Climate National Interest: Explaining Variation in Unilateral Climate Change Mitigation

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Word Count: 10,398

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 can facilitate future work on climate mitigation politics, from both international and domestic politics approaches.

1 Introduction

Despite the catastrophic projected costs of unmitigated climate change, global emissions continue to rise. Scholars have identified several barriers to political progress on climate change mitigation, including a global collective action problem (Barrett, 2005), a global bargaining problem (Schelling, 1992), domestic bargaining problems (Colgan, Green and Hale, 2021), and pervasive time horizons problems (Hovi, Sprinz and Underdal, 2009; Hale, 2024). Multilateral cooperation is necessary to resolve the global aspects of these problems, but mitigation treaties thus far have not incorporated punishments or significant inducements and have therefore failed to produce an effective agreement that extends beyond unilateralism. The Kyoto Protocol (negotiated 1997, effective 2005) was plagued by non-participation and non-compliance and widely recognized as a failure (Almer and Winkler, 2017). The Paris Agreement (negotiated and effective 2016) is represented by optimists as "coordinated unilateralism" rather than true multilateralism (Bernauer et al., 2016) and by pessimists as simply ineffective. Thus, observed climate change mitigation has been both unilateral and limited.

This failure contrasts sharply with another case of global cooperation on atmospheric protection. Efforts to reduce emissions of ozone-depleting chemicals during the 1980s were also characterized by global collective action, deadlocked bargaining between powerful special interests both within and between countries, and an acute inter-temporal tradeoff (Benedick, 1998). But after several years of dithering and deadlock, agreement was reached at the Montreal Protocol (negotiated 1987, effective 1989), and dramatic emission cuts shortly followed. Like Kyoto and Paris, Montreal initially lacked punishments or significant inducements, and thus could be described as merely coordinated unilateralism. But the concentration of ozone-depleting chemical emissions in a few large states allowed these actors to take effective unilateral action.

What explains observed patterns of unilateral climate change mitigation? Answering this question is key to any efforts to change mitigation levels, as well as to explaining the difference between the climate and ozone cases. Incentives for unilateral action are closely related to incentives in a multilateral context, given that international agreements must be self-enforcing in international anarchy (Barrett, 1992). In Section 2, I advance the simple argument that states are pursuing coherent climate national interests while constrained by an international collective action problem. States facing higher costs to mitigation because of large fossil fuel endowments will mitigate less. States facing higher benefits to mitigation because of high climate vulnerability will mitigate more. But only for large states will these interests closely determine mitigation levels. Small states' actions make little difference to global climate outcomes, so incentives to free-ride will be over-powering. Large states, on the other hand, have the ability to meaningfully affect global mitigation levels, and their actions will therefore more closely track their mitigation national interests. This mediating effect of size is an important corollary of collective action theory which helps to explain the success of ozone-depletion mitigation and and the failure of climate change mitigation. Ozone-depleting chemical emissions were highly concentrated, meaning that a few large actors each had significant control over the global outcomes that they would experience. Greenhouse gas emissions are largely diffuse, meaning that while a few of the largest actors exert some control and will take partial action, most do not.

A focus on national interests is distinctive in the study of environmental politics, in which much research emphasizes norms, ideas, and values (Haas, 1989, 1992; Gough and Shackley, 2001). Many of the studies that do emphasize climate self-interest do so at the sub-state level, focusing on firms or interest-groups as players in domestic bargaining (Colgan, Green and Hale, 2021; Stokes, 2020; Mildenberger, 2020). This area of research is useful but limited, as even perfectly rational and unitary states, optimizing policy for the median welfare of their citizens, would fail to mitigate climate change to anywhere near the globally optimal level due to collective action and varying national climate incentives. Even state-level studies that take self-interest seriously rarely delve into variation in that interest across states (Barrett, 2005). Moreover, while the collective action problem constraining those interests has been extensively theorized (Barrett, 2005), critics argue that it lacks empirical validation (Aklin and Mildenberger, 2020). This article provides, to my knowledge, the first test of the size corollary of collective action theory applied to climate change mitigation.[1] By demonstrating the robust effect of state size mediating climate national interests, I provide strong evidence of the collective action dilemma at work. This article's interaction of states' interests and size generates a rationalist state-level prediction for mitigation levels, but I do not argue that this explanation is exclusive or complete. Rather, state-level rationalist predictions provide useful benchmarks for work at other levels of analysis. A domestic interest group theory of climate change mitigation politics, for example, could demonstrate its usefulness by capturing variation not explained by the simple national interest prediction that I articulate. Moreover, my theoretical framework facilitates future incorporation of variables at multiple levels of

[1] Chen and Zeckhauser (2018) used correlations to test the effect of size on the Intended Nationally Determined Contributions at the Paris negotiations, but not on actual mitigation.

analysis, such as domestic institutions or capacity.

After operationalizing costs, benefits, size, and mitigation outcomes in Section 3, I leverage a cross-sectional time series of national emissions levels to empirically evaluate my theory in Section 4. In order to adjust for noise in the dependent variable, I develop a novel method to estimate counterfactual emissions levels that would be expected if states were following the global economy without diverging policy. To estimate this counterfactual, I predict changes in industrial value and industrial carbon intensity for each country with global industrial changes, using a multi-level model allowing some flexibility for development and geography. I weight the resulting estimates by (lagged) national industry shares and combine them to produce a national expected emissions estimate. The difference between real emissions and this counterfactual estimate can be considered the policy-induced change in yearly emissions. I test my theory by predicting this difference and find robust results in support of my theory. Large states mitigate more when they face greater benefits to mitigation because they are geographically vulnerable to climate change. Large states mitigate less when mitigation is costly because they have large fossil fuel endowments. Thus national variation in climate change mitigation is driven by varying climate national interests, but only for large states who are less constrained by collective action. In addition to testing my theory, my method of counterfactual emissions estimation will facilitate future research with emissions (or other forms of economic externality) as the dependent variable. In Section 5, I discuss the possible uses of this method for academic research and policy analysis, as well as the broader implications of my theory and framework.

2 Theory

Unmitigated climate change threatens to restructure global geography, yet effective mitigation requires 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. 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.

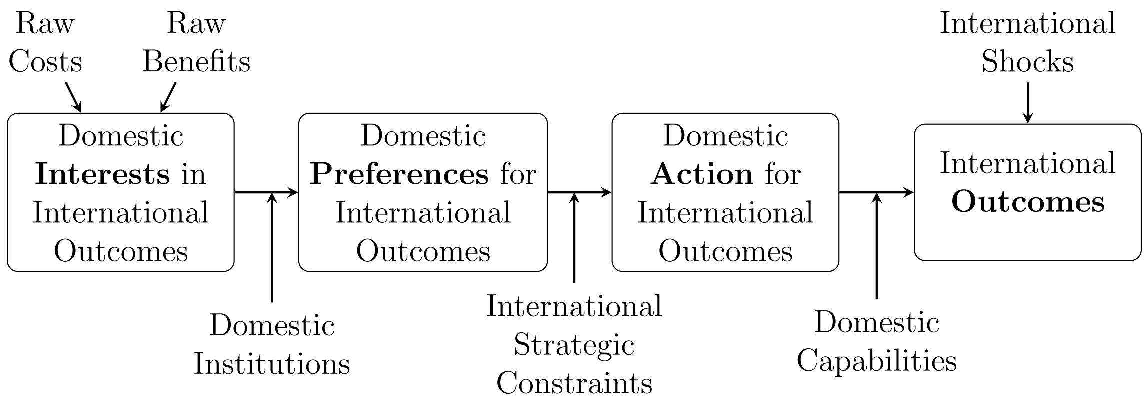
My argument differs from sub-state theories focused on distributive climate politics. Explaining state-level action with sub-state politics implies that domestic contestation results in an incoherent aggregation of costs and benefits such that national policy does not reflect national interests. My argument also differs from interstate theories that treat climate change mitigation as an ideal type public goods problem between homogeneous states. An exclusive focus on the collective structure of the climate change problem rather than the diverging interests of relevant actors cannot explain variation in national policy. While these alternative literatures have provided important insights, my novel focus on national interests conditioned by collective action provides broad explanatory power and generates a useful rationalist baseline expectation to facilitate future work at all levels of analysis.

