effect by year 15; 97.8% of cumulative effect by year 20.

ratio is negative and statistically significant, the short-run effect of urban population is positive and statistically significant, and the short-run effect of trade as % GDP is not statistically significant.

The point estimates for the long-run effects of MEPS and MPR on total emissions are reported towards the bottom of Table 1, and they are both positive and statistically significant across all three models. For MEPS, its estimated long-run effect is .147 in Model 1, which means that a 1 percent increase in MEPS leads to a cumulative increase in total emissions by .147 percent over time. The long-run effect of MEPS on total emissions is larger for the sample in Model 3 that is reduced to the 58 nations with no missing data, where a 1 percent increase in MEPS leads to a .233 percent increase in emissions over the long run. With a value of .107, the long-run effect of MEPS is a bit smaller for Model 2 than for Model 1. Turning to MPR, we see a similar pattern, where its long-run effect on total emissions is larger for the perfectly balanced panel dataset in Model 3, with an estimated effect of .308, than for Models 1 and 2, where its estimated effect is .195 and .161 respectively.

Figures 1 and 2 illustrate the percentage change in total emissions over a 20-year period resulting from a 1 percent increase in MEPS (Figure 1) and a 1 percent increase in MPR (Figure 2), based on Model 1 in Table 1.[3] The graphs, which provide period effects (the effect pertaining to each specific year) as well as cumulative effects (the cumulative sum of the current and past period effects), are constructed using Thombs's (2023) community-generated *lrplot* command in Stata.[4] For MEPS, 18.3 percent of its cumulative effect occurs in year 1, which is the equivalent of the short-run effect. Additionally, 63.2 percent of MEPS' cumulative effect occurs by year 5, followed by 86.1 percent by year 10, 94.5 percent by year 15, and 97.8 percent by year 20. For MPR, 18.0 percent of its cumulative effect occurs in year 1, followed by 62.4 percent by year 5, 85.4 percent by year 10, 94.2 percent by year 15, and 97.6 percent by year 20.

[3] The period-specific effect is estimated by solving the equation for each period due to a 1 percent increase in MEPS or MPR in period 0. In this case, the first period is equal to the simulated regression coefficient, and the remaining periods are equal to the simulated lagged dependent variable coefficient multiplied by the estimated value from the previous period. The cumulative effect is the cumulative sum of the current and past period effects.

[4] lrplot simulates the effects by taking draws from a multivariate normal distribution where the means of each variable are the coefficients from the regression and the variance–covariance matrix is the variance–covariance matrix stored in e(V). A seed must be set to reproduce results (Thombs 2023). We use lrplot to create all graphs in Figures 1 through 6.

