Collective Reciprocity and the Failure of Climate Change Mitigation Treaties

Abstract:
Climate change mitigation treaties have failed to induce emissions reductions in participating states. To explain this, I introduce a novel distinction to reciprocity theory, which forms the foundation of mitigation agreements negotiated thus far. These agreements rely on what I call "collective reciprocity," in which defection is punished by the reciprocal withholding of collective goods. Because collective goods are non-excludable, the impact of punishments cannot be limited to the initial defector. This form of reciprocity is weaker than what I call "club reciprocity," in which reciprocal defections occur through the denial of club goods and thus narrowly target the initial defector. While collective reciprocity is sharply limited in the depth or breadth of treaties it can sustain, climate change mitigation requires cooperation that is both deep and broad. I demonstrate the empirical failure of mitigation treaties with a generalized synthetic control. This method compares the emissions trajectories of participating states to a weighted average of non-participant trajectories.

1 Introduction

Climate change is an increasingly severe and urgent global problem. Efforts at international governance, therefore, place a growing priority on mitigation of its worst effects through the proactive reduction of greenhouse gas (GHG) emissions. But the multilateral cooperation required for effective mitigation can be difficult to achieve in the anarchic realm of international affairs, in which no central government exists to enforce agreements. Climate change mitigation treaties have attempted to deal with this dilemma through the well-studied and frequently utilized principle of reciprocity, in which participating states implement emissions cuts at home in return for emissions cuts abroad. In this vein, diplomats have searched for the appropriate balance between treaty depth and breadth, such that the cost of compliance fits the extent of participation across a population of states with varying valuations of costs and benefits.

But there is little evidence of success from the comprehensive climate change mitigation treaties negotiated under this model, which include the Kyoto Protocol (negotiated 1997, effective 2005), the Doha Amendment to the Kyoto Protocol (negotiated 2012, never effective), and the Paris Agreement (negotiated 2015, effective 2016), referred to below as Kyoto, Doha, and Paris respectively.[1] I demonstrate in Section 3 that consequential participation in these treaties' stringent emissions targets is narrow, mostly comprising wealthy democracies likely to cut emissions on their own. In the cases of Kyoto and Doha, a small group of wealthy democracies accepted emissions targets while other states participated only as observers. In the case of Paris, while nearly all states accepted some form of target, only wealthy democracies accepted consequential targets structured like those of Kyoto and Doha. Other states participated with highly conditional or partial targets that left ample room to avoid mitigation. I use logistic regressions to demonstrate the descriptive fact that wealth and democracy are the only clear determinants of accepting consequential mitigation treaty commitments.

Even more importantly, there is no statistically distinguishable causal effect of consequential participation on emissions levels in Kyoto and Paris, the two mitigation treaties that entered into force. In the case of Kyoto, states with targets did not lower emissions more than states without targets, after adjusting for emissions trajectories and participation propensity. In the case of Paris, where nearly all states took on some form of target, states with stringent targets did not lower emissions more than states with weak targets, after adjusting for emissions trajectories and participation propensity. This means that there has not been meaningful treaty compliance or, put more simply, that neither Kyoto nor Paris have lowered GHG emissions levels. I demonstrate this null result with the

[1] I focus on climate change mitigation agreements for which there is some standard of compliance; I omit those that lack individual targets, such as the 1992 United Nations Framework Convention on Climate Change, or those whose system of targets is formally non-binding, such as the 2009 Copenhagen Accord. While Paris targets are non-binding, countries are bound to set targets and take domestic policy measures to pursue them. I also omit agreements on adaptation or other climate topics and agreements that have climate effects but are not primarily focused on climate change mitigation, such as the 1987 Montreal Protocol.

generalized synthetic control method, which weights untreated states by their similarity to treated states in the pre-treatment period, thereby creating an artificial but comparable control unit for each treated state. Neither treaty leads to a significant gap between treated state emissions and synthetic control emissions. In short, climate change mitigation treaties thus far have failed to spread green commitments beyond those states that already have strongly green preferences, and have failed to induce an increase in green behavior in those states that take on green commitments.

To explain this troubling result, I preface the empirical evaluation of these treaties with Section 2's theoretical discussion of the impossible task faced by climate change mitigation treaties in their current form. Negotiators have stressed reciprocity and experimented with various points on the continuum between treaty depth and treaty breadth to try to make reciprocity work. Kyoto and Doha relied on specific reciprocity, pairing each state's targets directly to those of other states and to a strict timeline. Paris relied on diffuse reciprocity, allowing national flexibility on the intensity and timing of cuts while creating constant multilateral pressure for ambition to be ratcheted upwards. But because climate change mitigation is itself a collective benefit, Kyoto, Doha, and Paris have all relied on what I call collective reciprocity, meaning punishment for non-participation and non-compliance through the reciprocal threat of failure to provide the collective good. States are motivated to participate and comply with these treaties only by the collective good that the treaty supplies. Thus, defection is deterred by the implicit threat of treaty failure that could result from other states' reciprocal defection. This is a distinct and less capable version of reciprocity compared to club reciprocity, in which non-participation and non-compliance are punished through the reciprocal withholding of club goods provided by the treaty. Crucially, club reciprocity punishments can be limited to defectors, unlike the non-excludable punishments of collective reciprocity. This increases the credibility of club reciprocity punishments, allowing club reciprocity to sustain costlier cooperation for larger numbers of actors than collective reciprocity. Reciprocity is often credited with major successes in the history of international governance, but most examples of broad and deep cooperation, such as post-WWII trade liberalization, are based on club reciprocity. Moreover, while club reciprocity can often supply benefits at a variety of scales, collective reciprocity may have a floor for effective provision defined by the supply function of the collective good. In the case of climate change, effective mitigation can only be provided by high levels of participation and effort, well above the depth and breadth that collective reciprocity treaties can sustain.

After explaining the dilemma of collective reciprocity and demonstrating its failure to sustain cooperation in the cases of Kyoto, Doha, and Paris, I turn to an alternative case: the Kigali Amendment to the Montreal Protocol (negotiated 2016, effective 2019) in Section 3.4. Kigali extended Montreal's restrictions beyond ozone-depleting emissions to hydrofluorocarbons (HFCs), a potent greenhouse gas that had replaced Montreal-banned chemicals. But Kigali leveraged the club reciprocity architecture of Montreal rather than following the collective reciprocity path of climate change mitigation treaties. In addition to the collective good of HFC emissions cuts, the treaty provided the club good of market access. Unlike a collective good, this club good could be simultaneously denied to defectors and provided to compliers, increasing the credibility of punishment. I find that while Kigali stringent target participation is similar to that of Paris, Kigali sharply decreased HFC emissions among those participants. In short, Kigali has successfully induced significant compliance. The Kigali case serves both as an empirical placebo test and a theoretical counter-example. Empirically, I evaluate Kigali with the same logistic regression and synthetic control models that failed to find effects for Kyoto, Doha, and Paris. This indicates that null effects are the result of the particular cases of climate change mitigation treaties, not of the empirical method. Theoretically, this finding also buttresses my explanation for the failures of Kyoto, Doha, and Paris. Like these treaties, Kigali attempted a costly phase-down of industrial emissions to provide a global collective good. It targeted the same population of states in the same time period. Its starkly different result can best be explained by its different design.

This article advances the field's empirical and theoretical understanding of global climate change mitigation and other efforts at treaty-based goods provision. Empirically, my approach is a unique contribution in the study of climate politics for comparing across treaties, for integrating analysis of participation and compliance, and for using recent advances in synthetic control methodology. This approach can be easily exported to analysis of other treaties. Theoretically, I provide a clear overview of the distinction between collective and club reciprocity that is generally left implicit in the treaty design literature. This distinction is crucial for understanding the problems faced by climate change mitigation treaties. I outline the theoretical determinants, practical limitations, and distinguishing design features of collective versus club reciprocity treaties and their relation to other treaty types. I conclude in Section 4 by addressing alternative future climate change mitigation treaty designs.

2 The Design of International Treaties

Climate change mitigation treaties rely on the implicit threat of treaty failure to encourage participation and compliance. This system, which I call collective reciprocity, is a weak form of treaty enforcement that sharply limits the depth and breadth of potential cooperation. In this section, I outline when this enforcement design tends to be used and specify how it is limited. I follow the Rational Design of International Institutions (RDII) literature, which argues that treaties tend to be efficiently though not deterministically designed (Koremenos et al. 2001). For example, climate change mitigation treaties include dispute resolution systems because they address complex cooperation problems with incentives to cheat and free-ride. And in the absence of a hegemonic enforcer, they have relied on the self-enforcement strategy of reciprocity. While climate change mitigation treaties could be designed around reciprocity based on club goods, states have thus far chosen a more straightforward but limited design: reciprocity based on the collective good of climate change mitigation itself. I also follow Mitchell (1994) in treating treaty design as consequential for treaty efficacy. While collective reciprocity is a simple design that facilitated multilateral negotiation, its shortcomings relative to club reciprocity help to explain the failures of Kyoto and Paris to expand participation or induce compliance, which I demonstrate in Section 3.

Unlike climate change mitigation, many kinds of international cooperation are simple coordination games with no incentive to defect. In fact, about half of international agreements lack any dispute resolution systems, or mechanisms for identifying and adjudicating non-compliance (Koremenos 2007). According to a strict realist view of international agreements, these coordination games are the only successful international agreements. Treaties that push states to act against their narrow self-interest will fail. Effective treaties are possible only under two restrictive conditions. First, while international agreements can solve coordination problems, they cannot solve complex cooperation problems, i.e. mixed motive games such as a prisoners' dilemma. This means that treaties can work if they merely coordinate mutually beneficial activity, but not if they require restraint from potentially rewarding free-riding or defection (Mearsheimer 1994; Krasner 1991). Second, even in coordination games, international agreements cannot support outcomes misaligned with concerns for relative gains or with the balance of power. Even if all benefit, countries will be loath to support a treaty that benefits a rival more, and powerful countries will exert pressure to enact agreements that benefit themselves the most (Grieco 1988; Krasner 1991). Despite realist dismissals, resolving coordination games is no minor accomplishment: states have much to gain from exchanging information, establishing focal points and shared expectations, lowering transaction costs, or addressing shortcomings in partner state capacity (Keohane 1984; Chayes and Chayes 1993). Moreover, international politics provides numerous empirical examples of complex cooperation problems that are solved by international agreements, including trade liberalization and nuclear non-proliferation.

But the realist perspective highlights two important considerations. First, treaties addressing complex cooperation problems confront significant challenges not faced by those addressing coordination problems. In line with the RDII framework, these challenges will directly shape treaty design. The half of treaties that have dispute resolution systems to monitor compliance tend to be those that suffer from incentives for non-compliance. And among treaties with dispute resolution, the structure of punishment for non-compliance (and non-participation) also varies in line with the underlying features of the treaty issue, as I will explore below. Second, any assessment of treaty compliance in cases of complex cooperation must account for selection, i.e., for participation in the treaty (Downs et al. 1996). States with pre-existing interests aligned with a treaty's requirements may sign on to the treaty, but their behavior may not be changed by the signing. States who would not be predisposed to comply with a treaty may simply not sign it. I address this concern by adjusting my compliance analysis for participation propensity in Section 3.

Climate change mitigation treaties are among the half of treaties with dispute resolution systems. Because climate change mitigation is costly and plagued by free-riding, leakage, time inconsistency, and other complex cooperation problems, it is a mixed motive game in which states balance competing incentives to cooperate and to defect. Some examples of mixed motive games that describe classic complex cooperation problems in international relations include collective action (Olson 1965; Olson and Zeckhauser 1966) and hold-up problems (Carnegie 2014, 2015). Treaties addressing these issues need dispute resolution systems to ascertain compliance, but they also need punishment mechanisms to enforce compliance and participation. A few key features determine the possible punishment structures for these treaties. The simplest solution is third-party enforcement. In international anarchy, this can only occur in the scenario outlined by Hegemonic Stability Theory (Gilpin 1981). If a hegemon has a significant interest in treaty success and sufficient power to enforce the treaty at low cost, it may undertake enforcement in pursuit of its own self-interest. This solution does not apply to climate change mitigation treaties. While the United States may have had the hegemonic power to enforce Kyoto if it so chose, it did not do so, and its relative decline since the early 2000s made this possibility even less feasible for Doha and Paris.

Treaties that are not enforced by hegemonic power must be self-enforcing, or enforced by treaty signatories themselves in the Nash Equilibrium of international anarchy (Barrett 1994).[2] Effective self-enforcement is bound by two interdependent constraints. First, punishments for non-participation and non-compliance must be credible despite

[2]Hegemonic Stability Theory could be considered self-enforcement from the perspective of the hegemon, but effectively becomes third-party enforcement from the perspective of other states.

the strong incentives for defection by the punisher itself. In other words, enforcement regimes must be enforceable. Second, punishments must be non-negligible relative to the costs of participation and compliance. If defection is worth the costs imposed by the punishment, enforcement will fail.[3] Insofar as costlier punishments are also costlier for the punisher to execute, these two constraints are in tension.