There is little consensus in social scientific research about the determinants of climate national interest or about its relationship to actual mitigation levels. 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.

2.1 An OEP Framework for Climate Change Mitigation

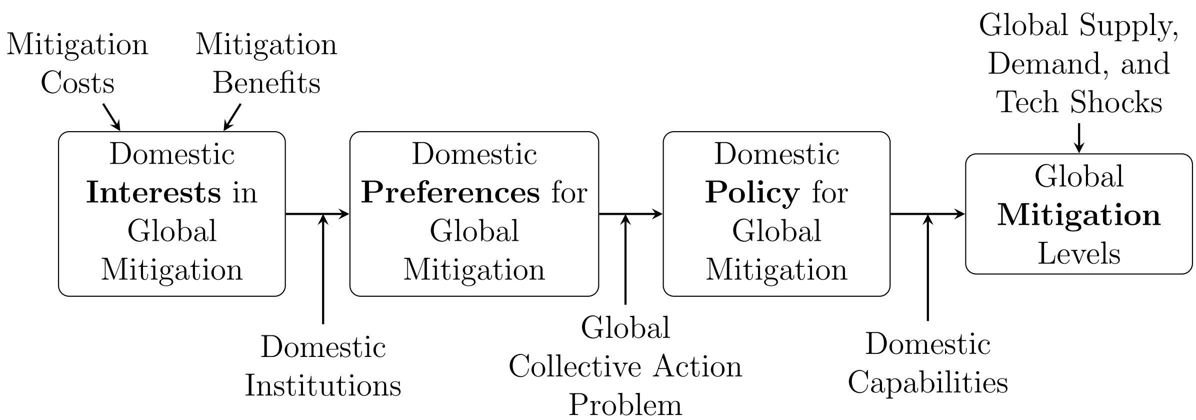
I integrate these diverse approaches to climate politics and generate my own theory with an Open Economy Politics (OEP) framework (Lake, 2009), which explains international relations outcomes through domestic interests and institutions, combined with international strategic dynamics. In Figure 1, I have 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). On the other hand, 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.

Figure 2: OEP Model of Global Climate Change Mitigation



2.2 National Interests: Costs and Benefits

Rather than treating national interests for climate change mitigation as a single dimension (i.e. "green-ness"), I decompose interests into costs and benefits. This decomposition allows more nuanced predictions about state-level mitigation interest.[2]

[2]The reduction of international environmental problems to independent costs and benefits for each state 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

2.2.1 Mitigation Costs

Mitigation requires economic transformation across multiple sectors that are key to most economies, including energy, transportation, and agriculture. There are two ways that states can cut GHG emissions. First, states can lower their carbon intensity of GDP through capital substitution or altered methods of production, requiring either research and development or purchase of existing green technology. This direct cost method is more feasible for wealthier states. Second, states can lower their production or consumption, either through outright restraint or by redirecting investment towards the green transition instead of towards productivity gains. This indirect cost, or opportunity cost, method is also likely to be easier for wealthier states. But other variables matter too. State's resource endowments, for example, determine much of the opportunity cost of climate change mitigation. Many types of mitigation can entail both direct costs and indirect opportunity costs. When a state with large coal reserves switches from coal to wind power, for example, it is both paying the direct cost of wind powerstation construction and coal powerstation decommissioning and paying the opportunity cost of leaving valuable coal in the ground.

2.2.2 Mitigation Benefits

Like costs, mitigation benefits vary significantly between states. Benefits are derived from the reduction in harm from climate change, and are therefore scaled by the inverse of national climate vulnerability. Scholars have identified two distinct forms of climate vulnerability: economic and geographic.

Economically vulnerable areas are those with "unmanaged systems," or production and consumption patterns dependent on the natural environment and therefore highly vulnerable to a changing climate (Nordhaus, 2013*b*; Schelling, 1992). Economies reliant on farming or fishing are one example. Economic vulnerability through unmanaged system dependence is closely related to low GDP per capita.

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treaty content rather than independent action outside of a binding treaty, the strategic constraint of free-riding is not considered in their analysis.

Geographic vulnerability, on the other hand, varies by location. Though the projected local effects of global climate change are complex, scientists generally expect future harms to scale by current environmental extremes (Emanuel, 2007). Currently hotter areas are vulnerable to devastating heat waves. Currently wet areas are vulnerable to increased flooding. Currently dry areas are vulnerable to increased droughts. And low-lying population centers along coastlines are vulnerable to rising sea-levels and intensified oceanic storms.

Another benefit of mitigation is deferred adaptation. This is true because mitigation and adaptation are generally strategic substitutes, meaning that increased investment in one lessens the marginal benefit of the other. While certain kinds of adaptation and mitigation may instead be strategic complements or strategically orthogonal, the logic of substitution generally applies: more adaptation will be needed if climate change is less mitigated, and vice versa. Thus, states that are less able to adapt to climate change have higher benefits to mitigating, and vice versa. The ability to adapt is likely related to geographic and economic vulnerability (more exposed societies will face more expensive adaptation) but also to economic development level (wealthier societies will be able to invest in more expensive and sophisticated adaptation infrastructure).

While the benefits of mitigated climate change vary by ability to adapt or by local economic or geographic vulnerability, mitigation itself is global and non-excludable, making it a collective good. But some types of mitigation action also confer local private benefits unrelated to mitigated climate change. These benefits are known as "co-benefits." Examples include local public health gains from air quality improvement, economic development from efficiency enhancements, or strategic independence from the limitation of fossil fuel imports. The availability of co-benefits may be somewhat non-systematic across states, but is likely partially determined by level of economic development. Wealthier states tend to place higher premiums on public health and efficiency. Because these benefits do not depend on the global climatic effect of mitigation, they are immune from the strategic constraints discussed below in Section 2.4, unlike the mitigation benefits brought by economic vulnerability, geographic vulnerability, or deferred adaptation.

2.3 Domestic Institutions

These raw interests in climate change mitigation determine state preferences after mediation by domestic politics and 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). Thus, domestic contestation between different sectors, endowments, locations, and other interest groups will determine how national interests are aggregated into state-level preferences. This contestation will play out differently under differing domestic institutions, leading to national variation in mitigation preferences beyond the variation in raw interests (Bättig and Bernauer, 2009). Variation in domestic institutions is likely to have large implications for the formation of national preferences, but I will omit this variation in the current analysis for the sake of simplicity.[3]

2.4 Strategic Constraints: Collective Action

Whatever a state's preferences for climate change mitigation, states are strategic actors responsive to their environments. The manner in which states act on their preferences will be mediated by strategic constraints.