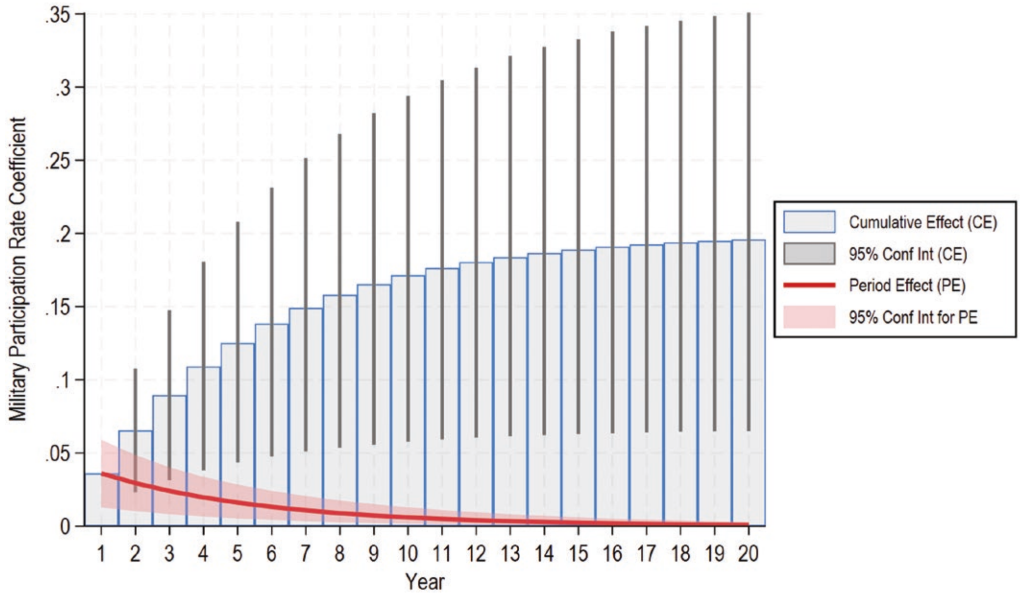

Figure 2: Long-Run Effect of Military Participation Rate on Total CO_2 Emissions. Notes: Based on Model 1, Table 1; 95% Conf Int = 95% confidence intervals; 18.0% of cumulative effect in year 1; 62.4% of cumulative effect by year 5; 85.4% of cumulative effect by year 10; 94.2% of cumulative effect by year 15; 97.6% of cumulative effect by year 20.

Table 2 reports the estimated models for the analysis of CO_2 emissions per unit of GDP. The same three models are estimated as for total emissions in Table 1. The only difference is that due to missing data, there are six fewer observations in the unbalanced panel dataset for emissions per unit of GDP compared to total CO_2 emissions. The cross-sectional dependence test statistics of the residuals (CD and CDw) are all not statistically significant, suggesting that there is no strong cross-sectional dependence in these models as well. For Models 1 through 3, the short-run effects of MEPS and MPR on emissions per unit of GDP are positive and statistically significant. The short-run effect coefficients for MEPS are .027, .023, and .024, and for MPR they are .029, .029, and .031, respectively. For the control variables, the effect of lagged emissions is positive and statistically significant across all models, the short-run effect of GDP per capita is not statistically significant across all models, the short-run effect of total population is positive and statistically significant in Models 1 and 2, the short-run effect of adult dependency ratio is negative and statistically significant in Model 2, while the short-run effects of urban population and trade as % GDP are not statistically significant.

The long-run effects of MEPS and MPR on emissions per unit of GDP are both positive and statistically significant across Models 1 through 3, with estimated effects of .183, .134, and .292 for MEPS, and .196, .169, and .382 for MPR, respectively. Like the analysis of total emissions, the long-run effects of both MEPS and MPR on emissions per unit of GDP are larger for the perfectly balanced panel dataset than for the much larger unbalanced panel dataset. Based on Model 1 in Table 2, Figures 3 and 4 illustrate the percentage change in CO_2 emissions per unit of GDP over a 20-year period resulting from a 1 percent increase in MEPS (Figure 3) and a 1 percent increase in MPR (Figure 4). For MEPS, 14.5 percent of its cumulative effect occurs in year 1, followed by 53.8 percent by year 5, 78.2 percent by year 10, 89.5 percent by year 15, and 94.8 percent by year 20. For MPR, 14.3 percent of its cumulative effect occurs in year 1, followed by 53.3 percent by year 5, 77.7 percent by year 10, 89.2 percent by year 15, and 94.6 percent by year 20.

The estimated models for CO_2 emissions per capita are reported in Table 3. The sample sizes are identical to those for the analysis of total emissions in Table 1, and the only difference in the structure of the three models is that total population is not included as a control in the analysis of emissions per capita. With the exception of Model 1, the cross-sectional dependence test statistics of the residuals (CD and CDw) are not statistically significant. For Model 1, the CD test is statistically significant, while the CDw test is not statistically significant.

Table 2. Coefficients for the Regression of CO_2 Emissions Per Unit of GDP

	Model 1	Model 2	Model 3
Military Expenditures Per Soldier	.027***	.023**	.024*
	(.007)	(.008)	(.010)
Military Participation Rate	.029**	.029**	.031*
	(.010)	(.011)	(.012)
GDP Per Capita	-.026	-.042	-.024
	(.022)	(.026)	(.019)
Total Population	.105**	.108**	.040
	(.034)	(.039)	(.033)
Adult Dependency Ratio		-.068*	
		(.027)	
Urban Population		.090	
		(.062)	
Trade as % GDP		.018	
		(.015)	
Lagged Emissions	.853***	.828***	.919***
	(.025)	(.031)	(.019)
Long-Run Effects for	.183***	.134**	.292**
Military Expenditures Per Soldier	(.045)	(.051)	(.108)
Long-Run Effects for	.196**	.169*	.382**
Military Participation Rate	(.074)	(.073)	(.146)
R-squared Overall	.919	.922	.981
Cross-Sectional Dependence: CD	.33	.32	-.78
Cross-Sectional Dependence: CDw	-1.78	1.70	-.85
N / Number of Nations	2857 / 104	2731 / 102	1740 / 58
Min / Mean / Max Obs Per Nation	11 / 27.5 / 30	10 / 26.8 / 30	30 / 30 / 30

