Explaining National Variation in Unilateral Climate Change Mitigation

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Abstract:
I argue that states pursue coherent climate national interests, which have received little theoretical or empirical attention in climate politics research. National climate change mitigation levels are the product of the costs/benefits of climate change action and state size, an indicator of invulnerability to free-riding. I derive this theory and connect it to the extant literature on climate politics with a framework that interrelates state climate change mitigation interests, preferences, behaviors, and outcomes. I validate my model of climate national interests by predicting the difference between real emissions changes and a novel estimate for counterfactual emissions changes. The theoretical framework and the counterfactual estimation methodology developed in this article will facilitate future work on climate mitigation politics, from both international and domestic politics approaches.

1 Introduction

The politics of global anthropogenic climate change are commonly understood as a dilemma of cooperation in international anarchy. Unmitigated climate change threatens to restructure global geography, yet effective mitigation requires fundamentally restructuring the global economy. Thus, both climate change and efforts to mitigate it incur immense and varied costs, with dramatic implications for relative power and prosperity. States, as self-interested actors not bound by any authoritative or enforcement-capable global government, will pursue climate policy in line with their own national interests. But there is little consensus in social scientific research about the determinants of climate national interest or about its relationship to actual mitigation levels. Establishing theoretical expectations for mitigation levels as a function of states' interests, preferences, and policies is crucial for exploring promising new directions in climate politics research at the interstate, state, and sub-state levels.

I argue that much of the observed interstate variation in climate change mitigation can be explained by a simple schema of national costs and benefits, moderated by state size. Larger states will feel a greater share of the externalities of their actions and thus should be relatively less vulnerable to free riding and more responsive to their national interest for mitigation. I develop this simple and testable hypothesis in Section 2, using a parsimonious theoretical framework that can be modified in future research to incorporate national institutions, state capacity, or other pertinent variables. My approach therefore consolidates and connects diverse extant literature on climate change mitigation, allowing direct comparison of past research and the generation of further hypotheses at multiple levels of analysis.

Unlike most empirical studies of climate change mitigation politics, I test my hypotheses by predicting actual emissions changes rather than by predicting ambiguous policies or intangible preferences. I further discuss the measurement and conceptualization of outcomes and other variables in Section 3. In order to isolate the signal of climate policy against the noisy environment of national yearly emissions, I estimate a novel counterfactual emissions projection (i.e. a "business-as-usual" (BAU) pathway) using an empirical model, specified in Section 4. For each state-year, I predict counterfactual emissions' growth as a weighted sum of counterfactual industry-state-year economic growth and carbon intensity growth, each flexibly predicted by global growth in the relevant industry-year. This method accounts for fluctuations in emissions due to economic and technological developments in the global economy. The resultant difference between real emissions growth and predicted emissions growth represents the policy-induced change in emissions, and is well predicted by state costs, benefits, and size.

This result confirms that states are pursuing coherent climate national interests through mitigation policy constrained by collective action dynamics. The implications of this article are theoretical, methodological, and practical. First, this study's findings validate classical theoretical approaches to climate change politics. Significant explanatory power from state-level variables indicates the usefulness of an international relations approach. At the same time, the robustness of free-riding constraints demonstrates the soundness of the collective action framework, rebutting recent criticisms of its empirical support. But rather than proposing collective action or any other model as a singular explanation, my theoretical framework facilitates integration of interstate-, state-, and substate-level theories of climate change mitigation politics. Second, this study develops a new empirical method for estimating BAU counterfactual emissions levels, thereby allowing the use of emissions themselves as an outcome of interest in future studies. New state-level theories of climate change mitigation, for example, can be validated by explaining deviations from the counterfactual. In addition, the empirical results from this study's predictions for states as rational and unitary actors can serve as a baseline for future work at the inter-state, state, and sub-state levels of analysis. Domestic politics research, for example, adds explanatory power through comparison to these simplistic state-level predictions. Third, the BAU method developed here has wide applicability as a tool for program evaluation or policy analysis. I conclude in Section 5 with these implications and with prospects for future research.

2 Theory

I argue that states have coherent climate national interests, and that variation in these interests drives patterns of observed mitigation. My theory of climate national interest is simple: states are sensitive to the economic opportunity costs of climate action and to the benefits of reduced climate vulnerability, but responsiveness to these factors is attenuated by the strategic constraint of collective action. Larger states are less vulnerable to free-riding concerns, and thus will be more able to act on their costs and benefits. This theory of climate national interest is effective at predicting mitigation outcomes, as I demonstrate in Section 4. It also helps to integrate diverse extant literatures on climate change politics into a cohesive Open Economy Politics (OEP) framework (Lake, 2009), which I outline in Section 2.1.

Climate national interests are especially consequential for explaining the patterns of limited mitigation observed thus far because such mitigation has been unilateral. Empirical evaluation of the Kyoto Protocol has found null effects (Almer and Winkler, 2017), as further confirmed in my own empirical analysis below. Meanwhile, even optimistic assessments of the Paris Agreement have described the treaty as "coordinated unilateralism" rather than multilateral action (Bernauer et al., 2016). International law relies on self-enforcing agreements (Barrett, 1994), and climate change mitigation treaties thus far have not incorporated self-enforcing incentives such as trade sanctions.[1]

2.1 Interests, Preferences, Behavior, and Outcomes

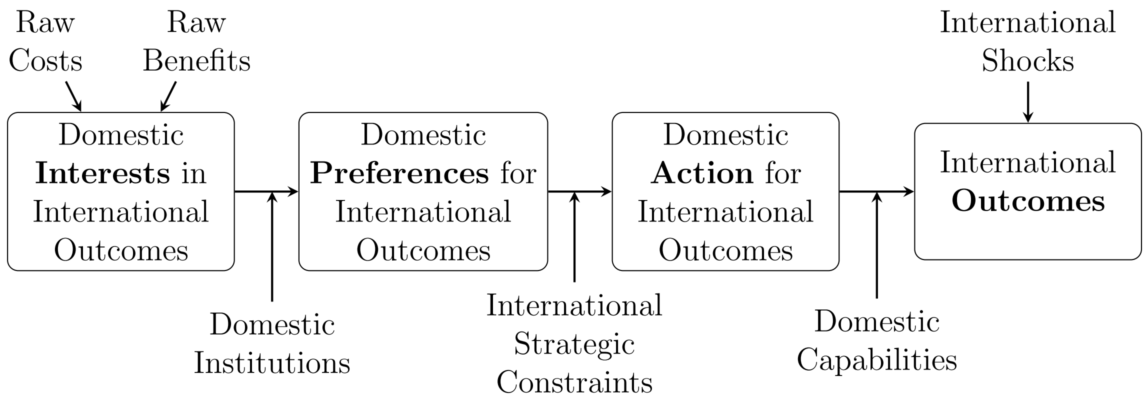
Recent attempts to explain the politics of climate change mitigation have varied by choice of independent and dependent variables, without agreement on a clear framework relating these different levels of analysis and outcomes. As an independent variable, scholars have alternated between studying the effects of raw costs and benefits (Gazmararian and Milner, 2022; Gaikwad, Genovese and Tingley, 2022; Colgan, Green and Hale, 2021), of domestic institutions (Gaikwad, Gonzalez and Wilkinson, 2023; Bättig and Bernauer, 2009), and of strategic considerations or international institutions (Aklin and Mildenberger, 2020; Gaikwad, Genovese and Tingley, 2023). As a dependent variable, scholars have alternated between studying the causes of public opinion (Gaikwad, Genovese and Tingley, 2023; Gaikwad, Gonzalez and Wilkinson, 2023; Gaikwad, Genovese and Tingley, 2022; Aklin and Mildenberger, 2020), of state policy (Gazmararian and Milner, 2022), and occasionally of emissions changes themselves (Bättig and Bernauer, 2009). But comparing or integrating these studies requires a framework, usually left implicit, relating alternative independent and dependent variables to each other.

An OEP framework explains international relations outcomes through domestic interests and institutions, combined with international dynamics such as bargaining. Applying a similar approach to climate change mitigation allows integration of the diverse

[1]The data used in my empirical analysis below ends in 2016, the year that the Paris Agreement entered into force. Thus, even if the treaty did have an independent effect, meaning that emissions are no longer purely unilateral, this would not bias my results. Instead, it would limit the scope of my explanatory traction to the pre-Paris period of true unilateralism represented by my data.

sets of variables in the extant research described above, as well as the generation of new hypotheses. In Figure 1, I have diagrammed a simple and highly stylized model of international relations outcomes derived from national interests, state preferences, and state behavior. Arrows pointing directly to a box represent additive effects, while arrows pointing to an arrow represent interactive effects.