2.4.1 Collective Action

Collective action is an n-player Prisoners' Dilemma in which actors would be best off if all cooperated but each finds it individually rational to defect, free-riding on others' cooperation (Olson, 1965).[4] This dilemma applies to climate change mitigation because it is a non-excludable good. States will only experience a small portion of the benefits of their own action but can costlessly enjoy the benefits of others' action by free-riding.

[3]This step could be complicated further by considering additional sub-state steps, such as individuals (who's preferences are derived from interest after mediation by psychological factors) or interest groups (who's preferences are derived from interest after mediation by organizational politics dynamics).

[4]Although usage of terms varies, I use collective goods to mean those with non-excludability (i.e., jointness of supply), or an inability to stop non-cooperators from enjoying the benefits of cooperation. Collective action, or the attempt to provide collective goods, is 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.

Absent external enforcement or incentives, actors will voluntarily contribute less than the optimal amount to the collective good in all equilibria.

While global collective action has long been a crucial lens for research on climate change (Barrett, 2005), some scholars have recently questioned whether states really respond to these strategic incentives and thus whether they are really vulnerable to the free-rider problem (Aklin and Mildenberger, 2020). There are two reasons that states may be un-responsive to the collective action constraint on mitigation action. First, mitigation action may be entirely motivated by co-benefits rather than by benefits derived from the global climatic effect. While co-benefits surely motivate some mitigation behavior, it is unlikely that states would mitigate the same amount if global climate change did not exist. Second, state's may be irrational, undertaking mitigation without competent consideration of the effects of that action. This scenario is analogous to states having incoherent climate national interests, or interests not derived from objective costs and benefits.

Fortunately, the relevance of the free-rider problem to climate change mitigation is empirically testable. Critiques of collective action as applied to climate change have claimed that the theory predicts uniform behavior (Aklin and Mildenberger, 2020). This is incorrect. Variation in actor types (costs and benefits) and relative size (vulnerability to free-riding) can lead actors to pursue different strategies in a collective action equilibrium, including relatively high (though still suboptimal) levels of contribution (Kennard and Schnakenberg, 2023).

In practice, responsiveness to free-riding concerns 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). For example, even if India and Nepal had the same raw interests in climate change mitigation, India would find it more rewarding to act on this interest given that its 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.

In fact, 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, for example, can be thought of as a simple collective action game that can be solved by a privileged group (Kindleberger, 1973; Krasner, 1976), meaning that one large actor (the hegemon) may find it worthwhile to provide public goods, and small actors (all other states) free-ride (Olson, 1965). Other scholars have extended the hegemonic stability model to k-groups (Snidal, 1985), or groups with multiple actors that may find it worthwhile to contribute to the collective good regardless of others' behavior (Schelling, 1978; Hardin, 1982).

The size corollary of collective action theory also helps to explain the successful mitigation of ozone-depletion and the as yet unsuccessful mitigation of climate change. Highly concentrated emissions of ozone-depleting chemicals meant that the problem was defined by a very small k-group. Climate change mitigation suffers from a much larger k-group, for which necessary action is more diffuse.

In short, collective action theory predicts that state action will fall short of state preferences, but that this shortfall will be smaller for large states. The effect of size has been leveraged to explain contribution differences in a variety of cases of international cooperation, including military alliances (Olson and Zeckhauser, 1966), OPEC production (Griffin and Xiong, 1997), and GHG emission reduction pledges (Chen and Zeckhauser, 2018). Crucially, the size effect will only hold for collective benefits, not co-benefits.

2.4.2 Leakage and Strategic Substitution

There are two additional forms of international interaction that attenuate the returns to national mitigation policies, and thereby reduce states' willingness to take such action. In the case of leakage, efforts to reduce emissions in one state lead to the relocation rather than the reduction of emissions-generating activity. If Mexico increases green regulations on its steel production, for example, this may drive steel production from Mexico to

Brazil, rather than leading to either reduced global steel production or cleaner global steel production. In the case of strategic substitution, on the other hand, Brazil may respond to the climate change mitigation efforts of Mexico by relaxing its own mitigation efforts, saving the costs of domestic mitigation policy while enjoying the benefits of Mexico's efforts.

Both leakage and strategic substitution reduce the efficacy of unilateral mitigation efforts, but these phenomenon are distinct from the classic collective action problem and from each other. Collective action describes each actors' independent under-provision of the collective good regardless of the actions of others, driven by a fundamental externality problem: actors feel all of the costs but a fraction of the benefits from their actions (Olson, 1965). Leakage and strategic substitution are interactive processes, where each states' emissions are partially a function of other states' emissions. Leakage describes a market re-equilibration process by decentralized private actors responding to changes in supply and demand. Strategic substitution describes a re-adjustment by states responding to changes in the supply of the collective good of climate change mitigation.

These effects are probably more minor than those of the collective action problem. Moreover, like collective action, they are likely to be mediated by size. Leakage and strategic substitution depend on slack in global emissions capacity. In other words, Mexico's vulnerability to leakage or strategic substitution vis a vis Brazil is greater insofar as Brazil has greater latent capacity to profitably increase emitting activities. Larger actors leave less slack in the external global economy, meaning that size should mediate the constraints of leakage and strategic substitution as it does the collective action constraint.

2.4.3 Bargaining

States will also be strategically constrained by bargaining. Unlike collective action equilibria, bargaining outcomes are inherently unpredictable. But actors' bargaining power will reflect the inverse of their initial dispositions to contribute, meaning that larger actors will tend to have weaker bargaining power in a collective action game (Olson and

Zeckhauser, 1966). In the case of climate change mitigation, because larger states are less vulnerable to externality problems, leakage, and strategic substitution, they will have a weaker hand when bargaining and contribute more to the collective good of climate change mitigation. Classic international relations examples of this surprising advantage of weakness at the bargaining table can be found in Schelling (1960).

2.5 Domestic Capabilities

Given the resulting levels of state mitigation policy, actual emissions mitigation will be moderated by state capacity. Highly corrupt states, for example, may fail to effectively shape environmental outcomes even when they try (Povitkina, 2018). The determinants of mitigation policy efficacy provide fertile ground for future research, but I will omit them from the current analysis for the sake of simplicity.

2.6 Global Shocks: Supply, Demand, and Technology

The preceding variables will determine state behavior, but even a highly effective state does not directly control its entire economy or all of the emissions from that economy. Domestic economies are responsive to fluctuating global economic conditions (Gourevitch, 1978), meaning that domestic economic activity and associated emissions will move partially independently of state policy. Specifically, domestic emission levels may vary due to global economic fluctuations in supply or demand or due to global carbon intensity fluctuations in technological development.

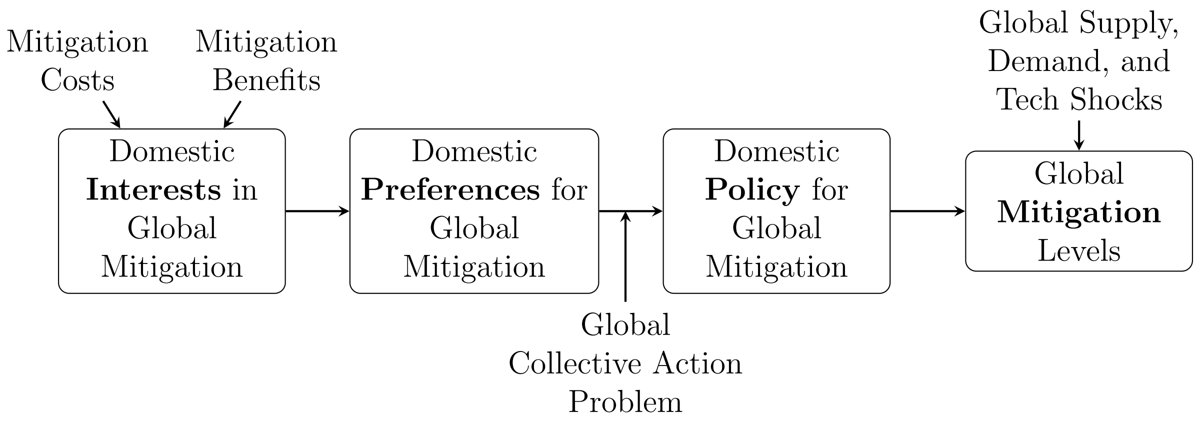
Supply or demand shocks affect prices and therefore consumption and production. An example of a demand shock is the growth in Chinese commodity imports in the first two decades of the 21st century, which led to global booms in commodities markets, especially for exporters in Asia and Latin America. An 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).