The principle of reciprocity is a primary mechanism for self-enforcing punishment regimes in international relations; it has been widely used by practitioners and exhaustively studied by scholars (Keohane 1984, 1986).[4] Often known as a Tit for Tat strategy when applied to two-player settings (Axelrod 1984), reciprocity occurs when an actor performs cooperative behavior contingent on roughly equivalent cooperative behavior from another actor. By tying states' participation and compliance to participation and compliance by other states, reciprocity draws a clear link between defection and punishment. The reciprocal defection of a state's counterparts is a punishment that is comparable to the initial defection by size, scope, and issue area. This increases the credibility of punishment as well as ensuring that it is a non-negligible cost relative to the punished behavior.

But strategies of reciprocity are not all alike. I differentiate between two types of reciprocity for providing self-enforcing punishment mechanisms: club reciprocity and collective reciprocity. Only under club reciprocity is it possible to limit the effects of reciprocal defection to the original defector. Club reciprocity, or the denial of club goods to non-participants and non-compliers (Buchanan 1965), is a common and highly effective self-enforcement mechanism. This strategy requires excludable benefits, which are more likely for those cooperation issues that can be reduced to a cluster of bilateral exchanges, any one of which can be ended without affecting others (Oye 1985). These withheld

[3] Scholars disagree about the negligibility of discursive or normative "shaming" punishments (Hafner-Burton 2008). When specifically applied to climate change mitigation agreements, scholars disagree on whether shaming is useful (Tingley and Tomz 2022), has little impact (Barrett and Dannenberg 2016), or can even undermine compliance (Stankovic et al. 2023). I consider discursive punishments to be negligible costs and exclude them my analysis.

[4] Note that research on issue linkage, iterated interaction (Axelrod 1984), or domestic interest groups (Davis 2004; Dai 2005) does not provide an alternative form of punishment mechanism to reciprocity, but rather additional means by which the pre-supposed reciprocity mechanism can become more credible or non-negligible.

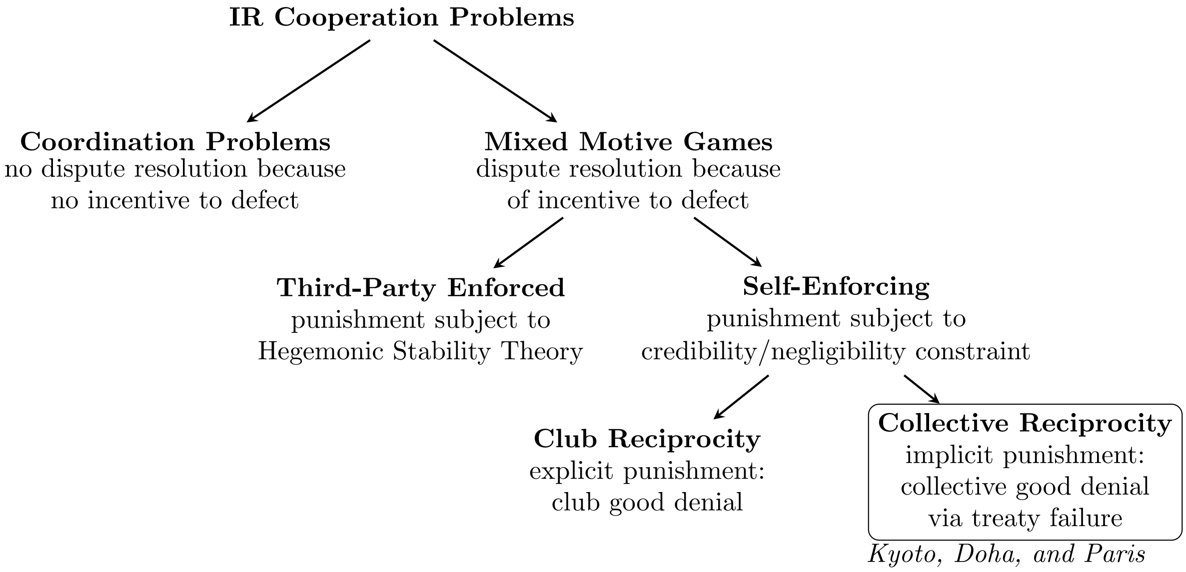
goods can be the main goods that the treaty is focused on supplying, such as open market access in the World Trade Organization, or secondary goods created by the treaty for the purposes of enforcement, such as civilian nuclear power assistance in the Treaty on the Non-Proliferation of Nuclear Weapons. But punishment credibility and non-negligiblity are generally supported by the club good's close relationship to the core treaty issue. Climate change mitigation treaties, however, tend to lack club reciprocity regimes because climate change mitigation itself is a collective good whose benefits cannot be denied to non-participants and non-compliers. Attempts to provide secondary club goods to treaty members, such as Kyoto's marketable emissions credits, were poorly designed and ultimately unenforceable (Victor 2001). While some scholars have proposed reform of emissions trading or the incorporation of bilateral trade restrictions to allow club reciprocity (Barrett 2011; Nordhaus 2015; Barrett and Dannenberg 2022), topics I return to in Section 4, these design elements remains hypothetical.

In short, treaties like Kyoto, Doha, and Paris address complex cooperation issues rather than simple coordination problems, but lack a third-party hegemonic enforcer and lack club goods to deny to non-participants and non-compliers. Thus, while they monitor compliance with dispute resolution systems, they lack a targeted punishment mechanism and rely on what I call collective reciprocity. This means that non-participation and non-compliance are punished only with the implicit threat of treaty failure. States will be motivated to participate and to comply insofar as their doing so contributes to treaty success. This enforcement structure is severely limited.

In line with the RDII framework, club reciprocity and collective reciprocity regimes are generally distinguishable in practice by differences in treaty design. Club reciprocity treaties will have explicit and formal rules for punishing those actors identified as defectors by the dispute resolution process, while collective reciprocity treaties will not.[5] When the structure of the treaty issue enables credible and non-negligible self-enforcing punishments without treaty failure, these punishments will be explicitly specified.

[5] Third-party enforced treaties could also be divided into two groups: those for which the hegemon executes punishments through explicit treaty rules and those which the hegemon enforces through implicit and ad hoc carrots and sticks.

Figure 1: Types of Agreements



The difficulty of supplying collective goods via reciprocity has been widely acknowledged by scholars (Keohane 1986). And the implications of collective reciprocity for environmental agreements, for which lack of club goods is common, have been extensively modeled (Barrett 2005, 2016). Like with club reciprocity, effectiveness is increasing in the value of the good being provided and declining in the cost of treaty participation and compliance. Unlike club reciprocity, collective reciprocity generally works best in small groups. Larger groups make the punishment less credible by decreasing the likelihood that any individual actor's defection will be pivotal to treaty failure (Barrett 1992). Schelling (1978) describes the minimum group for good provision as a "k-group," the size of which is a crucial determinant of cooperation plausibility. Olson (1965) divides collective reciprocity problems into three levels with decreasing success rates. At one end is a privileged group, in which the good can be provided by one actor.[6] Treaties are unnecessary in such a case. Next is an intermediate group, in which the good needs several actors to be supplied, but not so many actors that their individual decisions cannot influence one another. A small intermediate group is the plausible use case for a col-

[6] Along with providing enforcement, as discussed above, Hegemonic Stability theorists also discuss hegemonic provision of goods themselves, in the manner of Olson's privileged group (Kindleberger 1973; Krasner 1976).

lective reciprocity treaty, which can provide focal points and monitoring to identify and highlight effort levels, facilitating joint participation and compliance for fear of causing a cascading collapse or failure. Olson (1965)'s final level is a latent group, in which each actor plays such a small part in the good provision that individual defection can occur in safety, ironically dooming the issue to failure through defection by all.

At first glance, climate change mitigation may appear to be a small intermediate group problem. China, the largest current emitter, is the source of approximately a quarter of yearly global GHG emissions. But the United States, the next largest, only emits about half as much per year. No other state comes close to emitting even a tenth of the global total. Given the drastic cuts to global emissions called for by the IPCC, a large number of states would have to cooperate to effectively mitigate climate change, increasing the safety of any state's defection. Moreover, due to the high costs of serious mitigation, states will only act given a high likelihood that their action will be pivotal. Climate change mitigation cannot be called a pure latent group problem, as some limited unilateral mitigation efforts have taken place and large actors can independently exert some noticeable effect on the global climate. But it can be described as a large intermediate/k-group problem. The large number of necessary actors and a high cost to action make climate change mitigation unlikely to be solved through collective reciprocity.

Because of their use of reciprocity, climate change mitigation treaties have often been discussed through the lens of the well-known depth versus breadth tradeoff, or the similar but more complicated concept of a trilemma between participation breadth, substantive ambition, and compliance levels (Dimitrov et al. 2019; Tørstad 2020). Treaties with high participation must have either low ambition or low compliance so as to be low cost enough that states resist defecting from an agreement that they are not pivotal to. But for collective reciprocity treaties reliant on the threat of failure, this is a partially false tradeoff. While jointly high levels of participation, ambition, and compliance cannot be maintained through collective reciprocity, low levels cannot be maintained either due to the provision function of the collective good. Compliance will necessarily be low unless participation is broad enough and substantive aims are ambitious enough to provide the desired collective good. In other words, if an agreement will fail to provide the good even with full compliance, states will see no reason to comply. But if an agreement is broad and deep enough to effectively provide climate change mitigation, incentives to defect will be irresistible.

Thus, climate change mitigation treaties negotiated thus far have fallen into a difficult dilemma that hinders their participation and compliance and shapes their design. They are plagued by incentives to defect and so must include dispute resolution systems. But they lack a hegemonic backer or club goods with which to enforce compliance rulings from those systems. Climate change mitigation treaties rely on collective reciprocity, encouraging participation and compliance through fear of a global failure to mitigate climate change, either through treaty dissolution or treaty under-performance. But climate change mitigation is a good that can be provided only at high cost and through widespread participation, undercutting the non-negligibility and the credibility of collective reciprocity punishment.

3 The Effects of Treaty Design

Although they share a reliance on collective reciprocity, Kyoto, Doha, and Paris differ in crucial ways. The evolving design of these climate change mitigation treaties reflects an attempt to learn from and improve upon successive failed treaties, as well as a reaction to changes in the structure of the mitigation problem itself. These design differences and changing background conditions can be summarized with a few variables borrowed from the RDII framework: treaty flexibility, decentralization, and breadth have evolved in tandem with the changing certainty, urgency, and breadth of climate change.

While mitigation treaties have been negotiated and implemented, the underlying fundamentals of mitigation have changed along three dimensions. First, the certainty of climate science has continually increased, as new models and technologies have improved the scientific understanding of climate mechanisms and impacts. Second, with the passage of time, the urgency of climate change mitigation, which aims to ameliorate or stave off

Table 1: Treaty Comparison with RDII Variables

	Mitigation Problem Structure			Mitigation Treaty Design		
	Certainty	Urgency	Breadth	Flexibility	Decentralization	Breadth
Kyoto (2005)	low	low	low	medium	medium	medium
Doha (2012)	medium	medium	medium	low	low	low
Paris (2016)	high	high	high	high	high	high

Note: "low," "medium," and "high" designations are relative. Low certainty in 2005, for example, means that climate change knowledge was lower than in 2012 rather than low by an objective standard.

future impacts of current actions, has grown. Together, these developments mean that the importance and necessary intensity of climate change mitigation has grown (Tol 2023). Third, the breadth of emissions cuts necessary for effective climate change mitigation has grown, as robust industrial growth and higher-than-projected population growth in the developing world has undercut any hope that mitigation by rich countries alone could avoid the worst effects of climate change. In short, as the need for climate change mitigation has become monotonically more certain and urgent, the breadth of action necessary for mitigation to be effective has also increased substantially.

The plausibility of successful climate change mitigation treaties enforced through collective reciprocity has been pulled in opposite directions by these changes. Although greater certainty and urgency imply a more valuable collective good and a less negligible collective cost of treaty failure, greater breadth of necessary action requires that punishment remain credible for a greater number of actors, reducing the likelihood that any one state's actions are pivotal. In Section 3.3 below, I trace the concurrent evolution of treaty design and the resulting participation and compliance outcomes of Kyoto, Doha, and Paris. In short, treaty negotiators have attempted various points on the depth versus breadth continuum. But the resulting treaties have been unsuccessful both in eliciting participation from states not already interested in mitigation and in pushing participant states to comply by cutting emissions. Before showing this, I specify my empirical design, data, and scope in Sections 3.1 and 3.2.