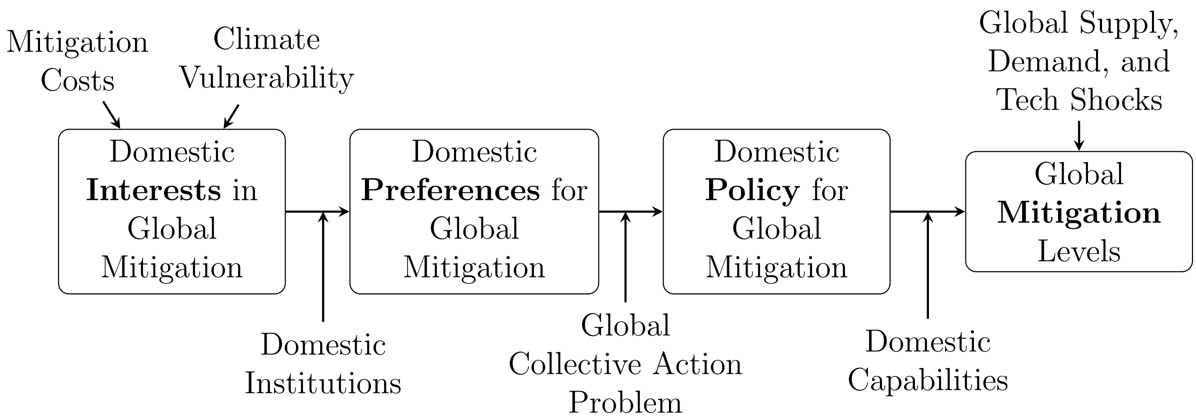
Figure 1: OEP Model of International Relations Outcomes



States can be thought of as having raw interests derived from the objective costs and benefits defining a particular issue. These raw national interests are translated into state preferences through a process determined by national political institutions. For example, democracies may value public good benefits more than autocracies (Deacon, 2009), while states that are relatively more permeable to interest groups may consider concentrated costs more than states with more majoritarian institutions. Next, state behavior is based on state preferences, but states are strategic actors and their behavior will thus be mediated by the strategic constraints of their environments. Finally, because states are the most decisive actors in international politics, international outcomes are shaped by state behavior. But differing state capabilities will determine how effectively state action shapes outcomes (Evans, Rueschemeyer and Skocpol, 1985). For example, states vary significantly in their ability to extract wealth from their societies and direct those resources to autonomously-defined purposes. International outcomes are also driven by shocks unanticipated by states attempting to shape international outcomes.

This general conceptualization of international relations can be specifically applied to climate change mitigation, as shown in Figure 2. One notable simplification made by this model is the lack of alternative choices to mitigation for dealing with climate vulnerability, namely adaptation. Adaptation is a strategic substitute to mitigation and the two concepts should be studied in tandem in future work. I discuss mitigation as an independent theoretical concept and control for ability to adapt (GDP per capita) in my main analysis. In Section 5.1 I also describe how future work can incorporate adaptation.

Figure 2: OEP Model of Global Climate Change Mitigation



A state's interests in mitigation are a product of the costs and benefits of mitigation. Specifically, mitigation requires economic transformation that incurs either direct costs (i.e., capital substitution costs) or indirect costs (i.e., opportunity costs of investing in mitigation over productivity growth). Costs are weighed against the benefits of mitigation, namely the reduction of harms from climate change. Like mitigation costs, vulnerability to the harms of climate change varies significantly across states. These costs and benefits are discussed at greater length in Section 2.2 and operationalized in Section 3.1.

Those raw interests in climate change mitigation determine state preferences after mediation by national political institutions. Mitigation costs are concentrated in particular sectors and in the rents of particular endowments. Climate vulnerability will also vary sub-nationally by geography or asset ownership (Colgan, Green and Hale, 2021).[2] Further research is needed to predict the precise relationship between state climate change mitigation preferences and government institutions.

Whatever a state's preferences for climate mitigation, its mitigation policy will be limited in its effectiveness by the international collective action problem. States will only experience a small portion of the benefit of their mitigation action but can enjoy the benefits of others' mitigation without cost, enabling free-riding. Insofar as states are purposive actors motivated by the results of their behavior, the collective action problem means that mitigation policy will fall short of mitigation preferences, lowering overall mitigation levels. The collective action problem will be further explained in Section 2.2 and operationalized in Section 3.2.

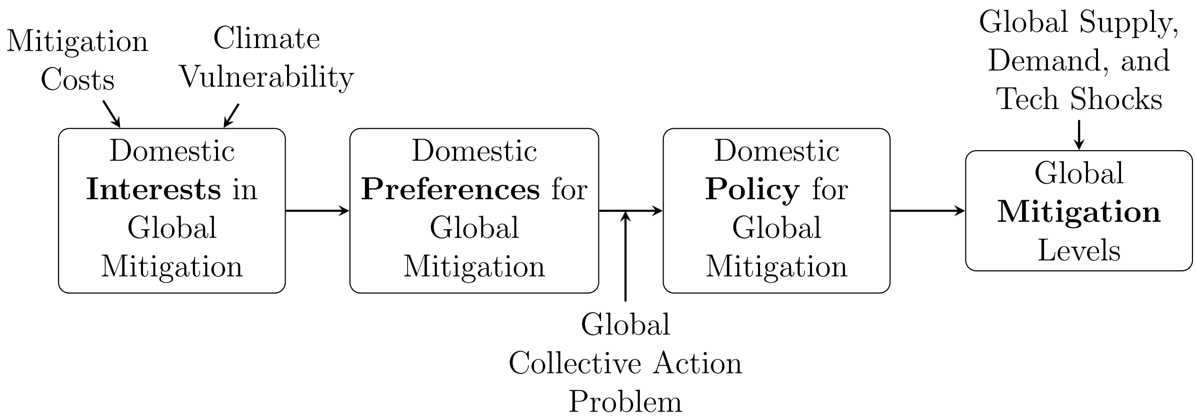
Finally, how well a state's mitigation policy actually mitigates emissions will be a function of state capacity. Highly corrupt states, for example, may fail to effectively shape environmental outcomes (Povitkina, 2018). The determinants of mitigation policy efficacy provide fertile ground for future research. But even a highly effective state does not directly control its entire economy, which will experience emissions fluctuations independent of state policy. Specifically, emission levels may vary due to economic fluctuation from supply or demand shocks or due to fluctuations in the carbon intensity of the economy from technological shocks. The conceptualization and measurement of these shocks will be further developed in Section 3.4.

The diagram described above makes dramatic simplifications to the reality of climate change mitigation politics, yet remains too complicated for parsimonious analysis. Mitigation costs and climate vulnerability each affect actual mitigation levels only through a four way interaction: with state institutions, collective action constraints, and state capacity. Although each of these topics deserves research attention, for now this study makes a unitary rational actor assumption, simplifying climate change mitigation politics further in order to maintain tractability.

I amend the theoretical diagram above with this simplifying assumption, assuming

[2] This step could be complicated further by considering sub-state mediators such as psychology, organizational politics, or bureaucratic politics.

Figure 3: OEP Model of Global Climate Change Mitigation (by unitary, rational states)



that state preferences rationally aggregate state interests into unitary preferences and that state capacity does not get in the way of state policy. If so, then after accounting for supply, demand, and technology shocks, climate change mitigation levels will be predicted by the interaction of the collective action constraint with mitigation and climate vulnerability.

2.2 Climate Change Mitigation by Rational States

Above, I argue that unitary rational states will mitigate climate change in accordance with their national interest, moderated by a collective action constraint. Rather than treating national interests for climate change mitigation as a single dimension (i.e. "green-ness"), I decompose interests into costs and benefits. States face varying costs of mitigation through economic differences. They also enjoy varying benefits of mitigation due to their differing geographical and economic vulnerabilities to climate change. This decomposition allows nuanced predictions about state-level mitigation interest, as demonstrated in the two-by-two Table 1.[3]

State responsiveness to these interests will be mediated by strategic constraints,

[3]This table's reduction of international environmental problems to the costs and benefits of particular states is similar to the approach taken by Sprinz and Vaahtoranta (1994) in their discussion of state preferences for acid rain and ozone treaties. But because their outcome variable is preferences about treaty content rather than independent action outside of a binding treaty, the strategic constraint of free-riding is not considered in their analysis.

Table 1: Costs and Benefits of Climate Change Mitigation

		Climate Change Vulnerability: Low	Climate Change Vulnerability: High
Mitigation Cost	High	low mitigation interest	intermediate
	Low	intermediate	high mitigation interest

namely the collective action problem. This n-player Prisoners' Dilemma occurs when actors would be best off if all cooperated but each finds it individually rational to defect, free-riding on others' cooperation (Olson, 1965).[4] Absent external enforcement or incentives, actors will voluntarily contribute less than the optimal amount to the collective good in all equilibria.

Scholars disagree about the usefulness of centering discussions of global climate outcomes around states as purposive actors, as in the collective action framework. While global collective action, which assumes as-if rational and as-if unitary state actors as units, has long been the primary lens for research on climate change (Barrett, 2005), some scholars have recently questioned whether states really respond to the strategic incentives of their environment and thus whether they are really vulnerable to the free-rider problem (Aklin and Mildenberger, 2020). This critique rests on the false premise that collective action forestalls any action and any variation in levels of action. But good provision in a collective action dilemma will not necessarily be uniform or equal to zero. Variation in actor types (costs and benefits) and relative size (vulnerability to free-riding) can lead actors to pursue different strategies in equilibrium, including relatively high (though still suboptimal) levels of contribution (Kennard and Schnakenberg, 2023).