2.7 Climate Change Mitigation by Unitary Rational States

The model 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, I make a unitary rational actor assumption, simplifying climate change mitigation politics further in order to maintain tractability.

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



In sum, I argue that mitigation is driven by coherent climate national interests mediated by the strategic constraint of global collective action. While small states may free-ride and avoid mitigation, large states will be responsive to the costs and benefits of climate change mitigation. This simple argument rests on a unitary rational actor assumption, in which I ignore the mediating effect of domestic political institutions and domestic government capabilities. While these variables are undoubtedly important and interesting, I show in Section 4 that they are not necessary for explaining much of the national variation in climate change mitigation. Future work can revisit these variables and leverage my theory as a first-cut rationalist baseline to use as a comparison. Figures 1-3 demonstrate the specific assumptions behind my theory of state interest and interstate collective action, and identify how alternative variables could be incorporated into a unified analysis in the future.

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 theory of 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, I use these operationalizations to test my theoretical hypothesis.

3.1 Operationalizing Mitigation Costs and Benefits

How should mitigation costs and benefits be operationalized specifically? One notable implication of Sections 2.2.1 and 2.2.2 is that economic development is highly correlated with multiple types of costs and benefits, sometimes with opposite implications. Higher GDP per capita is related to a lower cost to mitigate, in terms of a greater ability to pay both the direct cost of technology substitution and the indirect cost of foregone growth. Higher GDP per capita may also be correlated with higher co-benefits to mitigation in terms of greater willingness to pay for public health or efficiency improvements. Alternatively, higher GDP per capita is also related to lower benefits from climate change mitigation in two ways. Greater economic development implies lower economic vulnerability to climate change and a greater ability to adapt. The relationship of GDP per capita to mitigation interests is therefore indeterminate. Below, I control for GDP per capita in my main analysis and focus on forms of costs and benefits not directly related to development: resource endowments and geographic vulnerability.

3.1.1 Operationalizing Mitigation Costs: Fossil Fuel Endowments

Resource endowments are a critical determinant of the opportunity costs to mitigating. I use the natural log of proved fossil fuel reserves (measured in British Thermal Units (BTUs)) per capita as a proxy for higher costs. Fossil fuel reserves are valuable energy resources that states must commit to leaving unused in the ground in order to mitigate climate change. Thus, mitigation costs are measured as:

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

where,

- $F_{c,t}$ = costs for country c in year t
- $K_{c,t}$ = proved coal reserves (BTUs) in country c in year t
- $O_{c,t}$ = proved oil reserves (BTUs) in country c in year t
- $G_{c,t}$ = proved natural gas reserves (BTUs) in country c in year t
- $P_{c,t}$ = the population of country c in year t

3.1.2 Operationalizing Benefits: Geographic Vulnerability

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). These models tend to reduce to income and key geographic variables, such as heat (Tol, 2019).

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 sum 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):[5]

$$V_c = \frac{W_c - \mu_W}{\sigma_W} + \frac{Z_c - \mu_Z}{\sigma_Z} + \left| \frac{R_c - \mu_R}{\sigma_R} \right|$$

where,

- V_c = the vulnerability index value for country c
- W_c = the average temperature in country c
- Z_c = the share of country c's population on coasts below five meters of elevation
- R_c = the average yearly rainfall in country c
- μ = mean
- σ = standard deviation

[5] Data inputs for the vulnerability indicator are taken from the year 2005.

Due to diverging geographic effects in historical economic development, there is a strongly positive but not perfect correlation between vulnerability and national income (Acemoglu, Johnson and Robinson, 2001; Nordhaus, 2006). Exceptions include 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:[6]

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

where,

- $\rho_{c,t}$ = the discount rate for country c in year t
- y = years before impacts
- δ = the pure rate of time preference
- η = risk aversion
- $(\Delta\%\frac{G}{P})_{c,t}$ = the growth rate of GDP per capita for country c in year t

3.2 Operationalizing Collective Action: Size

Size can be conceptualized in multiple ways. Consider two states A and B that are alike in all ways except for size. In each, GDP per capita is \$1,000, emissions per capita is 100kg of C02-eq, and the marginal costs and benefits to mitigating climate change are \$10 and 10 utils per kg not emitted. But A is twice as large as B. A has a population

[6]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.

of 1,000, A's GDP is \$1,000,000 and A's emissions are 100,000kg. B has a population of 500, B's GDP is \$500,000 and B's emissions are 50,000 kgs.

First, consider size as relative population and suppose that A and B cut emissions by 1kg per person. In this case, A and B are mitigating in proportion to their size differential. A is cutting emissions by 1,000kg and B is cutting emissions by 500kg. Each is paying a mitigation cost of \$10 per capita. But A's actions provide each of its citizens with a mitigation benefit of 10,000 utils while B's actions provide each citizen with 5,000 utils.[7] Vicary (2009) and Boadway and Hayashi (1999) operationlize size as relative population.

Next, consider size as relative GDP and suppose that A and B each spend 1% of their GDP on mitigation. Again, A and B are mitigating in proportion to their size differential, but A is cutting emissions by 1,000kg and generating 100,000 utils for itself, while B is cutting emissions by 500kg and generating 50,000 utils for itself. Olson and Zeckhauser (1966), Murdoch and Sandler (1997), and Chen and Zeckhauser (2018) operationalize size as relative wealth.

Finally, consider size as relative emissions level and suppose that A and B each cut their own emissions by 1%. Again, A and B are mitigating in proportion to their size differential, but A is cutting emissions by 1,000kg and generating 100,000 utils for itself, while B is cutting emissions by 500kg and generating 50,000 utils for itself. Griffin and Xiong (1997) operationalize size as relative impact.

Under each definition of size, the larger actor enjoys a greater ratio of marginal benefits to marginal costs at a proportional level of mitigation. Thus, from this level either the larger actor will want to mitigate more or the smaller actor will want to mitigate less.[8]

[7] In this example and each of the following, each state's citizens also get utils from the other's mitigation, but this is omitted for simplicity.

[8] For these hypothetical examples, I have assumed linear marginal costs and benefits to mitigation. Decreasing marginal benefits or increasing marginal costs could reduce the size effect. But many scholars think that increasing marginal benefits and decreasing marginal costs are more likely in the case of climate change mitigation (Hale, 2016). Moreover, given the scale of size differentials between countries (consider India and Nepal) it is unlikely that even cases of steeply decreasing marginal benefits and increasing marginal costs would fully eliminate the size effect. Size would also fail to have any effect if climate change mitigation was a superior good, meaning that it was prioritized to such a degree that states spent all available resources on it (Olson and Zeckhauser, 1966). While this scenario may be

While size may be conceptualized multiple ways when describing a collective action problem,[9] relative GDP is the best definition of size for also addressing the leakage and strategic substitution problems. These problems are exacerbated by greater slack in foreign emissions capacity, and emissions are a by-product of economic production and consumption. I define size as share of global GDP:[10]

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

where,

- $S_{c,t}$ = country c's size in year t
- $G_{c,t}$ = country c's GDP in year t
- J = 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

conceivable many decades into the future under the worst possible impact projections, it is clearly not the case now.