3.1 Empirical Framework

A fundamental challenge in assessing treaty compliance by observing state behavior is discerning between simultaneous determinants of behavior. These include state aims, state capacity to reach aims, the effect of changing outside circumstances on state aims and state capacity, and the effect of the treaty on state aims and state capacity. I leave the question of state capacity aside for the purposes of this study, both to simplify the analysis below and because the treatment group for each treaty is largely high capacity actors. I also take three steps to distinguish the effects of treaties from those of states' aims or external circumstances.

First, to evaluate compliance, I ask whether treated states reduced emissions more than untreated states rather than asking whether they met their particular commitments. This helps to avoid the impact of external circumstances by focusing on whether the treaty changed behavior rather than whether states happened to meet treaty targets. For example, although a large majority of signatories met their emissions cut targets during the Kyoto Protocol treatment period, many observers ascribe these cuts to the recession following the 2008 Financial Crisis, which reduced economic activity and resultant GHG emissions across much of the planet, not just among Kyoto signatories. The decline in emissions from Kyoto signatories is thus multicausual, but a treaty effect would be visible as a greater decline among treaty signatories.

At Kyoto and Doha, targets were structured uniformly but applied to relatively few states, thus creating a clear treatment group. At Paris, a variety of commitment styles were allowed but all states were required to make some commitment. This means that there is no significant group of states without any Paris commitments and therefore no control group in the style of Kyoto. In order to deal with this discrepancy, I leverage an alternative comparison in the Paris analysis sections below, in which I compare states with "stringent" commitments as a treated group to states with "weak" commitments as a control group. I define stringent commitments as those similar to the style of Kyoto and Doha commitments: defined by unconditional (not pending foreign assistance) and absolute (relative to past emissions, not to projections) targets for emissions (not carbon intensity), covering at least six of the seven key GHGs defined in the Kyoto Protocol[7]. These types of commitments are significantly less flexible and are more likely to require states to change their behavior in order to comply. States with stringent commitments are therefore more aptly described as treated by the treaty. The case of China provides an example of a Paris commitment that falls below my stringency definition in two ways. First, China has committed to meeting a carbon intensity of GDP target rather than an absolute emissions reduction target. This allows China more flexibility to grow its economy, even at the expense of increased emissions. Second, China's commitment only applies to carbon dioxide, leaving methane and other critical GHGs uncovered. My approach allows a treatment and control group distinction for Paris, but assumes that the Paris treatment effect correlates to treaty content, i.e., that states with a stringent commitment are receiving a more intensive treatment from the treaty than are states with a weak commitment. The possibility that there is a treaty effect unrelated to treaty content, such as if signatories of the Paris Agreement cut emissions irrespective of the agreement's specification of emissions cuts, cannot be ruled out but runs counter to most theorized mechanisms of treaty efficacy.

Second, I adjust for varying state environmental aims by explicitly modeling the process of selection into treaties and by estimating the Average Treatment Effect on the Treated (ATT), i.e., the effect of the treaty on states like the signatories rather than on all states. I fit a logistic regression on the full sample of states, predicting treaty participation with co-benefit variables and climate interest variables. By co-benefit variables, I mean those that could predict emissions reductions due to concomitant incentives unrelated to climate change mitigation, such as smog reduction, increased energy efficiency, or reduced foreign energy dependency. I include logged GDP per capita, democracy, and fossil fuel reserves as co-benefit variables. By climate variables, I mean those that could predict emissions reductions through incentives for the mitigation of climate change. I include geographic vulnerability and size (logged GDP) as climate variables. Geographic vulnerability is calculated by averaging normalized values of national average tempera-

[7] CO2, CH4, N2O, HFCs, PFCs, SF6, and NF3

ture, population percentage in low lying coastline areas, and the absolute value of yearly rainfall. This index balances risk exposure to three major harms of climate change: extreme heat, sea-level rise, and floods/droughts (Emanuel 2007). Size serves as a proxy for vulnerability to free-riding in the provision of a global collective good (Olson 1965; Olson and Zeckhauser 1966). After determining the drivers of treaty participation, I include those variables as covariates in the compliance analysis.

Third, I also adjust for external circumstances with the synthetic control method (SCM) (Abadie et al. 2010, 2015), which weights control units by the similarity of their pre-treatment covariate and outcome trajectories to those of treated units. This method is a more flexible version of a difference-in-differences design (DiD), as it creates a parallel trend in the pre-treatment period rather than assuming one. Specifically, I use the generalized synthetic control method (GSM) developed by Xu (2017).[8] This method facilitates the use of multiple treated units and multiple treatment periods and improves uncertainty interpretability relative to traditional SCM. It also improves the adjustment for time-varying confounders. GSM works by first fitting an interactive two-way fixed effects model to the control units, leveraging leave-one-out cross validation to select the number of time-varying coefficients. It then applies this fit to the treated units in the control period and projects forward, generating counterfactual treatment-period trends.

Previous studies on the effectiveness of the Kyoto Protocol have had mixed results and conclusions due to varying DiD or SCM model specifications (Maamoun 2019; Almer and Winkler 2017; Grunewald and Martínez-Zarzoso 2016). I advance this literature by explicitly modeling treaty participation likelihood, which is not necessarily captured by pre-treatment outcome trends alone, and by extending the analysis to Paris. This paper provides, to my knowledge, the first quantitative analysis of Paris's effectiveness. Due to the recency of the Paris Agreement, studies thus far have focused more on potential rather than actual compliance (Raiser et al. 2020). However, with emissions data extending through 2022, I run my analysis on the first 7 years of the agreement (2016-2022), a comparable period to the 8-year study period for Kyoto (2005-2012).

[8] I use the R package *gsynth* to execute this method.

In Section 3.4, I provide a further validation of my empirical approach by fitting the same regression and GSM models to an alternative case: Kigali. This exercise serves as an effective placebo test because it leverages the exact same model specifications and because it studies the same population of actors in the same time period responding to the same kind of treatment (an international treaty). These similarities allow increased confidence that a significant compliance effect for Kigali cannot be explained by differences in the method or in the sample. However, one weakness in the placebo test is the use of a different outcome variable (HFC emissions rather than GHG emissions). HFCs are a small component of overall GHGs. On the one hand, this could mean that the two outcome variables are correlated and that HFC emissions are more noisy than GHG emissions, meaning that estimating a precise effect from the placebo is an especially hard test. On the other hand, HFC emissions may be easier to change than GHG emissions due to their smaller size, helping to generate a positive effect from the treaty. No placebo is perfect, but the significant effect estimated for Kigali only increases confidence in the validity of the null effects for Kyoto and Paris. It also provides a compelling theoretical contrast, which I elaborate on in Section 4.

3.2 Data and Scope

I take outcome data from the PRIMAP dataset from the Potsdam Institute for Climate Impact Research, which combines both self-reported and third-party estimates of GHG emissions for a variety of warming potential formulas (Gütschow et al. 2023, 2016). I privilege third-party estimates and use the most recent warming potential definition at the time of each treaty entering into force. I take economic and population data from the World Bank (World Bank 2024) and political data from the Varieties of Democracy (V-Dem) institute at the University of Gothenburg, Sweden (Coppedge et al. 2024; Pemstein et al. 2022).

I also limit the sample in my compliance analysis (but not in the participation models) in several ways in order to maintain internal validity. I exclude states with control over less than 80% of their territory, according to V-Dem, thereby excluding states like

Afghanistan and Iraq who likely also maintained little control over emissions during this period. I also exclude states classified by the United Nations at any point in the study period as Least Developed Countries (LDCs). None of these countries had (stringent) commitments under any of the relevant treaties, and they are extremely dissimilar to the treated group of mostly developed democracies.

I do not account for net emissions changes from land use, land-use change, and forestry (LULUCF). Estimates for LULUCF effects on net emissions are much noisier and less accurate than estimates of direct emissions. Moreover, while Kyoto, Doha, and Paris allowed the counting of LULUCF effects, most of the LULUCF changes in the study period have occurred in non-signatory states, which tend to be more agrarian.

Another problem is posed by climate finance. The Clean Development Mechanism, in operation since Kyoto, allows wealthy states to fund mitigation projects in developing states and receive credits that count towards treaty commitment targets. This poses a barrier to inference insofar as control countries can be treated by receiving mitigation funding from states with commitments. Although the scale of successful emissions reduction through climate finance has likely been small or non-existent, I minimize this bias be excluding the five largest recipients of CDM funding (China, India, Indonesia, Malaysia, Mexico, and Vietnam, collectively the recipients of about 80% of funds) from the compliance stage of my analysis (but not from the participation stage).

Table 2 summarizes the commitment data for each treaty. Immediate implications from this data include the increasing breadth of necessary climate mitigation due to the shrinking share of global emissions represented by regular treaty signatories, notable participation shrinkage from Kyoto to Doha and growth from Doha to Paris, as well as growing treaty commitments over time. In Section 3.3, I unpack the design drivers of Kyoto, Doha, and Paris participation, and analyze their ultimate effect on Kyoto and Paris compliance.

Table 2: Climate Treaty Participation and Ambition

State	Kyoto (2005) Target	% Emissions Share (2005)	Doha (2012) Target	% Emissions Share (2012)	Paris (2016) Target	% Emissions Share (2016)
Full Treaty	-3.3	47.4	-19.5	38.4	-27.5	37
United States	-	17.2	-	13.1	-26	13
Russia	0	5.3	-	5	-30	4.9
Japan	-6	3.5	-	2.8	-26	2.7
Brazil	-	2.5	-	2.5	-43	2.4
Germany	-21	2.4	-20	1.9	-40	1.9
Canada	-6	1.9	-	1.5	-30	1.6
United Kingdom	-12.5	1.7	-20	1.2	-37	1
Italy	-6.5	1.4	-20	1	-33	0.9
Australia	9	1.4	-5	1.4	-26	1.2
France	0	1.3	-20	1	-37	1
Ukraine	1	1.2	-20	0.9	-40	0.6
Spain	15	1.1	-20	0.8	-26	0.7
Poland	-6	1	-20	0.8	-7	0.8
Netherlands	-6	0.6	-20	0.5	-36	0.5
Kazakhstan	-	0.6	-7	0.7	-	0.7
Czechia	-7	0.4	-20	0.3	-14	0.3
Belgium	-7.5	0.3	-20	0.3	-35	0.3
Romania	-8	0.3	-20	0.2	-2	0.2
Greece	25	0.3	-20	0.2	-16	0.2
Austria	-13	0.2	-20	0.2	-36	0.2
Belarus	-	0.2	-8	0.2	-28	0.2
New Zealand	0	0.2	-	0.2	-30	0.2
Norway	1	0.2	-30	0.2	-40	0.2
Finland	0	0.2	-20	0.2	-39	0.1
Portugal	27	0.2	-20	0.1	-17	0.1
Sweden	4	0.2	-20	0.2	-40	0.1
Hungary	-6	0.2	-20	0.1	-7	0.1
Ireland	13	0.2	-20	0.1	-30	0.1
Serbia	-	0.2	-	0.1	-9.8	0.1
Denmark	-21	0.2	-20	0.1	-39	0.1
Bulgaria	-8	0.2	-20	0.1	0	0.1
Switzerland	-7	0.1	-20	0.1	-50	0.1
Slovakia	-8	0.1	-20	0.1	-12	0.1
Croatia	-5	0.1	-20	0.1	-7	0.1
Lithuania	-8	0.1	-20	0.1	-9	0.1
Estonia	-7	0.1	-20	0.1	-13	0.1
Slovenia	-8	0.1	-20	0	-15	0
Luxembourg	-28	0	-20	0	-40	0
Latvia	-8	0	-20	0	-6	0
Cyprus	-	0	-20	0	-24	0
Moldova	-	0	-	0	-64	0
Iceland	10	0	-20	0	-40	0
Malta	-	0	-20	0	-19	0
Montenegro	-	0	-	0	-30	0
Liechtenstein	-8	0	-20	0	-40	0
Monaco	-7	0	-30	0	-50	0

Note: Countries are ordered by rank of 2005 global emissions share. Only countries with strict commitments for one of the three treaties are listed. Target percentages represent cuts relative to 1990 emissions, with some exceptions. Full treaty target percentages represent an average of participant commitments.

