Collective Reciprocity and the Failure of Climate Change Mitigation Treaties

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Abstract:
Comprehensive climate change mitigation treaties negotiated thus far—the Kyoto Protocol and the Paris Agreement—have relied on enforcement through what I call "collective reciprocity," in which non-cooperation is punished by the reciprocal denial of collective goods. Because such goods are non-excludable, withholding them from defectors means also withholding them from compliers. This means that punishments affect all states, not just the defecting states. Such an enforcement regime is sharply limited and cannot sustain the kind of deep and broad cooperation that would be required for effective climate change mitigation. In what I call "selective reciprocity," on the other hand, defection is punished by the reciprocal denial of selective goods. These excludable goods can be withheld from defectors while simultaneously supplied to compliers, meaning that punishments can narrowly target the initial defector. Selective reciprocity is thus a more effective enforcement design than collective reciprocity and can scale to sustain deep and broad cooperation regimes. I contrast the failure of Kyoto and Paris–collective reciprocity treaties–with the success of the Kigali Amendment to the Montreal Protocol–a selective reciprocity treaty mitigating greenhouse gas emissions. This article's novel theoretical distinction between collective and selective reciprocity advances the literature on treaty design and international cooperation, connecting it to the burgeoning research program on climate clubs. To empirically demonstrate the failures of Kyoto and Paris as well as the success of Kigali, I use a generalized synthetic control; I compare the emissions of treated states to those of untreated states after weighting untreated states by their similarity to the treatment group.

1 Introduction

Climate change is an increasingly severe and urgent global problem, but its worst effects can be mitigated through the proactive reduction of greenhouse gas (GHG) emissions. Efforts at international governance have therefore placed a priority on enacting a global and comprehensive climate change mitigation treaty, resulting first in the Kyoto Protocol (negotiated 1997, effective 2005) and then the Paris Agreement (negotiated 2015, effective 2016).[1] Scholars and policymakers have emphasized the substantial differences between Kyoto and Paris. After Kyoto imposed jointly negotiated emissions targets on a small group of wealthy states, its failure drove negotiators to sacrifice strictness for flexibility; Paris prompts all states to set self-designed emissions targets (Keohane and Oppenheimer 2016). But focus on this contrast obscures crucial similarities between these treaties. In order to induce multilateral action without centralized enforcement, both have relied on the well-studied and frequently utilized principle of reciprocity: participating states implement emissions cuts at home in return for emissions cuts abroad. While Kyoto relied on specific reciprocity, in which reciprocation is equal and sequenced, Paris relies on diffuse reciprocity, in which reciprocation is not measured or timed as strictly but still underlies the mutual obligations inducing cooperation (Keohane 1986). Although many climate change policies are likely motivated by domestic factors rather than international reciprocation, the means by which participation in Kyoto or Paris could spur additional mitigation action is the logic of reciprocity on which the treaties are built.

I argue that Kyoto and Paris, both reciprocity treaties, share an even more fundamental design architecture. Specifically, both rely on what I term "collective reciprocity," in which non-participation and non-compliance are punished through the reciprocal withholding of collective good contributions. Collective goods, which include public goods and common pool goods, are non-excludable, meaning that they cannot be denied to one actor without being denied to all others. Under collective reciprocity, therefore, defection is deterred not by a targeted punishment but rather by the implicit threat of broad treaty failure that could result from reciprocal defection. This is a distinct and less

[1] I focus on comprehensive climate change mitigation agreements that have entered into force and for which there is some standard of compliance; I 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 (although I address one of its amendments below). I also omit climate change mitigation treaties that failed to come into force, such as the 2012 Doha Amendment to the Kyoto Protocol (although I also discuss it below). Finally, 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 themselves are non-binding, countries are bound to set targets and take domestic policy measures to pursue them.

capable version of reciprocity compared to what I call "selective reciprocity," in which non-participation and non-compliance are punished through the reciprocal withholding of selective goods provided by the treaty. Selective goods, which include club goods and private goods, are excludable, meaning that they can be provided or denied to a given actor without affecting their provision to another. The effects of selective reciprocity punishments are therefore limited to defectors, increasing enforcement credibility and allowing selective reciprocity to sustain costlier cooperation for larger numbers of actors than is possible with collective reciprocity, in which punishments are not targeted or credible. 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 selective reciprocity. Despite the evolution of climate change mitigation treaty design, therefore, I argue that Kyoto and Paris have failed similarly due to their shared reliance on collective reciprocity. In Section 2, I describe reciprocity in more detail, explain the collective-selective distinction, and apply this analysis to climate change mitigation treaties.

My theoretical emphasis on continuity in the international climate regime is supported by the empirical similarity between Kyoto and Paris, which I demonstrate in Section 3. Consequential participation in these treaties' emissions targets is narrow, mostly comprising wealthy democracies likely to cut emissions on their own. In the case of Kyoto, 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 stringent targets structured like those of Kyoto. Other states participated with highly conditional or partial targets that left ample room to avoid mitigation. I use logistic and linear regressions to demonstrate the descriptive fact that wealth and democracy are the only clear determinants of accepting stringent mitigation treaty commitments.

Even more importantly, there is no statistically distinguishable causal effect of participation on emission levels in either Kyoto or Paris. I demonstrate this null result with the 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. 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 emission levels. In short, I show in Section 3 that 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.

I turn to an alternative case in Section 3.4: the Kigali Amendment to the Montreal Protocol (negotiated 2016, effective 2019). Kigali restricted emissions of hydrofluorocarbons (HFCs), potent GHGs also targeted by Kyoto, Doha, and Paris, that had replaced many uses of ozone-depleting chemicals previously banned by Montreal. But Kigali leveraged the selective 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 selective club good could be simultaneously denied to defectors and provided to compliers, increasing the credibility of punishment. I find that while Kigali's stringent target participation is similar to that of Paris, Kigali sharply decreased HFC emissions among those participants, i.e., Kigali has successfully induced significant compliance. Empirically, Kigali serves as an effective placebo test. The same models that found null results for Kyoto and Paris find robust results for Kigali, indicating that the null results are not an artifact of the method. And theoretically, Kigali serves as an instructive comparison case. Kigali tackled a similar problem to Kyoto and Paris, namely the costly phase-down of industrial emissions to provide a global collective good. It also targeted the same population of states in a similar time period. Its starkly different results can best be explained by its fundamentally different design.