Notes: Models estimated with xtreg fe in Stata 18; non-binary variables are in logarithmic form; ***p < 0.001 **p<.01 *p<.05 (two-tailed); clustered robust standard errors in parentheses; models include country-specific fixed effects derived from the within estimator and unreported year-specific intercepts; long-run effects estimated with user-generated lreff command in Stata; CD refers to Pesaran test for weak cross-sectional dependence; CDw refers to Juodis & Reese weighted CD test.

Consistent with the analysis of total emissions and emissions per unit of GDP, the short-run effects of MEPS and MPR on CO_2 emissions per capita are both positive and statistically significant across all three models. In sequential order, the short-run effect coefficients for MEPS are .027, .025, and .022, and for MPR they are .035, .037, and .031. The short-run effect of GDP per capita is positive and statistically significant across all models, and the coefficient for lagged emissions is consistently positive and statistically significant. For Model 2, the short-run effect of adult dependency ratio is negative and statistically significant, the short-run effect of urban population is positive and statistically significant, and the short-run effect of trade as % GDP is not statistically significant.

The long-run effects of MEPS and MPR on emissions per capita are positive and statistically significant across Models 1 through 3. In sequential order, the estimated long-run effects of MEPS are .173, .123, and .247, and for MPR they are .231, .183, and .353. Based on Model 1 in Table 3, Figures 5 and 6 illustrate the percentage change in CO_2 emissions per capita over a 20-year period resulting from a 1 percent increase in MEPS (Figure 5) and a 1 percent increase in MPR (Figure 6). For MEPS, 15.2 percent of its cumulative effect occurs in year 1, followed by 55.9 percent by year 5, 80.0 percent by year 10, 90.8 percent by year 15, and 95.6 percent by year 20. For MPR, 15.0 percent of its cumulative effect occurs in year 1, followed by 55.2 percent by year 5, 79.5 percent by year 10, 90.4 percent by year 15, and 95.4 percent by year 20.

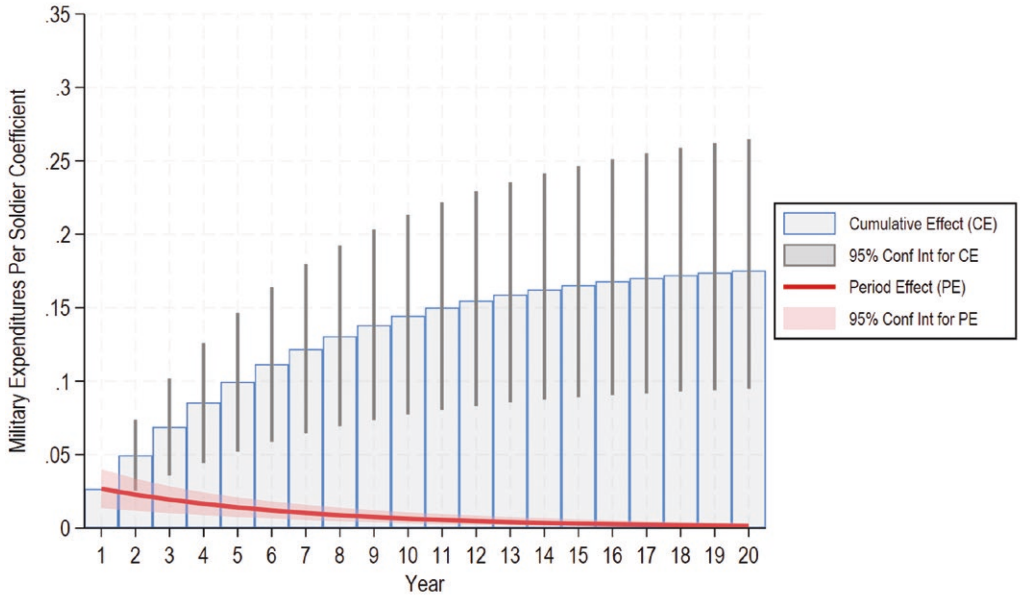

Figure 3: Long-Run Effect of Military Expenditures Per Soldier on CO_2 Emissions Per Unit of GDP. Notes: Based on Model 1, Table 2; 95% Conf Int = 95% confidence intervals; 14.5% of cumulative effect in year 1; 53.8% of cumulative effect by year 5; 78.2% of cumulative effect by year 10; 89.5% of cumulative effect by year 15; 94.8% of cumulative effect by year 20.