3.3 Climate Change Mitigation Treaties

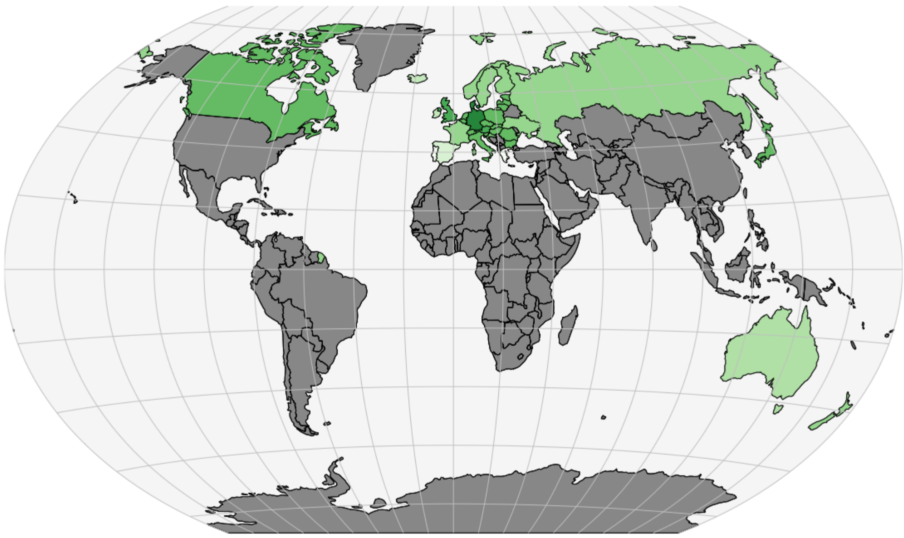
3.3.1 Kyoto

Kyoto negotiations involved intensive bargaining over the both the general terms of the treaty and the specific commitments of individual participants. This led to a degree of decentralization, in terms of individual states being able to semi-independently set their own targets through negotiation. The resulting disparity in emissions targets was substantial. For example, while Switzerland committed to changing emissions by -7% relative to its 1990 baseline, New Zealand committed to maintaining emissions at their 1990 level (i.e., 0% change) and Australia committed to an emissions change of no more than +9% from its 1990 baseline. Australia also negotiated a nearly 20% increase in its 1990 baseline through the so-called "Australia clause," which added LULUCF to the baseline only for those states with net negative LULUCF in 1990, which only included Australia (Hamilton and Vellen 1999). In addition to this semi-decentralization, the agreement offered semi-flexibility by maintaining a short commitment period.[9] A short time horizon offered the promise of quick renegotiation to adapt to any unforeseen changes in the state of climate change mitigation. Kyoto also maintained a somewhat narrow scope in its goals for participation breadth. Although it required ratification from countries representing 55% of 1990 emissions before coming into force, negotiations explicitly omitted any push for developing countries to cut emissions. In line with the 1995 Berlin Mandate, Kyoto acknowledged differential responsibility for climate change and hoped to lay the groundwork for future global emissions cuts through either expanded participation in a future renegotiation or green industrialization in developing countries through technology developed by greening rich countries.

Target participation in Kyoto was therefore concentrated among wealthy democracies, especially in Europe. Broad European participation was partially the result of an activist role played by the European Union, which mandated that its members join and doled out selective inducements to neighboring non-members (McLean and Stone 2012).

[9] Formally, Kyoto's commitment period was 2008-2012, but in the compliance analysis below I begin treatment at 2005, the year the Kyoto agreement came into effect.

Figure 2: Kyoto Commitment Targets



Note: shading indicates the level of Kyoto-mandated targets.

But even among wealthy democracies, Kyoto suffered from a participation shortfall. The United States signed but did not ratify the treaty, citing especially the agreement's limited breadth as problematic. Like Australia, other states used participation as a bargaining chip to extract generously weak targets. Ukraine and Russia, for example, had both experienced significant economic contraction since the fall of the USSR, but negotiated room for an emissions rebound that far outpaced any realistic expectations. Many observers attribute their participation to an attempt to sell the resulting "hot air" emissions credits to states with tougher targets (Victor 2001).

I describe Kyoto's binding-commitment participation with two logistic regressions summarized in Table 3. I first fit a full model, including both co-benefit variables and climate variables. State vulnerability to climate change is negatively related to Kyoto participation, reflecting a correlation with economic development even when controlling for GDP per capita. Size is unrelated, indicating that states with less vulnerability to free-riding were no more likely to join the Kyoto Protocol. In Appendix A.1, I demonstrate that alternative specifications with vulnerability broken into sub-components and with vulnerability interacted with size also fail to generate convincing results for a relationship between interest in mitigation and Kyoto participation.

I then fit a smaller model, using only local co-benefit variables, and recover a similarly strong fit. Kyoto participation is well-predicted by economic development and democracy. The association between Kyoto participation and logged fossil fuel reserves per capita cannot be precisely estimated.

Table 3: Determinants of Kyoto Participation

	Dependent variable:	
	Kyoto Participation	
	(1)	(2)
Ln GDP per Capita	1.28***	1.19***
	(0.47)	(0.33)
Electoral Democracy	5.35***	6.59***
	(2.02)	(1.82)
Ln Fossil Fuel Reserves Per Capita	0.03	0.05
	(0.06)	(0.04)
Vulnerability	−2.49***	
	(0.81)	
Size	0.08	
	(0.26)	
Constant	−19.61***	−16.95***
	(5.63)	(3.18)
Observations	165	166
Log Likelihood	−29.15	−36.93
Akaike Inf. Crit.	70.31	81.86
Note:	*p<0.1; **p<0.05; ***p<0.01	

In addition to limited participation, non-compliance was widespread. Although many states formally met their Kyoto commitments after the 2008 Financial Crisis sent global emissions tumbling, others failed to do so even under such extraordinary circumstances. Rather than be formally non-compliant, Canada withdrew from Kyoto in 2011, citing the unfavorable cost-benefit tradeoff between high costs to compliance and the agreement's ineffectiveness in mitigating climate change.[10]

[10]While Maamoun (2019) codes Canada as a non-participant due to its withdrawal, I code it as a (non-compliant) participant given that it ratified the treaty and withdrew a few months before the end

I estimate Kyoto's compliance effect on participant emissions as compared to a synthetic control in Table 4. As outlined above, this synthetic control is weighted so as to balance the covariates that predict Kyoto participation and pre-treatment outcome trends. I fit the model both with and without covariates, though the covariates reduce the fit uncertainty, as shown by the Mean Squared Prediction Error (MSPE). While the Kyoto ATT is negative and statistically significant in the first model, this result disappears after adjusting for the determinants of Kyoto participation: GDP per capita and democracy.

Table 4: Compliance Effect of Kyoto

	Dependent Variable:	
	GHG Emissions / 1990 GHG Emissions	
Kyoto ATT	-0.2539***	0.009
	(0.070)	(0.087)
Lag Ln GDP per Capita		0.139
		(0.122)
Electoral Democracy		0.118
		(0.125)
Treated Observations	34	34
Mean Squared Prediction Error	0.0031	0.0017
Note:	*p<0.1; **p<0.05; ***p<0.01	

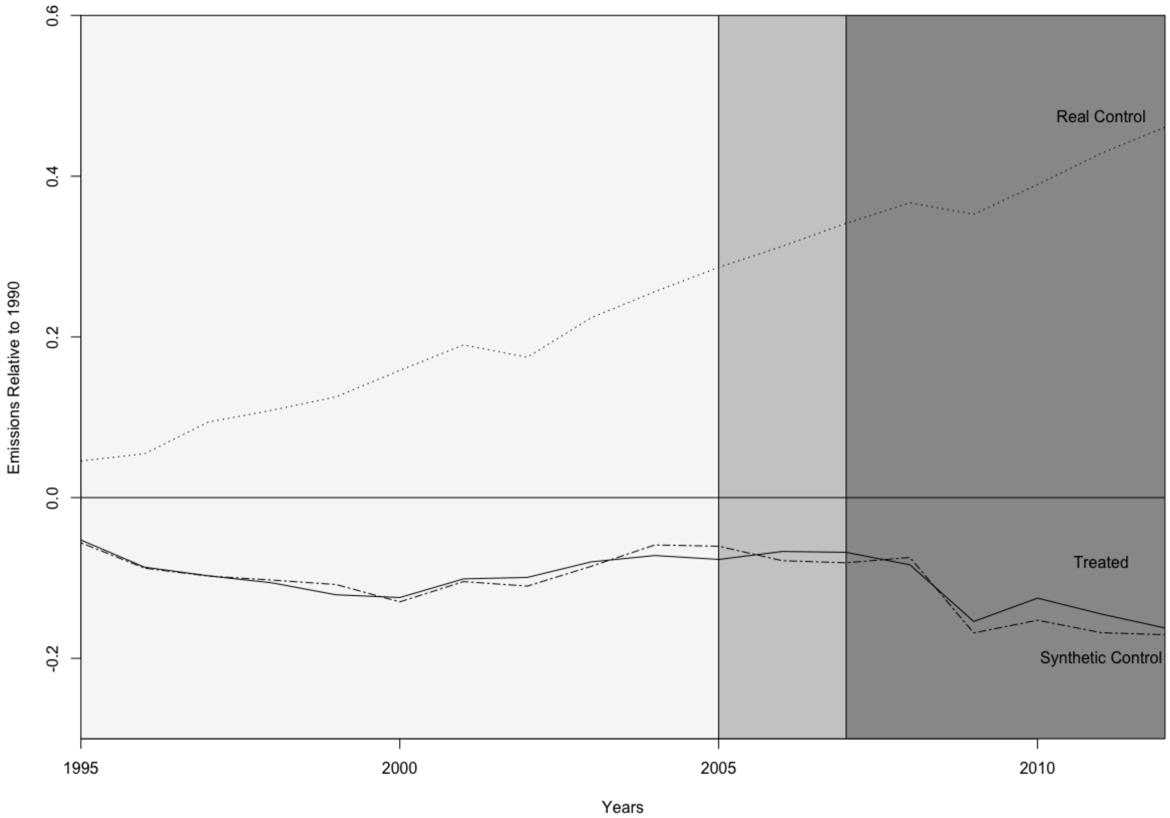
I illustrate this comparison in Figure 3, which shows average emissions in treated countries compared to those in control countries and those in the synthetic control. There is no visible evidence of a compliance effect from Kyoto.

3.3.2 Doha

As the Kyoto commitment period drew to a close, followup negotiations were shaped by a consensus view that the treaty was a failure. Kyoto's decentralization, flexibility, and limited breadth were recognized as major barriers to effective global mitigation. The final text agreed upon at Doha in 2012 deviated strongly from Kyoto's perceived shortcomings, centralizing commitment-making by forcing higher and more uniform targets on partici-

of the treaty commitment period.

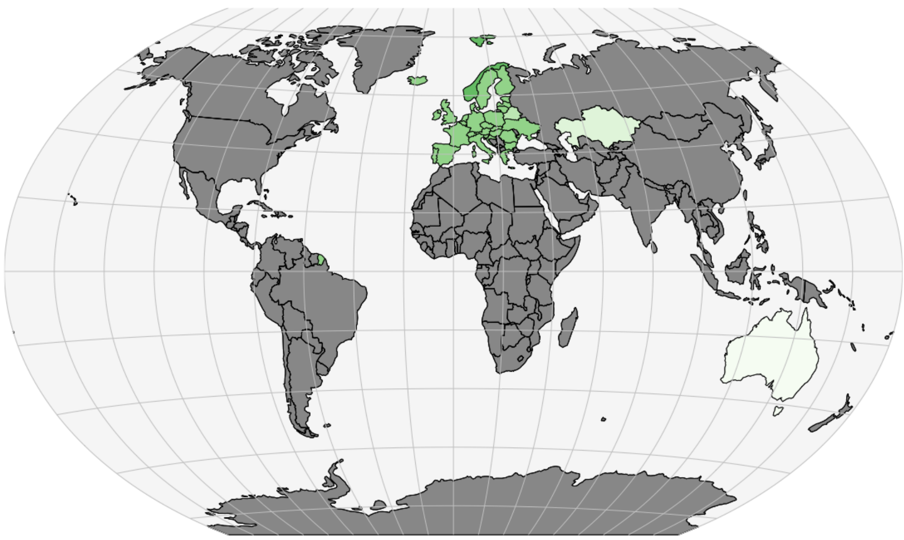
Figure 3: GHG Emissions Changes in the Kyoto Treatment Period



Note: shading indicates the Kyoto treatment period; the treaty gained enough signatories to enter into force in 2005. Australia's late entry in 2007 is illustrated by darker shading.

pants and reducing flexibility by aiming for a longer commitment period (ending in 2020). Reducing decentralization and flexibility was aimed at encouraging higher ambition and greater compliance than Kyoto, but also served as a response to the greater certainty and urgency motivating mitigation. Some states without Kyoto commitments, namely Kazakhstan and Belarus, entered the fold with binding but relatively weak commitments under Doha. But key Kyoto signatories Japan, Russia, Canada, and New Zealand declined to participate in the second round due to the overall stricter terms. In other words, after ambition and breadth were not jointly high enough to promise the collective good of climate change mitigation during the first round, increased ambition in the second round meant even lower participation. Ultimately, Doha participation was concentrated in an even smaller and more European-dominated group of mostly wealthy democracies.

Figure 4: Doha Commitment Targets



Note: shading indicates the level of Doha-mandated targets.