I conclude in Section 4 with policy solutions and theoretical and empirical implications. Selective reciprocity treaties for climate change mitigation, or so-called "climate clubs" (Nordhaus 2013), can induce participation and compliance by providing selective goods such as market access and conditional financing in addition to the collective good of mitigation. This article connects the burgeoning economics and public policy research programs on climate clubs to the rich political science literature on international cooperation and treaty design. It does so by making the novel theoretical distinction between collective and selective reciprocity, which tend to be lumped together or only implicitly distinguished in prior research. This article also advances the empirical debate on mitigation treaty efficacy (Maamoun 2019; Almer and Winkler 2017; Grunewald and Martínez-Zarzoso 2016) by comparing across treaties, by integrating analysis of participation and compliance, and by leveraging recent advances in synthetic control methodology. In short, I provide a theoretical explanation and an empirical demonstration of the failure of climate change mitigation treaties thus far before pointing towards the applicable policy solutions.

2 The Design of International Treaties

Scholars have long recognized that punishments or rewards are more effective if selective (Olson 1965) and that actors may struggle to sustain collective good provision if cooperation is based on reciprocity (Keohane 1986). But there has been surprisingly little engagement with these facts in the treaty design literature, which tends to lump reciprocal provision of selective and collective goods together. I situate reciprocity within the treaty design literature in Section 2.1 before outlining the differing structure and incentives of selective versus collective reciprocity in Section 2.2. The literature on environmental political economy, meanwhile, has extensively modeled cooperative collective goods provision, and some scholars have pointed out that the climate change mitigation treaties negotiated thus far are bound to fail due to the lack of selective benefits (Barrett

2005, 2016). But this insight has also not been connected to the broader literature on treaty design, preventing a more nuanced understanding of environmental treaties. I apply concepts from treaty design research and from my own distinction between selective and collective reciprocity to climate change mitigation treaties in Section 2.3. Finally, I leverage this theorizing to generate specific hypotheses in Section 2.4 for empirical tests in Section 3.

Throughout, my analysis focuses on states as actors and assumes that they have an interest in both mitigating climate change and minimizing the economic costs of mitigation. Although sub-state governments, non-governmental organizations, and even individuals often play a prominent role in global environmental politics, any effect that they have on treaty efficacy should be visible through the altered behavior of the states which are parties to the treaties. 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). I also follow Mitchell (1994) in treating treaty design as consequential for treaty efficacy. While climate change mitigation treaties could be designed around reciprocity based on selective goods, states have thus far chosen a more straightforward but limited design: reciprocity based on the collective good of climate change mitigation itself. Collective reciprocity is a simple design that facilitated multilateral negotiation, but its shortcomings relative to selective reciprocity help to explain the failures of Kyoto and Paris to expand participation or induce compliance, which I demonstrate in Section 3.

2.1 Types of International Agreements

Unlike climate change mitigation, many kinds of international cooperation are simple coordination games in which states organize mutually beneficial activity and there are no incentives to defect. In fact, about half of international agreements lack any dispute resolution systems, or mechanisms for identifying and adjudicating non-compliance (Koremenos 2007). 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).

A strict realist perspective would suggest that simple coordination games are the only effective cases for international treaties due to two restrictive conditions on treaty success. First, treaties cannot solve complex cooperation problems, or mixed motive games like the prisoners' dilemma, which require restraint from potentially rewarding defection (Mearsheimer 1994; Krasner 1991). This is because there exists no central government to enforce the agreement. Second, even in coordination games, treaties 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).

International politics, however, 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 usefully highlights two important considerations. First, treaties addressing complex cooperation problems confront significant enforcement 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. 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 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 the strong incentives for defection by the punisher itself. In other words, enforcement regimes must themselves 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 mechanism for self-enforcing punishment regimes in international relations that has been widely used by policy practitioners and exhaustively studied by scholars (Keohane 1984, 1986).[4] Reciprocity occurs when an actor performs

[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.

[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 from my analysis.

[4]Note that research on issue linkage (Keohane 1984), iterated interaction (Axelrod 1984), or domestic

cooperative behavior contingent on roughly equivalent cooperative behavior from another actor. A simple form of reciprocity in a two-player setting is the Tit for Tat strategy (Axelrod 1984). By tying one's participation and compliance to participation and compliance by other states, reciprocity draws a clear link between defection and punishment. Reciprocation does not have to occur on the same exact issue–in a trade agreement, one state may lower tariffs on automobiles while another state lowers tariffs on agricultural products–or even within the same issue area–in a security client relationship, one state may transfer arms in exchange for another state's vote in the U.N. General Assembly. But a close connection between the goods being offered by each side helps to ensure that the threat of reciprocal defection is comparable to the initial defection in size, scope, and domestic salience. This increases both the credibility of punishment and the likelihood that it is a non-negligible cost relative to the punished behavior.

2.2 Types of Reciprocity

Strategies of reciprocity are not all alike. Scholars have previously distinguished between specific and diffuse reciprocity arrangements, or those for which reciprocal behavior is precisely equivalent and sequenced and those for which more flexibility is allowed (Keohane 1986). I introduce an additional distinction in reciprocity theory independent of the specific-diffuse distinction. In collective reciprocity, actors engage in the reciprocal exchange of collective benefits, often by jointly contributing to the provision of the same collective good. Collective goods are non-excludable, meaning that access to their benefits cannot be denied to any party.[5] Non-excludabiliity means that punishment through reciprocal defection is a blunt instrument; punishment of the initial defector through reduced collective good provision also punishes other parties because all benefit from the collective good. In selective reciprocity, on the other hand, actors engage in the reciprocal exchange of selective benefits, often by exchanging private goods or by jointly contribut-

interest groups (Davis 2004; Dai 2005) does not provide an alternative type of enforcement mechanism to reciprocity, but rather an additional means by which the pre-supposed reciprocity punishment can become more credible or less negligible.

[5] Although usage of the term collective good varies, I follow Hardin (1982) in using the term to mean goods that are non-excludable, encompassing both public goods, or goods that are non-excludable and non-rivalrous, and common pool goods, or goods that are non-excludable and rivalrous.

ing to the provision of a club good. Selective goods are excludable, meaning that access to their benefits can be withheld from particular actors. This excludability means that punishment through reciprocal defection is a targeted instrument; punishment of the initial defector can occur without punishment of other parties. In a reciprocal exchange of market access between three states, for example, state A's defection can be punished by A losing market access to B and C without B and C losing market access to each other.