Critiques of collective action also make the testable claim that states are not re-

[4]Collective action problems hinge on non-excludability (i.e., jointness of supply), an inability to stop non-cooperators from enjoying the benefits of cooperation. Collective action problems are divided into two sub-types. In public goods games, the collective benefit is also non-rivalrous, meaning that one actors' use does not inhibit anothers' (Samuelson, 1954, 1955). In commons games, rivalrousness leads to a tragedy of the commons (Hardin, 1968; Ostrom, 1990). Climate change mitigation has been modeled in both ways.

sponsive to free-riding concerns. In practice, this responsiveness will be visible because of its variation: vulnerability to free-riding will be lower for larger actors (Olson and Zeckhauser, 1966). Larger actors will internalize a greater share of the consequences of their actions or will yield greater returns for the same amount of effort (depending on how the provision function is modeled). Even if India and Nepal, for example, had the same raw interests in climate change mitigation, India would find it more rational to act on this interest, given that India's size allows it to make a difference in the level of good provision (global mitigation) that it will experience. While all actors in a collective action problem will contribute to the collective good at a sub-optimal level, this shortfall will be proportionally greater for smaller actors than for larger actors. Olson (1965) notes the crucial distinction between a "privileged group," in which one actor is relatively large enough to find it worthwhile to provide the collective good alone, and a "latent group," in which no actor is large enough to rationally contribute in the absence of externally provided coercion or inducements. The later concept of a "k-group" extends the logic of privileged groups to cases where a small number (k) of large actors can find some level of joint contribution worthwhile even without contributions by every other actor (Schelling, 1978; Hardin, 1982).

The international system may have been a privileged group or contained a very small k-group when dealing with the ozone depletion crisis due to the significant concentration of problematic chemical production in a few key industries in a few key states (Benedick, 1998). Countries attempting local environmental protection, on the other hand, are generally latent groups of citizens who would each be irrational if acting alone. Taxes and regulation must rely on government enforcement rather than individual voluntary contributions. The climate crisis may be a latent group problem at the sub-state level but a large k-group problem at the interstate level. If so, state size should strongly predict the degree to which states act on their costs and benefits from climate mitigation.[5]

[5] Alternatively, the international politics of climate change could be thought of in terms of the related Olsonian concept of an "intermediate group," or a situation in which actors are not large enough to supply the good on their own but are large enough to meaningfully affect one another (Olson, 1965). This concept overlaps with that of a k-group, but makes clear that interaction between agents may drive unpredictable patterns of contribution and cooperation. For this reason, future research on the systems effects mentioned in Section 5.1 is crucial.

The idea of small actors effectively taking advantage of large actors by free riding on public good provision has been explored extensively in the international relations literature. Hegemonic stability theory (Kindleberger, 1973; Krasner, 1976), for example, can be thought of as a simple collective action game that can be solved if a privileged group exists: one large actor (the hegemon) may find it worthwhile to provide public goods, and small actors (all other states) free-ride. Other scholars have extended the hegemonic stability model to k-groups (Snidal, 1985).

The application of collective action theory to the international politics of climate change should not be seen as an all-or-nothing alternative to domestic (or other) approaches to climate politics. Climate change is a complicated phenomenon affecting and interacting with human behavior at almost any level of analysis. Instead of replacing other levels of analysis, this article makes an argument for an international collective action approach as necessary and useful to other levels of analysis. Because climate change is a global public good, the international collective action dilemma cannot be ignored without sacrificing the validity of rationalist theorizing. For example, Colgan, Green and Hale (2021) emphasize the climate effects of domestic policy on domestic actors, but overlook the fact that domestic policy only has a fractional effect on domestic climate outcomes, which are equal to global climate outcomes. Rather than theorizing around the free-rider dilemma, this exclusive focus on domestic politics ignores the indispensable role of collective action to the argument's mechanism. Although non-rationalist domestic politics mechanisms for climate preferences could conceivably ignore international collective action and may be valid means of predicting behavior, any rationalist domestic politics mechanism where the actor is motivated by climate effects rather than by the co-benefits of abatement must account for international collective action.

3 Conceptualization and Measurement

Above, I have outlined a framework for integrating discussion of national interests, preferences, behavior, and outcomes with respect to climate change mitigation. I have also used this framework to generate a simple, first-cut hypothesis explaining national variation in climate change mitigation. Under the rational unitary actor assumption, state costs and benefits, mediated by state size, predict emissions. This relationship should be visible once emissions changes are adjusted for supply, demand, and technology shocks. In this section, I dig deeper into each relevant variable, operationalizing costs, benefits, size, mitigation outcomes, and shocks. In Section 4 below, I use these operationalizations to test my theoretical hypothesis.

3.1 Costs and Benefits

How should mitigation costs and benefits be operationalized specifically? The two ways in which states can lower emissions are each economically costly. First, states may lower emissions by limiting production or consumption. This form of mitigation is a direct tradeoff with economic gain. Second, states may lower emissions by lowering their carbon intensity of GDP, or the amount emitted per unit of production or consumption. Lowering carbon intensity can be achieved through capital substitution, in which cleaner capital is developed through research or in which existing cleaner capital technology is purchased. Ability to use either mechanism could be proxied by GDP per capita, which could reflect both the willingness to forgo further economic gain due to diminishing returns and the ability to develop or purchase green technology. But GDP per capita is also indicative of ability to adapt to instead of mitigate climate change (Tol, 2019), and will be controlled for in the main analysis below. One major source of opportunity costs is fossil fuel reserves, which are valuable resources that states must commit to leaving unused in the ground in order to mitigate cliamte change. I use the natural log of proved fossil fuel reserves (measured in British Thermal Units) per capita as a proxy for higher costs to mitigating. This measure reflects the direct opportunity cost of decarbonizing as the amount of dirty energy left in the ground:

$$F_{c,t} = ln\left(\frac{Z_{c,t} + O_{c,t} + G_{c,t}}{P_{c,t}}\right)$$

where $F_{c,t}$ indicates costs for country c in year t, $Z_{c,t}$ indicates proved coal reserves in country c in year t, $O_{c,t}$ indicates proved oil reserves in country c in year t, $G_{c,t}$ indicates proved natural gas reserves in country c in year t, and $P_{c,t}$ is the population of country c in year t.

Figure 4: Logged Fossil Fuel Reserves per Capita (average, 1992-2016)

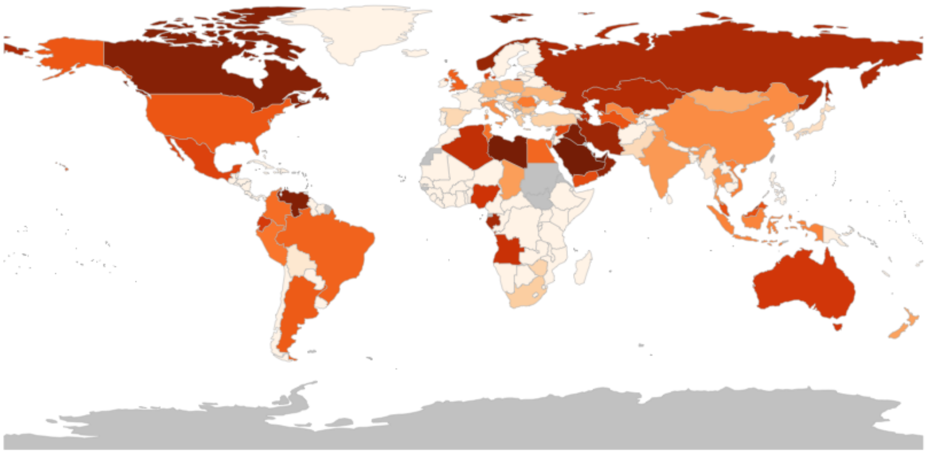


Figure 4 shows the distribution of this proxy for mitigation cost. High reserves are largely concentrated among known energy producers, while a large portion of the world have little to none.

The benefits of mitigation, on the other hand, are the inverse of an actor's vulnerability to the effects of climate change. Like costs, vulnerability is multifaceted. Climate change has a wide range of deleterious effects, including extreme storms, droughts, heat waves, sea level rise, and other damaging outcomes from altered natural systems. Numerous estimates exist for the aggregate projected costs of climate change for the world, for regions, or for particular states of political significance (Hsiang et al., 2017). But in order to compare across all states, scholars tend to reduce climate vulnerability to a few key variables.

Vulnerability can be divided into economic and geographic vulnerability. Economically vulnerable areas are those with "unmanaged systems", or those with production or consumption patterns that are highly vulnerable to changing environments and weather patterns (Nordhaus, 2013*b*; Schelling, 1992). Economies that are heavily dependent on farming or fishing are one example. Reliance on unmanaged systems, and therefore economic vulnerability to climate change, is closely related to low GDP per capita. Such vulnerability is also related to ability to adapt. As noted above, GDP per capita will be controlled for in the main analysis.

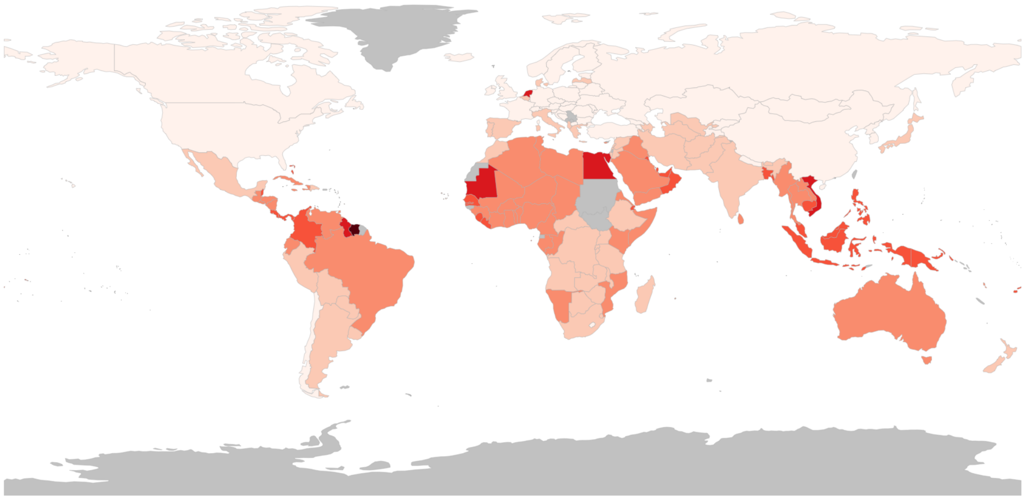
Geographic vulnerability, on the other hand, varies by location. Though complex, climate scientists consider geographic vulnerability to be broadly correlated with high temperatures, low-lying coastlines, and areas that are especially wet or dry (Emanuel, 2007). To measure geographic vulnerability, I average the standardized national average temperature, the standardized percent of population less than five meters above sea level, and the absolute value of standardized average rainfall per year (thus giving very wet and very dry areas a high value):

$$V_c = \left(\frac{W_c - \mu_W}{\sigma_W} + \frac{S_c - \mu_S}{\sigma_S} + \left| \frac{R_c - \mu_R}{\sigma_R} \right| \right) /3$$

where V_c is the vulnerability index value for country c, W_c is the average temperature in country c, S_c is the percent of country c's population living on coasts and less than five meters above sealevel, and R_c is the average yearly rainfall in country c. These vulnerability indicators are taken from the year 2005.