I describe binding-commitment participation in Doha with two logistic regressions summarized in Table 5. The models are somewhat more under-powered than those for Kyoto, likely because of the increasingly narrow profile of participants. As in the case of Kyoto, economic development and electoral democracy strongly predict Doha participation. Fossil fuel reserves per capita and size are again imprecisely estimated, and vulnerability is estimated in the opposite direction of substantive expectations. Again, I show alternative specifications in Appendix A.1, including the interaction of vulnerability and size and the breakout of vulnerability sub-components. As in the case of Kyoto, the smaller co-benefit model is a similarly strong fit to the model including variables for interest in climate change mitigation.

Table 5: Determinants of Doha Participation

	Dependent variable:	
	Doha Participation	
	(1)	(2)
Ln GDP per Capita	1.62***	1.14***
	(0.51)	(0.31)
Electoral Democracy	3.60**	4.60***
	(1.64)	(1.52)
Ln Fossil Fuel Reserves per Capita	−0.03	−0.01
	(0.05)	(0.04)
Vulnerability	−2.94***	
	(0.85)	
Size	−0.21	
	(0.25)	
Constant	−14.03***	−14.72***
	(4.89)	(2.69)
Observations	164	166
Log Likelihood	−34.12	−45.55
Akaike Inf. Crit.	80.24	99.10
Note:	*p<0.1; **p<0.05; ***p<0.01	

Ultimately, Doha did not reach the necessary participation threshold for enactment and so I do not perform a compliance test. This failure spurred calls to radically rethink the depth and breadth of mitigation treaty design, culminating in the Paris Agreement four years later. But reforms left the collective reciprocity basis for cooperation untouched.

3.3.3 Paris

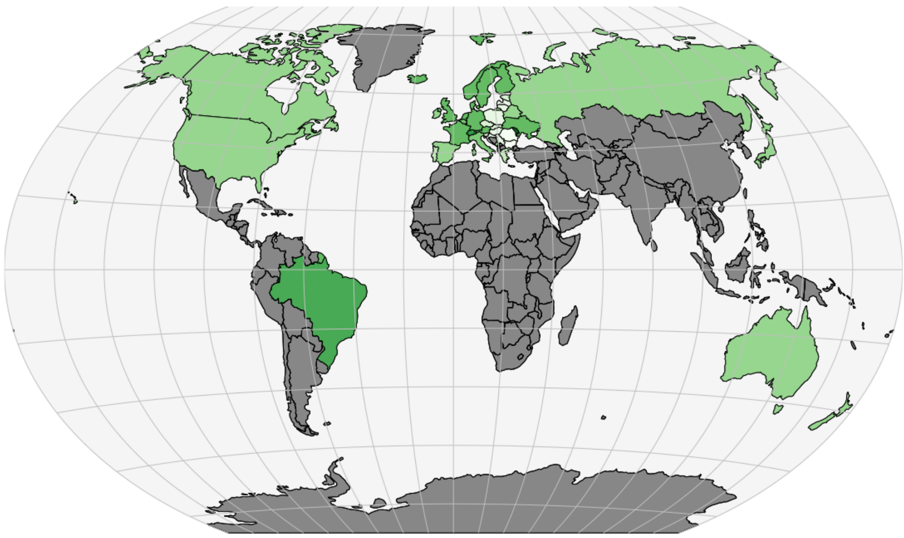
Paris abandoned the system of "targets and timetables," or jointly negotiated emissions cut timelines, for "pledge and review," or individually set and continually reevaluated goals. Thus, Paris allowed high decentralization through full national control over commitments and high flexibility through continuous revision of commitments. This design facilitates broad participation with significant differentiation in responsibilities, thereby attempting to balance depth and breadth (Farias and Roger 2023).

Some scholars have argued that this decentralized approach makes Paris a case of coordinated unilateralism rather than reciprocity (Bernauer et al. 2016). This argument misunderstands both reciprocity and the Paris Agreement. Reciprocity is defined by conditional and equivalent exchanges (Keohane 1986). Although Paris commitments are not jointly negotiated in advance so as to conform with these values, conditionality and equivalence are implicit in the pledge and review system. Pledges and outcomes are publicly and regularly declared and reviewed so as to inform other states' pledges and outcomes. Instead, the change from Kyoto or Doha to Paris can be understood as a change from specific to diffuse reciprocity. In specific reciprocity, exchanges are clearly equivalent and strictly sequenced (Keohane 1986), such as those arising from the formal joint negotiating process of Kyoto or Doha. In diffuse reciprocity, exchanges are more roughly equivalent and sequenced, often relying on generally defined standards and obligations (Keohane 1986), such as those occurring in sequential rounds of pledge and review. This distinction is independent of that between collective and club reciprocity: while Kyoto was a case of collective specific reciprocity, Paris is a case of collective diffuse reciprocity.

Although diffuse reciprocity often arises out of ongoing cases of successful specific reciprocity, Paris negotiators attempted to fix the unsuccessful specific reciprocity of earlier negotiations with flexible and decentralized diffuse reciprocity. In combination with the rising certainty and urgency of climate change mitigation, these generous rules successfully resulted in high ambition in addition to high participation, as evidenced by sharply increased targets of Paris commitments.

Like Kyoto and Doha, participation in Paris was heavily influenced by the European Union, leading to a strong concentration of (stringent) participants in Europe. Surveys of climate policy experts, in fact, have found that European commitments to Paris are seen as especially credible (Victor et al. 2022). But Paris also broadened participation beyond Doha to bring Japan, Russia, Canada, and New Zealand back into cooperation. It also successfully added states that had not participated in Doha or Kyoto, namely the United States and Brazil.

Figure 5: Paris Stringent Commitment Targets



Note: shading indicates the level of stringent first-round Nationally Determined Contributions in Paris.

Like Kyoto and Doha, I describe Paris participation with two logistic regressions summarized in Table 6. These models are similar to those for Kyoto and Doha, despite greater breadth and diversity in Paris participation. Again, size and fossil fuel reserves are unrelated to participation, and vulnerability is related in the opposite direction to substantive expectations, reflecting correlation with GDP per capita. Like Kyoto and Doha participation, Paris (stringent) participation is well predicted by economic development and democracy. Appendix A.1 includes alternative specifications.

Unfortunately, Paris has not successfully paired its high participation and ambi-

Table 6: Determinants of Paris Participation

	Dependent variable:	
	Paris Participation	
	(1)	(2)
Ln GDP per Capita	1.29***	1.22***
	(0.48)	(0.30)
Electoral Democracy	5.33***	5.38***
	(1.75)	(1.44)
Ln Fossil Fuel Reserves per Capita	−0.01	0.05
	(0.06)	(0.04)
Vulnerability	−2.69***	
	(0.73)	
Size	0.24	
	(0.26)	
Constant	−22.90***	−15.96***
	(6.04)	(2.80)
Observations	166	167
Log Likelihood	−30.87	−45.31
Akaike Inf. Crit.	73.74	98.61
Note:	*p<0.1; **p<0.05; ***p<0.01	

tion with high compliance. I test Paris compliance, or whether Paris participants with stringent commitments have reduced emissions relative to those with non-stringent commitments, against a new synthetic control. As with Kyoto, Paris's synthetic comparison is calculated by weighting control states to balance pre-treatment trends in emissions and covariates. Compared to this synthetic control, Paris seems to have had little discernible effect, even when covariates are not included.

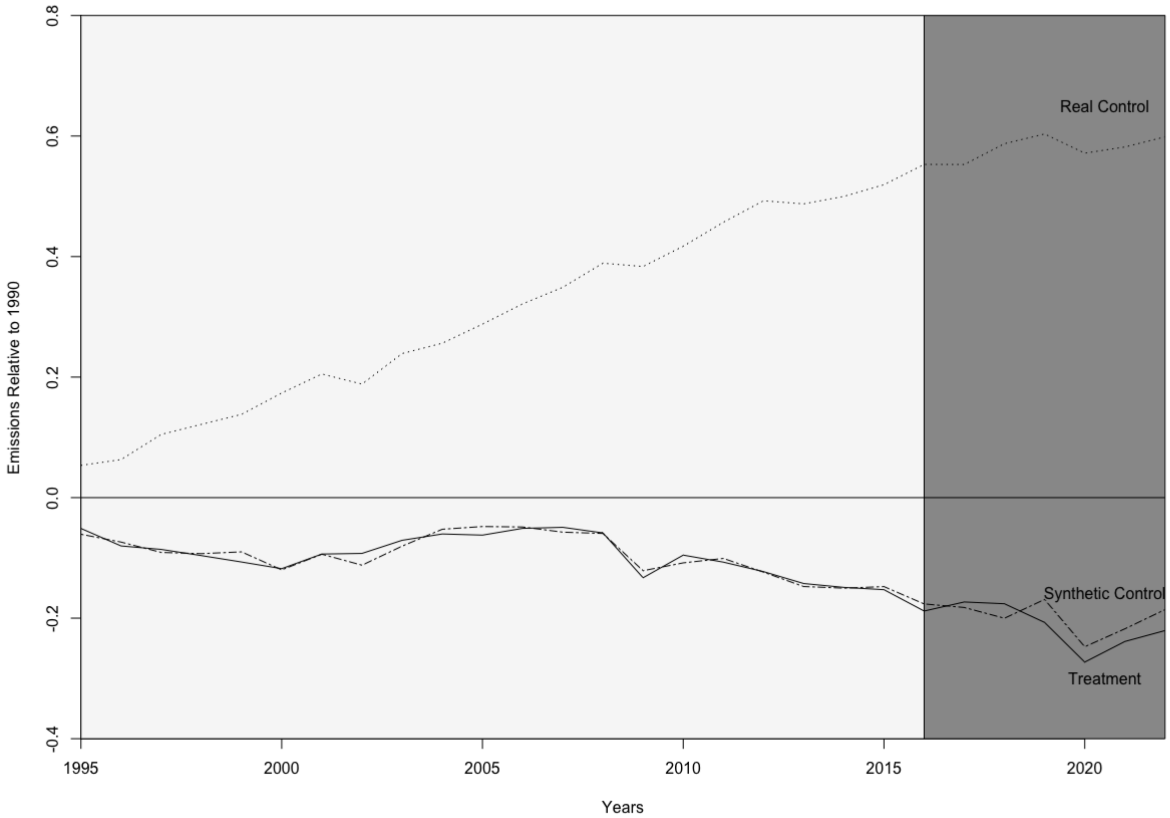
Table 7: Compliance Effect of Paris

	Dependent Variable: GHG Emissions / 1990 GHG Emissions	
Paris ATT	0.011	-0.014
	(0.035)	(0.035)
Lag Ln GDP per Capita		0.119
		(0.122)
Electoral Democracy		0.010
		(0.095)
Treated Observations	40	40
Mean Squared Prediction Error	0.0020	0.0018
Note:	*p<0.1; **p<0.05; ***p<0.01	

This null effect is plotted in Figure 6, which shows the trajectory of Paris participants barely deviating from the synthetic comparison. While some evidence of a weak effect is given by a gap between treatment and the synthetic control in later years of the agreement, this gap is not large enough to be statistically significant. Despite the increasing urgency and certainty of climate change mitigation, the depth and breadth of Paris have undercut compliance. Paris participants must weigh the high costs of large pledged emissions cuts against the small likelihood that their own compliance will prove pivotal.

Unlike Kyoto or Doha, Paris has not been widely perceived as a failure. Optimism about Paris increases the substantive salience of my finding and also explains the lack of efforts to reform mitigation treaty design once again. Observers may even conclude that there is no alternative design framework. The successive experimentation of Kyoto, Doha, and Paris may have exhaustively tested possible combinations of depth and breadth. I argue that policymakers have erred in their focus on the depth-breadth dilemma and

Figure 6: GHG Emissions Changes in the Paris Treatment Period



Note: shading indicates the Paris treatment period; the treaty gained enough signatories to enter into force in 2016.

their lack of focus on the reciprocity basis for mitigation treaties. The unchanged design feature that explains the failures of Kyoto, Doha, and Paris is collective reciprocity. But mitigation treaties could instead be modeled around club reciprocity, the potential of which I evaluate in Section 3.4.