Collective and selective reciprocity are not mutually exclusive. The World Trade Organization (WTO), for example, provides a collective good by publishing global trade statistics and provides a selective good of open market access. Enforcement reciprocity in the WTO therefore encompasses both collective and selective reciprocity; states are motivated to cooperate to ensure other states' reciprocal provision of both trade data and market openness. Because of its selectivity, however, the threat of market cutoff is probably the key to WTO participation and compliance, not the threat of unpublished trade statistics. Similarly, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) provides the collective good of reducing global nuclear proliferation as well as the selective good of civilian nuclear power assistance; it is therefore enforced by both collective and selective reciprocity. In the case of the NPT, these forms of reciprocity motivate different blocs of participants. States with nuclear weapons do not need civilian nuclear power assistance but place greater value on the collective good of non-proliferation among other states. States without nuclear weapons often lack nuclear power and therefore have much to gain from the selective good of civilian nuclear power assistance.

Although selective reciprocity is more effective, its application requires the existence of selective benefits. If a treaty's primary intended benefits are excludable goods, then enforcement through selective reciprocity is straightforward. This is especially common for issues like trade that can be reduced to a cluster of bilateral exchanges, any one of which can be ended without affecting others (Oye 1985). For example, the primary goal of the WTO is the provision of open market access, a club good that is created through bilateral ties that can be cut for defectors but not for cooperators. But if a treaty's primary intended aim is collective good provision, then its signatories will need to create auxiliary selective goods to provide in order to make selective reciprocity a viable enforcement strategy. For example, while the purpose of the NPT is the collective good of non-proliferation, enforcement is greatly enhanced by the auxiliary selective good of civilian nuclear power assistance. And although these goods are distinct, their close relation enhances the credibility and non-negligibility of punishment through selective reciprocity. Nevertheless, creating an auxiliary good requires contracting on more issues, which complicates the negotiation process.

In both selective and collective reciprocity, effectiveness is increasing in the value of the good being provided and declining in the costs of treaty participation and compliance. But unlike selective reciprocity, which can scale to any group size, collective reciprocity works better when the collective good can be provided by a small group (Olson 1965). Schelling (1978) and Hardin (1968) use k to represent the minimal efficacious group size in collective action provision. If five actors would need to contribute to the collective good in order for each of the five to be better off than the alternative of no contribution, then $k = 5$. When $k = 1$ the group is privileged in the terminology of Olson (1965), and cooperation as such is unnecessary because the collective good can be profitably provided unilaterally.[6] When $k > 1$ cooperation is required to provide the collective good, but cooperation will become more difficult as k grows. In a two-player setting, reciprocity can enable cooperation for a collective good as effectively as for a club good because defection by either actor will result in reciprocal punishment that is effectively targeted. But when larger groups are necessary for collective good provision, reciprocal punishments become less credible as greater size decreases the likelihood that any individual actor's defection will be pivotal to treaty failure (Barrett 1992, 2005) and hinders the ability of actors to calibrate their responses to each possible defector (Hardin 1982). Thus, both selective and collective reciprocity treaties will be unnecessary for a privileged group and will have similar efficacy when $k = 2$. But as k grows, selective reciprocity treaties will remain effective while collective reciprocity treaties will become increasingly unlikely to

[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).

work.

Figure 1: Types of International Agreements

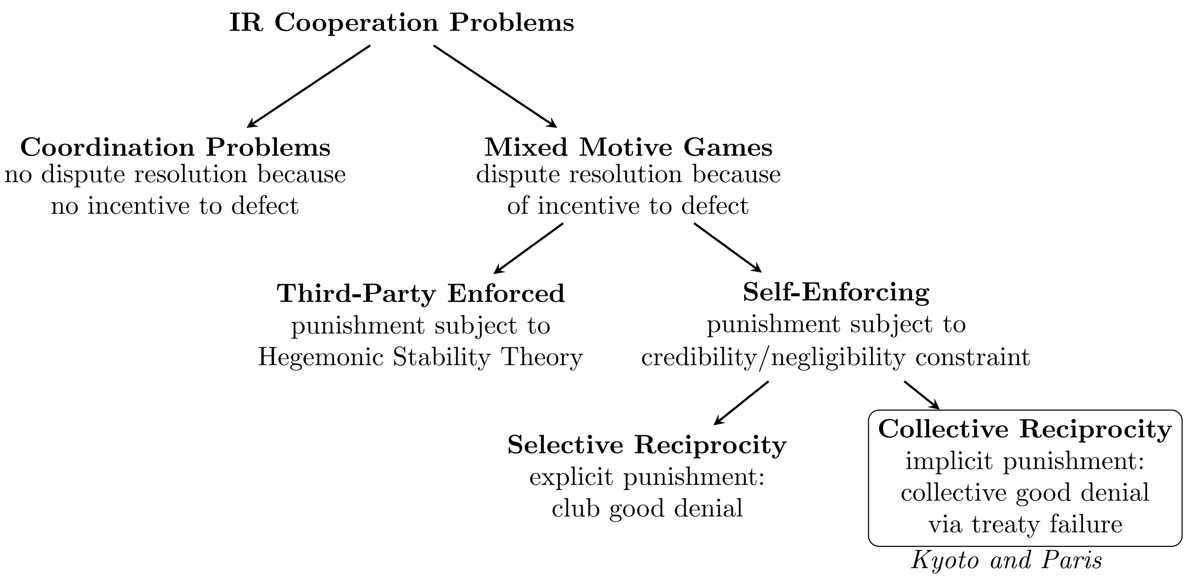


Figure 1 disaggregates international cooperation problems as described above. Cooperation problems in international politics can be divided into coordination problems, where actors lack any incentive to defect and agreements therefore generally lack dispute resolution systems, and mixed motive games, where actors balance incentives to cooperate and defect. Although hegemonic power can be used to enforce cooperation in a mixed motive game, the absence or disinterest of a hegemon leaves states to rely on self-enforcement subject to the credibility and negligibility constraints. Two types of self-enforcement are selective reciprocity and collective reciprocity. In line with the RDII framework, selective reciprocity and collective reciprocity regimes are generally distinguishable in practice by differences in treaty design. Selective 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.[7] When the structure of the treaty issue enables credible and non-negligible self-enforcing punishments without

[7]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.

treaty failure, these punishments will be explicitly specified.