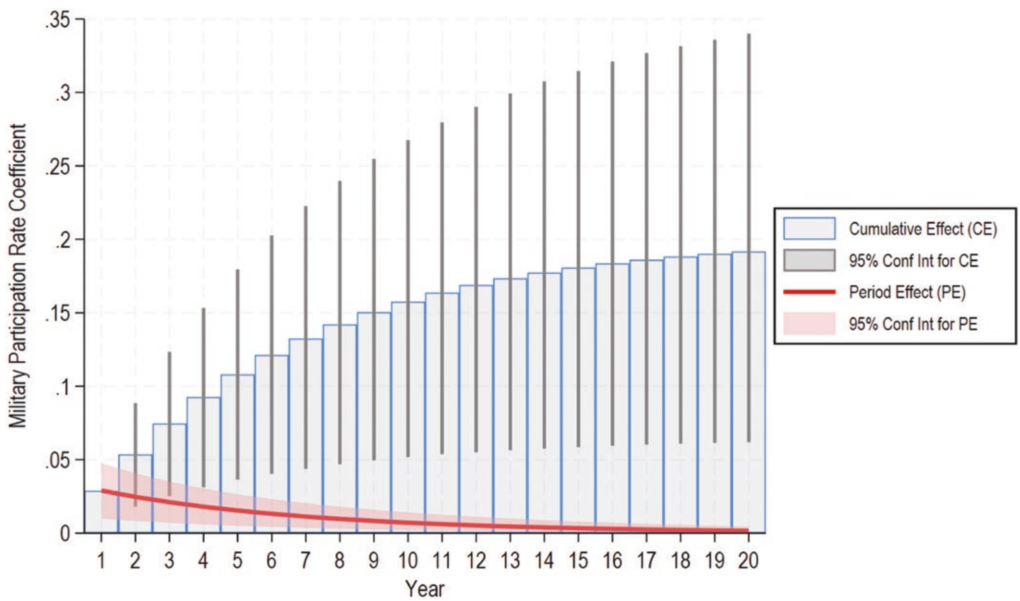

Figure 4: Long-Run Effect of Military Participation Rate on CO_2 Emissions Per Unit of GDP. Notes: Based on Model 1, Table 2; 95% Conf Int = 95% confidence intervals; 14.3% of cumulative effect in year 1; 53.3% of cumulative effect by year 5; 77.7% of cumulative effect by year 10; 89.2% of cumulative effect by year 15; 94.6% of cumulative effect by year 20.

Asymmetrical Analysis of MEPS and MPR

Next, we assess whether the short-run and long-run effects of MEPS and MPR on the three CO_2 emissions outcomes are asymmetrical, meaning that positive and negative changes in an independent variable differentially affect the dependent variable. To do so, and as described in the Methods section, we follow the standard approach to modeling asymmetry by including the positive and negative partial sums of MEPS and MPR in the models. The findings are presented in Table 4 (short-run effects) and Table 5 (long-run effects). The results of the Wald tests are all not statistically significant, indicating that there is no asymmetry in the short-run or long-run effects of either MEPS or MPR. In other words, an increase and a decrease in MEPS or MPR result in the same proportional change in total CO_2 emissions, CO_2 emissions per unit of GDP, and CO_2 emissions per capita. Therefore, the initial estimated short-run and long-run effects reported in Tables 1 through 3 can be interpreted as the effect of an increase or decrease in MEPS or MPR.

