Climate Change Policy is in Season: Complementarities in Global Climate Action

Justin Melnick*

March 24, 2025

Incomplete Draft for Harvard Global Climate Policy Pipeline

Abstract

In canonical theories of international climate cooperation, countries' abatement efforts are strategic substitutes, encouraging free-riding—the marginal impact of one state's efforts decreases when others are likely to contribute—negatively correlating countries' climate actions. This paper presents quantitative evidence that calls into question the dominance of the strategic substitutes assumption, documenting a weakly positive correlation between countries' mitigation efforts. Using a formal model, the paper shows how, in equilibrium, countries' climate actions can be either strategic complements or substitutes. Beyond providing global public goods, other countries' mitigation efforts signal information about the economic value and policy success of a green transition. Others states' climate measures influence policy adoption via two channels. When beliefs in the economic success of green policy outweigh aversion to risk incurred from investing in climate policies with unknown returns, the complementarity effects from the learning mechanism dominate the substitution effects from free-riding.

*Ph.D. Candidate, Department of Politics, New York University. Contact: melnickj@nyu.edu and justinmelnick.github.io.

How does the behavior of other nations influence climate policy adoption? Long-standing scholarship emphasizes the temptations to free-ride inherent to collective action concerns (e.g., Olson 1965; Ostrom 1990; Barrett 2003; Stern 2007; Bernauer 2013; Keohane and Victor 2016). On this view, the marginal gains from refraining to engage in nationally costly abatement efforts—because other countries could do so instead—outweigh the global benefits of environmental protection, so emissions reduction efforts should be negatively correlated across countries. This paper challenges the conventional wisdom by engaging in three tasks. First, with descriptive analysis, I present quantitative evidence that shows a weakly positive, rather than strongly negative, relationship between other nations' behavior and climate mitigation efforts. This reflects potential complementarities in countries' environmental policies rather than effort substitution. Second, to unpack this empirical finding, I develop a theoretical framework that allows for the endogenous generation of strategic substitutes as well as strategic complementarities in countries' mitigation measures, and characterize the conditions under which we should expect to see a positive versus a negative correlation in cross-country climate policies. Finally, I examine previously unidentified empirical implications of the theory that follow from understanding countries' actions as strategic complements.

The paper makes empirical contributions, by assessing the validity of previous conceptual assumptions, as well as theoretical contributions by proposing a new formal framework to explain international climate policymaking. In the model, countries engage in climate policymaking over time and observe the mitigation measures implemented by other nations. As in collective action theories, everyone is better off when nations exert more effort to abate the effects of climate change, but there are diminishing marginal returns to subsequent investments and taking action is locally costly. But unlike conventional models, there is a fundamental uncertainty about the economic gains from the green transition: countries want to make costly climate policy investments that are commensurate with their beliefs that the green transition will be "successful." Optimal emissions reduction policies thus balance the interplay between countries' private beliefs about a successful green transition and their willingness to institute green policies with uncertain economic benefits, while simultaneously shouldering domestic political costs of implementation (e.g., Bechtel and Scheve 2013; Stokes 2016; Gazmararian and Tingley 2023; Voeten 2025).

Other nations' climate remediation policies influence the decision to implement environmental reforms via two channels. On one hand, previous mitigation efforts diminish the marginal contributions of future policies, which incentivizes free-riding. This causal pathway induces strategic substitution in countries' climate investments. Concomitantly, the adoption of climate policies by other countries is a signal of public optimism in a green economy, which can spur subsequent climate action. This learning effect elucidates a causal mechanism through which countries' actions can instead become complementary (cf. Banerjee 1992; Bikhchandani, Hirshleifer and Welch 1992; Smith and Sørensen 2000). These competing effects imply that some countries, looking at their expected costs and benefits, will do as the conventional literature says—free-ride. But other nations will in equilibrium conclude that they can reinforce the effects of global cooperation via diffused learning, simply "following the leader" upon observing extant, more ambitious climate reforms (Elkins and Simmons 2005; Dobbin, Simmons and Garrett 2007). According to the theory, the learning effects that engender strategic complementarities are strongest when a country's belief in the economic returns to green policy dominates its aversion to risk incurred by implementing costly climate policies with uncertain success.

The learning mechanism produces several empirical implications about the relationship between countries' beliefs and their climate efforts that the free-riding mechanism would not predict. Quite naturally, greater optimism within countries should incentivize greater effort. Additionally, if the learning effect is operant, countries should hold more optimistic beliefs about the economic returns from green policy if they have observed others doing the same versus when other nations slack, so optimism should, in reduced form, engender greater action across countries as well. Using data on mass beliefs about the importance of climate change as well as elite beliefs about the ambition of nationally determined contributions (Victor, Lumkowsky and Dannenberg 2022), I uncover a positive relationship between beliefs and subsequent climate policy stringency within and across nations, consistent with theoretical expectations. This evidence highlights the importance of disentangling possible free-riding effects from learning effects in evaluating countries' climate policies.

Contribution

Scholars and policymakers have viewed the free-rider problem as the dominant impediment to progress on climate policymaking (see Carattini, Levin and Tavoni 2017; Weitzman 2017). Domestic and international policy solutions have been advanced to specifically address free-riding's negative externalities (Barrett 2003; Victor 2011; Hovi, Ward and Grundig 2015).[1] Debate launched by Aklin and Mildenberger (2020) eschews collective action concerns and instead emphasizes that heterogeneous preferences for climate reforms could be traced to domestic factors.[2] However, recent literature, while correctly identifying an "over-emphasis" on free-riding concerns (Colgan, Green and Hale 2021, 586-587), sidesteps the question of how international factors affect climate policy decisionmaking. Indeed, heterogeneity of preferences may be compatible with a free-riding story at the international level (Kennard and Schnakenberg 2023).

This paper reconciles these ontological camps with empirical and theoretical contributions. It provides a direct empirical test of the fundamental assumption that free riding incentives induce a negative correlation between countries' climate actions, which underlies

[1] Ross (2025) notes that the policy bias toward carbon pricing instruments likely reflects that the effects of climate change had largely been studied by economists.

[2] This strand of literature points to the role of special interest lobbying (Meckling 2011; Mildenberger 2020; Stokes 2020), electoral institutions and electoral incentives (Lipscy 2018; Finnegan 2022; Melnick 2024; Finnegan et al. 2025), veto players (Madden 2014), and sectoral composition (Aklin and Urpelainen 2013; Cheon and Urpelainen 2013), among other subnational explanators, as determinants of climate policymaking.

extant arguments. By finding a weak positive correlation, the results reject the premise that free-riding concerns dominate international climate cooperation concerns, affirming some of the argument posed by Aklin and Mildenberger (2020). However, these authors and their intellectual successors do not propose a theoretical alternative for how a country's climate policy might be affected by other nations. Thus, I offer a new theoretical framework that is consistent with the data at the international level and, while treating domestic political factors in reduced form, allows for a unification of international-level arguments with theories that rely on subnational institutions to explain variation in climate policymaking across nations.

To achieve this goal, I appeal to the literature on policy diffusion (Elkins and Simmons 2005; Simmons, Dobbin and Garrett 2006; Dobbin, Simmons and Garrett 2007) and learning in foreign policy decisionmaking (Levy 1994). I argue that countries' policy actions can be complementary through a mechanism of learning, where countries' beliefs about a successful green transition are influenced by the policy adoption decisions of previous movers. Within climate politics, the idea of policy diffusion has been applied to study policies such as carbon pricing (Harrison 2010; Thisted and Thisted 2020; Linsenmeier, Mohommad and Schwerhoff 2023), feed-in tariffs (Baldwin, Carley and Nicholson-Crotty 2019), and domestic and international climate legislation (Sauquet 2014; Fankhauser, Gennaioli and Collins 2016); these studies point to several mechanisms to explain diffusion that include learning and emulation, technological innovation, and "peer pressure" (Savin, Mundt and Bellanca 2024).[3]

This paper also contributes to the literature within the political economy of climate change that emphasizes the role of uncertainty. Melnick (2025) demonstrates how uncertainties about climate vulnerabilities can be exploited by special interest groups to stymie

[3]Qualitative accounts of climate policymaking also highlight complementarity effects. Hochstetler (2020) notes that former South African President Jacob Zuma committed to strong climate pledges in 2009 at the Copenhagen summit—despite resistance from pro-status quo actors like Eskom—perhaps in response to similarly ambitious commitments made by China, India, and Brazil.

climate action at home and abroad. Gazmararian and Milner (2024) argue that natural disasters induce learning within countries about climate vulnerabilities which facilitates the adoption of climate laws. Uncertainty about climate change's effects can also interact with politician behavior to inspire political mobilization (Balcazar and Kennard 2025). In this paper, uncertainty is important insofar as it coordinates countries' expectations about whether costly climate investments will yield economic gains.

The rest of this paper proceeds as follows. First I assess the empirical validity of extant theories by testing the assumptions associated with free-riding in the climate policymaking realm. The analysis presents findings that call into question the assumption of pre-existing arguments that countries' propensities to adopt climate laws are decreasing in the actions of others, instead suggesting a complementary effect of policy across borders. Given these results, I then build a formal-theoretic framework to provide an explanation for the patterns observed in the data: countries' climate actions can arise as complementarities endogenously through a process of learning about the success of a green transition. Finally, I tease out some of the empirical implications of the learning mechanism that tie beliefs to climate policy stringency.

Are Countries' Climate Actions Strategic Substitutes?

In a typical story of global climate policymaking, the marginal value of taking climate action is decreasing in the actions of other countries. This is because the benefits of abatement are global while the marginal costs are local. This theoretical account emphasizes the temptations to free ride off of other nations—others could plausibly supply the global benefits from abatement—which formally assumes that countries' actions are *strategic substitutes*.

Consider the following simplified formalization of the climate collective action problem (cf. Harrison and Lagunoff 2017; McAllister and Schnakenberg 2022; Kennard and Schnakenberg 2023). There are two countries, i and j, that each simultaneously choose carbon emissions (inverse abatement efforts) $k_i, k_j \in [0, 1]$. Preferences are parameterized as

$$u_i(k_i, k_j) = \log(k_i) + \log(1 - k_i - k_j),$$

where the first term captures the benefits of consumption (opportunity costs of abatement) and the second term captures the benefits of global remediation. Each country's best response function $k_i(k_j)$ satisfies

$$k_i(k_j) = \frac{1 - k_j}{2} \;\Leftrightarrow\; \frac{\partial k_i(k_j)}{\partial k_j} < 0.$$

As a consequence of the strategic substitutability encoded in this setup—established formally by $\frac{\partial k_i(k_j)}{\partial k_j} < 0$—country i's marginal value of abatement is decreasing when country j exerts more effort. Simply put, when other nations do more, it is a best response to do less, and when other nations do less, it is a best response to do more. This premise lies at the core of extant theoretical approaches to global climate cooperation.

The rest of this section establishes a series of empirical facts about the relationship between a country's climate policy decisionmaking and the behavior of other nations. These tests should be treated as descriptive findings, not causal relationships: it is an assumption of extant models that actions are strategic substitutes, not an equilibrium implication. As such, I look to uncover simple correlations that bolster or refute the empirical validity of this modeling feature.