In the case of climate change mitigation, negotiators settled on collective reciprocity designs at Kyoto and Paris. Cooperation is driven by the collective good of mitigation itself rather than by any auxiliary selective goods created for the sake of enforcement. Unfortunately, mitigation is a problem defined by a large k-group, as discussed further below. 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.

2.3 Reciprocity for Climate Change Mitigation

Climate change mitigation treaties negotiated thus far have relied on collective reciprocity for enforcement. Attempts to provide auxiliary selective 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 selective reciprocity (Barrett 2011; Nordhaus 2015; Barrett and Dannenberg 2022), topics I return to in Section 4, these design elements remain hypothetical. In short, treaties like Kyoto and Paris address complex cooperation issues rather than simple coordination problems but lack a third-party hegemonic enforcer and lack selective 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 collective reciprocity. Non-participation and non-compliance are punished only with the implicit threat of treaty failure through widespread reciprocal defection. States will be motivated to participate and to comply insofar as their doing so contributes to treaty success. This enforcement structure is severely limited.

Some scholars may argue that climate change mitigation is problem with a small k-group and could therefore be amenable to collective reciprocity. But although GHG emission volumes vary considerably by country, effective mitigation would require cooperation among a large number of actors. 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 may not be a fully 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 its k-group is larger than the small handful of states that could conceivably cooperate through collective reciprocity. The large number of necessary actors and a high cost to action make climate change mitigation unlikely to be solved through collective reciprocity.

Other scholars have questioned whether climate change mitigation is really a global collective action problem (Aklin and Mildenberger 2020; Colgan et al. 2021). While any climatic effect of emissions reductions are literally global collective goods, or ones whose benefits are non-excludable, these scholars may argue that states have enough private benefits to reduce emissions without consideration of this global collective benefit. If green transitions are worthwhile for their local co-benefits alone rather than for the resulting mitigation of global climate change, it follows that they are blocked not by interstate free-riding but by concentrated domestic interests, such as the fossil fuel industry (Mildenberger 2020; Stokes 2020). These scholars who locate the primary barriers to mitigation at the domestic rather than the international level may therefore argue that international climate change mitigation is not a complex cooperation problem where states have an incentive to defect but rather a simple coordination problem, meaning that climate change mitigation treaties like Paris do not need to deter free-riding but merely need to share information or establish focal points. But even among scholars focused on the important questions of the domestic politics of climate change, few would deny that mitigating countries would benefit from reciprocal mitigation by others, whether because of the additional climatic effect, as emphasized by the collective action school, or because of the catalytic economic effects of technology development or economies of scale, as emphasized by many in the distributive politics school (Hale 2020).

Indeed, although some scholars have argued that Paris is a "coordinated unilateralism" treaty rather than a reciprocity treaty (Bernauer et al. 2016), these arguments either re-label reciprocity or obviate the need for a comprehensive and global treaty. Hale (2020) argues that Paris targets are meant to signal commitment abroad and spur "catalytic cooperation," but commitments are only catalyzed insofar as they are reciprocated. Melnick and Smith (forthcoming) argue that Paris targets are meant to signal commitment at home and bind governments domestically, but governments could signal green commitments at home through legislation rather than a treaty. Hale (2016) and Jernnäs and Lövbrand (2022) argue that Paris targets are meant to empower green domestic constituencies through transnational linkages, but linkages based on new markets for green investment will only develop through interstate reciprocation and linkages based on sharing information or resources could occur more easily in a treaty limited to these issue areas rather than one mandating emissions targets.

Although Paris's diffuse reciprocity, in which states are given immense flexibility in the size and timing of their contributions, is strikingly different from Kyoto's specific reciprocity, in which contributions were jointly negotiated, both treaties rely on collective reciprocity for enforcement. This is unfortunate, because it has sharply limited their potential for effectiveness. But collective reciprocity is not an inevitable design choice for climate change mitigation treaties. The Kigali Amendment to the Montreal Protocol provides an alternative model. Kigali restricts one type of GHG emissions (HFCs), thereby providing a global collective good of climate change mitigation. But it also provides an auxiliary selective good to cooperators in the form of market access for the HFC trade. Because treaty participants can punish non-participants or non-compliers by cutting them out of HFC markets without punishing compliant participants, the threat to enact this punishment is highly credible. Moreover, because losing access to HFC markets negates much of the potential benefit of cheating, the punishment is non-negligible. Rather than cooperate out of the fear of broad treaty failure to supply the collective good due to other reciprocal defections, states cooperate due to the fear of individually losing access to the treaty's selective benefits. Kigali thus entails a significantly more robust enforcement regime than Kyoto or Paris. I predict that Kigali will successfully generate broad participation and sustain deep compliance, Kyoto and Paris will struggle to do so.

2.4 Hypotheses

In the next section, I evaluate the effects on participation and compliance of the comprehensive climate change mitigation treaties: Kyoto and Paris, and an additional non-comprehensive treaty: Kigali. For each, I descriptively evaluate participation and causally estimate treaty compliance. Below, I specify the causal hypotheses that I will test, which are derived from my theoretical analysis of club and collective reciprocity above.

Hypothesis 1: The Kyoto Protocol will fail to reduce GHG emissions among participants with targets compared to participants without targets and non-participants.

Hypothesis 2: The Paris Agreement will fail to reduce GHG emissions among participants with stringent targets compared to participants with weak targets and non-participants.

Hypothesis 3: The Kigali Amendment will successfully reduce HFC emissions among participants with stringent targets compared to participants with weak targets and non-participants.