Robustness Checks and Additional Sensitivity Analysis

The reported findings are consistent across outcomes, the cross-sectional dependence test statistics of the residuals, with one exception, are not statistically significant, and the key findings are statistically symmetrical. However, there are a few potential issues to consider regarding fixed-effects estimation of dynamic models. First, estimating dynamic panel models can produce the "Nickell bias," which stems from the correlation between the error term and the lagged dependent variable, a product of the demeaning process of fixed-effects estimation (Nickell 1981). This bias tends to lessen as T increases (Hsiao, Pesaran, and Tahmiscioglu 2002). Second, fixed-effects estimation of a dynamic model with slope heterogeneity can lead to inconsistent and misleading estimates (Pesaran and Smith 1995; Thombs, Huang, and Fitzgerald 2022).

Thus, as a set of robustness checks, for the overall dataset, we use the *xtivdfreg* command to estimate models of all three outcomes with the instrumental-variable estimation approach with

Table 3. Coefficients for the Regression of CO_2 Emissions Per Capita

	Model 1	Model 2	Model 3
Military Expenditures Per Soldier	.027**	.025**	.022*
	(.009)	(.009)	(.009)
Military Participation Rate	.035**	.037***	.031**
	(.012)	(.010)	(.011)
GDP Per Capita	.125***	.135***	.088***
	(.026)	(.029)	(.022)
Adult Dependency Ratio		-.127***	
		(.030)	
Urban Population		.182*	
		(.071)	
Trade as % GDP		.014	
		(.016)	
Lagged Emissions	.847***	.798***	.912***
	(.026)	(.033)	(.018)
Long-Run Effects for	.173***	.123**	.247*
Military Expenditures Per Soldier	(.053)	(.044)	(.105)
Long-Run Effects for	.231**	.183**	.353*
Military Participation Rate	(.082)	(.063)	(.141)
R-squared Overall	.993	.991	.994
Cross-Sectional Dependence: CD	2.22*	.70	-1.60
Cross-Sectional Dependence: CDw	.56	1.22	.51
N / Number of Nations	2863 / 104	2737 / 102	1740 / 58
Min / Mean / Max Obs Per Nation	11 / 27.5 / 30	10 / 26.8 / 30	30 / 30 / 30

Notes: Models estimated with xtreg fe in Stata 18; non-binary variables are in logarithmic form; ***p < 0.001 **p<.01 *p<.05 (two-tailed); clustered robust standard errors in parentheses; models include country-specific fixed effects derived from the within estimator and unreported year-specific intercepts; long-run effects estimated with user-generated lreff command in Stata; CD refers to Pesaran test for weak cross-sectional dependence; CDw refers to Juodis & Reese weighted CD test.

common factors—an estimation technique that is robust to the Nickell bias (Kripfganz and Sarafidis 2021). This is a two-stage procedure that works by eliminating the common factors in the covariates using principal component analysis in stage one, and obtains consistent estimates using defactored covariates as instruments (Norkutė et al. 2021). In stage two, the whole