Figure 5 depicts countries by this vulnerability index. A descriptive fact made clear by the map is the high correlation between vulnerability and national income, given

Figure 5: Index for National Vulnerability to Climate Change



the equatorial location of much of the developing world. Some exceptions are Singapore and Australia, which are relatively vulnerable but very wealthy, or Mongolia and North Korea, which are relatively invulnerable but very poor.

Unlike the costs of mitigation, which are paid as states cut emissions each year, the benefits of mitigation are future goods. Thus, the benefit of current mitigation is reflected by discounted future vulnerability. I use the Ramsey rule for variable discounting to allow different states to discount at different rates (Ramsey, 1928; Arrow et al., 2013, 2014). States with higher GDP growth rates will discount the future at a higher rate, because sacrificing for the future entails greater opportunity cost in the present:

$$\rho_{c,t} = \frac{1}{(1 + \delta + \eta(\frac{G}{P})^{\Delta}_{c,t})^{y}}$$

where $\rho_{c,t}$ is the discount rate for country c in year t, y is years before impacts, δ is the pure rate of time preference, η is risk aversion, and $(\frac{G}{P})^{\Delta}_{c,t}$ is the growth rate of GDP per capita for country c in year t. Following common usage, I set $\delta = 1\%$ and $\eta = 1$ (Tol, 2019). I use the end of the time series as the date of climate impacts.

3.2 Size

I argue for a simple operationalization of size. Larger actors are less tempted to free-ride because they feel a greater share of benefit of their action; larger actors lose less of the benefit of their actions as an externality because their actions result in greater provision of the public good for themselves. Thus, I define size as share of global emissions:[6]

$$S_{c,t} = \frac{E_{c,t-1}}{\sum_{j=1}^{J} E_{j,t-1}}$$

where $E_{c,t}$ is country c's emissions in year t, and J is the total number of countries.

3.3 Emissions Changes as Mitigation Outcomes

The above operationalizations of costs, benefits, and size should predict climate change mitigation levels according to the theory sketched in Section 2. But how can mitigation levels themselves be operationalized? Much research on climate politics attempts to measure state preferences or behavior as a proxy for mitigation. Below, I outline the significant problems with this strategy of focusing on mitigation preferences or mitigation behavior alone, and argue for the relative usefulness of focusing on the ultimate outcomes of mitigation: yearly changes in emissions.

State-level preferences are opaque on both a conceptual and practical level. Conceptually, it is unclear whose preferences should be considered state preferences: should researchers treat national public opinion, elite opinion, or policymaker opinion as the valid preference of the state? If elite opinion, what form of capital constitutes the elite? If policymaker opinion, is the executive, the legislature, the judiciary, or the bureaucracy more important? The correct answer clearly depends on the country in question, but also on the researcher's theory of politics. There is little agreement on what constitutes the preferences of the United States, much less the preferences of less exhaustively studied countries.

[6] Other research on international collective goods defines size as share of global population, meaning share of benefits of the global public good felt by the actor (Vicary, 2009), or as share of global population weighted by GDP, following the structure of the UN contribution share scheme (Barrett, 2007).

Preferences are also difficult to study in practice. Although great advances have been made in estimation of representative public opinion, elite or policymaker opinion is obscured both by lack of access and by strategic incentives. Talk is cheap, especially in international relations, and strategic actors may have incentives to misrepresent their preferences.

Given the difficulties of studying preferences directly, some research focuses on studying state behavior as revealed state preferences. But this strategy has limitations in the case of climate change mitigation. Greenhouse gases are emitted by nearly every human activity, and nearly every transaction in the economy has a carbon footprint, either directly or indirectly. Any policy with implications for consumption, production, technology, mobility, or trade has implications for emissions levels. States may therefore act on climate change in too many ways to count. States may cut emissions through regulation, subsidies, taxes, appropriations, or even inaction in particular circumstances. Many government actions that are not explicitly or directly dealing with climate change will have a large effect on emissions, which may have factored into the reasoning for the ultimate policy decision. In the case of recent United States politics, was the Inflation Reduction Act of 2022 or the Infrastructure Investment and Jobs Act of 2021 a larger case of climate change mitigation policy? Neither act was explicitly or primarily about climate change mitigation, but both had large climate-relevant policy changes. How does each act compare to the dozens of climate-related executive actions that the Biden administration has taken? Any attempt to catalogue and weigh climate mitigation policies into a usable index will grapple with these significant dilemmas.[7]

Just as the study of international collective action does not preclude the study of domestic politics, this article's focus on real changes in emissions is not contrary to research on climate change mitigation preferences or behavior. In fact, these alternative dependent variables can be directly related to one another through the theoretical framework

[7]There are several examples of relevant indices which provide differing weighted sums of climate-focused policies. General environmentalism could be measured by the Environmental Performance Index (or its predecessor the Environmental Sustainability Index) (Block et al., 2024). Climate-environmentalism specifically is summarized by the Climate Change Laws of the World Index (Nachmany et al., 2017). Alternatively, international climate mitigation commitment levels are operationalized by Baettig, Brander and Imboden (2008).

laid out in Section 2.1. But using emissions changes as a dependent variable is a novel contribution to the climate change mitigation literature that serves to ground discussions of preferences or policy in measurements of real and final outcomes. Studying emissions themselves is also worthwhile given their intrinsic importance. Ultimately, climate change is driven by real changes in emissions.

3.4 Supply, Demand, and Technology Shocks

The use of yearly changes in emissions as an outcome variable is rare in previous research because of two related methodological problems. First, yearly national emissions experience large degrees of fluctuation, making it difficult to separate the signal from the noise. Second, much of the variation in yearly national emissions is outside of the direct control of the state. Nearly every economic transaction emits greenhouse gases, but even highly capable states have only partial control over the economic activities within their own borders. Many of the shocks driving economic fluctuations will transcend national borders, either from a cause in one country having effects in others, or from causes in multiple countries being correlated.

Supply or demand shocks affect prices and therefore consumption and production. An example of a demand shock is the growth in Chinese commodity imports in the first two decades of the 21st century, which led to global booms in commodities markets, especially for exporters in Asia and Latin America. An example of a recent supply shock is the 2022 Russian invasion of Ukraine, which has contributed to dramatic increases in the prices of oil, wheat, and other goods worldwide but especially in Europe and the Middle East.

Technological shocks occur when technology development or adoption changes modes of production, thereby affecting the carbon intensity of GDP. An example of a climate-relevant technological shock is the development of hydraulic fracturing, or “fracking.” The development of large-scale commercial fracking technology surprised many observers in government and industry alike, leading to a scramble of economic adjustment, including a shift away from coal and towards natural gas, made cheaper by the new method. This transition dramatically lowered the carbon intensity of the electricity mix in relevant markets, especially the United States and Canada (Yergin, 2012).

Thus, supply, demand, and technology shocks are changes to the economic or technological conditions of greenhouse gas emitting activities, independent of any particular state's climate policy. They are widespread due to global interconnectivity, but often vary in direction or magnitude by industry and region. They can also have varying effects by level of economic development. Shocks affect emissions because they affect production and consumption levels and methods. These in turn determine emissions, as illustrated by the partial Kaya identity below.[8]

$$E^{\Delta} = G^{\Delta} + \left(\frac{E}{G}\right)^{\Delta}$$

where E^{Δ} is emissions growth, G^{Δ} is GDP growth, and $\left(\frac{E}{G}\right)^{\Delta}$ is carbon intensity of GDP growth. In the next section I estimate these shocks empirically. After adjusting for these shocks, the remaining change in emissions can be thought of as the policy-induced emissions change for a given country-year.

4 Empirics

In this section, I test the consistency of observed mitigation outcomes with the theoretical framework presented above. If states are pursuing a coherent climate national interest, then mitigation costs and climate vulnerability, mediated by state size, should predict climate change mitigation levels once supply, demand, and technology shocks are adjusted for.