3 The Effects of Treaty Design

In Section 3.3 below, I show that despite some changes in treaty design from Kyoto to Paris, both treaties have been similarly unsuccessful in eliciting participation from states not already interested in mitigation and in pushing participant states to comply by cutting emissions. In Section 3.4, I show that Kigali, a more substantial departure from the design of Kyoto and Paris, has had significant success. Although Kigali did not broaden participation beyond wealthy democracies, it successfully induced compliance, reducing emissions as intended. Before showing these findings, 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, 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 commitments: defined by unconditional (not pending foreign assistance) and absolute (relative to past emissions, not to projections) targets for emissions (not carbon intensity) that are economy-wide rather than limited to certain sectors (in practice this also means targets that apply to at least the three main GHGs: CO2, CH4, and N20.[8] 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

[8]The seven major GHGs defined by the IPCC also include HFCs, PFCs, SF6, and NF3.

emissions reductions through incentives for the mitigation of climate change. I include climate resilience and size (logged GDP) as climate variables. Climate resilience reflects both economic readiness and exposure to the major physical 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).[9] 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. I include diagnostic plots for the GSM method in Appendix A.5. Overlap between variables is sufficient and these plots demonstrate no cause for concern.

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 and Kigali. This paper provides, to my knowledge, the first quantitative analysis of the effectiveness of Paris and Kigali. Due to the recency of the Paris Agreement, studies thus far have

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

focused more on potential rather than actual compliance (Raiser et al. 2020). However, with emissions data extending through 2023, I run my analysis on the first 8 years of the Paris Agreement (2016-2023), a comparable period to the 8-year study period for Kyoto (2005-2012).

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 take a climate resilience measure from the ND-GAIN database (noa 2025).

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.

In my main analysis 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 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. I re-run the Kyoto and Paris models while including LULUCF emissions in Appendix A.1 and find substantively similar results to those shown in the article.[10]

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 been small and its effectiveness highly doubtful (Sovacool and Brown 2009; Victor 2011), I address this concern in Appendix A.2 by re-running the Kyoto, Paris, and Kigali models after adding emissions reductions credited to CDM investments back into recipient country totals. In other words, this robustness check artificially inflates the emissions of those control units which hosted CDM projects.

[10] I do not re-run Kigali models with LULUCF emissions because HFCs are not emitted by any LULUCF processes.

3.3 Climate Change Mitigation Treaties

Table 1 summarizes the commitment data for each comprehensive climate change mitigation treaty. The most notable fact from this data is the increasing breadth of participation and depth of ambition from Kyoto to Paris. Although the share of global emissions represented by each Kyoto participant tended to decline by the time of the Paris Agreement, the addition of new participants at Paris more than compensated for this. While Kyoto participants constituted only about 27% of global emissions when the treaty came into force in 2005, Paris participants constituted about 41% of global emissions when it came into force in 2016. The vast majority of this increase is due to the entrance of the United States in the agreement, although US participation has been periodical, entering in 2016, departing in 2017, re-entering in 2021, and departing again in 2025 (Table 1 depicts membership and targets in 2023, the latest year for my outcome data in the analysis below as well as the year of broadest participation). Nevertheless, even with significantly broader participation, Paris still falls well short of engaging states representing a majority of global GHG emissions.

But Paris also represents an increase in ambition relative to Kyoto. To convey the relative ambition of each treaty, I convert each formal target into necessary changes in national emissions trends. This is useful for two reasons. First, formal targets are not directly comparable. At Kyoto, while participants were assigned targets that were similar in style, targets often used different base years or different accounting methods, meaning that the simple percentage emission cut target could be a misleading representation of the tonnes of C02-equivalent emissions required to be cut. At Paris, participants styled their own targets, meaning that while some used base year percentages in the style of Kyoto (although again, with differing base years and accounting), others made targets in the form of absolute emissions caps or absolute net emissions caps.[11] Second, formal targets do not convey the emissions trajectories that states are on in the lead up to accepting a commitment. A 1% emissions cut target will have very different implications for a developing economy whose emissions are growing by 2% per year than for a post-

[11] These are the only forms of targets that meet my stringency definition because they are unambiguous rather than situationally dependent such as a target in terms of a projected emissions pathway.

industrial economy whose emissions are shrinking by 1% per year. As such, I have followed the methodology of Rowan (2019) for comparing emissions targets by converting them into an aggregate amount of emissions allowable at a future date, calculating the national emissions trajectory necessary to hit that cap, and comparing that targeted trajectory to the state's real past trajectory.[12] As can be seen by comparing the target trends for each treaty, while the average Kyoto target required participants simply to limit themselves to emissions growth of less than 1.4%, the average stringent Paris target requires participants to reduce emissions by 5.4% per year. Although Paris participants tended to already be experiencing a downward trend in emissions (as visible in the Pre-Paris Trend column), Paris targets still required an acceleration of those emissions reductions.

Thus, Paris broadened participation and deepened ambition relative to Kyoto. Below, I explore the drivers of each treaty's participation and, more significantly, test whether Paris's ambition has translated into real compliance, causing real emissions reductions and the mitigation of global climate change.

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,

[12] I calculate past trajectories for the ten years leading up to the Paris Agreement: 2006-2016. I calculate trajectories as compound annual growth rates.

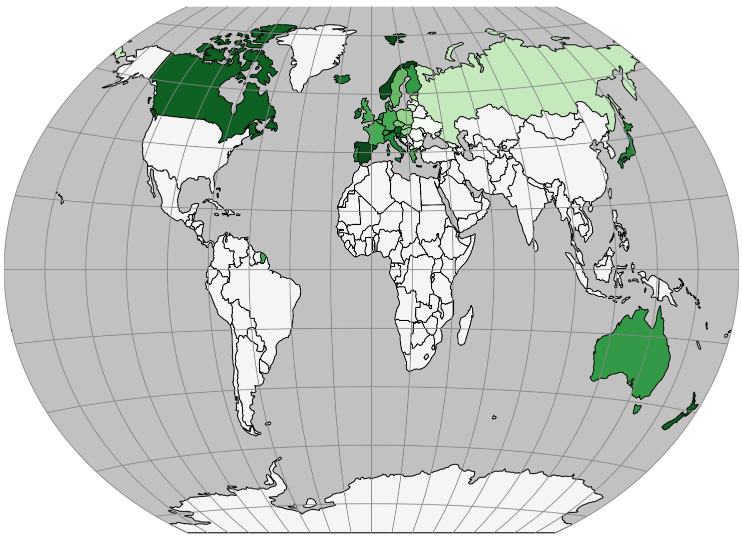
Table 1: Participation and Ambition in Kyoto and Paris