Empirical Assessment 1: Climate Law Adoption

First, I use data from the Climate Change Laws of the World project (Nachmany et al. 2017), which provides information on adopted climate laws from 1990 to 2024.[4] For each country i, I observe the number of climate laws adopted in year t and I also measure the number of laws adopted by all other nations in year $t-1$. At the country-year level, I run the following fixed effects model with country-clustered standard errors:

$$\text{Adopt}_{it} = \beta \ \log(\text{Previous Laws}_{-it-1}) + X'_{it-1}\gamma + \alpha_i + \lambda_t + \varepsilon_{it},$$

where Adopt_{it} is either a binary indicator for whether country i adopted a climate law in year t, or is the total count of climate laws that country i adopted in year t. The independent variable $\text{Previous Laws}_{-it-1}$ is the number of previous laws enacted by all other nations in the previous year $t-1$. The vector X_{it-1} contains country-level time-varying controls (lagged dependent variable, population, GDP per capita, growth, regime type). I also include country fixed effects α_i and year fixed effects λ_t. Country fixed effects proxy for any time-invariant, country-specific factors that affect the likelihood of climate policy adoption. Year fixed effects adjust for any global benefits that might incentivize climate policy, which includes any general equilibrium effects of increased mitigation benefits that could correlate with a contemporaneous rise in climate policies across countries.

The sign of the coefficient β is the estimand of interest; extant theoretical approaches would expect that $\beta < 0$, which would capture the presence of strategic substitutes in reduced form. Table 1 displays the results. Contra extant theories, the adoption of climate laws by other nations in the past year is a positive predictor of climate law adoption. In the case of a binary dependent variable, it is not statistically significant, but it is when considering

[4]The data covers laws adopted by the national governments of 196 countries plus the European Union. Laws passed by the EU are coded at the EU level. To be included as a law, a document must have full legal force or set out a current set of government policy objectives motivated by climate change.

	Adopt (Binary)		Adopt (Count)	
	(1)	(2)	(3)	(4)
Previous Other Laws	0.015	0.397	-0.144	2.45^{***}
	(0.110)	(0.259)	(0.163)	(0.441)
Controls	No	Yes	No	Yes
Observations	6,713	5,316	6,713	5,316
R^2	0.386	0.394	0.454	0.492
Within R^2	1.67×10^{-6}	0.003	8.83×10^{-5}	0.051
Country fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Table 1: Effect of Previous Laws on Climate Law Adoption
Standard errors clustered by country in parentheses

the total count of laws that country i adopted in year t. Since this correlation is positive, it suggests a complementarity rather than a substitutability in the adoption of climate laws across countries.

Empirical Assessment 2: Policy Stringency

While the first empirical assessment provides mixed evidence against a free-riding story, one may be worried that the adoption of laws proxies quantity of action, but that conditional on a secular increase in climate action, countries' efforts are still strategic substitutes. Or, perhaps countries adopt climate laws but do not intend to fulfill their promises, allowing other nations to exert effort instead (Melnick and Smith 2025). From a measurement perspective, the discretized choice to adopt might mask substantial heterogeneity or information that a continuous measure could pick up.

To probe these concerns, I turn to the OECD's Environmental Policy Stringency (EPS) Index (Botta and Koźluk 2014; Kruse et al. 2022). The EPS ranges from 0 to 6, where greater values imply greater stringency. Stringency is defined as the ability to explicitly or implicitly place a price on pollution through market-based (taxes, trading schemes, feed-in tariffs, and deposit and refund schemes) and non-market policies (command-and-control standards and subsidies). The data covers 40 countries between 1990 and 2020 and is measured at the country-year. Additionally, I examine the Climate Action Policies and Measurement Framework (CAPMF) developed by Nachtigall et al. (2024) as a measure of policy stringency. The CAPMF runs between 1990 and 2022 and measures the breadth of mitigation policy actions for 50 countries and the European Union on a scale from 0 to 10 for each country-year. I focus on "sectoral policies" rather than "cross-sectoral policies" or "international frameworks" although results are robust to the inclusion of these policy variables as well. For country i in year t, I run the following regression:

$$\text{Stringency}_{it} = \beta \text{ Average Stringency}_{-it} + X'_{it-1}\gamma + \alpha_i + f(t) + \varepsilon_{it},$$

which fits country i's policy stringency in year t as a function of the average policy stringency of all other nations besides i in year t. I also include country fixed effects α_i and time-varying controls (lagged dependent variable, population, GDP per capita, growth, winning coalition size), which includes time trends (linear, cubic, country $\times$ year) and cluster standard errors by country.

Table 2 displays the results. In a similar fashion to the first test, the sign of β determines whether other countries' average stringency induces more or less stringent climate policy from a given nation. Measuring stringency using the EPS, a 1 point (out of 6) increase in the average policy stringency of other nations is associated with approximately a 0.21 point *increase* in country i's environmental policy stringency score. The CAPMF results are similar, with a 1 point (out of 10) increase in average global stringency increasing a nation's policy stringency score by about 0.13 points. This effect again contradicts pre-existing theoretical arguments. Moreover, given the sample, this empirical test demonstrates

	EPS			CAPMF		
	(1)	(2)	(3)	(4)	(5)	(6)
Average Stringency	0.205***	0.306***	0.269***	0.228***	0.382***	0.498***
	(0.045)	(0.082)	(0.058)	(0.044)	(0.049)	(0.064)
Observations	1,165	1,165	1,165	1,469	1,469	1,469
R^2	0.969	0.970	0.972	0.982	0.983	0.986
Within R^2	0.944	0.945	0.949	0.979	0.981	0.984
Country fixed effects	✓	✓	✓	✓	✓	✓
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Linear	Cubic	Country $\times$ Year	Linear	Cubic	Country $\times$ Year

Table 2: Effect of Average Global Policy Stringency on Climate Policy Stringency
Standard errors clustered by country in parentheses

a positive correlation in climate actions among large countries with substantial impact on the climate, which bolsters the claim that countries are learning from pivotal emitters. Results are also robust to weighting by GDP per capita or by emissions per capita, as well as by using median stringency instead of average stringency. See Appendix B for robustness checks.

Empirical Assessment 3: U.S. Presidential Elections

As a third piece of evidence, I examine the effects of United States presidential elections on the adoption of climate laws. The identity of the American president heavily skews the incentives to enact climate laws around the globe: in 2016, Donald Trump campaigned on withdrawing the United States from the Paris Agreement and retrenching the U.S. from the global climate regime, while Joe Biden's 2020 campaign promoted American engagement in climate policymaking. The outcome of the 2016 (2020) election thus represents a negative (positive) perturbation to countries' best responses and subsequently informs their optimal decisionmaking in light of expected American behavior following the election. The classical logic predicts that, outlined by the formalization above, other nations should increase (decrease) their adoption of climate laws following Trump's (Biden's) victory.

To capture the effects of the elections, I run a regression discontinuity in time at the country-month level using the following local linear regression specification:

$$\text{Adopt}_{im} = \beta\mathbb{1}(t > t_k) + \varphi f(t - t_k) + \alpha_i + \lambda_m + \varepsilon_{im},$$

where the outcome is either a binary indicator for whether country i adopted a climate law in month m or the logged count of climate laws adopted by country i in month m, t_k is the calendar date of the election (either 2016 or 2020), and $f(\cdot)$ is a smooth function of time. Fixed effects at the country and month level are also included to capture country-specific idiosyncrasies in law adoption as well as common temporal shocks. I report conventional as well as bias-corrected and optimal bandwidth selected estimates (Calonico, Cattaneo and Titiunik 2014), and cluster standard errors by country.

The sign of β identifies the local average treatment effect of the U.S. election on other nations' adoption of climate laws right at the date of the election. A free-riding argument would expect β to be positive (negative) in 2016 (2020). In this account, Trump's apathy toward climate policies would increase the marginal value of policymaking for other nations to compensate, while Biden's willingness to enact climate policy would decrease the incentives for others to exert costly effort.

The threat to identification of the LATE would be countries strategically adopting climate laws around the time of the election. Specifically, in the 2016 election, the relevant bias in favor of the free-riding argument is if countries were to delay adoption of climate laws until after the election, which would bias the LATE downward. However, such a case seems unlikely as adoption would only become more difficult with a U.S. president who is less favorable to climate action in power. Analogously, in 2020, countries would have to pass all of their laws right before the election and then strategically withhold effort once Biden won the election.

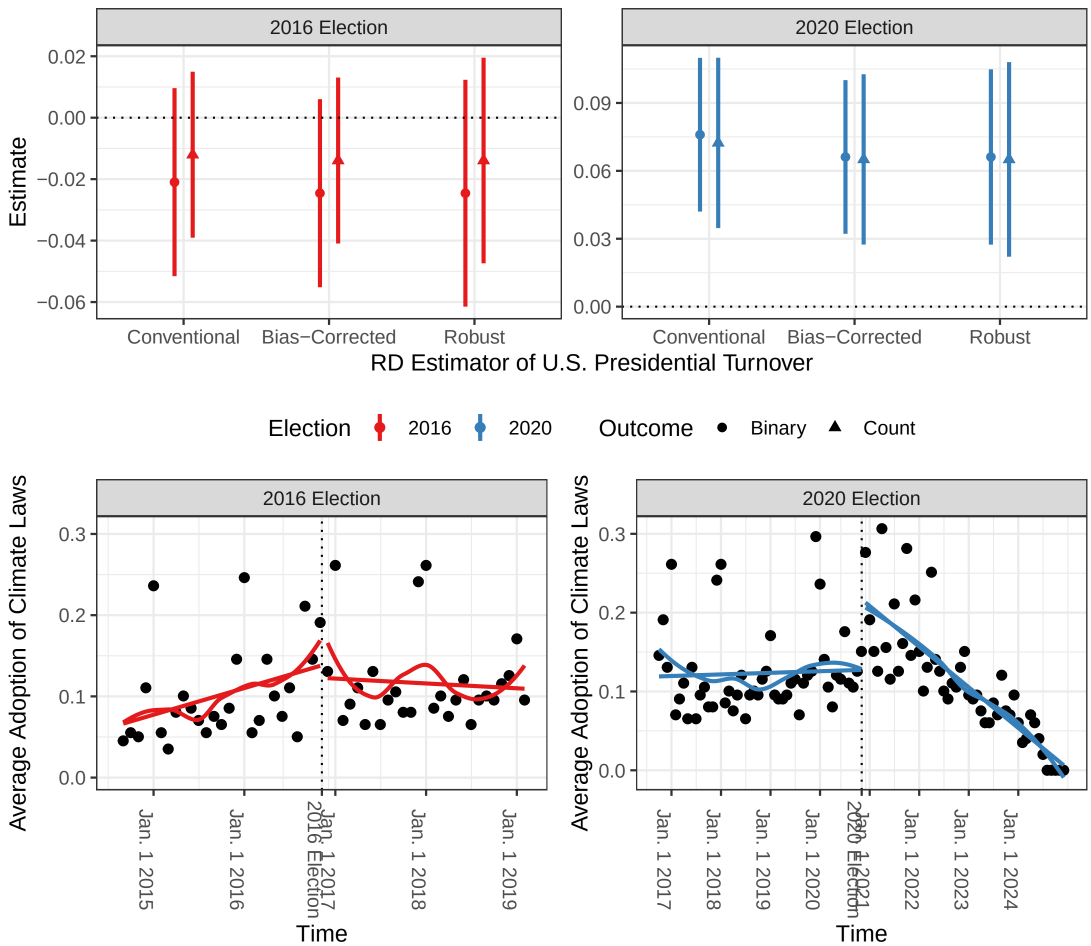

Figure 1: Effects of U.S. Presidential Turnover on Climate Law Adoption (RD)

Figure 1 displays point estimates as well as graphical depictions of the evolution of climate laws over time as a function of U.S. presidential elections.[5] In the top-left panel of the figure, it is clear that Trump's 2016 election victory is associated with about a 1-2 percentage point reduction in climate laws but is not statistically significant. Conversely, the top-right panel demonstrates that Biden's win in 2020 did meaningfully increase the adoption of climate laws, by approximately 7 percentage points. In both cases, the sign of the RD estimates refute a story of strategic substitutes. When an anti-climate leader was elected in 2016, other countries followed suit and enacted fewer climate laws. In 2020, with the emergence

[5] RD plots are for the binary adoption outcome; logged counts display similar results.

of a pro-climate U.S. presidential winner, the international community responded with more climate action.