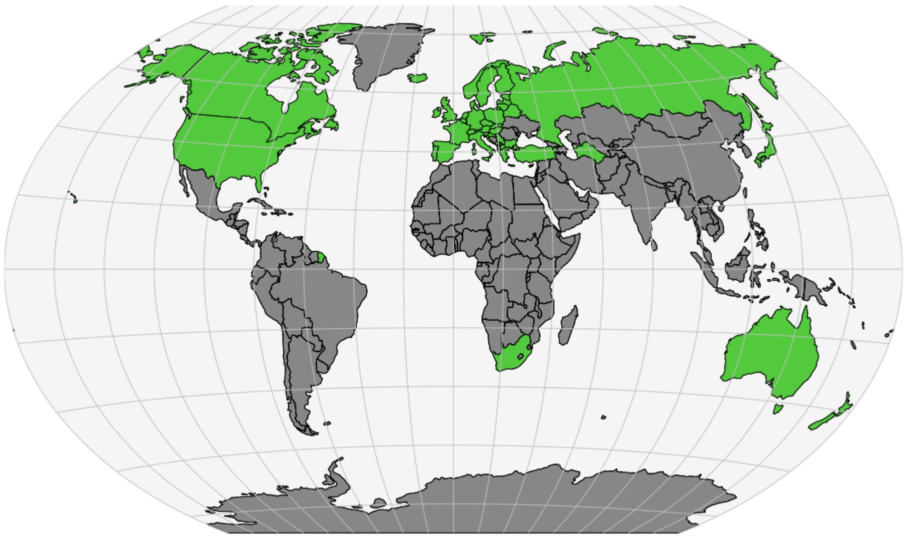
3.4 Placebo Test: Kigali

The Kigali Amendment was omitted from my analysis for being an extension of the Montreal regime rather than a comprehensive climate change mitigation agreement. After the Montreal Protocol (1985) penalized the use of ozone-depleting chlorofluorocarbons (CFCs), use of HFCs as substitutes rose steadily. Unlike CFCs, HFCs are not ozone-depleting but are potent GHGs. Kigali extended Montreal's reduction commitments to HFCs so as to limit the treaty's inadvertent harm. Thus, while Kigali is not an agreement to comprehensively mitigate climate change, it does have a non-negligible climate change mitigation effect. Moreover, its design is distinct from that of the comprehensive agreements focused on above.

While Kyoto, Doha, and Paris punish non-participation and non-compliance with collective reciprocity, Kigali utilizes Montreal's club reciprocity system. Defecting states are sanctioned with sticks in the form of trade restrictions. Moreover, compliant states are rewarded with carrots in the form of adjustment finance. These club goods can be denied to non-participants and non-compliers without hurting participants and compliers. This design facilitates self-enforcement of costly action among many parties by ameliorating the negligibility-credibility tradeoff of compliance punishment and allows treaty success with any number of parties.

Club reciprocity has made Kigali more effective in inducing compliance Kyoto, Doha, or Paris. Like Paris, a large majority of states have signed on to Kigali, but stringency of commitments varies. Developing States (as defined by the UN) in areas vulnerable to extreme heat have the longest timeline for HFC reduction, followed by the rest of the Developing States, followed by a collection of Developed (defined by the UN) but post-Soviet states with struggling economies, followed by the rest of the Developed world. As in my analysis of Paris, I treat states with relatively stringent commitments (Developed States) as the treated group and ask if the treaty has increased mitigation in that group relative to both non-participant states and states with weaker commitments. Figure 7 shows the participants of Kigali with stringent commitments in 2022, the latest year of my emissions data.

Figure 7: Kigali Stringent Commitment Targets



Note: all Kigali participants with stringent commitments share the same commitment level.

I describe Kigali participation with two logistic regressions summarized in Table 8. These models are similar to participation models above, but do not account for fossil fuel reserves, as HFC emissions do not originate with burning fossil fuels. As in the case of climate change mitigation treaties, size is unrelated to participation, and vulnerability is related in the opposite direction to substantive expectations, reflecting correlation with GDP per capita. Kigali (stringent) participation is well predicted by economic development and democracy. Appendix A.1 again includes alternative specifications.

I test the compliance effect of Kigali with the same GSM model as I applied to the climate change mitigation treaties above. But unlike the fits for Kyoto or Paris, the Kigali ATT is negative and statistically significant, indicating that Kigali successfully

Table 8: Determinants of Kigali Participation

	Dependent variable:	
	Kigali Participation	
	(1)	(2)
Ln GDP per Capita	0.95*	1.01***
	(0.53)	(0.34)
Electoral Democracy	7.16**	6.01***
	(2.95)	(2.03)
Vulnerability	−1.95***	
	(0.75)	
Size	0.02	
	(0.22)	
Constant	−16.24***	−14.73***
	(4.77)	(3.01)
Observations	140	141
Log Likelihood	−30.95	−38.91
Akaike Inf. Crit.	71.90	83.81
Note:	*p<0.1; **p<0.05; ***p<0.01	

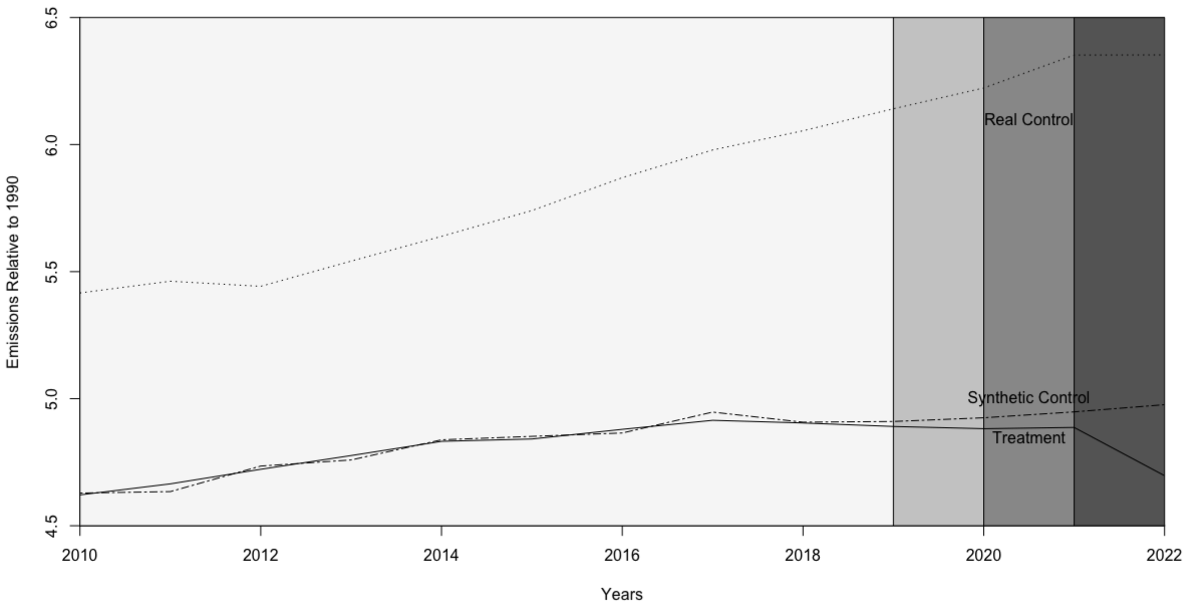
induced emissions cuts in participating states. The result is also substantively large; when controlling for GDP per capita and democracy, participation in Kigali causes a yearly decline in HFC emissions commensurate to approximately 12% of a state's 1990 HFC emissions.

Table 9: Compliance Effect of Kigali

	Dependent Variable:	
	HFC Emissions / 1990 HFC Emissions	
Kigali ATT	-0.123***	-0.117***
	(0.028)	(0.033)
Lag Ln GDP per Capita		0.052
		(0.136)
Electoral Democracy		-0.064
		(0.161)
Treated Observations	40	40
Mean Squared Prediction Error	0.042	0.045
Note:	*p<0.1; **p<0.05; ***p<0.01	

I plot this effect in Figure 8, which shows a clear gap between treated states and their synthetic control comparison, emerging after Kigali gained enough participants to enter force in 2019. This gap is also growing over time, which coheres to the fact that participation has also grown each year. The United States, for example, joined Kigali in 2022 (at the end of my emissions time-series).

Figure 8: HFC Emissions Changes in the Kigali Treatment Period



Note: shading indicates the Kigali treatment period; the treaty gained enough signatories for its trade restriction provisions to enter into force in 2019. More states joined in 2020 and 2021, as indicated by darker shading.

The finding that Kigali has successfully caused emissions reductions in states participating with stringent commitments is important for two reasons. First, this finding supports the validity of the null results found for Kyoto and Paris compliance. The same empirical model fit to the same population of states in the same years, exposed to the same type of treatment (an international treaty), successfully identified a significant effect. The insignificance of Kyoto and Paris effects is therefore unlikely to be due to a problem with the model. Second, this finding buttresses the theoretical argument that collective reciprocity is to blame for the struggles of Kyoto, Doha, and Paris. A crucial distinction between these treaties and Kigali is the latter's use of club reciprocity to enforce its provisions.

4 Discussion

The empirical analysis in Section 3 has demonstrated the challenges of enforcing climate change mitigation with collective reciprocity, as detailed in Section 2. Despite experimentation with various points on the depth-breadth continuum, participation in Kyoto, Doha, and Paris has been sub-optimally low, driven more by local co-benefit factors than an interest in climate change mitigation. Moreover, once covariates that explain participation and pre-treatment outcome trends have been adjusted for, neither Kyoto nor Paris demonstrate evidence of meaningful compliance. Neither treaty led participants to reduce emissions. This result contrasts sharply with the case of Kigali, a treaty enforced through club reciprocity. Participation in Kigali with stringent commitments is similar to participation in Paris. But Kigali has a statistically significant negative effect on emissions, indicating that it has a compliant effect on participants, unlike Kyoto or Paris.

This study provides a unique and comprehensive assessment of climate change treaties with binding mitigation commitment systems thus far. Is multilateral climate change mitigation therefore impossible? I argue that it is not: mitigation treaties could leverage club reciprocity to square the circle of a collective good requiring high depth and high breadth. Two types of club goods linked to mitigation could serve this purpose, are already used by the Kigali Amendment to encourage HFC mitigation, and already exist in some form with respect to GHGs: climate finance and carbon tariffs.

4.1 Enforcement with Carrots: Climate Finance

One element of Kyoto not discussed in depth in this article is the Clean Development Mechanism (CDM), which arranges for actors in rich states to fund decarbonization projects in poor states. The CDM has been funding mitigation projects since 2001, even before Kyoto's commitment targets came into effect in 2005. Aside from its enforcement potential, such climate finance could be compelling for two reasons. First, economic redistribution through financial investments in poor states could serve to ameliorate some of the inequity of the projected impacts of climate change, which will fall hardest on the poor world. Second, given that poor states tend to have a higher carbon intensity of GDP, it should be more economically efficient to mitigate in poor states.

But climate finance, especially as practiced in the CDM, has widely recognized problems. Verification of projects and their effects incurs substantial transaction costs. But even the costly and cumbersome verification regime set up in the CDM is considered rife with fraud and failure, such as funding projects that would have been built anyways (i.e., non-additionality). This is especially troubling because if climate finance abroad eases pressure for mitigation at home, such as generating tradeable carbon credits awarded by the CDM, then cases of climate finance failure actually crowd out and reduce total global mitigation. Scholars have recognized these difficulties and proposed several design elements that could improve the CDM or SDM, including buyer liability for emissions credits and sunset clauses for project eligibility (Victor 2011). In response to ongoing challenges with CDM implementation, Paris included provisions for a revised institution, dubbed the Sustainable Development Mechanism (SDM). Despite Paris's commitments coming into effect, stalled negotiations on the SDM mean that it has not yet replaced or substantially overhauled the CDM.

Even a more efficient CDM would require one fundamental reform in order to serve as a club good to enforce climate agreements. Climate finance eligibility must be tied both to participation with stringent commitments and to compliance with those commitments. Currently, states can access CDM funding even after making weak mitigation pledges and not following through. Withholding climate finance as a conditional carrot to reward mitigation behavior, could change the incentives for states not yet interested in mitigation.

Nevertheless, it must be acknowledged that climate finance will probably always be limited in scale. The projected cost for decarbonizing the poor world dwarfs current yearly flows of economic development aid, which themselves dwarf current flows of climate finance. A dramatic increase in the political willingness of rich states to send money abroad is unlikely, especially as the populations of much of the rich world are projected to age or even shrink, increasing welfare burdens at home. Nevertheless, if climate finance can be reformed and expanded beyond the level of the CDM, as well as tied to participation and compliance, it could serve as one part of a club reciprocity strategy.

4.2 Enforcement with Sticks: Carbon Tariffs

No form of stick, or targeted punishment (i.e., the denial of a club good), has been designed into climate change mitigation treaties thus far. But trade restrictions targeting treaty non-participants and non-compliers are a common method of club good reciprocity in treaties as diverse as the WTO and the Montreal Protocol. Carbon tariffs have been widely studied by scholars (Barrett 2011; Nordhaus 2015; Barrett and Dannenberg 2022), and some actors have committed to future implementation. In 2023, the European Union passed a Carbon Border Adjustment Mechanism (CBAM) policy, in which select carbon-intensive industries will be protected from international competition in proportion to the decarbonization-pressure they face from home government policy. These tariffs will take effect in 2026. In 2024, the UK passed a similar policy, to take effect in 2027.