State	Formal Kyoto Target	Pre-Kyoto Trend	Kyoto Target Trend	Kyoto Trend Difference	2005 Emissions Share	Formal Paris Target	Pre-Paris Trend	Paris Target Trend	Paris Trend Diff	2016 Emissions Share
Kyoto Participants	-3.5%	0.3%	1.4%	1.1%	27.2%	-	-	-	-	-
Paris Participants	-	-	-	-	-	-35.4%	-0.9%	-5.4%	-4.5%	40.9%
USA	-	-	-	-	17.9%	-50%	-0.7%	-5.9%	-5.2%	13.1%
Russia	0%	-0.1%	10.1%	10.2%	5.3%	-30%	1.2%	-1.9%	-3.1%	4.9%
Japan	-6%	0.1%	-3.2%	-3.3%	3.6%	-46%	-1.4%	-4.8%	-3.4%	2.7%
Germany	-21%	-1.1%	0.5%	1.6%	2.5%	-50%	-2.8%	-4.9%	-2.2%	1.8%
Brazil	-	-	-	-	2.4%	-48.4%	0.6%	-35.8%	-36.4%	2.5%
Canada	-6%	1.5%	-5.4%	-6.9%	1.9%	-40%	0.5%	-5.4%	-6%	1.6%
United Kingdom	-12%	-0.7%	0.7%	1.4%	1.7%	-68%	-3.2%	-6.4%	-3.3%	1%
Italy	-6%	0.8%	-2.9%	-3.7%	1.5%	-43.7%	-1.7%	-1.9%	-0.2%	0.9%
Australia	8%	1.5%	-0.3%	-1.8%	1.4%	-43%	-1.6%	-7.2%	-5.7%	1.2%
France	0%	0.3%	1.2%	0.9%	1.4%	-47.5%	-2.3%	-4.5%	-2.2%	1%
South Korea	-	-	-	-	1.4%	-40%	0.7%	-5.3%	-6%	1.5%
Ukraine	0%	-2.7%	14.7%	17.4%	1.2%	-40%	-4.1%	4.3%	8.5%	0.6%
Spain	15%	3.2%	-5.1%	-8.3%	1.1%	-37.7%	-0.8%	-1.4%	-0.6%	0.7%
Poland	-6%	-1.5%	6%	7.5%	1%	-17.7%	-1.2%	-0.9%	0.3%	0.8%
Argentina	-	-	-	-	0.8%	-	-0.3%	-1.6%	-1.3%	0.8%
Netherlands	-6%	-0.4%	-2.6%	-2.2%	0.6%	-48%	-2.6%	-4.3%	-1.7%	0.4%
Kazakhstan	-	-	-	-	0.6%	-15%	-0.7%	0.7%	1.3%	0.7%
Belgium	-7%	-0.3%	-0.1%	0.2%	0.4%	-47%	-1.1%	-6.2%	-5.1%	0.3%
Czechia	-8%	-0.4%	4.3%	4.8%	0.4%	-26%	-1.9%	0.3%	2.2%	0.3%
UAE	-	-	-	-	0.4%	-19%	2.2%	-5%	-7.2%	0.6%
Colombia	-	-	-	-	0.4%	-	1.1%	-1.9%	-3%	0.4%
Greece	25%	1.9%	1.9%	0%	0.3%	-22.7%	-2.7%	4.4%	7.1%	0.2%
Romania	-8%	-2.2%	14%	16.2%	0.3%	-12.7%	-0.8%	2.8%	3.6%	0.2%
Austria	-13%	1.5%	-5.5%	-7%	0.2%	-48%	-1.2%	-5.4%	-4.2%	0.2%
Bulgaria	-8%	-2.1%	14.2%	16.3%	0.2%	-10%	-0.7%	1.7%	2.5%	0.1%
Denmark	-21%	-1.6%	-2.6%	-1%	0.2%	-50%	-2.6%	-3.7%	-1.1%	0.1%
Finland	0%	0.2%	-0.6%	-0.7%	0.2%	-50%	-3.5%	-3.3%	0.2%	0.1%
Hungary	-6%	-0.2%	6.6%	6.8%	0.2%	-18.7%	-0.1%	1%	1.1%	0.1%
Ireland	13%	1.8%	-2.4%	-4.2%	0.2%	-42%	-0.4%	-4.8%	-4.4%	0.1%
Norway	1%	2.8%	-6.7%	-9.5%	0.2%	-45%	-1.8%	-8.1%	-6.3%	0.1%
New Zealand	0%	0.7%	-5.5%	-6.2%	0.2%	-50%	0%	-7.1%	-7.1%	0.2%
Portugal	27%	1.9%	-0.8%	-2.7%	0.2%	-28.7%	-0.9%	0.5%	1.4%	0.1%
Sweden	4%	-0.8%	1.3%	2.1%	0.2%	-50%	-2.8%	-4%	-1.2%	0.1%
Belarus	-	-	-	-	0.2%	-35%	-0.6%	-0.3%	0.3%	0.2%
Israel	-	-	-	-	0.2%	-27%	-0.8%	-3%	-2.2%	0.2%
Peru	-	-	-	-	0.2%	-	0.8%	9%	8.2%	0.2%
Serbia	-	-	-	-	0.2%	-13.2%	0.1%	-1.5%	-1.5%	0.1%
Switzerland	-8%	0.4%	-0.6%	-1%	0.1%	-50%	-1%	-4.8%	-3.8%	0.1%
Estonia	-8%	0%	11.1%	11.1%	0.1%	-24%	-4.6%	0.5%	5.1%	0.1%
Croatia	-5%	1.9%	-2.1%	-4%	0.1%	-16.7%	-0.1%	0%	0.1%	0.1%
Lithuania	-8%	-0.1%	12.9%	13%	0.1%	-21%	-0.8%	-2.1%	-1.3%	0.1%
Slovakia	-8%	-0.6%	5.8%	6.4%	0.1%	-22.7%	-0.8%	-0.6%	0.2%	0.1%
Slovenia	-8%	1%	-2.2%	-3.1%	0.1%	-27%	-2.6%	1.6%	4.2%	0%
Bosnia-Herzegovina	-	-	-	-	0.1%	-9.1%	-0.4%	-4.6%	-4.2%	0.1%
Gabon	-	-	-	-	0.1%	-	0.3%	-30.5%	-30.8%	0%
Singapore	-	-	-	-	0.1%	-	2.1%	-3.7%	-5.8%	0.1%
Uruguay	-	-	-	-	0.1%	-	0.4%	-0.3%	-0.7%	0.1%
Iceland	10%	2.3%	-2.6%	-4.9%	0%	-45%	0.6%	-7.8%	-8.4%	0%
Liechtenstein	-8%	1.1%	-2.7%	-3.9%	0%	-40%	-1.9%	-1.9%	0%	0%
Luxembourg	-28%	2.7%	-5.6%	-8.3%	0%	-50%	-2.8%	-3.7%	-0.9%	0%
Latvia	-8%	-1.2%	15.4%	16.5%	0%	-17%	-1%	-1.4%	-0.4%	0%
Monaco	-8%	-2.3%	-10.2%	-7.8%	0%	-55%	-1.6%	-4.2%	-2.6%	0%
Costa Rica	-	-	-	-	0%	-	-6.4%	3.1%	9.5%	0%
Cyprus	-	-	-	-	0%	-32%	2.7%	-7.8%	-10.5%	0%
Georgia	-	-	-	-	0%	-35%	1.3%	-0.2%	-1.6%	0%
Moldova	-	-	-	-	0%	-70%	0.8%	0.4%	-0.4%	0%
Malta	-	-	-	-	0%	-19%	-2%	0.2%	2.2%	0%
Montenegro	-	-	-	-	0%	-35%	-0.9%	-4.4%	-3.5%	0%
San Marino	-	-	-	-	0%	-20%	-1.8%	0%	1.8%	0%
Tajikistan	-	-	-	-	0%	-30%	5.4%	-3.7%	-9.1%	0%