[8] The classical Kaya identity is in terms of levels, not growth rates, and includes terms for population and energy as well as GDP and emissions: $Emissions = Population * \frac{GDP}{Population} * \frac{Energy}{GDP} * \frac{Emissions}{Energy}$. See Kaya, Yokobori and Vereinte Nationen (1997) and Yamaji et al. (1993)

4.1 Design

Adjusting for these shocks means estimating a counterfactual emissions pathway for each state that reflects the pushes and pulls of supply, demand, and technology trends. Simply put, what would each state be emitting if it was bobbing along in the flow of the global economy without divergent policy to raise or cut emissions levels? I estimate the hypothetical value of counterfactual emissions changes for each state in each year with regression-based predictions of economic and technological changes for each industry in each state in each year. I sum these industry-state-year counterfactuals across industries after weighting by each state's industry shares. Below, I use the term "value" or "value-added" to refer to the industry-level equivalent of GDP.

Specifically, I run two separate regressions (one for value-added and one for carbon intensity), predicting industry-country-year growth with industry-year growth (i.e., global growth in that industry in that year, excluding the growth from the industry-country-year being predicted). I fit a multi-level regression with industry-region-year levels. For each level, I allow varying intercepts and varying slope for the global growth variable. This means that, for example, I am estimating value growth in the Chilean mining and quarrying industry in 2005 with value growth in the global mining and quarrying industry in 2005, using a flexible estimation strategy that allows a greater effect of global growth on the mining and quarrying industry in Latin America for that year, given the geographic concentration of the Chinese-demand-driven commodities boom. I also adjust for each country-year's GDP per capita, acknowledging that supply, demand, and technological shocks may have heterogeneous effects on economies at different stages of development.

I use these first stage regression results to generate predicted values for industry value growth and industry carbon intensity growth for each industry-country-year. I then estimate each country-year's total expected emissions growth as a weighted sum of these predicted values. Thus, yearly national shifts in industry value and carbon intensity are combined by industry economic share for each domestic economy. The resulting estimate for expected emissions change represents each country-year's expected growth in emissions given supply, demand, and technology shocks in the global economy.

I plug estimated emissions changes into a second stage linear regression with the theoretical variables of interest from Sections 3.1 and 3.2. Real emissions changes minus predicted emissions changes are predicted by mitigation costs, time-discounted vulnerability to climate change, state size, and the interaction of state size with mitigation costs and vulnerability. I also adjust for GDP per capita and democracy, given that economic development and political institutions may each effect emissions changes as well as cost and vulnerability measures. If these variables are highly predictive of the outcome, then domestic politics may explain much of the residual variation. Finally, I adjust for potential international strategic factors that may affect domestic emissions choices, including membership in OPEC and treaty obligations under the Kyoto Protocol. If these variables are significant, then that would indicate that other international strategic factors besides collective action are affecting state emissions. I also use a multi-level regression model for the second stage, allowing varying intercepts by level. I use states and years as levels. This provides much of the benefit of two-way fixed effects by ruling out confounders associated with particular countries or years, while using partial-pooling between levels in order to allow estimation of coefficients for covariates that sometimes have low variation within level, (such as fossil fuel reserves).

The complete empirical design is outlined below, in which the Δ superscript indicates growth rate, the r-series subscripts indicate world regions, the c-series subscripts indicate countries, the i-series subscripts indicate industries, and the t-series subscripts indicate years.

Empirical Design:

1st Stages:

$$\begin{aligned} A^{\Delta}_{i,c,t} &= A^{\Delta}_{c,t} + X_{i,c,t} + \psi_{i,r,t} \\ \left(\frac{E}{A}\right)^{\Delta}_{i,c,t} &= \left(\frac{E}{A}\right)^{\Delta}_{c,t} + X_{i,c,t} + \psi_{i,r,t} \end{aligned}$$

Weighted Average:

$$\widehat{E}^{\Delta}_{c,t} = \sigma_{i,c,t-1} * \nu_{i,c,t-1} * \left[\widehat{A}^{\Delta}_{i,c,t} + \widehat{\left(\frac{E}{A}\right)}^{\Delta}_{i,c,t} \right]$$

2nd Stage:

$$E^{\Delta}_{c,t} - \widehat{E}^{\Delta}_{c,t} = F_{c,t-1} + \rho_{c,t}V_{c,t-1} + S_{c,t-1} + F_{c,t-1} * S_{c,t-1} + \rho_{c,t}V_{c,t-1} * S_{c,t-1} + X_{c,t} + \pi_c + \phi_t$$

where A indicates industry value added, $(\frac{G}{P})$ indicates GDP per capita, ψ indicates the industry-region-year random effect for the first stages, E indicates emissions, $(\frac{E}{A})$ indicates carbon intensity (i.e., emissions over value added), σ indicates an industry's emissions share, $\frac{F}{P}$ indicates logged fossil fuel reserves per capita, ρ indicates the variable discount rate, V indicates climate vulnerability, S indicates size, X indicates a vector of control variables (GDP per capita in the first stages, plus polity score, Kyoto membership, and OPEC membership in the second stage), π indicates the country random effect in the second stage, and ϕ indicates the year random effect in the second stage. I allow the regression intercept and the slope of the global change variable to vary by level in the first stage model. I allow only the regression intercept to vary for each level in the second stage model.

This methodology bears some resemblance to a shift-share instrumental variable as well as to multi-level regression and post-stratification. I comment on the similarities and differences between my approach and these methods in Appendix A. Bias could arise from endogeneity of industry shares with explanatory variables of interest. I plot the relationships of these variables in Appendix C to show the lack of problematic correlations. Bias could also arise due to the likely correlation between state size and international supply, demand, and technology trends. But this bias points in a conservative direction; if global trends track the trends in large economies, then a counterfactual based on global trends will also tend to track the trend in a large economy, biasing results for large actors towards zero. Because my theory predicts stronger effects for larger states, significant results will be significant in spite of this bias rather than because of it.

There are numerous alternative strategies to estimating counterfactual emissions trajectories. Simple solutions include aggregating structured expert scoring of counterfactual scenarios (Helm and Sprinz, 2000; Miles et al., 2001) or using a status quo ante as a baseline (Young, 2001). A more common and sophisticated approach is formally modeling emissions, either by solving for actors' non-cooperative Nash Equilibria (Sprinz and Helm, 1999) or by simulation. Integrated assessment models (IAMs) are complex formal models of emissions decisions that are theory-based but may be empirically tuned. These models are the most popular method of counterfactual emissions projection, but often rely on hundreds of assumptions and tuning parameters (Nordhaus, 2013*a*).

My approach, on the other hand, is empirical. I predict expected emissions changes with real changes in corresponding industries, countries, and time periods. My model therefore offers simplicity and clarity. Another approach to empirically estimating counterfactual emissions changes is to create a synthetic control via matching on previous emissions pathways (Bayer and Aklin, 2020; Lépissier and Mildenberger, 2021) or on relevant covariate values. My approach, however, offers greater granularity and flexibility in estimation, through the use of multi-level modeling and the ability to disaggregate emissions changes into industries and between value growth and carbon intensity growth.

4.2 Data

For industry-level economic and emissions data used in the first-stage regression to estimate a counterfactual for the second stage, I use private data gathered by EORA (Lenzen et al., 2012, 2013). This data is commonly used for calculations of cross border emissions flows, including in reports by the World Bank, the IMF, and various UN agencies. The dataset covers 184 countries across 27 years (1991-2016). EORA data uses a standard 26-industry disaggregation listed in Appendix B.

I supplement this data with measures of population, national average temperatures, and percentages of national population less than five meters above sea level from the

World Bank (*World Development Indicators*, 2024). I take estimates of proven fossil fuel reserves from the Statistical Review of World Energy, published by the energy institute (Energy Institute, 2023). Finally, I use Polity 2 measure of political institutions from the Polity 5 dataset as a control variable in the second stage regression (Center for Systemic Peace, 2020).

4.3 Estimating the Counterfactual

The first stage of the analysis is estimating the counterfactual BAU change in emissions for each state-year, or the emissions changes to be expected solely due to global supply, demand, and technological shocks. Tables 2 and 3 show the results of the first stage regressions, which I have estimated with a multi-level model, using levels for unique industry-region-years and allowing varying intercepts and varying slopes for the global growth variable. The log likelihoods of each fit are negative and of large magnitude, indicating a highly noisy fit, although such extreme log likelihoods are to be expected in any multi-level model with such a large N.

A tighter fit could likely be achieved through machine learning or another non-parametric estimation strategy. But over-fitting the data would prove problematic in the second stage analysis, for which the first stage residual is the dependent variable. Relatedly, these models cannot be compared to others by their fits, such as in a cross-validation exercise, because the optimal residual is unknown but not zero. This strengthens the case for using a parametric estimator, as I have. A parametric model's fit is theoretically intelligible even if not empirically testable.

Although the coefficient values in this stage are not substantively important given that the purpose is generation of predicted values rather than causal interpretation, it is reassuring that the global log change predictor in each regression is near 1 and statistically significant to the level of $p < 0.01$. According to these results, a difference of 1 in the log change of a global industry's value added corresponds with a difference of 0.718 in the log change of a national industry's value added. Similarly, a difference of 1 in the log change of a global industry's carbon intensity corresponds with a difference of 0.709 in the log change of a national industry's carbon intensity.