Theoretical Framework

How could the complementarities in countries' climate policies arise? Consider sequential climate policymaking by $n = 2$ countries indexed by i. Each country determines a level of climate mitigation efforts $a_i \in \mathbb{R}$. Positive levels of effort $a_i > 0$ signify climate reforms that contribute to global abatement or remediation efforts, while negative effort $a_i < 0$ can be thought of as anti-climate measures like deforestation or other means of increasing carbon emissions. The order in which each country moves is fixed and exogenous; country 2 ("she") observes country 1's ("he") choice prior to taking an action.

Countries' payoffs from efforts toward climate reform depend on a fundamental uncertainty, the global economic returns from a green transition. This is modeled as a state of the world, θ. Neither country knows the true realization of θ—whether or not the green transition pays off or will be "successful" is unknown—but share the common prior $\theta \sim N(\mu, \frac{1}{\gamma})$. In addition, each country observes a noisy signal of the state of the world, $x_i = \theta + \varepsilon_i$ where $\varepsilon_i \sim N(0, \frac{1}{\beta})$. Countries' signals are their private information and are thus their private beliefs about the economic returns to green policy; higher signals are on average more likely to indicate larger θ, so a country with a higher signal is more optimistic about the success of a green transition. Countries' returns from effort depend on the value of θ and thus capture the idea that countries only want to exert effort in mitigating the effects of climate change if they are sufficiently optimistic that a green transition would reap economic benefits.

As in conventional theoretical accounts of international climate policymaking, countries' abatement efforts generate global benefits but impose local costs. Let $A = a_1 + \lambda a_2$ be the weighted average of global efforts where $\lambda \geq 0$ parameterizes the relative weight of country

2's future efforts on the global mitigation goal. Countries receive a global benefit of $g(A)$ given total global policy implementation where $g(\cdot)$ is an increasing and concave function. Additionally, adopting climate-friendly policies is costly, and exerting effort comes at a cost $c(a_i)$ where $c(\cdot)$ is an increasing and convex function. To keep the problem tractable, let $g(A) = \begin{cases} \sqrt{A} & A \geq 0 \\ -\sqrt{|A|} & A < 0 \end{cases}$ and $c(a_i) = c_i|a_i|$. We might think that the costs associated with mitigation efforts incorporate both a common cost representing technological requirements to undertake environmental reforms, and a heterogeneous cost for any domestic political consequences from imposing costs on citizens or large domestic polluters to implement reforms (Aklin and Mildenberger 2020; Colgan, Green and Hale 2021).

Putting things together, country i's utility is written as

$$u_i(a_i, A; \theta) = \theta g(A) - c(a_i).$$

Countries' utility functions capture the logic of strategic substitutes encoded in canonical models—countries derive global benefits from mitigation actions but these gains exhibit diminishing marginal returns—while also allowing for the generation of strategic complementarities in countries' behavior because of the incentives to learn about the economic returns to green policy from the actions of others. Both mechanisms are present in countries' effort decisions at the goal of the theoretical analysis will be to characterize the conditions under which one effect dominates the other.

I examine weak Perfect Bayesian equilibria. Country 1's strategy is a function $\alpha_1 : \mathbb{R} \to \mathbb{R}$ that maps his signal x_1 into an effort level a_1. Country 2's strategy is a function $\alpha_2 : \mathbb{R} \times \mathbb{R} \to \mathbb{R}$ that maps her signal x_2 and country 1's effort a_1 into an effort level a_2. Beliefs are formed via Bayes's rule.

Comments on the Model

The model's assumptions are reminiscent of canonical theories of observational learning (for a review, see Bikhchandani et al. 2024). In particular, two assumptions require further comment: the limit of $n = 2$ countries and the exogeneity of the sequence of moves among them. In contrast to extant observational learning models which allow the number of agents n to grow arbitrarily large, I fix the number of countries at $n = 2$.[6] Increasing the number of countries would add mathematical complexity without developing further theoretical nuance. The effect of other countries' climate policy adoption behaviors could be accommodated either by changing the prior expected economic gains from green investments μ or the concavity of the global abatement value function $g(\cdot)$. Moreover, agents' payoffs in most observational learning models are backward-looking as their behavior is only linked through the information conveyed by prior movers, while in this model countries' actions exhibit forward-looking strategic interdependence. See Appendix C for a model with more than 2 countries that resembles this setup.

In a departure from extant collective action approaches to modeling international climate policymaking (e.g., Kennard and Schnakenberg 2023), this model introduces uncertainty about the benefits accrued from climate abatement efforts and sequential moves. Both of these elements are necessary to model the learning mechanism. The endogenous timing of countries' climate actions could stem from heterogeneously precise signals, meaning that some countries have better information about the possibility of a successful green transition than others, or from heterogeneity in countries' vulnerabilities to climate change's effects; better informed countries would then have incentives to act first (Zhang 1997).

[6]The literature on tensor complementarity in games with multiple players (e.g., Huang and Qi 2017; Guan and Li 2020) demonstrates that an $n > 2$ player interaction can be broken into many $n = 2$ subproblems, which converge on the solution of the $n > 2$ player game. We can consider the results of the $n = 2$ case described herein as converging to a more general $n > 2$ model and when taking the model to data, consider the exogenous ordering of the $n = 2$ countries as arbitrary.

Analysis

First I derive each country's optimal climate effort decision given their expectations about the economic returns from a green transition and the pre-existing international climate policy regime (Proposition 1). I then demonstrate that climate efforts increase in public optimism generated by investments from other nations, but decrease in the level of those efforts by diminishing further marginal contributions. The former effect generates policy complementarities across countries, while the latter engenders substitution effects. Finally, I characterize the conditions under which either of these two factors dominates countries' climate policy decisionmaking process (Proposition 2).

Equilibrium Climate Efforts

To solve for the equilibrium of the model, I conjecture the existence of country 1's strategy $a_1 = \alpha_1(x_1)$ where $\alpha_1(\cdot)$ is one-to-one. Then, for any a_1 that country 2 observes, she can invert to obtain country 1's signal, $x_1 = \alpha_1^{-1}(a_1)$. This means that, conditional on her signal x_2 and country 1's effort level a_1, country 2 believes that $\theta|x_2, a_1 \sim N(\frac{\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2}{\gamma+2\beta}, \frac{1}{\gamma+2\beta})$. Given her private signal x_2 and country 1's effort a_1, country 2's expected utility is

$$u_2(a_2; x_2, a_1) = E[\theta|x_2, a_1]g(a_1 + \lambda a_2) - c(a_2),$$

where her optimal mitigation effort $\alpha_2(x_2, a_1)$ solves the following first-order condition:

$$E[\theta|x_2, a_1]g'(a_1 + \lambda\alpha_2(x_2, a_1))\lambda - c'(\alpha_2(x_2, a_1)) = 0.$$

Country 2 balances her expectations about returns from costly climate investments $E[\theta|x_2, a_1]$ and her marginal value to global climate efforts $\lambda g'(A)$, with the marginal costs of climate policy implementation c_2. Note that if $x_2 < -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1)$ then country 2 has particularly pessimistic signal about the value from exerting effort toward mitigating the effects of climate change, and would exert negative effort because $E[\theta|x_2, a_1] < 0$. Given the functional form specifications, a closed-form solution for country 2's optimal effort is obtained:

$$\alpha_2(x_2, a_1) = \begin{cases} -\frac{1}{\lambda}a_1 + \frac{\lambda(\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2)^2}{4c_2^2(2\beta+\gamma)^2} & x_2 \geq -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1) \\ -\frac{1}{\lambda}a_1 - \frac{\lambda(\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2)^2}{4c_2^2(2\beta+\gamma)^2} & x_2 < -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1) \end{cases}$$

Country 2's mitigation efforts are commensurate with her expectations about a green transition, quantified by her posterior mean $E[\theta|x_2, a_1]$. As her belief in a successful green transition grows, so too does her level of climate investments. Unsurprisingly, $\alpha_2(x_2, a_1)$ is increasing in x_2, country 2's private signal of the economic returns from climate policies. In addition to her own information, country 2's optimal effort depends on the relationship between country 1's effort a_1, which affects $\alpha_2(x_2, a_1)$ through two channels. First, country 1's effort changes country 2's marginal contribution to global mitigation efforts, as seen in the first term of $\alpha_2(x_2, a_1)$. That is, if country 1 has already committed to large emissions reductions, then country 2's policies have a smaller marginal impact on global efforts, thereby creating a temptation to free-ride. In this way, country 1's behavior engenders a substitutability across nations' mitigation actions, which is reminiscent of classical collective action pathologies. However, country 1's effort also affects country 2 through a second channel—her expectations about the benefits from green policies—as seen in the second term of $\alpha_2(x_2, a_1)$ by $\alpha_1^{-1}(a_1)$. When country 1 exerts more effort, it leads country 2 to believe that country 1's signal x_1 was higher, and thus also more optimistic about the economic returns from a green transition, which behooves country 2 to also exert more effort. This latter effect encourages country 2 to adopt more ambitious climate reforms because it induces learning across countries, generating complementarities in actions.