[9]In addition to aggregate wealth, population, or emissions, some studies treat size as size of interest, which can be proxied by GDP per capita (Boadway and Hayashi, 1999; Barrett, 2007; Vicary, 2009; Chen and Zeckhauser, 2018). I do not use this operationalization but I control for GDP per capita in my analysis below.

[10]See Appendix C for alternative specifications of the main analysis using national population and national emissions as proxies for state size.

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.

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 or may not 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.[11]

[11] 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

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 laid out in Section 2. 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.

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 equation below, in which a country's expected emissions changes are determined

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).

by the sum of the GDP changes and carbon intensity changes in similar countries.[12]

$$\widehat{\Delta\%E}_{c,t} = \Delta\%G_{c*,t} + \left(\Delta\%\frac{E}{G}\right)_{c*,t}$$

where

- $\widehat{\Delta\%E}_{c,t}$ = expected growth of emissions in country c in year t
- $\Delta\%G_{c*,t}$ = growth of GDP in countries similar to c in year t
- $\left(\Delta\%\frac{E}{G}\right)_{c*,t}$ = growth of carbon intensity of GDP in countries similar to c in year t

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 coherent climate national interests, 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.

4.1 Design

Adjusting for shocks means estimating a counterfactual emissions pathway for each state that reflects the pushes and pulls of supply, demand, and technology trends. Simply

[12] This equation is a partial Kaya identity. 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)

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? 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 (lagged) industry shares. Below, I use the term "value" or "value-added" inter-changeably 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 varying intercepts for each industry-region-year level. 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. But I use a flexible estimation strategy that allows a Latin America-specific mining and quarrying industry effect for that year in order to account for 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 2.2 and 2.4. 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 adjust for GDP per capita, given its correlation with multiple types of mitigation costs and benefits discussed above. In one specification, I also adjust for democracy and corruption, variables that I excluded from my key theoretical analysis for the sake of simplicity. If these variables are highly predictive of the outcome, then domestic politics may explain much of the residual variation. Finally, another potential international strategic factor that may affect domestic emissions choices: treaty obligations under the Kyoto Protocol. I include year fixed effects for the second stage in order to adjust for time-specific counfounding. I do not include state fixed effects due to the low within-state variation some key variables of interest (such as fossil fuel reserves). In Appendix C I run an alternative fit as a multi-level model with varying-intercept levels for state and year. This provides much of the benefit of two-way fixed effects by ruling out confounders associated with particular countries or years, while leveraging partial-pooling between levels in order to allow estimation of coefficients for covariates that sometimes have low variation within level.

The complete empirical design is outlined below, in which $\Delta\%$ indicates a 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:

$$\begin{aligned}
\Delta\% A_{c,i,t} &= \beta_0 + \beta_1 \Delta\% A_{i,t} + \beta_2 X_{c,i,t} + \psi_{r,i,t} + \epsilon_{c,i,t} \\
\Delta\% \left(\frac{E}{A}\right)_{c,i,t} &= \beta_0 + \beta_1 \Delta\% \left(\frac{E}{A}\right)_{i,t} + \beta_2 X_{c,i,t} + \psi_{r,i,t} + \epsilon_{c,i,t}
\end{aligned}$$

Weighted Average:

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

2nd Stage:

$$\Delta\%E_{c,t} - \widehat{\Delta\%E}_{c,t} = \beta_0 + \beta_1 F_{c,t-1} + \beta_2 \rho_{c,t} V_{c,t-1} + \beta_4 S_{c,t-1} + \beta_5 F_{c,t-1} * S_{c,t-1} + \beta_6 \rho_{c,t} V_{c,t-1} * S_{c,t-1} + \beta_7 X_{c,t} + \phi_t + \epsilon_{c,t}$$

where ψ indicates the industry-region-year random effect for the first stages, A indicates industry value added, E indicates emissions, $(\frac{E}{A})$ indicates carbon intensity (i.e., emissions over value added), σ indicates an industry's domestic emissions share, F 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 democracy, corruption, and Kyoto commitments in the second stage), and ϕ indicates the year fixed effect in the second stage.

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, but no such relationship is evident in plots of the data displayed in Appendix C. 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 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 designed to facilitate calculations of cross border emissions flows, and has used in reports by the World Bank, the IMF, and UN agencies. The dataset covers 184 countries across 21 years (1995-2016). EORA data uses a standard 26-industry disaggregation listed in Appendix B.

I supplement this data with measures of population and climate vulnerability from the World Bank (World Bank, 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 take measures of corruption and electoral democracy from the Varieties of Democracy (V-Dem) institute at the University of Gothenburg, Sweden (Coppedge et al., 2024; Pemstein et al., 2022).

4.3 Estimating the Counterfactual

The first stage of the analysis is estimating the counterfactual "business-as-usual" (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 1 and 2 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.[13]

All coefficients are estimated with statistical significance to the level of $p < 0.01$. The standard deviation between groups is larger than the coefficients (except the intercept in the value-added regression), indicating significant growth differences captured as shocks specific to industry-region-years. Nevertheless, the group standard deviation is about half the size of the the residual standard deviation, which describes variation within groups, indicating that there is a great deal of national-level variation not captured by these broad international shocks.

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 change predictor in each regression is positive and well above zero. This indicates that there is a substantively significant relationship between global and domestic shifts within industries. According to these results, a difference of 1 in a global industry's yearly value added growth corresponds with a difference of 0.36 in the growth rate of a national industry's value added. Similarly, a difference of 1 in a global industry's yearly carbon intensity growth corresponds to a difference of 0.36 in the growth rate of a national industry's carbon intensity.

[13]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.

Table 1: First Stage: Value Growth

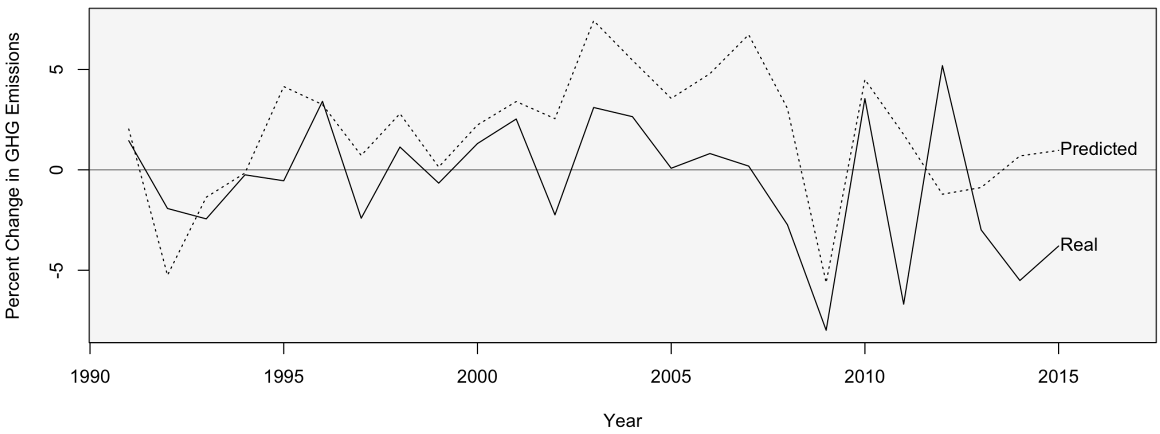
	Value-Added Change
Global Value-Added Change	0.30***
	(0.01)
Lagged Log GDP Per Capita	−0.84***
	(0.03)
Constant	11.86***
	(0.26)
Observations	91,610
Number of Groups	4,702
Group Standard Deviation	6.53
Residual Standard Deviation	12.65
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 2: First Stage: Intensity Growth