The benefits of using carbon tariffs in a club reciprocity strategy are several. Market access has proven to be a uniquely effective club good in other international agreements. Its denial tends to be non-negligible and credible. Carbon tariffs also neatly solve leakage, which is the main target of the CBAMS passed by the EU and the UK. This fundamental inefficiency of unilateral mitigation increases the individual marginal cost of emissions reduction by ensuring that domestic economic activity lost through mitigation policy is disproportionately larger than the global emissions reduction caused by that policy.

But this approach has its own drawbacks. As with climate finance, there may be high transaction costs to mutual verification of effective carbon prices on which tariff levels could be based. The World Trade Organization currently restricts trade protection, and careful planning would be required to make carbon tariffs cohere with trade rules. Carbon tariffs could also give cover to domestic special interests seeking protection for their own benefit. Tariffs tend to benefit the few producers who end up protected at the expense of everyone else, resulting in both inequity and lower overall prosperity. Carbon tariffs will thus have to be designed so as not to be hijacked by special interests. An even more troubling issue is that tariffs could internationally shift the costs of the green transition from rich to poor countries. Poor states will be forced to implement green policies that they cannot afford or else be cut off from vital markets. But poor states also stand to suffer the most from unmitigated climate change, and carbon tariffs may be a uniquely powerful tool for avoiding that outcome.

4.3 Conclusion

Section 3 demonstrates that current and past efforts at multilateral climate change mitigation have failed. Kyoto, Doha, and Paris only obtained participation from states already inclined to cut emissions for domestic reasons. And neither Kyoto nor Paris enjoyed any evident compliance. In the case of Kyoto, states with targets did not cut emissions any more than those without, once participation and past emissions trends are adjusted for. In the case of Paris as well, states with stringent targets have not cut emissions any more than those with weak targets, implying that the treaty's targets have no causal effect on state behavior. In short, these results make clear that neither Kyoto nor Paris led to any reduction in emissions.

This result is sobering and may be hard to reconcile with the gravity of the problem and with the genuine and tireless decades-long efforts of policymakers and activists. But theoretically, the failures of these treaties are unsurprising. As I explain in Section 2, the strategy of collective reciprocity central to Kyoto, Doha, and Paris design is severely limited. While collective reciprocity can enforce agreements at low levels of depth or breadth, it cannot sustain costly cooperation among a large number of actors. Effective climate change mitigation, however, would be both costly and expansive.

Luckily, there are better strategies available. Although collective reciprocity is the most straightforward way for a treaty providing a collective good to be designed, it is also possible to attach club goods to climate change mitigation, including financial investment and market access. Rather than supplant the Paris Accords or begin years of global negotiations anew, club good strategies can begin quickly at the minilateral level. Small groups of countries could exchange climate finance or form tariff-protected low-emissions clubs, either through new agreements or through renegotiation of existing economic agreements.

As discussed, finance- and tariff-based club strategies each have significant drawbacks and risks. But these strategies must be compared to the alternative. The strategy of collective reciprocity has repeatedly failed to advance climate change mitigation in practice, and there is little reason to believe that it could work in theory. Moreover, the downsides of club strategies can be ameliorated by smart and careful design, which further research should be focused on. The most serious of the downsides discussed above can also be solved by using these strategies together such that states must enter the low-emissions club both to evade costly trade restrictions and to access climate finance flows. While coercing compliance from developing states through punitive tariffs is unfair, redistribution through rich-to-poor climate finance can help to rectify this inequity. And while the additionality of climate finance projects is extremely hard to prove outside of a low-emissions club, entrance into the club would ensure that recipient states already have policy encouraging a green transition and that further funds are additive.

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A Online Appendix

A.1 Alternative Specifications for the Determinants of Participation

Table A.1.1: Alternative Specifications for the Determinants of Kyoto Participation

	Dependent variable:	
	Kyoto Participation	
	(1)	(2)
Ln GDP per Capita	1.44***	1.36*
	(0.50)	(0.74)
Electoral Democracy	4.80**	5.11*
	(1.99)	(2.68)
Ln Fossil Fuel Reserves per Capita	0.01	0.04
	(0.06)	(0.07)
Vulnerability	−18.44	
	(11.50)	
Standardized Temperature		−2.60***
		(0.76)
Standardized Wetness		−0.71
		(1.07)
Standardized Sealevel Population		0.63
		(0.78)
Size	0.38	−0.02
	(0.35)	(0.35)
Vulnerability*Size	0.62	
	(0.44)	

Table A.1.2: Alternative Specifications for the Determinants of Doha Participation

	Dependent variable:	
	Doha	
	(1)	(2)
Ln GDP per Capita	1.84***	1.75***
	(0.56)	(0.64)
Electoral Democracy	3.60**	4.27**
	(1.65)	(1.87)
Standardized Temperature		−1.98***
		(0.59)
Standardized Wetness		−2.31**
		(0.93)
Standardized Sealevel Population		0.11
		(0.62)
Ln Fossil Fuel Reserves per Capita	−0.03	−0.06
	(0.05)	(0.06)
Vulnerability	−20.18*	
	(10.54)	
Size	0.05	−0.25
	(0.30)	(0.30)
Vulnerability*Size	0.67*	
	(0.40)	
Constant	−22.76***	−15.63**
	(7.89)	(6.33)
Observations	164	164

Table A.1.3: Alternative Specifications for the Determinants of Paris Participation

	Dependent variable:	
	Paris Participation	
	(1)	(2)
Ln GDP per Capita	1.48***	1.08*
	(0.51)	(0.56)
Electoral Democracy	4.91***	5.38***
	(1.71)	(2.01)
Standardized Temperature		−1.72***
		(0.49)
Standardized Wetness		−1.00
		(0.74)
Standardized Sealevel Population		0.12
		(0.76)
Ln Fossil Fuel Reserves per Capita	−0.02	−0.02
	(0.06)	(0.07)
Vulnerability	−22.64*	
	(11.62)	
Size	0.59	0.21
	(0.36)	(0.30)
Vulnerability*Size	0.76*	
	(0.44)	
Constant	−33.60***	−20.71***
	(10.04)	(6.52)
Observations	166	166

Table A.1.4: Alternative Determinants of Kigali Participation

	Dependent variable:	
	Kigali Participation	
	(1)	(2)
Ln GDP per Capita	1.23**	0.76
	(0.60)	(0.58)
Electoral Democracy	6.96**	7.24**
	(3.20)	(3.04)
Vulnerability	−29.65**	
	(13.90)	
Standardized Temperature		−1.43***
		(0.51)
Standardized Wetness		−1.14
		(0.73)
Standardized Sealevel Population		0.10
		(0.56)
Size	0.48	0.02
	(0.33)	(0.23)
Vulnerability*Size	1.05**	
	(0.52)	
Constant	−31.29***	−15.41***
	(9.97)	(5.46)
Observations	140	140
Log Likelihood	−28.24	−27.52
Akaike Inf. Crit.	68.47	69.04

A.2 Weights from the Generalized Synthetic Control

Table A.2.1: Average Weight of Kyoto Control Units

	Avg Weight
AZE	0.029
SUR	0.028
NGA	0.023
ZWE	0.021
BLR	0.021
GUY	0.019
MKD	0.019
SWZ	0.017
SGP	0.016
CUB	0.016
GAB	0.014
JAM	0.014
USA	0.013
TJK	0.012
SYR	0.012
KGZ	0.010
URY	0.010
MNE	0.010
CMR	0.008
MNG	0.008
ALB	0.007
PRY	0.007
FJI	0.007
PER	0.007
CRI	0.005
SLV	0.005
ZAF	0.005
UZB	0.005
KOR	0.005
ECU	0.005
MLT	0.004
BHR	0.004
DOM	0.004
PHL	0.003
KAZ	0.003
ARG	0.002
QAT	0.002
ARM	0.002
BOL	0.002
CHL	0.001
NAM	0.0004
GHA	0.0002
LBY	-0.0001
CIV	-0.0002
BRB	-0.001
ISR	-0.001
BRA	-0.001
DZA	-0.002
PAN	-0.002
KEN	-0.003
TUR	-0.003
THA	-0.005
TUN	-0.006
COG	-0.008
KWT	-0.009
MAR	-0.009
NIC	-0.009
GTM	-0.010
PAK	-0.011
IRQ	-0.011
JOR	-0.012
HND	-0.014
EGY	-0.016
IRN	-0.018
SYC	-0.019
MUS	-0.021
TKM	-0.021
SAU	-0.024
PNG	-0.026
ARE	-0.027
OMN	-0.032
TTO	-0.036
BIH	-0.054

Table A.2.2: Average Weight of Paris Control Units

	Avg Weight
JAM	0.028
MKD	0.023
CUB	0.018
FJI	0.018
SWZ	0.018
GAB	0.018
AZE	0.017
BRB	0.016
ZWE	0.015
ZAF	0.014
SLV	0.014
UZB	0.013
NGA	0.012
ALB	0.010
URY	0.010
ARG	0.009
KAZ	0.009
CRI	0.006
ISR	0.006
ECU	0.005
TJK	0.004
GUY	0.004
CMR	0.003
TTO	0.003
LKA	0.003
COG	0.002
NAM	0.002
DOM	0.002
GEO	0.002
KOR	0.002
THA	0.0004
CHL	0.0003
ARM	0.0001
SYR	-0.0003
LBY	-0.001
TUN	-0.001
PRY	-0.002
PAN	-0.002
CIV	-0.002
BOL	-0.003
SGP	-0.003
COL	-0.003
TKM	-0.004
PER	-0.004
JOR	-0.005
MAR	-0.005
SUR	-0.005
HND	-0.005
NIC	-0.005
PNG	-0.005
EGY	-0.005
PHL	-0.006
PAK	-0.006
DZA	-0.006
KWT	-0.007
BHR	-0.007
KGZ	-0.007
IRN	-0.008
GTM	-0.008
MUS	-0.008
TUR	-0.010
SYC	-0.010
KEN	-0.011
IRQ	-0.011
QAT	-0.012
SAU	-0.015
GHA	-0.016
BIH	-0.018
OMN	-0.025
ARE	-0.027
MNG	-0.028

Table A.2.3: Average Weight of Kigali Control Units

	Avg Weight
AZE	0.029
SUR	0.028
NGA	0.023
ZWE	0.021
BLR	0.021
GUY	0.019
MKD	0.019
SWZ	0.017
SGP	0.016
CUB	0.016
GAB	0.014
JAM	0.014
USA	0.013
TJK	0.012
SYR	0.012
KGZ	0.010
URY	0.010
MNE	0.010
CMR	0.008
MNG	0.008
ALB	0.007
PRY	0.007
FJI	0.007
PER	0.007
CRI	0.005
SLV	0.005
ZAF	0.005
UZB	0.005
KOR	0.005
ECU	0.005
MLT	0.004
BHR	0.004
DOM	0.004
PHL	0.003
KAZ	0.003
ARG	0.002
QAT	0.002
ARM	0.002
BOL	0.002
CHL	0.001
NAM	0.0004
GHA	0.0002
LBY	-0.0001
CIV	-0.0002
BRB	-0.001
ISR	-0.001
BRA	-0.001
DZA	-0.002
PAN	-0.002
KEN	-0.003
TUR	-0.003
THA	-0.005
TUN	-0.006
COG	-0.008
KWT	-0.009
MAR	-0.009
NIC	-0.009
GTM	-0.010
PAK	-0.011
IRQ	-0.011
JOR	-0.012
HND	-0.014
EGY	-0.016
IRN	-0.018
SYC	-0.019
MUS	-0.021
TKM	-0.021
SAU	-0.024
PNG	-0.026
ARE	-0.027
OMN	-0.032
TTO	-0.036
BIH	-0.054