Now consider the problem of country 1, who faces a similar decision but knows that his actions will influence the trajectory of global climate efforts. Given his signal x_1, country 1 has a posterior belief about the state $\theta|x_1 \sim N(\frac{\gamma\mu+\beta x_1}{\gamma+\beta}, \frac{1}{\gamma+\beta})$ and country 2's signal $x_2|x_1 \sim N(\frac{\gamma\mu+\beta x_1}{\gamma+\beta}, \frac{2\beta+\gamma}{\beta(1+\gamma)})$. Since he does not know x_2, country 1 does not know how much effort country 2 will commit to downstream, and thus has expected utility

$$u_1(a_1; x_1) = E_{x_2}\Big[E[\theta|x_1]g(a_1 + \lambda\alpha_2(x_2, a_1))\Big] - c(a_1),$$

and his optimal mitigation effort $\alpha_1(x_1)$ satisfies the following first-order condition:

$$E_{x_2}\Big[E[\theta|x_1]g'(a_1 + \lambda\alpha_2(x_2, a_1))\Big(1 + \lambda\frac{d\alpha_2(x_2, a_1)}{da_1}\Big)\Big] - c'(a_1) = 0.$$

Analogous to country 2, notice that if $x_1 < -\frac{\gamma\mu}{\beta}$ then $E[\theta|x_1] < 0$ and country 1's inference about the returns from climate investments are particularly sour. Given the functional form assumptions, a closed-form solution for country 1's effort can be found, so $\alpha_1(x_1)$ can be expressed as

$$\alpha_1(x_1) = \begin{cases} \frac{\beta\lambda x_1(2\gamma\mu+\beta x_1)+\lambda\gamma^2\mu^2}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} & x_1 \geq -\frac{\gamma\mu}{\beta} \\ \frac{-\beta\lambda x_1(2\gamma\mu+\beta x_1)-\lambda\gamma^2\mu^2}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} & x_1 < -\frac{\gamma\mu}{\beta}. \end{cases}$$

As demonstrated in the formal analysis, country 1's optimal behavior is also determined by the interplay between his own private signal x_1 and subsequent expectations about the economic value of a green transition $E[\theta|x_1]$, the marginal political costs to implementing climate reforms c_1, and his marginal contribution to abatement efforts $g'(A)$. In equilibrium, country 1 balances the temptation to free-ride off of the possible future climate implementation efforts of country 2 with the knowledge that his own inaction could discourage future reforms by sending a bad signal about the viability of a green transition. The following proposition thus summarizes the equilibrium (with formal proofs in Appendix A).

Proposition 1. *There exists a unique equilibrium characterized by the functions $\alpha_1(x_1)$, $\alpha_2(x_2, a_1)$ such that $a_1^* = \alpha_1(x_1)$ and $a_2^* = \alpha_2(x_2, a_1^*)$.*

Since countries only want to engage in costly climate investments if they are sufficiently optimistic that they will pay off, country 1's implementation of climate policy conveys information to country 2 about country 1's belief in a successful green transition. The following corollary demonstrates that country 1's action is informative of the state of the world: the implementation of climate policy is itself a signal to country 2.

Corollary 1. *Country 1's climate policy is informative about θ:*

- *Country 1's equilibrium climate effort is increasing in its signal x_1, $\frac{da_1^*}{dx_1} > 0$;*
- *Country 2's posterior expectation of θ is increasing in country 1's effort, $\frac{dE[\theta|x_2, a_1^*]}{da_1} > 0$.*

Complements and Substitutes

We can now consider the fundamental tradeoff between countries' climate mitigation effort investments. Fix two possible effort levels by country 1, $a_1' > a_1$, and recall that country 2's optimal effort level solves

$$E[\theta|x_2, a_1]g'(a_1 + \lambda a_2)\lambda = c'(a_2).$$

In other words, country 2 trades off the marginal domestic costs of implementation with her beliefs in a successful green transition and her marginal contribution to global abatement efforts. The left-hand side of this equation has two components that are in tension with one another. Given country 1's efforts, country 2's marginal contribution is smaller when country 1 has already invested large amounts of effort into providing the global benefit of mitigation, $g'(a_1' + \lambda a_2) < g'(a_1 + \lambda a_2)$, so there are smaller marginal gains from additional costly abatement, which tempts country 2 to free-ride off of country 1's efforts. This force engenders substitution across countries' climate policies because the effort exerted by country 1 discourages reforms from country 2. However, country 1, having adopted costly climate reforms, signals belief in a successful green transition to country 2, $E[\theta|x_2, a_1'] > E[\theta|x_2, a_1]$, which emboldens country 2 to take climate action, generating complementarities in countries' behavior. By contrast, if country 1's climate investments are small, country 2's marginal contribution is larger, and thus could provide a greater global benefit with its mitigation efforts, but the expected economic returns of such reforms are diminished because country 1's lack of climate action is a signal of his pessimism.

From the vantage point of country 1, his actions are influential in determining the course of global climate investments. On one hand, country 1 could undertake costly mitigation measures, jumpstarting a sizable contribution to international climate cooperation, hoping that its decision to implement reforms will have sufficient informational value to deter country 2 from free-riding. Alternatively, country 1 might wish to avoid the domestic costs of climate policy adoption with the anticipation that country 2 will provide global benefits, although such a move is risky as country 2 could interpret country 1's inaction as a signal that green investments are not worth the costs.[7]

To summarize, countries' actions influence each other through two channels. The temptation to free-ride because of diminished marginal contributions creates a strategic substitutability in countries' climate policies; however, the incentive to learn about a successful green transition by signaling information induces strategic complementarities. Corollary 2 formalizes this discussion by decomposing $\frac{d\alpha_2(x_2,a_1)}{da_1}$ into these two constituent effects and Figure 2 illustrates these comparative statics. The first panel depicts the effects of increasing the effort value of country 1's mitigation policies, holding constant the informational value of such effort, which begets less ambitious climate action from country 2 because her marginal

[7]Given this tradeoff, it might appear that country 2 is always advantaged, as she has more information about the state of the world when choosing how much effort to exert. Country 1's first-mover advantage is that, since his marginal contribution to global mitigation investments is always weakly greater than country 2's, for a strong enough signal x_1, he can guarantee some international effort in the event that country 2 takes minimal action. Even net of its signaling value, a sufficiently optimistic country 1 finds it advantageous to implement climate reforms.

contributions are diminished. The second panel shows that increasing the informational value of country 1's effort, thereby engendering greater optimism about the economic returns from green investments, also inspires more ambitious efforts from country 2, thus documenting complementarities. Finally, the right panel demonstrates the total effect: countries' actions, depending on which mechanism dominates, can either be substitutes or complements.

Corollary 2. *Country 2's optimal mitigation effort is:*

- *Decreasing in the effort value of country 1's effort,* $\frac{\partial \alpha_2(x_2,a_1)}{\partial a_1} \leq 0$*;*
- *Increasing in the informational value of country 1's effort,* $\frac{\partial \alpha_2(x_2,a_1)}{\partial \alpha_1^{-1}(a_1)} \geq 0$*.*

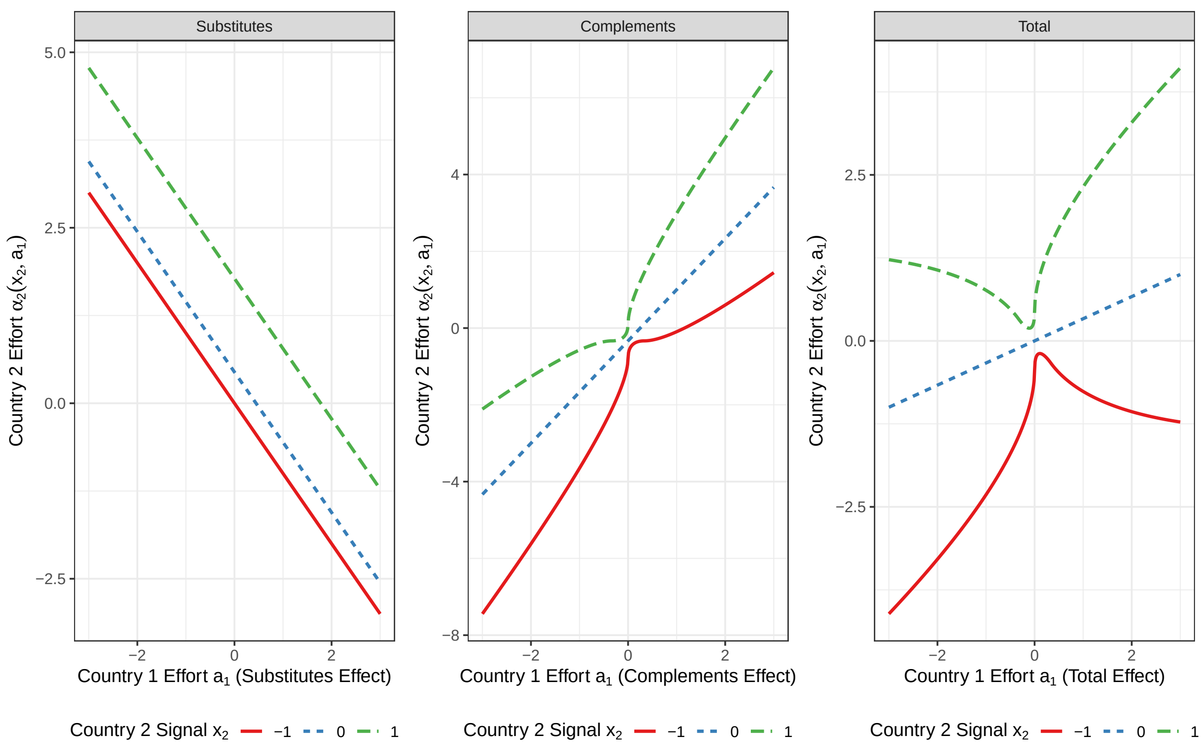

Figure 2: Substitutes and Complements Mechanisms on Climate Mitigation Efforts
$\mu = 0.5$, $\gamma = 1$, $\beta = 1$, $\lambda = 1$, $c_1 = 0.5$, $c_2 = 0.25$

Which factor dominates? Under what conditions are countries' actions strategic complements or strategic substitutes in equilibrium? To conceptualize this, I consider the conditions under which the effects of changing country 1's informational value outweigh the effects of changing his effort value on country 2's decisionmaking. The result is simple: when country 2's posterior update about the success of a green transition, the public optimism from country 1 along with her private signal x_2, dominates her aversion toward exerting costly effort into policies with unknown return, then the learning channel that engenders strategic complementarities is stronger than the free-riding channel that generates strategic substitutes. Alternatively, when the risk involved in implementing green policies is large—the returns to such investments are unknown and their implementation is domestically politically costly—then substitution effects are likely to dominate learning incentives.

Proposition 2. *Complementarity effects dominate substitution effects when public optimism is large relative to the risks of green policy investment,*

$$\frac{\beta}{|\gamma\mu + \beta\alpha_1^{-1}(a_1) + \beta x_2|} < -\frac{g''(A)}{g'(A)}.$$

Proposition 2 states, in reduced form, which mechanism—the substitution effect or the learning effect—is dominant in country 2's climate policy decisionmaking. These two mechanisms are both always operant, but the proposition determines which outweighs the other. That is, it tells us the sign of the correlation between countries' climate efforts. Moreover, the proposition states that we can assess the competing effects of complementarity and substitutability based on the interplay between public assessments of optimism toward green policy and the induced risk that comes with implementing costly mitigation policies with unknown economic returns. The left-hand side of the inequality approximates the inverse of country 2's expectations about θ, which is her informational value of making costly climate investments, while the right-hand side is a measure of country 2's "risk aversion." Since the economic value of the green transition is unknown, the value of country 1's effort on country

2's posterior update must outweigh her tolerance for implementing policies with uncertain returns in order for the total effect of country 1's effort on her own effort to be positive. The result also underscores that uncertainty exacerbates the temptation to free-ride (McAllister and Schnakenberg 2022): if country 2 becomes less willing to tolerate the uncertainties of the green transition's benefits, thereby decreasing the right-hand side of the inequality, country 2's incentive to free-ride becomes stronger relative to her incentive to learn.