	Carbon Intensity Change
Global Carbon Intensity Change	0.36***
	(0.02)
Lagged Log GDP Per Capita	0.14***
	(0.04)
Constant	−1.75***
	(0.32)
Observations	91,610
Number of Groups	4,702
Group Standard Deviation	6.32
Residual Standard Deviation	16.76
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. The second stage dependent variable, the difference between real and expected emissions, is equivalent to an industry-weighted sum of the the first stage residuals. To illustrate the plausibility of this counterfactual comparison, I plot real and predicted emissions for two individual country cases in Figures 4 and 5.

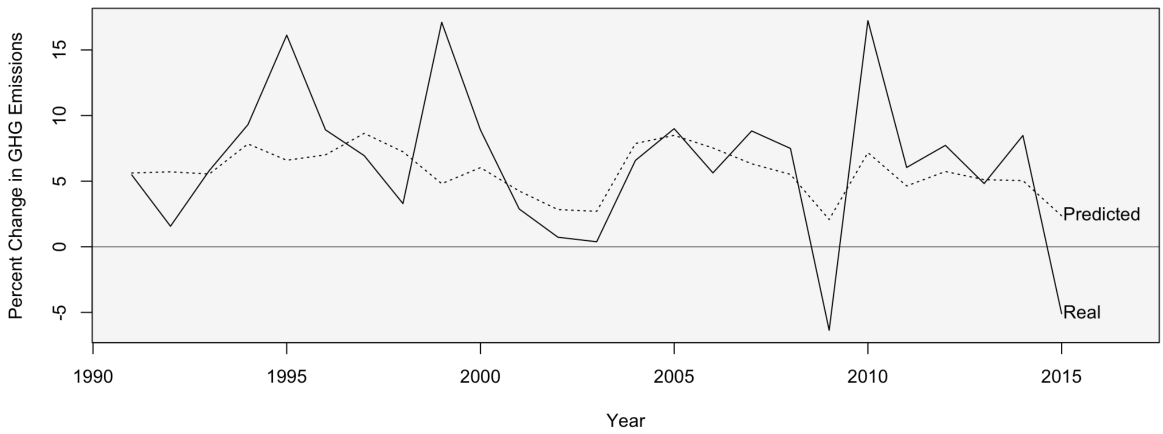
Figure 4: Yearly Changes in the United Kingdom's GHG Emissions



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.

Brazil's predicted values also closely track its real values for much of the relevant

Figure 5: Yearly Changes in Brazil's GHG Emissions



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 not statistically significant, reflecting its ambiguous interpretation due to income's relationships to multiple variables of interest discussed above. In the model fit that includes additional control variables, democracy and corruption are also not statistically significant. This finding undermines claims of the these independent importance of these variables from climate politics research on domestic institutions and capacity (Bättig and Bernauer, 2009; Povitkina, 2018). Future work on the mitigation implications of institutions and capacity may benefit from treating them as moderators of state interest rather than independent causal forces.

The important coefficients for validating my theory of climate national interest 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 standardized vulnerability index corresponds to about 0.4% less yearly emissions for a country that represents 1% of global emissions but about 9.2% 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 ameliorate 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. A one unit difference in the standardized index of fossil fuel reserves per capita corresponds to about 10% more yearly emissions for a state that emits 10% of global emissions but only about 1.3% 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 reflecting efforts at multilateralism are only weakly supported by the analysis. The coefficient for binding treaty obligations under the Kyoto Protocol is negative and statistically significant. But the effect of a Kyoto commitment is less than half the size of the effect of a one percent difference in size. Moreover, the Kyoto effect is an extremely weak test of treaty efficacy because membership in each is voluntary. This means that the Kyoto variable suffers from selection bias in a way that state size does not. Kyoto commitments may simply reflect independent national interests in mitigation.

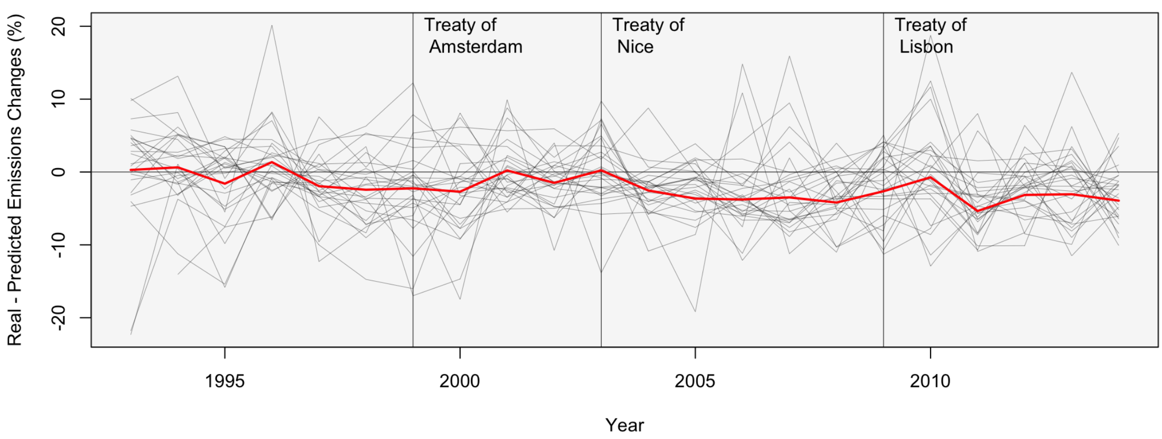
In order to illustrate the logic of the effects above, I plot real minus predicted emissions changes for each member of the EU across time. I also highlight the median member's outcome in red. Given the ongoing centralization of EU decision-making, especially

Table 3: Second Stage

	DV: Real - Predicted Emissions Changes (%)	
Size	0.31***	0.33***
	(0.07)	(0.07)
Geographic Vulnerability	0.70**	0.56*
	(0.25)	(0.26)
Size * Geographic Vulnerability	−0.92***	−0.98***
	(0.23)	(0.22)
Fossil Fuel Endowment	0.42**	0.36**
	(0.13)	(0.14)
Size * Fossil Fuel Endowment	1.08*	0.97*
	(0.46)	(0.47)
Ln GDP per Capita	0.14	0.25
	(0.13)	(0.15)
Democracy		−.51
		(0.71)
Corruption		0.20
		(0.69)
Kyoto		−1.48**
		(0.55)
Constant	−5.15*	−5.23*
	(2.06)	(2.32)
Year Fixed Effects	Yes	Yes
Observations	2,819	2,806
Residual Standard Error	7.11	7.11
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 6, as median EU mitigation has grown after successive rounds of political integration.