Table 2: First Stage: Value Growth

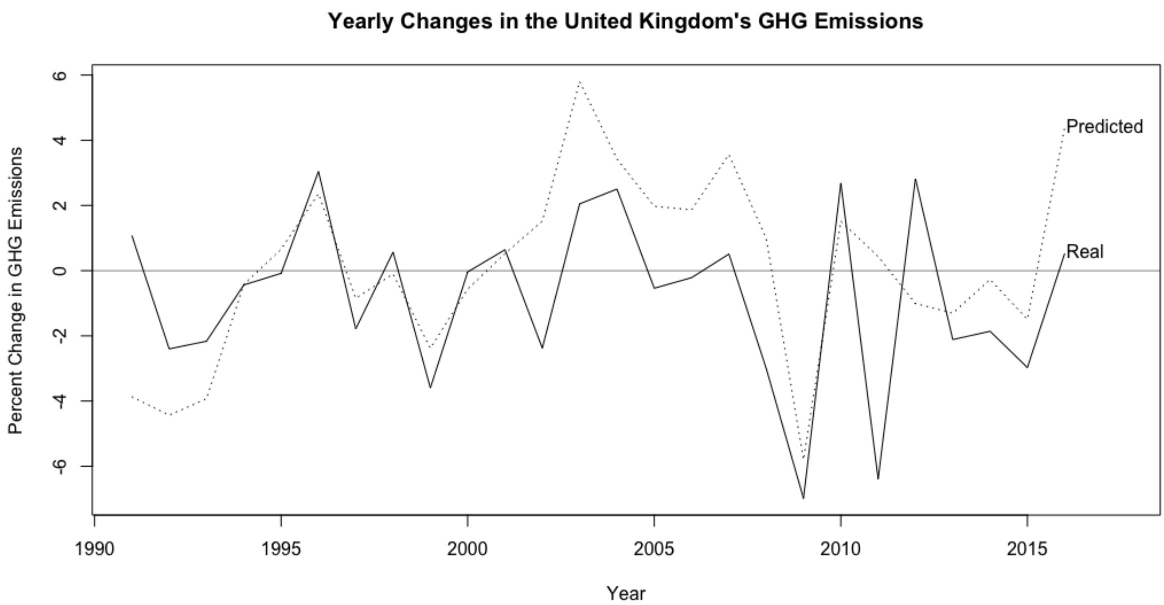
	Log Change in Value
Global Log Change in Value	0.718***
	(0.014)
Lagged GDP Per Capita	−0.323***
	(0.021)
Constant	5.467***
	(0.185)
Observations	64,604
Log Likelihood	−212,928.500
Akaike Inf. Crit.	425,873.000
Bayesian Inf. Crit.	425,945.700
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 3: First Stage: Intensity Growth

	Log Change in Intensity
Global Log Change in Intensity	0.709***
	(0.017)
Lagged GDP Per Capita	−0.087***
	(0.027)
Constant	−0.650***
	(0.225)
Observations	65,133
Log Likelihood	−236,375.400
Akaike Inf. Crit.	472,766.800
Bayesian Inf. Crit.	472,839.500
Note:	*p<0.1; **p<0.05; ***p<0.01

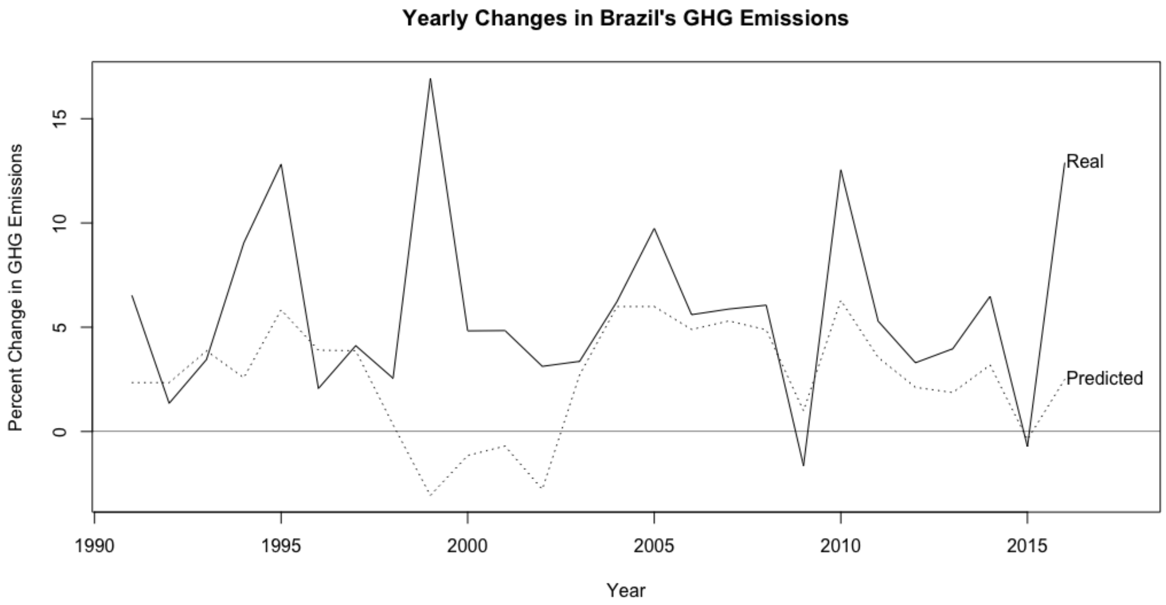
As outlined in Section 4.1, I calculate expected changes in yearly national emissions with a weighted sum of the fitted values from the first stage regressions. These expected emissions changes constitute the counterfactual BAU baseline to which I will compare observed yearly national emissions changes in Section 4.4. Next, I subtract these predicted values from real values to create the dependent variable. This difference is equivalent to an industry-weighted sum of the the residuals of the first stage. To illustrate the usefulness of this counterfactual comparison, I plot real and predicted emissions for two individual country cases in Figures 6 and 7.

Figure 6:



The UK's predicted yearly emissions changes closely track its real values. Moreover, the divergence of the predicted and real values makes sense given an understanding of UK policy and the international environment. The beginning of a divergence is evident after 2001, following the 2000 passage of major emissions legislation called the Climate Change Programme. The effect of this policy is evident from the slump in real yearly emissions changes below their predicted values. Later, the UK's predicted and real values converge again during the Great Recession, during which decreases in production and consumption caused emissions to plummet worldwide. During this period, the UK's green policies were no longer the binding constraint on emissions.

Figure 7:



Brazil's predicted values also closely track its real values for much of the relevant period. But a distinct and large gap emerges between them for much of the 1994 through 2003 period. During this time, Brazilian emissions were rising much faster than predicted. This largely corresponds to the presidency of Fernando Henrique Cardoso, during which rapid economic growth was fueled by heightened natural resource extraction and other heavily polluting activities. Amazon deforestation, for example, also experienced a local maximum during this period. The end of this period corresponds with the 2003 beginning of Luiz Inácio Lula da Silva's presidency, which was noted for significantly heightened environmental protection.

4.4 Main Results

Using real minus predicted emissions as a dependent variable, the main analysis confirms this study's hypothesis, as shown in the second stage regression table below. The coefficient for GDP per capita is negative but not statistically significant, although its interpretation is ambiguous given income's relationships to multiple variables of interest discussed above. The coefficient for Polity score is positive and not statistically significant, contrasting previous claims in the literature that more democratic states will provide more environmental public goods (Bättig and Bernauer, 2009).

The important coefficients for validating the theory outlined above are those of the interaction terms, each of which is in the expected direction and statistically significant. The interaction of state size and climate vulnerability is negative, meaning that larger and more vulnerable states will mitigate more. A one unit difference in the vulnerability index corresponds to about 1.7% less yearly emissions for a country that represents 1% of global emissions but about 4.3% less yearly emissions for a country that comprises 10% of global emissions. Thus, states that are more vulnerable to climate change seem to be mitigating more, but especially so if they can reduce the free-rider problem through size.

The interaction of state size and fossil fuel rents is positive and statistically significant, meaning that larger and more fossil fuel dependent states will mitigate less. An approximately one hundred percent difference in fossil fuels reserves per capita corresponds to about 0.18% more yearly emissions for a state that emits 10% of global emissions but only about 0.01% more yearly emissions for a state that emits 1% of the global total. In other words, the cost of mitigating is not the binding constraint for small states, who will not find it rational to mitigate even at low cost.

Meanwhile, international strategic effects beyond the collective action problem are only weakly supported by the analysis. The coefficient for OPEC is positive and statistically significant, indicating that OPEC membership may induce states to mitigate less. The coefficient for binding treaty obligations under the Kyoto Protocol, on the other hand, is negative but statistically insignificant. Both the Kyoto and OPEC coefficients are also extremely weak tests of the effects of those international organizations because membership in each is voluntary. This means that these variables suffer from selection bias in a way that state size does not. This fact makes it especially noteworthy that there is no effect of Kyoto commitments statistically distinguishable from zero.