Note: Countries are ordered by rank of 2005 global emissions share. Only countries with strict commitments for one of the two treaties are listed. Formal target percentages represent cuts relative to a baseline year, sometimes with different baseline years (and other irregularities) per country. Pre-treaty trends represent yearly emissions growth rates in preceding ten years. Treaty target trends represent necessary yearly emissions growth rate to hit target. Targets and trends are averaged for the full treaty value.

the agreement offered semi-flexibility by maintaining a short commitment period.[13] 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.

Figure 2: Kyoto Commitment Targets



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

Kyoto participants with binding targets were 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

[13]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.

and doled out selective inducements to neighboring non-members (McLean and Stone 2012). 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 participants with two-step regression analysis in Table 2. I first fit logistic regressions to predict participation in Kyoto's targets. While the full model with co-benefit and climate-related variables is potentially underpowered, a narrower model focusing on co-benefits achieves statistical significance for all of its explanatory variables. Wealth and democracy both predict participation, as does being on a declining emissions trajectory leading up to Kyoto. In short, this model confirms the descriptive fact that Kyoto primarily gave targets to wealthy democracies, who likely already had their own incentives to cut emissions.

I then fit linear regressions to predict Kyoto's target ambition after narrowing the sample to participants. Again, wealthy states on a downward emissions trajectory were more likely to take on commitments, although in this case democracy loses its predictive power.

In addition to such 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.[14]

[14]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 of the treaty commitment period.

Table 2: Determinants of Kyoto Participation and Ambition

	Dependent variable:			
	Kyoto Participation		Kyoto Ambition	
	logistic regression		*linear regression*	
	(1)	(2)	(3)	(4)
Pre-Kyoto GHG Trend	−0.68***	−0.79***	2.97***	2.54***
	(0.23)	(0.21)	(0.45)	(0.45)
Ln GDP	0.15		0.74	
	(0.31)		(0.44)	
Ln GDP per Capita	0.11	1.77***	2.61	4.89***
	(0.88)	(0.49)	(1.60)	(0.97)
Electoral Democracy	5.55**	5.31**	4.81	0.23
	(2.58)	(2.23)	(5.74)	(5.96)
Ln Fossil Fuel Reserves per Capita	0.04		0.07	
	(0.07)		(0.08)	
Climate Resilience	0.24**		0.18	
	(0.12)		(0.18)	
Constant	−22.30***	−20.35***	−63.75***	−51.74***
	(7.30)	(4.55)	(9.84)	(7.76)
Observations	167	167	35	35
Log Likelihood	−23.13	−27.16	−85.20	−89.87
Akaike Inf. Crit.	60.27	62.32	184.39	187.74
Note:		*p<0.1; **p<0.05; ***p<0.01		

I estimate Kyoto's compliance effect on participant emissions as compared to a synthetic control in Table A.1.2. Along with adjusting for pre-treatment outcome trends with the synthetic control method, I adjust for the covariates that predict Kyoto participation: logged GDP per capita and democracy. 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). The Kyoto ATT is statistically insignificant in both models. This result supports Hypothesis 1, that Kyoto will fail to induce GHG emission reductions among its participants.