Implications of the Learning Mechanism

The theory identifies a learning mechanism that connects the proliferation of climate action to the accretion of beliefs in the success of the green transition. In particular, the model generates two implications connecting beliefs and actions within and across countries. First, a country's beliefs about the success of a green transition should correlate positively with its effort, $cor(x_i, a_i) > 0$. Moreover, if the learning mechanism is operant, a country's beliefs should also positively correlate with the effort of others in reduced form, $cor(x_i, a_j) > 0$. This section teases out these implications of the learning mechanism by studying the relationship between beliefs and subsequent climate policy stringency.

Since the model's information structure is sparse, I empirically enrich the context by examining both mass-level and elite-level beliefs. For mass beliefs, I employ repeated cross-sectional data from Eurobarometer and AmericasBarometer (LAPOP), which have asked whether respondents think climate change is a serious problem (1-4 scale) over several surveys between 2011 and 2021 for Eurobarometer and between 2016 and 2023 for Americas-Barometer. In total, data is available for 31 countries across Europe and Latin America. This data is valuable because it allows for measurement of beliefs within countries over time to assess learning dynamics and helps to uncover how citizens' beliefs covary with the policy stringency of their countries. Moreover, we might think of the private beliefs that countries hold in the model as a function of public opinion sentiments. Citizen beliefs about the importance of climate change can facilitate action (Melnick 2025), and empirical studies of public opinion have concluded that climate policy is fairly responsive to mass beliefs (Bromley-Trujillo and Poe 2020; Schaffer, Oehl and Bernauer 2022).

For elite beliefs, I make use of a survey of approximately 900 climate negotiators and climate scientists compiled between September 2020 and January 2021 which constitutes one of the largest samples of climate policy elites ever systematically polled (Victor, Lumkowsky and Dannenberg 2022). Respondents were asked to assess the ambition of nationally determined contributions for 10 different countries (relative to the country's economic strength) as well as their confidence that each country would fulfill their nationally determined contribution (1-5 scale). These survey items assist in examining the second implication of the model—whether respondent beliefs ultimately predict the policy stringency of other nations given the climate commitments that each country had set prior—as we could imagine countries making further remediation efforts after their stating their climate commitments with belief updating in between (cf. Melnick and Smith 2025). Unfortunately, each respondent was only surveyed once, so we cannot assess the dynamics of negotiators' beliefs, but I leverage within-respondent variation in negotiators' assessments of multiple countries' climate commitments to study the relationship between beliefs and policy stringency.

Beginning with mass beliefs, I examine the mean and variance over time on how respondents assess the seriousness of climate change. This exercise allows us to examine belief dynamics: if countries are learning, then the variance in respondents' beliefs should decrease, and the average seriousness of climate change should converge to the truth.[8] In Figure 3,

[8]This extrapolates slightly from the model since the theory does not generate results about convergence—although the model does imply full information transition from country 1 to country 2, so if this game were repeated across more countries then beliefs should converge on the true value of θ—but over time we should observe a convergence of average seriousness to the truth as well as a decline in variance of beliefs. The dynamic model developed in Appendix C does however produce results about belief convergence that are consistent with the results in Figure 3.

pooled means and variances over time are in red while country-specific trends are in grey. The top panels of the figure show that over time, there is a slight increase in the average seriousness rating that respondents assign to the problem of climate change. In the bottom panels of the figure, the variances across respondents are fairly constant in Europe, but the variance is slightly decreasing in Latin America.

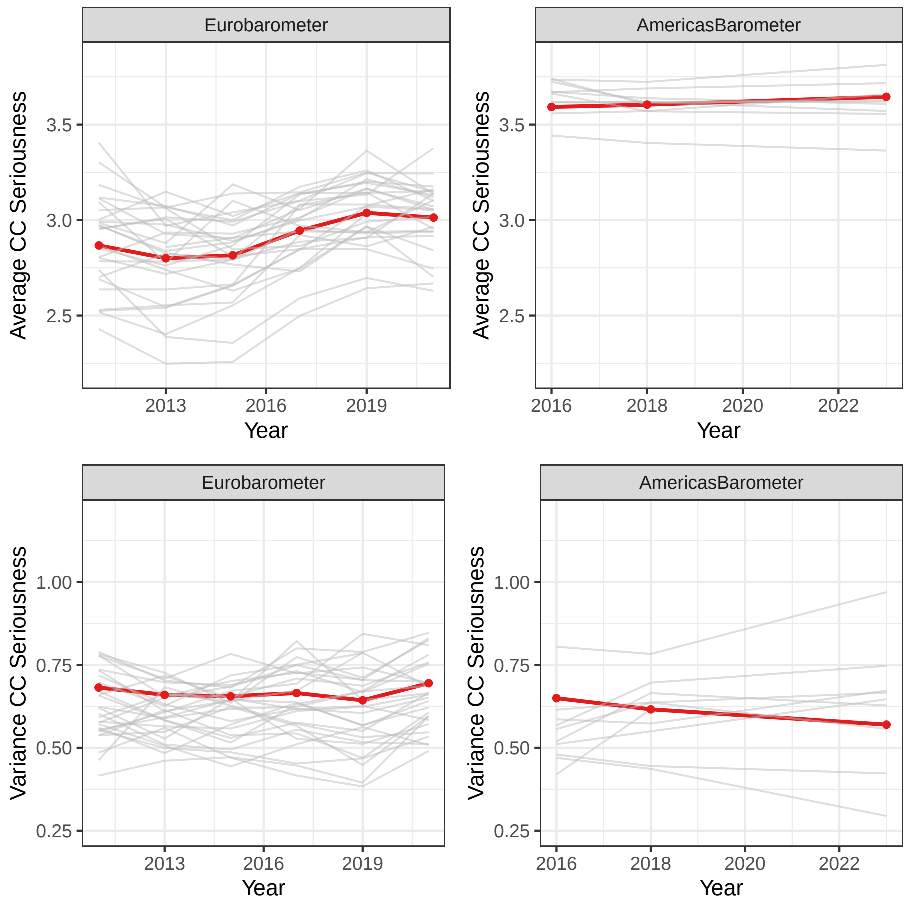

Figure 3: Mass Belief Means and Variances of Climate Change Seriousness

To think about the theory's implications for the mapping between beliefs and effort, I estimate the following regression for respondent i living in country c surveyed in year t:

$$\text{Stringency}_{ct} = \beta \text{ CC Serious}_{ict} + \alpha_c + \lambda_t + \varepsilon_{ict},$$

where stringency is measured using both the EPS and the CAPMF, as in empirical assessment 2. The independent variable is the extent to which respondent i judged climate change to be a serious problem, which higher values indicating greater seriousness. I also estimate country and year fixed effects and cluster standard errors by country. This regression specification seeks to establish empirical evidence consistent with the model's first implication, concerning the relationship between beliefs and effort within countries.

	EPS (1)	CAPMF (2)
CC Serious Problem	0.006	0.011^{***}
	(0.004)	(0.003)
Number of Countries	22	31
Observations	130,665	172,946
R^2	0.879	0.964
Within R^2	0.0005	0.002
Country fixed effects	✓	✓
Year fixed effects	✓	✓

Table 3: Mass Beliefs and Climate Policy Stringency

Table 3 displays the results and demonstrates that there is a positive correlation between a respondent's assessment of the serious of climate change and the stringency of policy that the country's government has undertaken. Consistent with the model, within countries, respondents' private beliefs positively covary with policy stringency. This effect is not statistically significant when measuring policy stringency using the EPS but it is statistically significant when using the CAPMF (which has greater temporal and geographic coverage). Results are robust to aggregation to the country-year level rather than analyzing at the respondent level (see Table A.5).

Turning to elite beliefs, I consider how climate negotiators and scientists assess the nationally determined contributions of other nations and correlate these beliefs with the subsequent future behavior of those nations. Respondents were asked to assess pledges made by Australia, Brazil, China, the European Union, India, Russia, Saudi Arabia, South Africa, the United States, and their own country. For respondent i assessing the commitment of country c, I estimate the following regression:

$$\text{Stringency}_{ct} = \beta \text{ Beliefs}_{ic} + \alpha_i + \eta_c + \varepsilon_{ic},$$

where stringency is country c's CAPMF score in year t (either 2021, 2022, or 2023), and respondent i's beliefs are either their assessment of country c's ambition or the confidence that country c will fulfill its nationally determined contribution. I also estimate respondent fixed effects to control for any person-specific biases in assessments as well as country fixed effects to capture baseline levels of variation in the ambition in countries' climate commitments. Standard errors are clustered at the respondent level.

In Figure 4, the top row of panels indicates that respondents' beliefs about the ambition of countries' climate commitments is positively correlated, at statistically significant levels, with the ultimate policy measures that countries undertake. These results bolster confidence in the learning mechanism by considering the second empirical implication: as countries' private beliefs increase, other nations are also on average more likely to exert more effort. This reduced-form relationship works because survey respondents have updated posterior beliefs about the success of the green transition given nations' climate commitments, which then correlate with sustained climate efforts downstream.

Moreover, when disaggregating the effect by policy negotiators versus climate scientists, both groups are optimistic about the ambition of countries' climate commitments although scientists' beliefs are more strongly correlated with nations' future mitigation measures. In the bottom rows, there is again a positive and statistically significant correlation between respondents' beliefs that nations will fulfill their commitments and the stringency of cli-

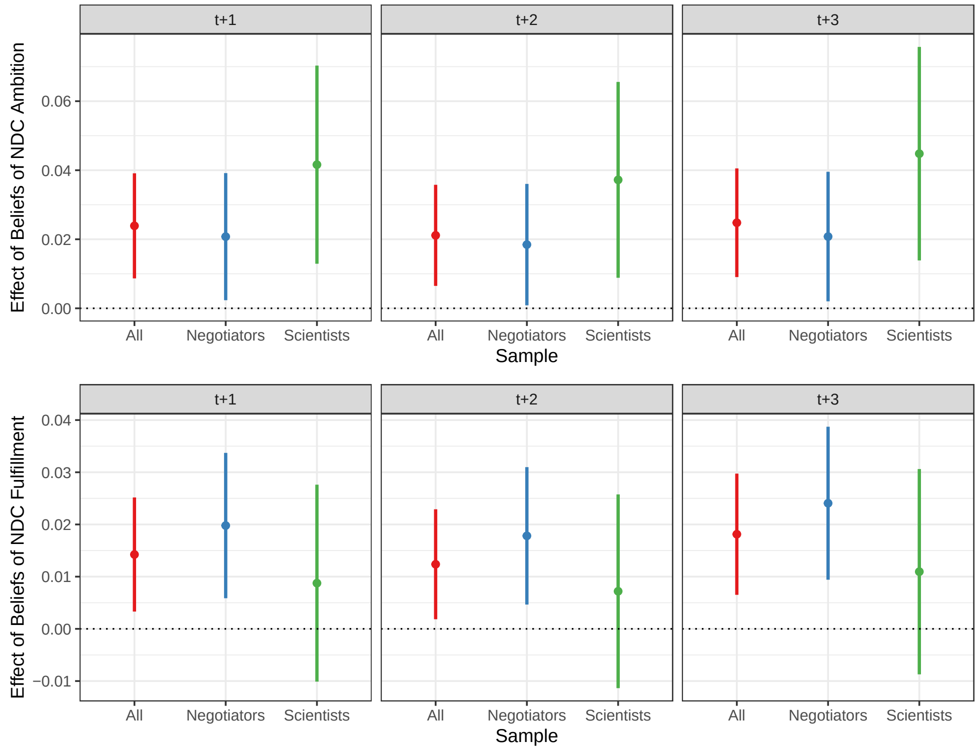

Figure 4: Elite Beliefs and Climate Policy Stringency

mate policy. This effect appears to be driven by climate negotiators rather than scientists; scientist confidence in commitment fulfillment is still positively correlated with policy stringency although weakly so, and this correlation fails to reach conventional levels of statistical significance.