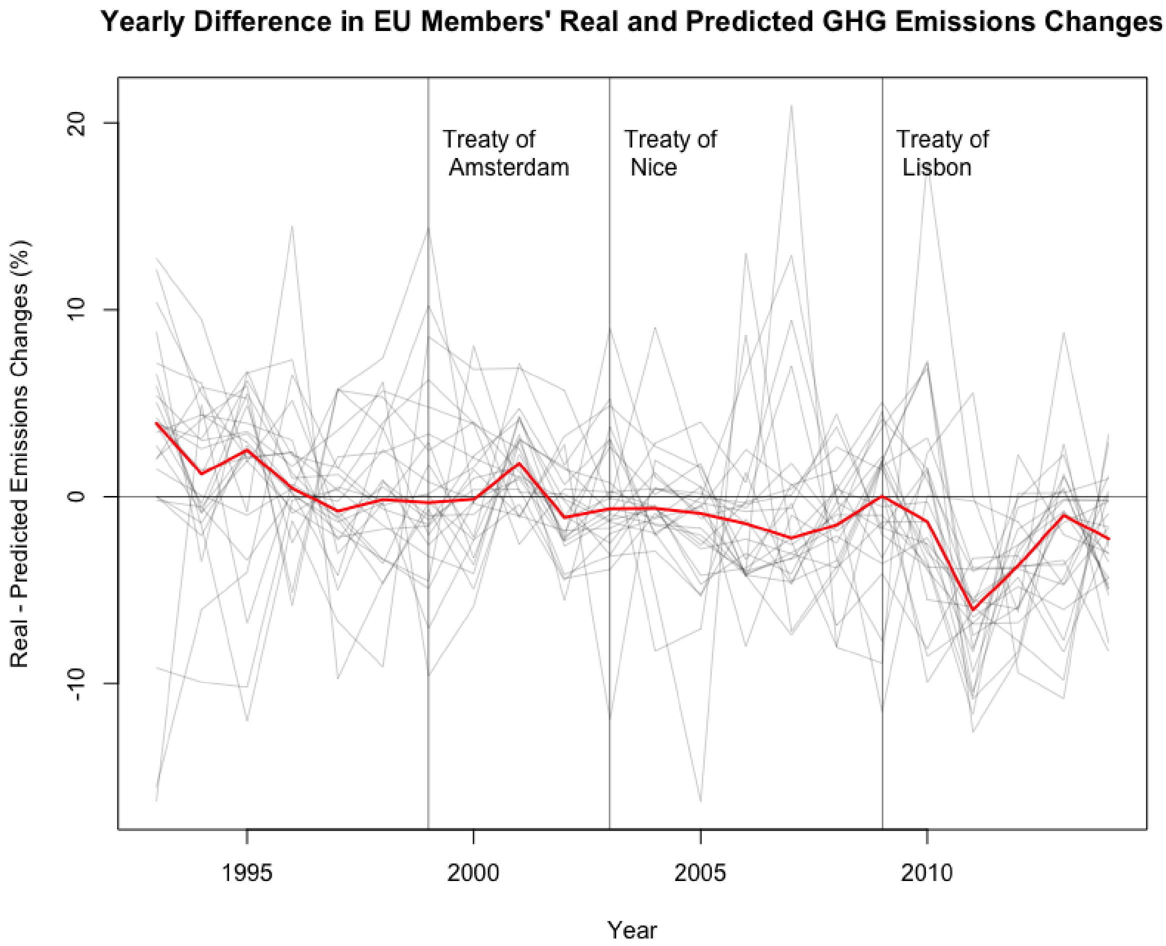
In order to illustrate the logic of the effects above, I plot real minus predicted emissions changes for each member of the EU across time. I also highlight the median member's outcome in red. Given the ongoing centralization of EU decision-making, especially

Table 4: Second Stage

	Real - Predicted Emissions Changes (%)
Log GDP per Capita	-0.116
	(0.086)
Polity	0.005
	(0.021)
Size	0.003
	(0.088)
Vulnerability	-1.405***
	(0.320)
Log Fossil Fuel Reserves per Capita	-0.007
	(0.025)
OPEC	1.048**
	(0.500)
Kyoto	-0.332
	(0.557)
Size * Vulnerability	-0.294**
	(0.147)
Size * Log Fossil Fuel Reserves per Capita	0.019**
	(0.009)
Constant	3.318***
	(1.215)
Observations	2,887
Log Likelihood	$-8{,}487.512$
Akaike Inf. Crit.	17,001.020
Bayesian Inf. Crit.	17,078.610
Note:	*p<0.1; **p<0.05; ***p<0.01

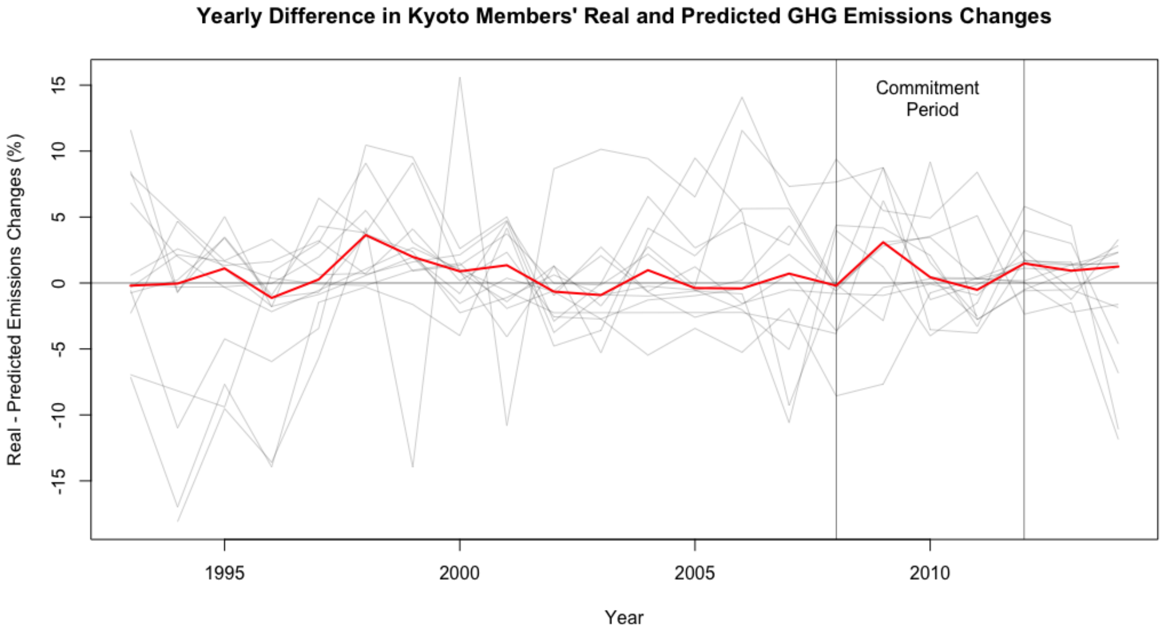
in the Treaties of Amsterdam (1999), Nice (2003), and Lisbon (2009), EU members should be acting less like individual small actors and more like one large actor over time. In other words, the collective action problem for EU members should be declining over time. Despite the EU's relatively low vulnerability to the effects of climate change, its scarcity of fossil fuel reserves and growing centralization should mean increasing mitigation. This is evident in Figure 8, as median EU mitigation has grown after successive rounds of political integration.

Figure 8:



Similarly, I plot real minus predicted emissions changes for each member of the Kyoto Protocol with a binding treaty commitment in the first commitment period (2008-2012), and highlight the median member's outcome in red. Despite the fact that states select themselves into participating in the Kyoto Protocol, thereby indicating that they at least have green preferences, no evident mitigation is visible from Kyoto members. This illustrative example demonstrates the weakness of international commitment devices relative to other strategic considerations, such as collective action.

Figure 9:



5 Implications

In the analysis above I have demonstrated consistency between observed state-level climate change mitigation outcomes and basic state environmental and economic interests interacted with the collective action constraint. Patterns of unilateral mitigation are roughly consistent with as-if unitary and as-if rational states pursuing their national climate interests but constrained by the free-rider problem. More specifically, states' climate change mitigation actions are correlated with their climate costs and benefits, and the correlation is stronger for larger states.

5.1 Theoretical Implications

The validation of state-level environmental and economic interests buttresses the usefulness of analyzing climate politics from an international relations perspective. Further, the validation of the free-rider phenomenon demonstrates the power of the collective action framework. But there are four major ways in which the theoretical framework from Section 2.1 is unsatisfying and could be expanded upon in future work.

First, the limitations of assuming unitary rational actors are obvious, not only due to the importance of state institutions in determining state preferences and of state capacity in determining outcomes, but because the nature of climate change exacerbates many well-studied sources of bias at both the individual and organizational level. Climate change mitigation's benefits are delayed over a long time horizon, are subject to high uncertainty and limited information, and often seem to be contested more through ideological movements than by rational cost-benefit calculation. States are clearly not rational or unitary, but modeling them as as-if-rational and as-if-unitary proves useful for a combination of descriptive power and parsimony (Friedman, 1953). Future work could weaken this assumption by incorporating state capacity or institutions variables or by modeling the individual and organizational pathologies unique to climate change.

Second, this article focuses on mitigation without considering adaptation. This omission was partially addressed by adjusting for GDP per capita in the main analysis (i.e., comparing the mitigation outcomes for states that have equal abilities to adapt to climate change). But future work could directly incorporate adaptation as an alternative to mitigation in a state's modeled choices. While these two actions could be substitutes, they have important differences. For example, only mitigation is a collective good.

Third, while this article acknowledges that states face a collective action problem, states are simultaneously confronting a bargaining problem. In classic collective action games, actors may vary by size and by marginal cost of goods provision (i.e. of mitigation), but in the climate change dilemma, actors also vary in their vulnerability, as discussed in Section 3.1. This means that climate change is not an ideal-type collective action problem, but rather exists somewhere on a spectrum between collective action and upstream/downstream problems (Mitchell, 2010). Equivalently, greenhouse gas emissions are not a perfectly symmetric negative externality, but are not strongly asymmetric either (Mitchell, 2010) Insofar as climate change is an upstream/downstream issue, then it is a global bargaining problem between the polluters and the vulnerable, rather than a collective action problem (Schelling, 1992). While bargaining is left out of the explicit model, future work on side payments or coercion could enrich its predictions.