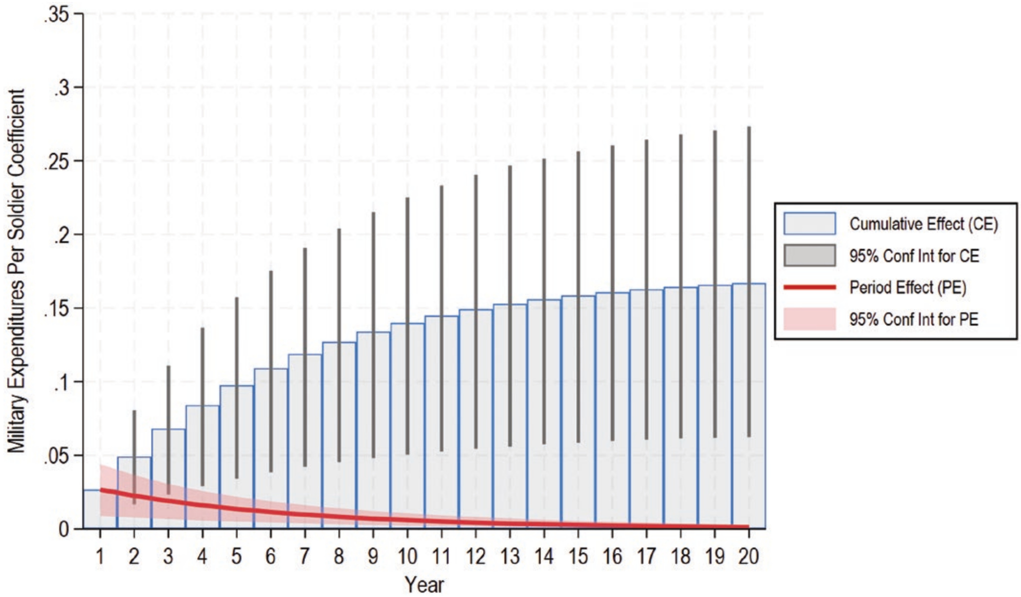

Figure 5: Long-Run Effect of Military Expenditures Per Soldier on CO_2 Emissions Per Capita. Notes: Based on Model 1, Table 3; 95% Conf Int = 95% confidence intervals; 15.2% of cumulative effect in year 1; 55.9% of cumulative effect by year 5; 80.0% of cumulative effect by year 10; 90.8% of cumulative effect by year 15; 95.6% of cumulative effect by year 20.

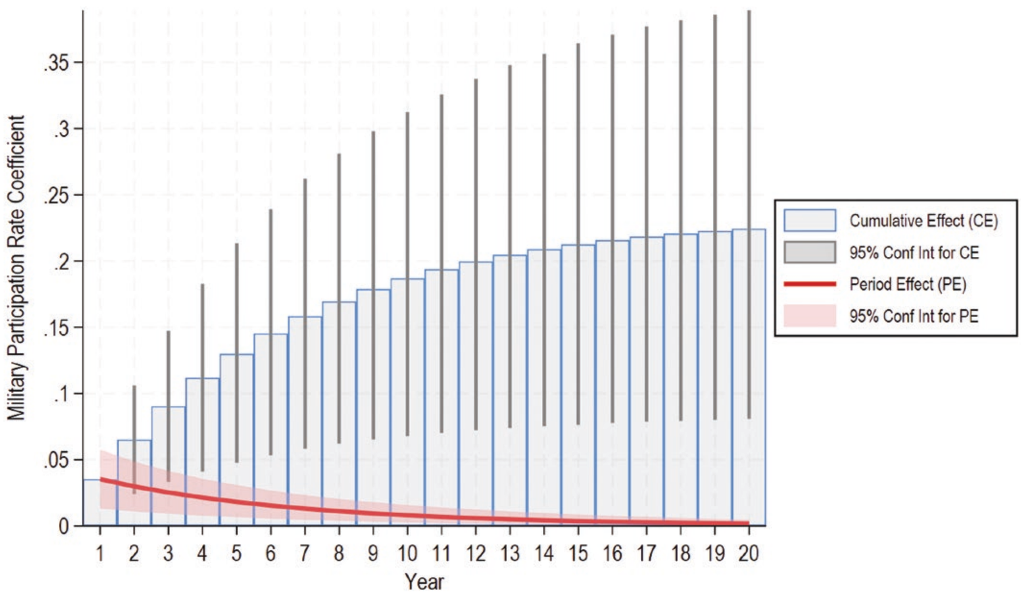

Figure 6: Long-Run Effect of Military Participation Rate on CO_2 Emissions Per Capita. Notes: Based on Model 1, Table 3; 95% Conf Int = 95% confidence intervals; 15.0% of cumulative effect in year 1; 55.2% of cumulative effect by year 5; 79.5% of cumulative effect by year 10; 90.4% of cumulative effect by year 15; 95.4% of cumulative effect by year 20.

Table 4. Asymmetric Regression of Total CO_2 Emissions, CO_2 Emissions Per Unit of GDP, and CO_2 Emissions Per Capita (Short-Run Effects)

	Total Emissions		Emissions Per Unit of GDP		Emissions Per Capita	
	MEPS	MPR	MEPS	MPR	MEPS	MPR
Military Expenditures Per Soldier (+)	.025** (.008)		.026*** (.007)		.026** (.009)	
Military Expenditures Per Soldier (-)	.014 (.013)		.030** (.011)		.013 (.013)	
Military Participation Rate (+)		.046** (.015)		.023 (.013)		.039* (.016)
Military Participation Rate (-)		.024 (.013)		.022 (.012)		.022 (.013)
Short-Run Asymmetry (Wald Test)	.63	2.36	.12	.01	1.07	1.26
N	2863		2857		2863	
Number of Nations	104		104		104	
Min / Mean / Max Obs Per Nation	11/27.5/30		11/27.5/30		11/27.5/30	