These results provide evidence of a learning mechanism that connects private beliefs to climate mitigation efforts. They complement the empirical assessments presented at the beginning of the paper by documenting how positive correlations in countries' mitigation efforts might arise. Consistent with the theory, there is a positive correlation between mass and elite beliefs and climate policy stringency. Moreover, these results are useful to disentangle between mechanisms because if the free-riding mechanism were dominant, we should not expect to see any relationship between beliefs and the actions of other nations.

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Appendix: Climate Change Policy is in Season: Complementarities in Global Climate Action

Contents

A Formal Proofs

Proof of Proposition 1. To solve for the equilibrium, I conjecture the existence of a strategy for country 1 $a_1 = \alpha_1(x_1)$ and assume that $\alpha_1(x_1)$ is one-to-one. Proceeding by backward induction first consider country 2's effort investment given her signal x_2 and country 1's effort a_1. Given that $\alpha_1(x_1)$ is one-to-one, we have $x_1 = \alpha_1^{-1}(a_1)$ and so country 2's posterior update about θ is $\theta|x_2, a_1 \sim N(\frac{\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2}{\gamma+2\beta}, \frac{1}{\gamma+2\beta})$. Country 2 therefore solves

$$\max_{a_2} \; E[\theta|x_2, a_1]g(a_1 + \lambda a_2) - c(a_2).$$

Differentiating with respect to a_2, country 2's first-order condition is

$$E[\theta|x_2, a_1]g'(a_1 + \lambda a_2)\lambda - c'(a_2) = 0.$$

Note that if $E[\theta|x_2, a_1] < 0$, which occurs when $x_2 < -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1)$ then $E[\theta|x_2, a_1] < 0$ and country 2 exerts effort in the opposite direction. Given the functional form specifications and solving the above first-order condition, we have the following piecewise function:

$$\alpha_2(x_2, a_1) = \begin{cases} -\frac{1}{\lambda}a_1 + \frac{\lambda(\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2)^2}{4c_2^2(2\beta+\gamma)^2} & x_2 \geq -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1) \\ -\frac{1}{\lambda}a_1 - \frac{\lambda(\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2)^2}{4c_2^2(2\beta+\gamma)^2} & x_2 < -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1) \end{cases}$$

It is clear from the second-order condition that for any x_2 and any a_1, $\alpha_2(x_2, a_1)$ is unique as the second-order condition as always negative:

$$E[\theta|x_2, a_1]g''(a_1 + \lambda a_2)\lambda^2 - c''(a_2) < 0.$$

Now consider country 1's effort choice. Given his own signal x_1, he believes that $\theta|x_1 \sim N(\frac{\gamma\mu+\beta x_1}{\gamma+\beta}, \frac{1}{\gamma+\beta})$ and that country 2's signal $x_2|x_1 \sim N(\frac{\gamma\mu+\beta x_1}{\gamma+\beta}, \frac{2\beta+\gamma}{\beta(1+\gamma)})$. Let $m = \frac{\gamma\mu+\beta x_1}{\gamma+\beta}$ and $z = \sqrt{\frac{\beta(1+\gamma)}{2\beta+\gamma}}$. Further, denote $q = \frac{\lambda(\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2)^2}{4c_2^2(2\beta+\gamma)^2}$ and $t = -\frac{\gamma\mu}{\beta} - \alpha_1^{-1}(a_1)$. By backward induction, country 1's problem is to maximize

$$\max_{a_1} \int_{-\infty}^{t} \Big[mg(-q)z\phi(z(x_2 - m))\Big] \; dx_2 + \int_{t}^{\infty} \Big[mg(q)z\phi(z(x_2 - m))\Big] \; dx_2 - c(a_1).$$

Differentiating with respect to a_1, country 1's first-order condition is

$$\begin{aligned} FOC = {} & mg(0)z\phi(z(t-m))\frac{dt}{da_1} + \int_{-\infty}^{t} -mg'(-q)\frac{dq}{da_1}z\phi(z(x_2 - m)) \; dx_2 \\ & - mg(0)z\phi(z(t-m))\frac{dt}{da_1} + \int_{t}^{\infty} mg'(q)\frac{dq}{da_1}z\phi(z(x_2 - m)) \; dx_2 - c_1 = 0 \\ = {} & \int_{-\infty}^{t} \frac{m\beta\lambda}{2c_2(2\beta+\gamma)} \frac{1}{\alpha_1'(\alpha_1^{-1}(a_1))} z\phi(z(x_2 - m)) \; dx_2 \end{aligned}$$

$$+\int_t^\infty \frac{m\beta\lambda}{2c_2(2\beta+\gamma)} \frac{1}{\alpha_1'(\alpha_1^{-1}(a_1))} z\phi(z(x_2-m))\ dx_2 - c_1 = 0$$
$$\Leftrightarrow\ \alpha_1'(\alpha_1^{-1}(a_1)) = \frac{(\gamma\mu+\beta x_1)\beta\lambda}{2c_2c_1(2\beta+\gamma)(\gamma+\beta)}.$$

Observe that for $x_1 < -\frac{\mu\gamma}{\beta}$, $m < 0$ and so country 1 would then exert effort in the negative direction. By equilibrium conjecture, $a_1 = \alpha_1(x_1)$ so $\alpha_1^{-1}(a_1) = x_1$ and integrating with respect to x_1 yields

$$\alpha_1(x_1) = \frac{\beta\lambda x_1(2\gamma\mu+\beta x_1)}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} + C.$$

The constant of integration is pinned down by the boundary condition that, at $x_1 = -\frac{\gamma\mu}{\beta}$, we have $E[\theta|x_1] = 0$. The equilibrium effort is thus

$$\alpha_1(x_1) = \begin{cases} \frac{\beta\lambda x_1(2\gamma\mu+\beta x_1)+\lambda\gamma^2\mu^2}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} & x_1 \geq -\frac{\gamma\mu}{\beta} \\ \frac{-\beta\lambda x_1(2\gamma\mu+\beta x_1)-\lambda\gamma^2\mu^2}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} & x_1 < -\frac{\gamma\mu}{\beta}. \end{cases}$$

Note that this is one-to-one in x_1, confirming that $\alpha_1(x_1)$ is one-to-one in equilibrium. This means that $\alpha_1^{*^{-1}}(\cdot)$ is well-defined so country 2 knows $x_1 = \alpha_1^{*^{-1}}(a_1)$ in equilibrium.

Finally, observe that the second order condition is

$$-\frac{m\beta\lambda}{2c_2(2\beta+\gamma)} \frac{\alpha_1''(\alpha_1^{-1}(a_1))}{(\alpha_1'(\alpha_1^{-1}(a_1)))^3} < 0,$$

so the solution $\alpha_1(x_1)$ is the unique maximizer of country 1's utility. □

Proof of Corollary 1. Immediate given the equilibrium strategy of country 1:

$$\frac{d\alpha_1(x_1)}{dx_1} = \frac{2\beta\lambda(\gamma\mu+\beta x_1)}{4c_1c_2(2\beta^2+3\beta\gamma+\gamma^2)} \geq 0.$$
$$\frac{dE[\theta|x_2,a_1]}{da_1} = \frac{\beta}{\beta+\gamma}\frac{1}{\frac{d\alpha_1(x_1)}{dx_1}} \geq 0.$$

□

Proof of Corollary 2. Given country 2's first-order condition,

$$\frac{\partial^2 u_2}{\partial a_2 \partial \alpha_1^{-1}(a_1)} = \frac{\beta}{\gamma+2\beta} g'(a_1+\lambda a_2)\lambda > 0 \ \Leftrightarrow\ \frac{\partial \alpha_2(x_2,a_1)}{\partial \alpha_1^{-1}(a_1)} \geq 0.$$
$$\frac{\partial^2 u_2}{\partial a_2 \partial a_1} = E[\theta|x_2,a_1]g''(a_1+\lambda a_2)\lambda < 0 \ \Leftrightarrow\ \frac{\partial \alpha_2(x_2,a_1)}{\partial a_1} \leq 0.$$

□

Proof of Proposition 2. From Corollary 2,

$$\begin{aligned}
&\Big|\frac{\partial\alpha_2(x_2,a_1)}{\partial\alpha_1^{-1}(a_1)}\Big| > \Big|\frac{\partial\alpha_2(x_2,a_1)}{\partial a_1}\Big| \\
\Leftrightarrow\ &\frac{\beta}{\gamma+2\beta}g'(a_1+\lambda a_2)\lambda < -|E[\theta|x_2,a_1]|g''(a_1+\lambda a_2)\lambda \\
\Leftrightarrow\ &\frac{\beta}{|\gamma\mu+\beta\alpha_1^{-1}(a_1)+\beta x_2|} < -\frac{g''(A)}{g'(A)}.
\end{aligned}$$

□

B Additional Tables and Figures

	Adopt (Binary)			
	(1)	(2)	(3)	(4)
Previous Other Laws	-0.012	0.053	0.563***	0.239
	(0.096)	(0.139)	(0.148)	(0.265)
Previous Other Laws × Post-Paris	0.269**	0.095		
	(0.124)	(0.157)		
Previous Other Laws × Post-Kyoto			-0.545***	-0.133
			(0.166)	(0.269)
Other Laws	Logged Count	Average	Logged Count	Average
Observations	6,449	6,449	6,449	6,449
R^2	0.423	0.423	0.423	0.423
Within R^2	0.0003	0.0002	0.0004	0.0002
Country fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Table A.1: Effect of Previous Laws on Climate Law Adoption by Agreement Timing
Standard errors clustered by country in parentheses

The following tables demonstrate that the results of the empirical assessment 2, which relates climate policy stringency of country i to the average stringency of countries $-i$, is robust to several modifications. Tables A.2 and A.3 demonstrate that results are robust to weighting policy stringency variables either by log GDP per capita or log GHG emissions per capita, which eases concerns about results being driven by less relevant countries. Table A.4 shows robustness to measuring the behavior of other nations at the median rather than the average policy stringency, which eases concerns about extreme values.