Figure 6: Yearly Difference in EU Members' Real and Predicted GHG Emissions Changes

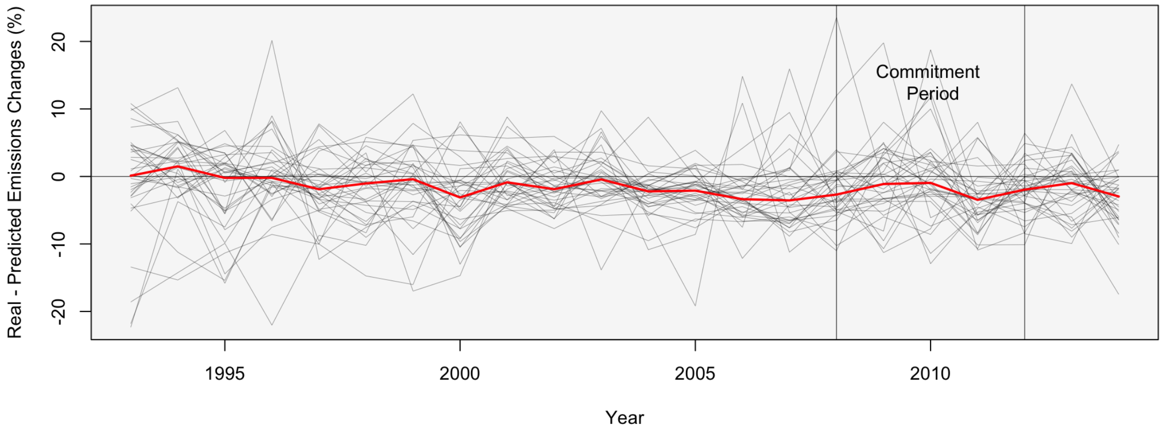


Similarly, I plot real minus predicted emissions changes for each member of the Kyoto Protocol with a binding treaty commitment in the first commitment period (2008-2012), and highlight the median member's outcome in red. Despite the fact that states select themselves into participating in the Kyoto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

5 Discussion

My results show that states are pursuing coherent climate national interests subject to the constraint of collective action. States that are more vulnerable to climate change

Figure 7: Yearly Difference in Kyoto Members' Real and Predicted GHG Emissions Changes



are more likely to mitigate, but especially so if they are large states whose mitigation can make a difference in global climate outcomes. Even large states, however, will mitigate less if they possess ample fossil fuel reserves and therefore face steep opportunity costs when cutting emissions. In other words, because large states are less vulnerable to free-riding, their actions will hew more closely to their national interests for global climate change mitigation.

The dependence on large states for action is due to the unilateral nature of climate change mitigation thus far, and explains the striking difference in outcomes between the results of the Montreal Protocol and those of climate change mitigation efforts. In 1989, the year that Montreal came into force, the US, the European Community (which entered the treaty as a block, as the European Union entered Kyoto and Paris), and Japan alone comprised nearly 70% of the global yearly emissions of ozone depleting chemicals. In 2016, the year that Paris came into force and the last year of my timeseries above, the US, the European Union, and Japan comprised only about 20% of global yearly GHG emissions. China, the world's largest yearly emitter, comprised another 20%. And after including India, Russia, and Indonesia, the combined share of emissions from these seven actors rises to nearly 60%. Thus, while not completely diffuse, GHG emissions are significantly less concentrated than ozone-depleting emissions were, hindering the practical benefits of unilateral action, even for the largest emitters.

Given this diffusion, unilateralism has severely limited mitigation. While large actors will mitigate proportionally more than small actors, even the largest actors will mitigate less than the globally optimal mitigation rate. Only an actor that comprised 100% of global emissions would be totally insulated from free-riding concerns. Moreover, in the case of climate change, the largest actors tend to be least vulnerable to climate change and thus have the lowest national interests in climate change mitigation. This is because the largest GHG emitters are wealthy economies and tend to be further from the equator due to divergent historical paths of economic development between equatorial and temperate regions (Acemoglu, Johnson and Robinson, 2001; Nordhaus, 2006).

When capabilities are not concentrated and national interest varies significantly, unilateralism will tend to fall short. This article has demonstrated that national interest has driven much of observed climate change mitigation. But it also demonstrates that unilateral national interest is sharply limited–it cannot drive the international system to high mitigation levels. In other words, the strong effect of national size that I find above indicates that most globally optimal mitigation is simply not happening.

One theoretical solution to the limitations of unilateral action is a world state, which could make globally optimal policy without suffering from free-riding. Some scholars have suggested that interstate unification is the inevitable response to global Prisoners' Dilemmas driving existential threats, such as nuclear proliferation or climate change (Wendt, 2003). But these proposals fail to specify a viable path towards world unification, especially one not defined by conquest or oppression with humanitarian costs even greater than climate change. Even if global government could be achieved, it is unclear whether it could function to effectively aggregate the immense variety of global interests. In other words, as implausible as it may seem to consider current states unitary and rational, a world state would likely be much less so.

A more realistic solution to unilateral limitations is multilateral cooperation. This would require international agreements not designed merely to coordinate and facilitate policy which is already unilaterally justifiable, but rather to incentivize jointly beneficial behavior. Under an effective multilateral regime, states would enjoy treaty-imposed benefits from cooperation and suffer treaty-imposed costs from defection, so as to deter free-riding. In practice, this would raise the total level of emissions and also eliminate any gap between large and small actor emissions. True multilateral cooperation is difficult and rare in international politics due to anarchy, or the lack of any central body to enforce law. Multilateral agreements must therefore be "self-enforcing," or structured such that multilateral enforcement is unilaterally rational (Barrett, 1994). Frameworks for effective multilateral climate change mitigation agreements have been outlined at length elsewhere (Nordhaus, 2015), and rely on a self-enforcing system of sticks and carrots, such as carbon tariffs and significantly reformed climate finance. These measures may have been omitted thus far due to the tendency of climate negotiators to model regime-design on the originally toothless Montreal Protocol. This design worked for mitigating highly concentrated ozone-depleting emissions but not for diffuse GHG emissions. Ironically, later amendments to Montreal incorporated expansive carrots and sticks, thereby transitioning from merely coordinated unilateralism to true multilateralism. These design elements, thus far not copied by any GHG mitigation regime, could make such a regime workable in spite of diffusion.

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 mediation of these interests by state size demonstrates the free-rider phenomenon in practice, validating the collective action framework.

Much of the recent body of research on climate change politics has focused on domestic distributional politics and other sub-national bargaining dilemmas. This work is both interesting and important for describing processes by which sub-national interests are not efficiently aggregated into state-level preferences. But climate change is a global phenomenon, meaning that states cannot supply climate change mitigation for their own population and territory. Thus, an exclusive focus on distributional politics, which has been advocated by some scholars (Aklin and Mildenberger, 2020), could be warranted in only two cases. First, a green transition could be unilaterally worthwhile for reasons unrelated to climate change mitigation. For example, if renewable energy was cheaper and more reliable than fossil fuels, states would be seeking to transition to renewables without regard to the global climate. In this case, global collective action would not be hindering renewable energy construction, but domestic distributional politics could be. While many forms of emissions reductions offer local co-benefits in addition to their global climatic effects, few scholars would claim that the green transition will not be costly. Second, if states were non-strategic actors that made climate policy without understanding the effects of that policy on the global climate, then they would also not be limited by free-riding concerns. While states are clearly not perfectly rational, it is unlikely that they are completely unaware of the connection between their mitigation actions and global mitigation outcomes. In either of these two cases, mitigation levels could be correlated with national costs and benefits, but would not be mediated by state size. If emissions reductions were not aimed at climate change mitigation, then larger actors with a greater ability to affect mitigation outcomes would not be cutting emissions more than smaller actors. And if states were unaware of larger actors' greater ability to affect mitigation outcomes, then larger actors would not be cutting emissions more than smaller actors. Thus, the predictive power of national interests and state-level strategic constraints in describing observed patterns of climate change mitigation indicates that theories of climate change mitigation that focus on domestic politics are, at best, limited.