Notes: Models estimated with xtreg fe in Stata 18; non-binary variables are in logarithmic form; ***p < 0.001 **p<.01 *p<.05 (two-tailed); clustered robust standard errors in parentheses; models include country-specific fixed effects derived from the within estimator and unreported year-specific intercepts; MEPS refers to military expenditures per soldier; MPR refers to military participation rate; models control for lagged emissions and GDP Per Capita; total population is controlled for in Total Emissions and Emissions Per Unit of GDP models; Wald Tests are not statistically significant.

model is defactored using the residuals from stage one, and instrumental-variable estimation is performed using the same instruments from the first stage (Kripfganz and Sarafidis 2021). With this approach, the regressors are assumed to be a function of unobserved common factors and an idiosyncratic error term that is independent of the model error term, and thus the defactored lags of the regressors are valid instruments. We test the effect of slope heterogeneity on the model with the Hansen test of overidentifying restrictions (*J*-statistic, H_0: overidentifying restrictions are valid).

The results are reported in Table A3 in the online appendix. The estimated coefficients for the short-run and long-run effects of MEPS and MPR are positive and statistically significant across all three measures of CO_2 emissions, and the *J*-statistic is not statistically significant for each model. Overall, the findings of interest appear robust to various potential modeling concerns.

Finally, to further determine if the analyses are sensitive to any particular nations included in the study, we re-estimate models for each emissions outcome where we systematically exclude, one at a time, each of the 104 nations in the overall dataset. The results indicate that none of the included nations are overly influential: the estimated short-run and long-run effects of MEPS and MPR across all re-estimated models are positive and statistically significant.

DISCUSSION AND CONCLUSION

Sociology is well-positioned to increase our understanding of the climate crisis (Davidson 2022; Dunlap and Brulle 2015; Fisher 2024; Lockie 2022; Longo et al. 2021; Mezy 2020; Pellow and Brehm

Table 5. Asymmetric Regression of Total CO_2 Emissions, CO_2 Emissions Per Unit of GDP, and CO_2 Emissions Per Capita (Long-Run Effects)

	Total Emissions		Emissions Per Unit of GDP		Emissions Per Capita	
	MEPS	MPR	MEPS	MPR	MEPS	MPR
Military Expenditures Per Soldier (+)	.140** (.047)		.177*** (.053)		.172** (.058)	
Military Expenditures Per Soldier (-)	.079 (.074)		.206** (.076)		.086 (.084)	
Military Participation Rate (+)		.246** (.092)		.156 (.097)		.253* (.118)
Military Participation Rate (-)		.128 (.074)		.150 (.088)		.144 (.090)
Long-Run Asymmetry (Wald Test)	.64	2.20	.12	.01	1.05	1.20
N	2863		2857		2863	
Number of Nations	104		104		104	
Min / Mean / Max Obs Per Nation	11/27.5/30		11/27.5/30		11/27.5/30	

Notes: Models estimated with xtreg fe in Stata 18; non-binary variables are in logarithmic form; ***p < 0.001 **p<.01 *p<.05 (two-tailed); clustered robust standard errors in parentheses; models include country-specific fixed effects derived from the within estimator and unreported year-specific intercepts; MEPS refers to military expenditures per soldier; MPR refers to military participation rate; models control for lagged emissions and GDP Per Capita; total population is controlled for in Total Emissions and Emissions Per Unit of GDP models; Wald Tests are not statistically significant.

2013). While various streams of scholarship and research within the discipline contribute to such efforts, sociological analyses on the anthropogenic drivers of greenhouse gas emissions is one of the most far-reaching and impactful (Dietz 2017; Dietz et al. 2020; Jorgenson et al. 2024; Rosa and Dietz 2012; Rosa et al. 2015). Without question, enhancing knowledge on the societal causes of climate change is essential. A sociologically informed understanding of anthropogenic drivers is also foundational for pursuing well-rounded and deeper understandings of the unjust consequences and equitable solutions to the climate crisis.