Fourth, this framework assumes non-interference/no spillovers between states. In other words, state A's interests are not affected by B's costs and benefits, and state C's outcomes are not modified by D's capabilities, etc. Moreover, the shocks are exogenous to the behavior and capabilities of all states. Clearly, states are not independent of one another, but this simplifying assumption is necessary for a tractable first-cut analysis and can be loosened in future research exploring the nature of system effects in interstate climate politics (Jervis, 1997).

5.2 Methodological and Practical Implications

Testing alternative formulations of this study's variable choices or model design could improve robustness. This may include using alternative proxies for state cost or vulnerability. It could also include the use of alternative regression models or alternative specifications, such as allowing the effect of size to be non-linear.

This article develops a novel empirical method for estimating a counterfactual emissions trajectory. An empirical approach yields a conservative estimate that forgoes the large number of assumed parameters necessary for any theoretically-derived alternative, such as an Integrated Assessment Model. Future work can benefit from this new method by applying it to program evaluation. The true effects of purported green policies can be determined through comparisons to the BAU estimate. Such a counterfactual can be used to evaluate climate treaty design and efficacy, for example. A comparable BAU counterfactual could also be estimated for other environmental goods, such as the ozone or acid rain dilemmas.

5.3 Avenues for Future Research

This article provides two avenues for future research. First, theoretical or methodological extensions rectifying the current limitations discussed in Sections 5.1 or 5.2 would add greatly to the model's robustness.

Second, this model can be useful as a first cut rationalist baseline prediction to which other work can be compared. The contribution of this study in predicting state-level outcomes is all the more important for cases where the model's predictions do not hold. The significance of the control variables and the generally large residuals in the regressions above indicate idiosyncrasies among and within states that complicate this study's simple story of as-if unitary and as-if rationalist states. But defining said interests and constraints provides a baseline expectation against which more complicated theories can be compared. Researchers can bolster an argument that a government is not abating due to industrial state-capture if the model in this study would strongly predict the state's interest in greater carbon abatement, for example. Such baseline predictions are crucial for the methodologically and theoretically pluralist approach to the study of climate politics that is necessary for such a complex and important phenomenon. Promising approaches to the study of climate politics that could benefit from a more direct baseline comparison against a rationalist interstate collective action model include international approaches emphasizing greater strategic interaction such as catalytic cooperation (Hale, 2020) or signaling games, domestic distributive politics approaches emphasizing firm-level competition (Kennard, 2020) or interest group cleavages Colgan, Green and Hale (2021), ideological politics approaches, psychological approaches, and others.

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A Further Model Explanation

This methodology bears some resemblance to the Shift-Share Instrumental Variable (IV) approach commonly used to estimate the effects of trade, immigration, or labor shocks (Barff and Iii, 1988). I am using global economic *shifts* weighted by local industry *shares* in order to account for variation in the dependent variable. One crucial distinction is that a Shift-Share IV is used to isolate exogenous variation, while my method cancels out exogenous variation. In practice, this means that rather than estimating a coefficient for the fitted values in the second stage, I subtract them from the dependent variable.

Given the similarity of my approach to a Shift-Share, it is also useful to point out the concordance of my empirical model with the three key assumptions of IVs. *Relevance* requires that the instrument or, in my case, global economic and technological shifts, has a substantial effect on national economic and technological shifts. This is indisputable in an age of economic and technological globalization, but is also demonstrated by the statistically and substantively significant first-stage regression results below. The *Exclusion Restriction* requires that global economic and technological shifts only affect the outcome of interest, national emissions, through their effect on national economic and technological shifts. While the domestic economy is undoubtedly the primary means by which the global economy affects domestic emissions, one could imagine alternative system effects. I make the case for future work to model and account for such complications in Section 5. Finally, *Ignorability* requires that global economic and technological shifts are (conditionally) independent of explanatory variables (size and costs/benefits), outcomes (domestic emissions), and weights (domestic industry shares). Use of global shifts insulates this method from such risk. But in a Shift-Share design, bias could also arise from endogeneity of the industry shares, such as correlation between industry shares and the key explanatory variables, namely fossil fuel reserves and vulnerability (i.e. local geography). The level of bias is dependent on the degree to which correlated shares are driving the variation in estimates (Goldsmith-Pinkham, Sorkin and Swift, 2020), and should be evident in the correlation between the first stage's predicted values and the second stage's explanatory variables. I demonstrate the lack of concerning patterns in this relationship in plots in Appendix C.

This methodology is also related to but distinct from Multilevel Regression and Post-stratification (MRP) (Gelman and Little, 1997). Typically used to extrapolate group or sub-group outcomes from sparse data, MRP uses a first-stage multi-level regression to flexibly estimate individual outcomes with group and sub-group covariates. In the second stage, fitted values from the first stage are post-stratified, or combined in a weighted average to resemble a particular group or sub-group of interest. My method also post-stratifies fitted values representing individual predictions from sub-group characteristics. But although both methods post-stratify a regression-based estimate, MRP uses this estimate to regularize sparse data while my method treats the difference between real data and the estimate as the quantity of interest.

Another difference between my method and most applications of Shift-Share IVs or MRP is that the first stage has two regressions with separate independent variables (global value growth and global carbon intensity growth). The fitted values from these two regressions are combined as well as weighted by share in order to calculate expected emissions. This difference allows me to estimate shifts in industry value independently of shifts in industry carbon intensity, which could allow more precision in cases where these two variables diverge.

B EORA Industries

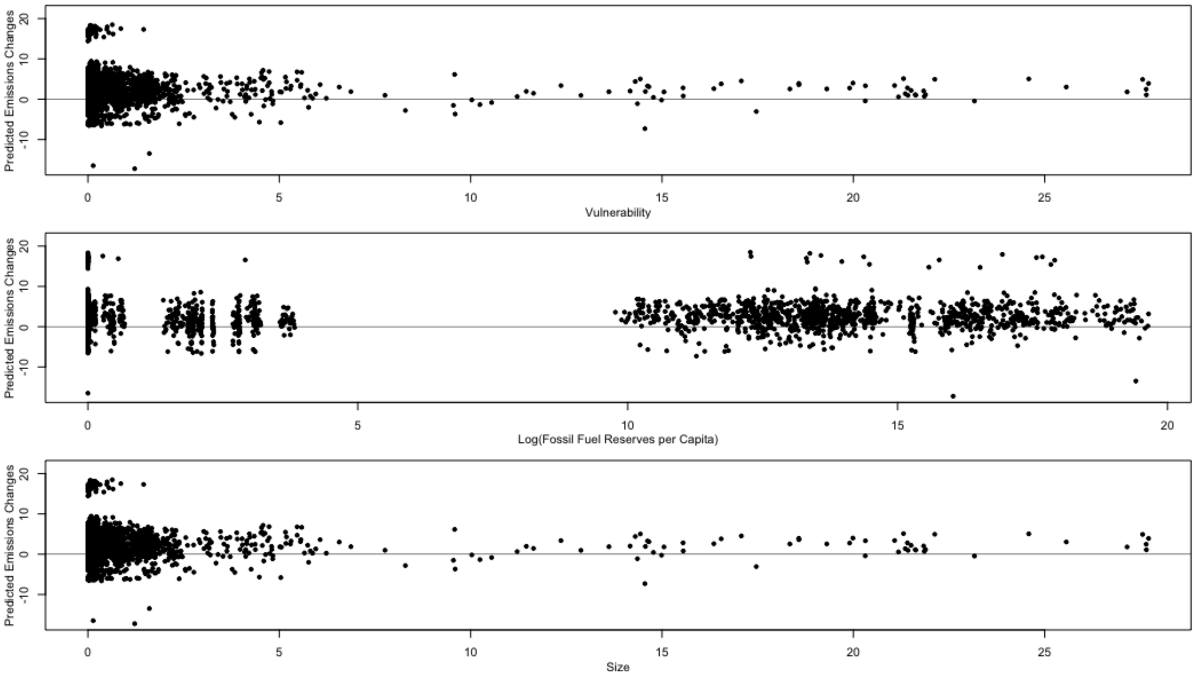
Table 5: Industries in the EORA Dataset

Agriculture
Fishing
Mining and Quarrying
Food and Beverages
Textiles and Wearing Apparel
Wood and Paper
Petroleum, Chemical and Non-Metallic Mineral Products
Metal Products
Electrical and Machinery
Transport Equipment
Other Manufacturing
Recycling
Electricity, Gas and Water
Construction
Maintenance and Repair
Wholesale Trade
Retail Trade
Hotels and Restraurants
Transport
Post and Telecommunications
Finacial Intermediation and Business Activities
Public Administration
Education, Health and Other Services
Private Households
Others
Re-export and Re-import

C Additional Tables and Plots

As discussed in Section 4.1, one potential source of bias exists if the shares used to weight predicted emissions are correlated with the main explanatory variables in the second stage. To address this concern, I plot the share-weighted estimates (predicted emissions changes) against vulnerability, logged fossil fuel reserves per capita, and size in Figure 10. These plots show no concerning pattern, as the distribution of predicted emissions changes is roughly similar at different values of each explanatory variable.

Figure 10: Predicted Emissions Changes Compared to Stage Two Explanatory Variables



To test robustness of the counterfactual, I plot my second-stage dependent variable against a variety of possible confounders. Figure 11 demonstrates no concerning patterns in real minus predicted emissions when compared across years or the logged values of population, GDP, GDP per capita, emissions, or emissions per capita.

Figure 11: Real - Predicted Emissions Changes Compared to Potential Confounders