	Environmental Policy Stringency					
	(1)	(2)	(3)	(4)	(5)	(6)
Avg. Stringency × GDP	0.768***	0.253	0.856***			
	(0.137)	(0.191)	(0.137)			
Avg. Stringency × GHG				0.871***	0.284	0.927***
				(0.143)	(0.193)	(0.154)
Observations	1,195	1,195	1,195	1,195	1,195	1,195
R^2	0.893	0.895	0.945	0.875	0.877	0.936
Within R^2	0.794	0.800	0.895	0.740	0.745	0.866
Country fixed effects	✓	✓	✓	✓	✓	✓
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Linear	Cubic	Country × Year	Linear	Cubic	Country × Year

Table A.2: Effect of Weighted Average Global Policy Stringency on Environmental Policy Stringency
Standard errors clustered by country in parentheses

	Climate Action and Policies Measurement Framework					
	(1)	(2)	(3)	(4)	(5)	(6)
Avg. Stringency × GDP	0.878***	0.922***	0.977***			
	(0.066)	(0.086)	(0.060)			
Avg. Stringency × GHG				0.875***	0.859***	0.943***
				(0.088)	(0.096)	(0.079)
Observations	1,504	1,504	1,504	1,504	1,504	1,504
R^2	0.925	0.925	0.981	0.894	0.894	0.973
Within R^2	0.909	0.909	0.976	0.862	0.862	0.965
Country fixed effects	✓	✓	✓	✓	✓	✓
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Linear	Cubic	Country × Year	Linear	Cubic	Country × Year

Table A.3: Effect of Weighted Average Global Policy Stringency on CAPMF
Standard errors clustered by country in parentheses

	Environmental Policy Stringency			CAPMF		
	(1)	(2)	(3)	(4)	(5)	(6)
Median Stringency	0.567***	0.347***	0.607***	0.906***	0.887***	0.957***
	(0.104)	(0.121)	(0.102)	(0.068)	(0.077)	(0.068)
Observations	1,195	1,195	1,195	1,504	1,504	1,504
R^2	0.891	0.893	0.935	0.939	0.939	0.977
Within R^2	0.806	0.809	0.884	0.929	0.929	0.973
Country fixed effects	✓	✓	✓	✓	✓	✓
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Linear	Cubic	Country × Year	Linear	Cubic	Country × Year

Table A.4: Effect of Median Global Policy Stringency on Policy Stringency
Standard errors clustered by country in parentheses

C Alternative Model with $n > 2$ Countries

The model in the main text assumes a two-country interaction. The theoretical purchase of this approach was that it allowed for a parsimonious study of forward-looking incentives to exert effort or not. In this section, I describe a model that features $n > 2$ countries but remove this strategic interdependence. Similar to observational learning models (Banerjee 1992; Bikhchandani, Hirshleifer and Welch 1992; Smith and Sørensen 2000), countries are

	EPS (1)	CAPMF (2)
CC Serious Problem	0.388	0.709***
	(0.244)	(0.201)
Number of Countries	22	31
Observations	127	168
R^2	0.879	0.963
Within R^2	0.034	0.147
Country fixed effects	✓	✓
Year fixed effects	✓	✓

Table A.5: Mass Beliefs and Climate Policy Stringency (Country-Year Level)

only backward-looking in their valuation of contributions to global effort.

Model Setup

Consider sequential climate policymaking between n countries indexed by $i = 1, \ldots, n$ who decide whether to pursue climate reforms $a_i = 1$ or not $a_i = 0$. The action $a_i = 1$ represents climate reforms or policies instituted to facilitate a green transition in country i, while $a_i = 0$ represents maintaining the status quo. These countries take actions in a fixed order and can observe the choices of all countries before them.

Countries' payoffs to climate reform depend on two uncertain elements: the global benefit to a green transition and the private domestic cost of implementing reforms. The global benefit to a green transition is a binary state variable $\theta \in \{0, 1\}$. No country knows the true realization of θ—whether or not the green transition pays off or will be "successful" is unknown—but share the common prior $P(\theta = 1) = \pi \in (0, 1)$. If a country does not take climate action, it receives a payoff of zero. By taking climate action, country i receives a benefit normalized to 1 only if $\theta = 1$: this captures the idea that countries only want to pursue climate reforms if it is appropriate to do so or if the green transition is sufficiently likely to be successful.

While the benefits of a green transition are state dependent, their costs are not: implementing climate friendly policies is domestically costly—political opportunity costs may arise, perhaps because of redistributive frictions that drive new societal cleavages (Aklin and Mildenberger 2020; Colgan, Green and Hale 2021) or because large polluters face greater costs to adjust their mitigation burdens—and choosing $a_i = 1$ comes at a cost $c_i \sim U[0, 1]$. These costs represent the domestic political feasibility of the green transition. Formally, these costs create heterogeneity in preferences for climate policy across countries (Goeree, Palfrey and Rogers 2006). Country i's costs of implementation are privately known, drawn independently for each country, and are independent of θ.

There are two information sources that countries have at their disposal when determining whether to implement climate policy. The first is the history of observed actions, $h_i = (a_1, \dots a_{i-1})$. Countries learn about the suitability of green policy θ through the behavior of others. They also receive conditionally independent private signals, which, along with the prior, generate private beliefs $p_i \in [0, 1]$. I work with these beliefs rather than signals and the prior π directly (p_i is a sufficient statistic). These beliefs are not publicly known, but insofar as they translate into actions they may partially inferred. Let the cumulative distribution function of a private belief p in state θ be $F(p|\theta)$ with density $f(p|\theta)$ such that $F(p|1) < F(p|0)$.[1]

Given some history of countries' climate policies h_i, define the public belief $P(\theta = 1|h_i)$ as the informational content about the suitability of the green transition. There is an associated public likelihood ratio $\ell_i = \frac{1-P(\theta=1|h_i)}{P(\theta=1|h_i)}$ such that lower values of ℓ_i imply a greater likelihood that $\theta = 1$, or that a green transition would be successful.

The climate problem is often described as one of strategic substitutes because it is nationally costly to exert effort to address climate change despite that this effort provides a global benefit. To capture this tension, I introduce *collective action penalties*, which are action-specific, history-dependent costs (Eyster et al. 2014). It becomes more costly to pursue climate reform if many other countries have done so already. In reduced form, these penalties capture the strategic substitutability of climate actions across countries present in other models. Denote collective actions penalties as $z(h_i)$ (and suppress dependence on h_i where it is not confusing). This function is increasing in the number of countries who have already taken climate action, or $\sum h_i$. For simplicity, assume the penalty is bounded, $z_i \in [0, 1]$; since the domestic costs c_i are on the same scale, there is no explicit assumption as to whether implementation costs are greater than collective action penalties. As an example, consider a linearly proportional cost function for any country $i \geq 2$ (with $z_1 = 0$),

$$z_i = \frac{\sum h_i}{i-1}.$$

In countries' payoffs I scale these externalities by $k > 0$ in order to parameterize the extent to which countries weigh potential complementarities (generated by information about θ) and potential substitutes (generated by collective action penalties). This parameter can be thought of as scaling the extent to which countries internalize free-riding concerns; larger k implies stronger free-riding incentives as collective action penalties are weighted more heavily.

Given this setup, country i's payoff can be written as

$$u_i(a_i, h_i, \theta; c_i) = a_i(\theta - c_i - kz(h_i)).$$

A strategy for country i is a choice to implement climate reforms or not, $a_i \in \{0, 1\}$,

[1] By Bayes's Rule, the state-conditional densities $f(p|\theta)$ satisfy $p = \frac{\pi f(p|1)}{f(p)}$ and $1 - p = \frac{(1-\pi)f(p|0)}{f(p)}$ with $f(p) = \pi f(p|1) + (1-\pi)f(p|0)$. Then $\frac{f(p|1)}{f(p|0)} = \frac{p}{1-p}\frac{1-\pi}{\pi}$; this stochastic ordering implies that the conditional distributions are mutually absolutely continuous, share the same support, and that $F(p|1) < F(p|0)$ for all private beliefs strictly inside the support.

given the choices of other prior-moving countries contained in history h_i, and its type (p_i, c_i), comprised of its private belief about θ and its domestic costs of implementing green policy. I examine weak perfect Bayesian equilibria and derive all posterior beliefs via Bayes's Rule.

Results and Proofs

Fix a history $h_i = (a_1, \ldots, a_{i-1})$ of past climate policy adoption decisions that induce a public likelihood ratio ℓ_i and potential collective action penalties z_i. Given ℓ_i and the private belief p_i, country i can make an assessment about the appropriateness of climate policy, i's posterior belief that $\theta = 1$ is defined as

$$\mu_i = P(\theta = 1 | p_i, \ell_i) = \frac{p_i}{p_i + (1 - p_i)\ell_i}.$$

Then, country i prefers to implement climate reforms if and only if

$$\begin{aligned} \mu_i - c_i - kz_i &\geq 0 \\ \Leftrightarrow \ \mu_i &\geq c_i + kz_i \\ \Leftrightarrow \ p_i &\geq \frac{\ell_i(c_i + kz_i)}{1 - (c_i + kz_i) + \ell_i(c_i + kz_i)} \ \equiv \ \tilde{p}(c_i, \ell_i). \end{aligned}$$

Country i pursues climate action if and only if their private belief about a successful green transition is sufficiently high, given the domestic political costs of implementing climate reforms and the potential collective action penalties. If $\tilde{p}(c_i, \ell_i) > 1$, then i never takes climate action regardless of the value of p_i, which occurs whenever $c_i > 1 - kz_i \ \equiv \ \bar{c}_i$. Intuitively, if the domestic costs of implementing climate policy are prohibitively high, it does not matter how optimistic i is about the green transition, implementing green policy is not domestically feasible. Then, for any $c_i \in [0, \ \bar{c}_i]$, i pursues climate action if and only if $p_i > \tilde{p}(c_i, \ell_i)$, which occurs with probability $1 - F(\tilde{p}(c_i, \ell_i)|\theta)$.

Proposition A.1. *Let $\alpha^*(a_i|\ell_i, \theta)$ be the probability that country i takes climate action a_i in state θ. Then*

$$\alpha^*(1|\ell_i, \theta) = \int_0^{\bar{c}_i} 1 - F(\tilde{p}(c_i, \ell_i)|\theta) \ dc_i \ = \ 1 - \alpha^*(0|\ell_i, \theta).$$

Lemma A.1. *The threshold $\tilde{p}(c_i, \ell_i)$ is:*

- *increasing in the public likelihood ratio ℓ_i;*
- *increasing in domestic implementation costs c_i;*
- *increasing in collective action penalties z_i;*
- *increasing in the strength of free-riding incentives k.*

Proof of Lemma A.1.

$$\begin{aligned}
\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial \ell_i} &= \frac{(1-c_i-kz_i)(c_i+kz_i)}{(1-(c_i+kz_i)+\ell_i(c_i+kz_i))^2} \;\geq\; 0. \\
\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial c_i} &= \frac{\ell_i}{(1-(c_i+kz_i)+\ell_i(c_i+kz_i))^2} \;\geq\; 0. \\
\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial z_i} &= \frac{k\ell_i}{(1-(c_i+kz_i)+\ell_i(c_i+kz_i))^2} \;\geq\; 0. \\
\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial k} &= \frac{\ell_i z_i}{(1-(c_i+kz_i)+\ell_i(c_i+kz_i))^2} \;\geq\; 0.
\end{aligned}$$

□

Proof of Proposition A.1. Immediate from text. □

Corollary A.1. *Climate policy is informative about θ. The probability of climate action is greater when $\theta = 1$ versus $\theta = 0$: $\alpha^*(1,\ell_i,1) > \alpha^*(1,\ell_i,0)$. The probability of climate inaction is greater when $\theta = 0$ versus $\theta = 1$: $\alpha^*(0,\ell_i,1) < \alpha^*(0,\ell_i,0)$.*

Proof of Corollary A.1.