A.3 Diagnostic Plots from the Generalized Synthetic Control

Figure A.3.1: Latent Factors Estimated for Kyoto

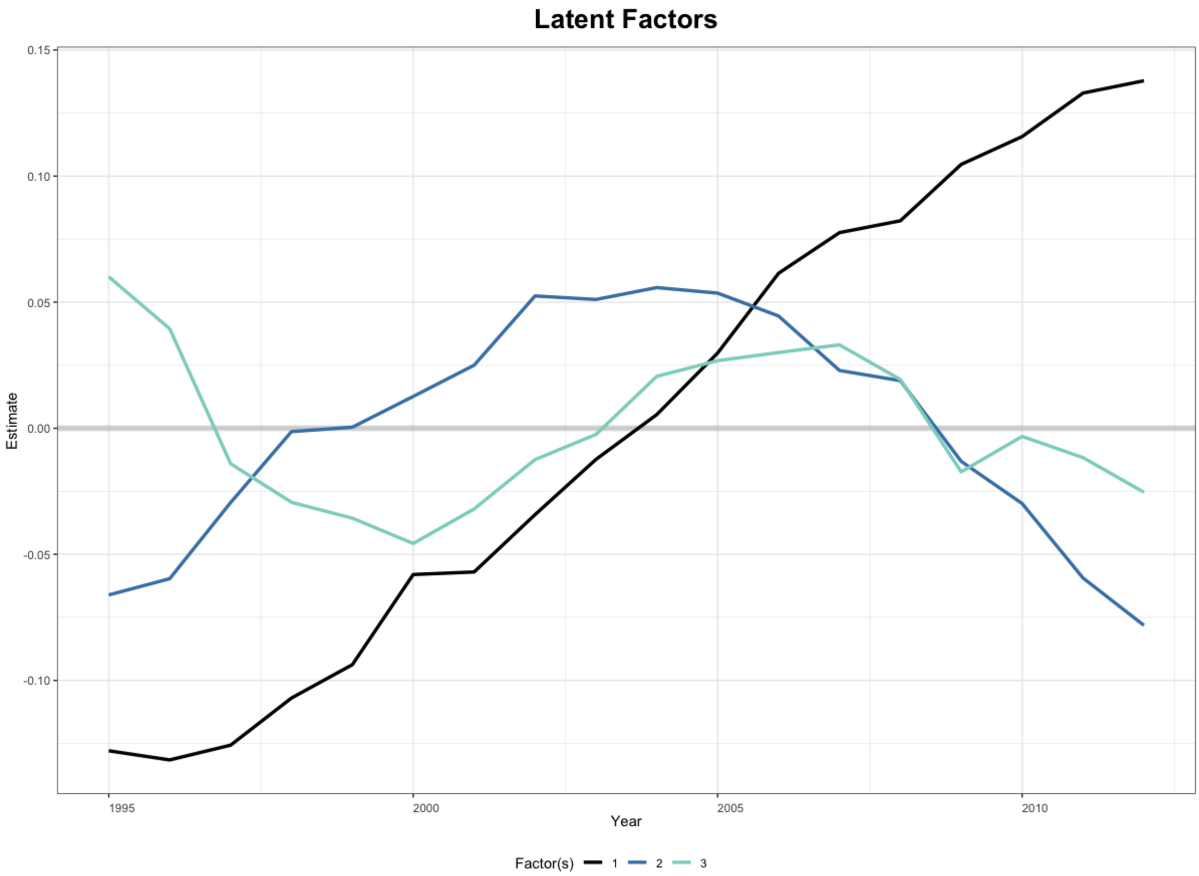

Figure A.3.2: Factor Loadings Estimated for Kyoto

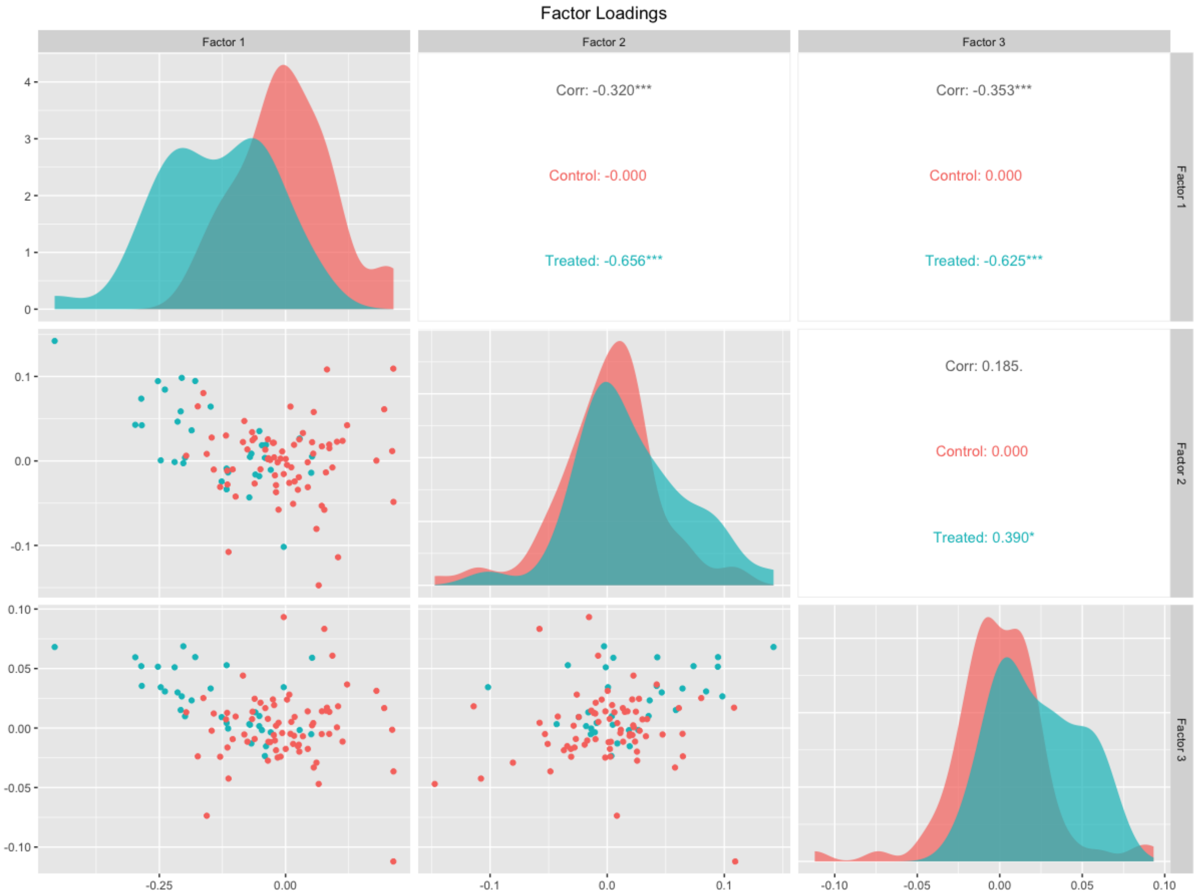

Figure A.3.3: Latent Factors Estimated for Paris

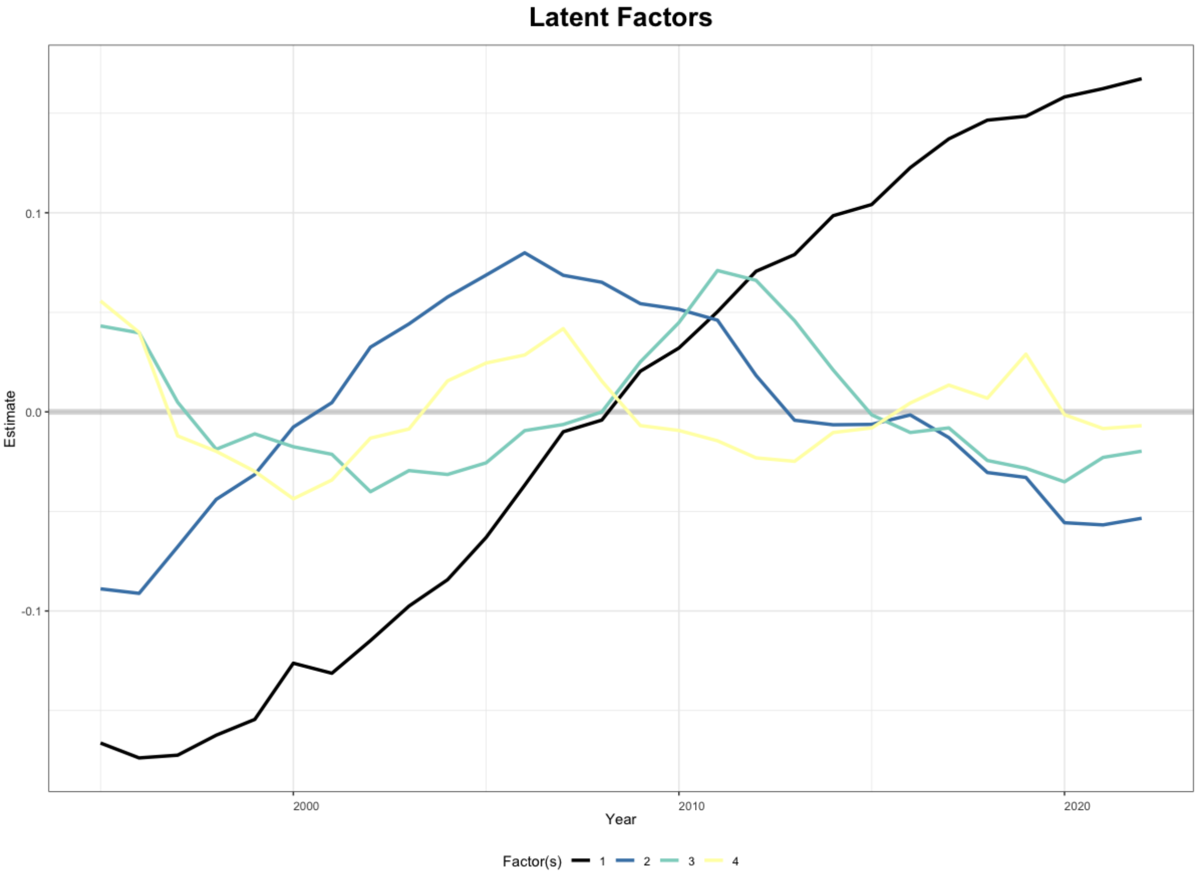

Figure A.3.4: Factor Loadings Estimated for Paris

Figure A.3.5: Latent Factors Estimated for Kigali

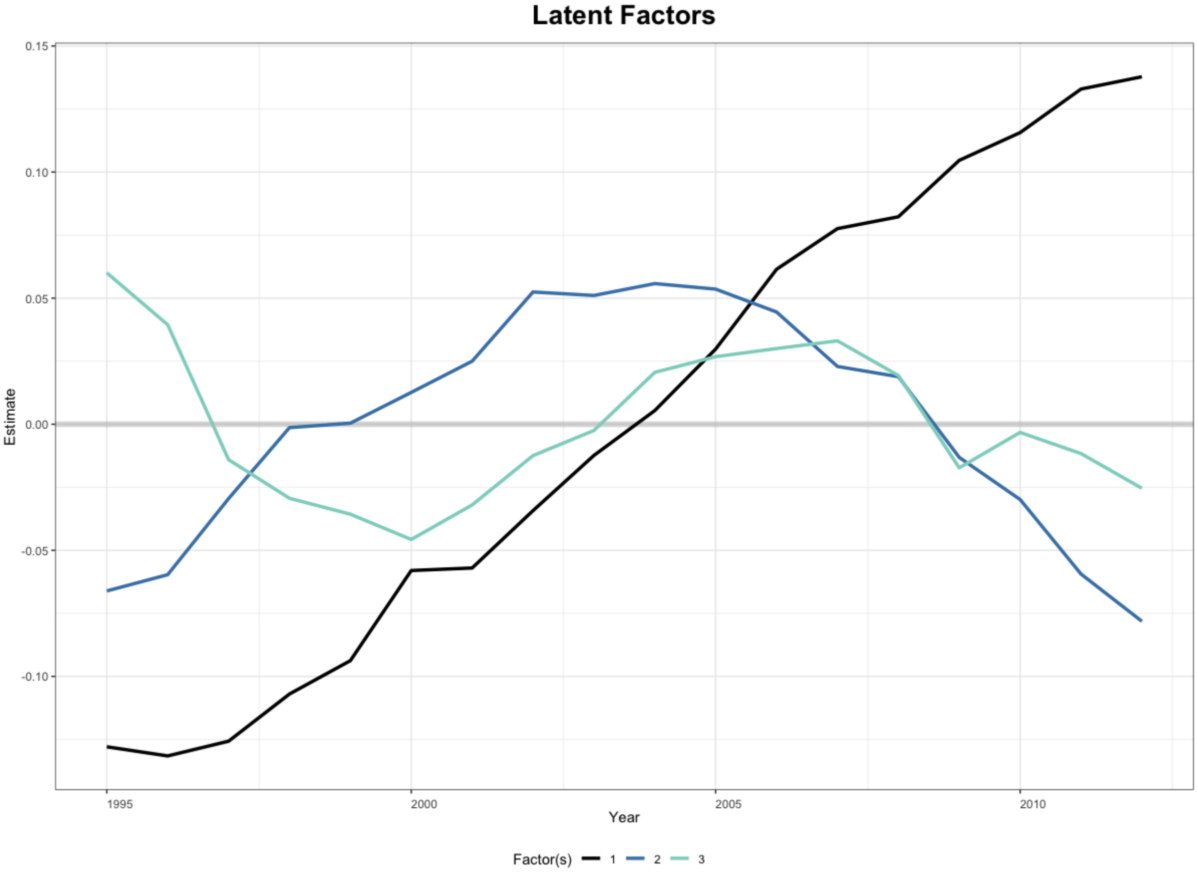

Figure A.3.6: Factor Loadings Estimated for Kigali