This study and its findings advance anthropogenic drivers research and climate change sociology more generally. Building on arguments in global political economy and historical sociology about coercive power (e.g., Chase-Dunn 1998; Kentor 2000; Mann 2014; Tilly 1990; Weber 1978), environmental sociology scholarship in the treadmill of destruction tradition, as well as other environmental social science work on the environmental impacts of militaries (e.g., Alvarez et al. 2024; Auerbach 2024; Hooks and Smith 2004, 2005; Lengefeld et al. 2021), and especially empirical research on militarization and climate change (e.g., Bradford and Stoner 2017; Clark et al. 2010; Crawford 2022; Givens 2014; Jorgenson et al. 2010, 2023; Smith and Lengefeld 2020; Smith et al. 2024), we theorized about and subsequently evaluated the short-run and long-run effects of two distinct characteristics of militarization on national carbon pollution. In particular, we argued that emergent and changing conditions associated with the capital-intensiveness and relative size of militaries shape path dependencies, which structure short-run and long-run effects on carbon emissions.

The results of our analyses are consistent with our arguments. Capital-intensiveness, measured as military expenditures per soldier, and relative size, measured as military participation rate, both exhibit notable short-run and long-run positive effects on total, per capita, and per unit of GDP carbon emissions of nations for the 1990 to 2020 period. These effects are far from trivial. For example, based on Model 1 in Table 1, and using the emissions data included in the reported analysis of 104 nations, a 1 percent increase in military expenditures per soldier in the year 2020 would lead to a short-run increase in their combined emissions of 784,067 kt, and a long-run increase in their combined emissions of 4,268,808 kt. Likewise, a 1 percent increase in military participation rate would lead to a short-run increase in their combined emissions of 1,045,422 kt, and a long-run increase in their combined emissions of 5,662,704 kt. For just the five nations in the overall dataset with the highest total emissions in 2020 (China, United States, India, Russian Federation, Japan), a 1 percent increase in military expenditures per soldier in the year 2020 would lead to a short-run increase in their combined emissions of 542,700 kt, and a long-run increase in their combined emissions of 2,954,700 kt. A 1 percent increase in military participation rate would lead to a short-run increase in their combined emissions of 723,600 kt and a long-run increase in their combined emissions of 3,919,500 kt.

Furthermore, the short-run and long-run effects of both militarization characteristics on each emissions outcome are statistically symmetrical, suggesting that decreases in militarization could lead to immediate reductions in emissions, as well as larger reductions in the long-run. These particular findings are encouraging from a mitigation and solutions perspective. Nonetheless, it is important to acknowledge that the mechanisms and structural conditions that facilitate the observed short-run and long-run positive effects of military expenditures per soldier and military participation rate on emissions will be incredibly challenging to overcome, given the overall nature of the globalized permanent war economy and the treadmill of destruction, as well as other related geopolitical factors and issues of path dependency and infrastructural momentum embedded within national militaries. Finally, the reported analyses are robust across different model estimation techniques, consistent for both unbalanced and balanced panel datasets, and are not sensitive to the inclusion of any particular nation.

While this study makes notable contributions to the anthropogenic drivers literature, treadmill of destruction scholarship, and climate change sociology more broadly, like all research, it has limitations that we hope to address in future analyses. For example, current data availability limits the analysis to the 1990 to 2020 period. As additional data become available, ideally for earlier years as well as for more recent years, we will broaden the temporal depth in a follow-up study. Although we offer theoretical explanations for the observed short-run and long-run effects of militarization on national carbon emissions, the proposed underlying mechanisms that shape these relationships are largely absent from the estimated models, due to data availability. We plan to address this shortcoming in historical case studies as part of a larger project. In future work, we also plan to assess how political-economic factors, such as policy changes, might moderate the short-run and long-run effects of militarization.[5] Finally, this study focuses on how national-level militarization characteristics affect national-level carbon emissions. While this is consistent with our overall arguments and much research on anthropogenic drivers, as well as many other areas of macro-comparative sociology, it potentially underestimates how militarization directly contributes to carbon emissions and the climate crisis, both in the short-run and the long-run. We hope to address this potential issue, data permitting, through individual time series analyses of military expenditures and military size on direct measures of military carbon emissions for different militaries throughout the world.

SUPPLEMENTARY MATERIAL

Supplementary material is available online at *Social Problems* (https://academic.oup.com/socpro).

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[5] We thank an anonymous reviewer for this suggestion.

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