$$\begin{aligned}
\alpha^*(1|\ell_i,1) - \alpha^*(1|\ell_i,0) &= \Big(\int_0^{\bar{c}_i} 1 - F(\tilde{p}(c_i,\ell_i)|1)\; dc_i\Big) - \Big(\int_0^{\bar{c}_i} 1 - F(\tilde{p}(c_i,\ell_i)|0)\; dc_i\Big) \\
&= \int_0^{\bar{c}_i} F(\tilde{p}(c_i,\ell_i)|0) - F(\tilde{p}(c_i,\ell_i)|1)\; dc_i > 0,
\end{aligned}$$

where the result follows from the stochastic ordering of private beliefs. □

Corollary A.2. *The probability of climate action is increasing in the public optimism about a successful green transition, $\frac{d\alpha^*(1|\ell_i,\theta)}{d\ell_i} \leq 0$.*

Proof of Corollary A.2. Differentiating with respect to ℓ_i yields

$$\frac{d\alpha^*(1|\ell_i,\theta)}{d\ell_i} = -\int_0^{\bar{c}_i} f(\tilde{p}(c_i,\ell_i)|\theta)\frac{\partial \tilde{p}_i}{\partial \ell_i}\; dc_i \leq 0.$$

□

Corollary A.3. *The probability of climate action is decreasing in collective action penalties, $\frac{d\alpha^*(1|\ell_i,\theta)}{dz_i} \leq 0$.*

Proof of Corollary A.3. By the Leibniz integral rule, differentiating with respect to z_i yields

$$\begin{aligned}\frac{d\alpha^*(1|\ell_i,\theta)}{dz_i} &= \frac{\partial \bar{c}_i}{\partial z_i} - F(\tilde{p}(\bar{c}_i,\ell_i)|\theta)\frac{\partial \bar{c}_i}{\partial z_i} - \int_0^{\bar{c}_i} f(\tilde{p}(c_i,\ell_i)|\theta)\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial z_i}\ dc_i \\ &= -\int_0^{\bar{c}_i} f(\tilde{p}(c_i,\ell_i)|\theta)\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial z_i}\ dc_i \leq 0.\end{aligned}$$

where the first two terms simplify because $\tilde{p}(\bar{c}_i,\ell_i) = 1$. □

Corollary A.2 states that more optimistic public beliefs about a successful green transition begets more climate action. That is, these beliefs endogenously generate *complementarities* in countries' climate actions. Conversely, increased collective action penalties—which arise because more countries have already pursued climate policies—depress subsequent climate action, as stated in Corollary A.3. The actions of prior movers induce *substitution* in the behavior of later policymakers.

Which factor dominates? Under what conditions are countries' actions strategic complements or strategic substitutes in equilibrium? To conceptualize this, I consider the ratio of the marginal effects of public beliefs and collective action penalties. Define $\rho(\ell_i, z_i|\theta)$ as

$$\rho(\ell_i, z_i|\theta) = \frac{d\alpha^*(1|\ell_i,\theta)}{d\ell_i}\Big/\frac{d\alpha^*(1|\ell_i,\theta)}{dz_i}.$$

The magnitude of $\rho(\ell_i, z_i|\theta)$ is always positive, but we can think about which factor dominates—strategic complementarities that stem from increased public beliefs or strategic substitutes from collective action penalties—based on where it is greater than or less than 1. If $\rho(\ell_i, z_i|\theta) > 1$, then, all else equal, varying public beliefs has a larger effect on the equilibrium probability of climate action than does varying collective action penalties. In this case, we can say that the net effect of other countries' behavior generates complementarities for country i. By contrast, when $\rho(\ell_i, z_i|\theta) < 1$, then the incentives to free ride swamp the potential benefits from climate policy investment.

Proposition A.2. *Complementarity effects dominate when free-riding incentives are small, and substitution effects dominate when free-riding incentives are large: there exists a threshold $\overline{k}_i$ such that if $k < \overline{k}_i$ then $\rho(\ell_i, z_i|\theta) > 1$.*

Proof of Proposition A.2. It follows that

$$\rho(\ell_i, z_i|\theta) > 1 \iff \int_0^{\bar{c}_i} f(\tilde{p}(c_i,\ell_i)|\theta)\frac{\partial \tilde{p}_i}{\partial \ell_i}\ dc_i > \int_0^{\bar{c}_i} f(\tilde{p}(c_i,\ell_i)|\theta)\frac{\partial \tilde{p}(c_i,\ell_i)}{\partial z_i}\ dc_i.$$

Define $Q(k) = (1-(c_i+kz_i)+\ell_i(c_i+kz_i))^2 \geq 0$, which is the denominator of the comparative statics on $\tilde{p}(c_i,\ell_i)$. Simplifying yields

$$\int_0^{\bar{c}_i} \frac{f(\tilde{p}(c_i,\ell_i)|\theta)}{Q(k)}\Big((1-c_i-k_i)(c_i+kz_i) - k\ell_i\Big)\ dc_i > 0.$$

Now note that for any $k < \frac{1}{z_i}$, the integral is well-defined (otherwise $\overline{c}_i = 0$). Furthermore, for any $k < \frac{1}{z_i}$, $\frac{f(\tilde{p}(c_i,\ell_i)|\theta)}{Q(k)} \geq 0$ and we are integrating over a positive interval of the c_i space. So the integrand is negative if and only if

$$(1 - c_i - k_i)(c_i + kz_i) - k\ell_i < 0,$$

which simplifies to $k > \frac{z_i - 2c_i z_i - \ell_i + \sqrt{\ell_i^2 - 2\ell_i z_i + 4c_i\ell_i z_i + z_i^2}}{2z_i^2} \equiv \overline{k}_i$. Hence a sufficient condition for the integrand to be negative is if $k > \overline{k}_i$ which implies that $\rho(\ell_i, z_i|\theta) < 1$. □

We can now use the model to think about the long-run dynamics of climate policy across countries based on the analysis in the previous subsection. We have shown that the decision problem facing each country at the time of climate adoption is static, meaning history-relevant parameters such as ℓ_i and z_i can be treated in reduced form, but now wish to trace the evolution of actions and beliefs across countries.

Since private signals are conditionally independent, the likelihood ratio updates such that

$$\ell_{i+1} = \varphi(a_i, \ell_i) = \ell_i \frac{\alpha^*(a_i|\ell_i, 0)}{\alpha^*(a_i|\ell_i, 1)}.$$

Observe that by Corollary A.1, relative to ℓ_i, ℓ_{i+1} shrinks if $a_i = 1$ but ℓ_{i+1} grows if $a_i = 0$. The public belief becomes more or less optimistic depending on the previous action a_i, which in turn informs the decision to enact climate policy in the subsequent period. Then, given the updated public belief and any additional collective action penalties, country $i+1$ considers the tradeoff between implementing climate reforms and incurring domestic implementation costs and collective action penalties or free-riding, where climate policy occurs with probability $\alpha^*(1|\ell_{i+1}, \theta)$.

As is standard in the informational cascades and herding literature (e.g., Smith and Sørensen 2000), convergence results are stated conditioning on $\theta = 1$. This is also the more interesting case from a substantive perspective anyway, as this is where the tradeoff between the two mechanisms is present.

Lemma A.2. *Conditional on $\theta = 1$, the public likelihood ratio $< \ell_i >$ is a martingale.*

Proof of Lemma A.2. Recall that the public likelihood ratio updates according to

$$\ell_{i+1} = \ell_i \frac{\alpha^*(a_i|\ell_i, 0)}{\alpha^*(a_i|\ell_i, 1)},$$

by the conditional independence of signals. Taking expectations yields

$$\begin{aligned} E[\ell_{i+1}|\ell_1, \ldots, \ell_i, \theta = 1] &= \sum_{a \in \{0,1\}} \alpha^*(a|\ell_i, 1)\ell_i \frac{\alpha^*(a|\ell_i, 0)}{\alpha^*(a|\ell_i, 1)} \\ &= \ell_i \sum_{a \in \{0,1\}} \alpha^*(a|\ell_i, 0) \end{aligned}$$

$$= \ell_i.$$

□

Proposition A.3. *In the limit, countries learn whether the green transition will be successful: public beliefs converge to the true state of the world almost surely.*

Proof of Proposition A.3. Without loss of generality condition on state $\theta = 1$. Since $< \ell_i >$ is a martingale and all values are nonnegative, it converges almost surely to a random variable $\ell_\infty = \lim_{i\to\infty} \ell_i$ with support $[0, \infty)$ by the Martingale Convergence Theorem (Doob 1953). This rules out nonstationary limit beliefs. Since private beliefs p_i are unbounded within $[0, 1]$, then the only stationary finite likelihood ratio in state $\theta = 1$ is 0, so $\ell_\infty \to 0$ almost surely (Smith and Sørensen 2000, Theorem 1). □

Proposition A.4. *In the limit, countries take the correct action $a_i = \theta$ if and only if $c_i \leq \overline{c}_i$.*

Proof of Proposition A.4. Recall that i chooses $a_i = 0$ if $c_i > \overline{c}_i$ for any private belief p_i, which occurs with probability $P(c_i > \overline{c}_i) = kz_i$. This probability is increasing in z_i, which increases in the number of countries that choose $a_i = 1$. Now suppose that $\theta = 1$ and $c_i \leq \overline{c}_i$ so i chooses $a_i = 1$ iff $p_i \geq \tilde{p}(c_i, \ell_i)$. By Proposition A.3, the likelihood ratio converges almost surely to $\ell_i \to 0$. Then we have $\lim_{\ell_i\to 0} \tilde{p}(c_i, \ell_i) = 0$. Hence conditional on $c_i < \overline{c}_i$, i chooses $a_i = 1 = \theta$ for any private belief.

If countries are taking action on a measure zero subset, $\overline{c}_j \to 0$ or $k > \frac{1}{z_j}$ for some $j \leq n$, then countries pool on $a_j = 0\ \forall j, \ldots, n$. □

Corollary A.4. *Let $z_i(h_i) = \frac{\sum h_i}{i-1}$. The probability of climate action converges to $\frac{1}{1+k}$.*

Proof of Corollary A.4. Conditional on state $\theta = 1$, climate action occurs with probability $\overline{c}_i$, as $\tilde{p}(c_i, \ell_i) \to 0$ as $\ell_i \to 0$. Moreover, given that $z_i = \frac{\sum h_i}{i-1}$, it is a linear proportional function of previous actions, so in the limit, $z_i \to \alpha^*(1|\ell_i, \theta)$. Then we have

$$\begin{aligned}
\alpha^*(1|\ell_i, \theta) &= \overline{c}_i = 1 - kz_i \\
&= 1 - k\alpha^*(1|\ell_i, \theta) \\
\Leftrightarrow \quad \alpha^*(1|\ell_i, \theta) &= \frac{1}{1+k}.
\end{aligned}$$

□

Corollary A.5. *In the limit, $\rho(\ell_i, z_i|\theta) > 1$ if $k < 1 - c_i$.*

Proof of Corollary A.5. Per Proposition A.2, a sufficient condition for $\rho(\ell_i, z_i|\theta) > 1$ is $k < \overline{k}_i$ where $\overline{k}_i = \frac{z_i - 2c_i z_i - \ell_i + \sqrt{\ell_i^2 - 2\ell_i z_i + 4c_i \ell_i z_i + z_i^2}}{2z_i^2}$. Then in the long run, $\lim_{\ell_i\to 0} \overline{k}_i = 1 - c_i$. □