But there are two ways in which the theoretical framework from Section 2 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 framework assumes no interaction, interference, or 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

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 ozone protection or acid rain prevention.

This article also has several important methodological limitations. First, while my outcome variable represents direct emissions from consumption and production, it omits emissions from land-use, land-use change, and forestry (LULUCF). While LULUCF is a major source of global emissions, which is also not distributed proportionate to direct CO2 emissions, its measurement is significantly more difficult than that of direct emissions. Estimates of LULUCF emissions are less certain and significantly more noisy.

Additionally, my analysis has not accounted for climate finance, in which actors from rich states pay for mitigation in poor states. This could produce bias by attributing mitigation to the host state rather than the funder. Nevertheless, research has found climate finance to be small and largely ineffective at reducing emissions (Sovacool and Brown, 2009; Victor, 2011), meaning that this is likely a small source of bias.

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.

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 attempts to cancel 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. Both methods post-stratify a regression-based estimate, but 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 4: 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 Restaurants
Transport
Post and Telecommunications
Financial Intermediation and Business Activities
Public Administration
Education, Health and Other Services
Private Households
Others
Re-export and Re-import

C Additional Tables and Plots

Table 5: Second Stage fit with a multilevel model

	DV: Real - Predicted Emissions Changes (%)	
Size	0.29***	0.31***
	(0.09)	(0.09)
Geographic Vulnerability	0.68**	0.59*
	(0.30)	(0.30)
Size * Geographic Vulnerability	−0.87***	−0.94***
	(0.28)	(0.28)
Fossil Fuel Endowment	0.35**	0.30*
	(0.16)	(0.16)
Size * Fossil Fuel Endowment	1.12**	1.01*
	(0.57)	(0.57)
Ln GDP per Capita	0.15	0.27
	(0.15)	(0.17)
Democracy		−0.60
		(0.85)
Corruption		0.28
		(0.81)
Kyoto		−1.11**
		(0.51)
Constant	−4.63**	−4.95*
	(2.36)	(2.60)
Observations	2,846	2,836
Number of Groups (State)	150	150
Group Standard Deviation (State)	1.25	1.21
Number of Groups (Year)	21	21
Group Standard Deviation (Year)	0.00	0.00
Residual Standard Deviation	6.99	7.00
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 6: Second Stage using population as size

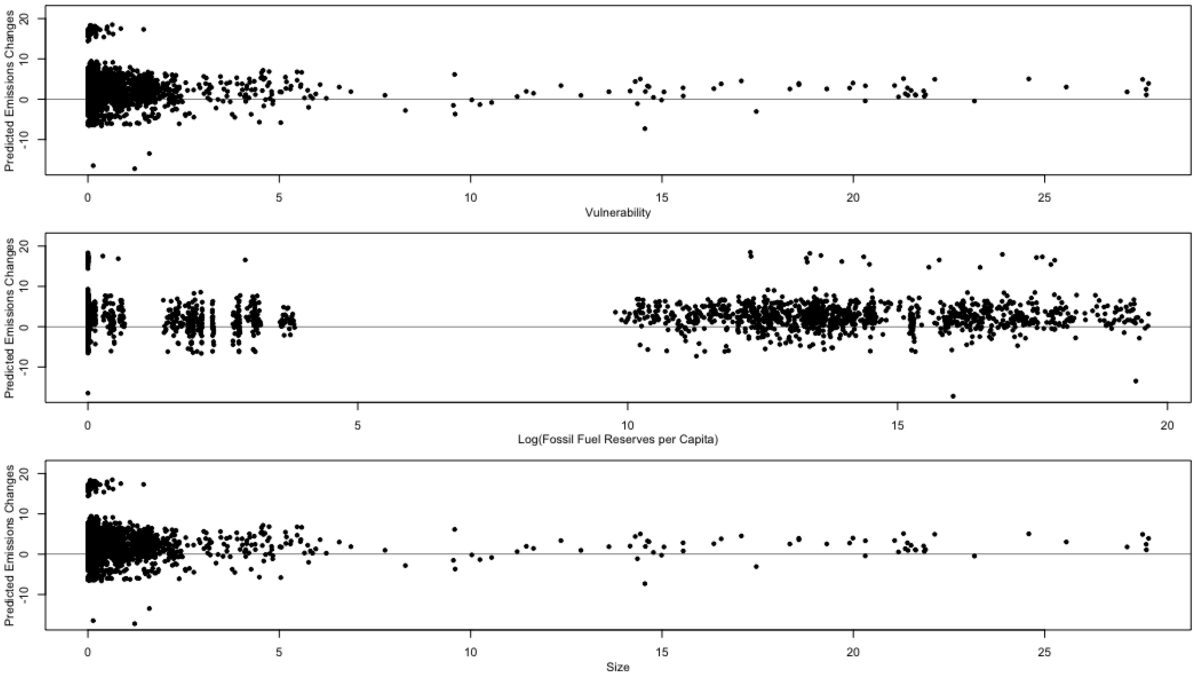
	DV: Real - Predicted Emissions Changes (%)	
Size	0.27	0.16
	(0.36)	(0.37)
Geographic Vulnerability	0.55**	0.39
	(0.26)	(0.26)
Size * Geographic Vulnerability	0.47	0.71
	(0.86)	(0.87)
Fossil Fuel Reserves	0.42***	0.37***
	(0.12)	(0.13)
Size * Fossil Fuel Endowment	5.41***	5.42***
	(1.10)	(1.11)
Ln GDP per Capita	0.07	0.10
	(0.13)	(0.15)
Democracy		−0.40
		(0.73)
Corruption		−0.51
		(0.69)
Kyoto		−1.76***
		(0.55)
Constant	−4.02*	−3.01
	(2.10)	(2.37)
Year Fixed Effects	Yes	Yes
Observations	2,846	2,836
Residual Std. Error	7.14 (df = 2819)	7.14 (df = 2806)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 7: Second Stage using emissions as size

	DV: Real - Predicted Emissions Changes (%)	
Size	0.30***	0.30***
	(0.06)	(0.06)
Geographic Vulnerability	0.59**	0.42
	(0.25)	(0.26)
Size * Geographic Vulnerability	−0.86***	−0.88***
	(0.16)	(0.16)
Fossil Fuel Reserves	0.43***	0.36**
	(0.14)	(0.15)
Size * Fossil Fuel Reserves	0.73*	0.73*
	(0.44)	(0.44)
Ln GDP per Capita	0.04	0.13
	(0.13)	(0.15)
Democracy		−0.73
		(0.71)
Corruption		−0.15
		(0.69)
Kyoto		−1.58***
		(0.55)
Constant	−3.99*	−3.37
	(2.07)	(2.34)
Year Fixed Effects	Yes	Yes
Observations	2,846	2,836
Residual Std. Error	7.11 (df = 2819)	7.11 (df = 2806)
Note:		*p<0.1; **p<0.05; ***p<0.01

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 8. These plots show no concerning pattern, as the distribution of predicted emissions changes is roughly similar at different values of each explanatory variable.

Figure 8: 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 9 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 9: Real - Predicted Emissions Changes Compared to Potential Confounders