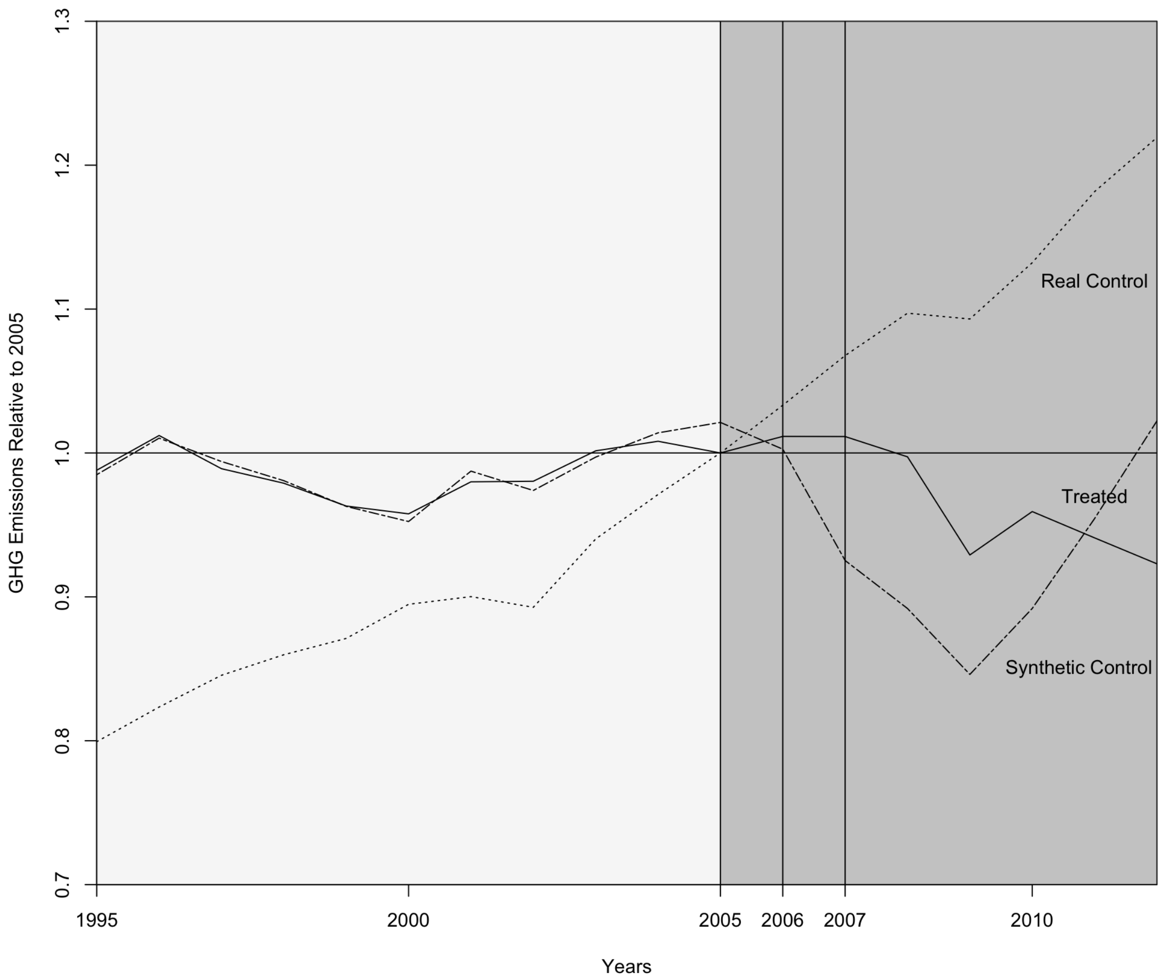
Table 3: Compliance Effect of Kyoto

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Kyoto ATT	0.083	0.050
	(0.152)	(0.137)
Lag Ln GDP per Capita		0.000
		(0.000)
Electoral Democracy		0.098
		(0.127)
Treated Observations	34	34
Mean Squared Prediction Error	0.0022	0.0019
Note:	*p<0.1; **p<0.05; ***p<0.01	

I visually illustrate this comparison between the Kyoto treatment group and their synthetic control in Figure 3. There is no visible evidence of a compliance effect from Kyoto.

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. An amendment to reform and extend the treaty into a new commitment period was agreed upon at Doha in 2012. The final amendment text deviated strongly from Kyoto's perceived shortcomings, centralizing commitment-making by forcing higher and more uniform targets on participants and reducing flexibility by aiming for a longer commitment period (ending in 2020). Reducing decentralization and flexibility was aimed at encour-

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. Late entries in 2006 and 2007 are illustrated by vertical lines in those years.

aging 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. Ultimately, Doha participation was concentrated in an even smaller and more European-dominated group of mostly wealthy democracies. But Doha did not reach the necessary participation threshold for enactment. This compounding of Kyoto's failure spurred calls to radically rethink the depth and breadth of mitigation treaty design, culminating in the Paris Agreement four years later. But these reforms left the collective reciprocity basis for cooperation untouched.

3.3.2 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).

Like Kyoto, participation in Paris was heavily influenced by the European Union, leading to a strong concentration of participants with stringent targets 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 to bring the United States, Brazil, and other major non-participants from Kyoto. But Paris remained, like Kyoto, a treaty mostly engaging wealthy democracies. Major and growing emitters like China and India remained on the sidelines.

I describe Paris participation with another two-step regression analysis summarized in Table 4. The results are similar to those for Kyoto, despite greater breadth and diversity in Paris participation. Again, climate variables seem unrelated to participation.

Figure 4: Paris Stringent Commitment Targets

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

Paris participation is well predicted by economic development and democracy. Paris ambition, on the other hand, is not easily predicted. Neither climate variables nor co-benefit variables can significantly predict the ambition of Paris targets for participating states.

Unfortunately, Paris has not successfully paired its high participation and ambition 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. This result strongly supports Hypothesis 2, that Paris will fail to induce GHG emission reductions among participants with stringent emissions.

This null effect is plotted in Figure 5, which shows the trajectory of Paris participants barely deviating from the synthetic comparison. While some evidence of a weak effect is

Table 4: Determinants of Paris Participation and Ambition

	Dependent variable:			
	Paris Participation		Paris Ambition	
	logistic		*normal*	
	(1)	(2)	(3)	(4)
Pre-Paris GHG Trend	−0.28**	−0.35***	0.68	0.86
	(0.13)	(0.11)	(0.56)	(0.55)
Ln GDP	0.13		0.39	
	(0.22)		(0.80)	
Ln GDP per Capita	−0.30	1.38***	3.71*	1.58
	(0.49)	(0.28)	(2.03)	(1.20)
Electoral Democracy	2.94**	2.52**	−6.36	−6.12
	(1.38)	(1.07)	(6.14)	(5.95)
Ln Fossil Fuel Reserves per Capita	0.05		0.03	
	(0.06)		(0.16)	
Climate Resilience	0.29***		−0.38	
	(0.08)		(0.23)	
Constant	−18.04***	−14.00***	−16.00	−8.09
	(5.58)	(2.52)	(16.40)	(10.25)
Observations	167	167	56	56
Log Likelihood	−37.05	−49.48	−187.43	−189.21
Akaike Inf. Crit.	88.10	106.97	388.86	386.41
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table 5: Compliance Effect of Paris

	Dependent Variable: GHG Emissions/2016 GHG Emissions	
Paris ATT	-0.049	-0.0193
	(0.045)	(0.041)
Lag Ln GDP per Capita		0.000**
		(0.000)
Electoral Democracy		-0.068
		(0.084)
Treated Observations	54	54
Mean Squared Prediction Error	0.0038	0.0041
Note:	*p<0.1; **p<0.05; ***p<0.01	

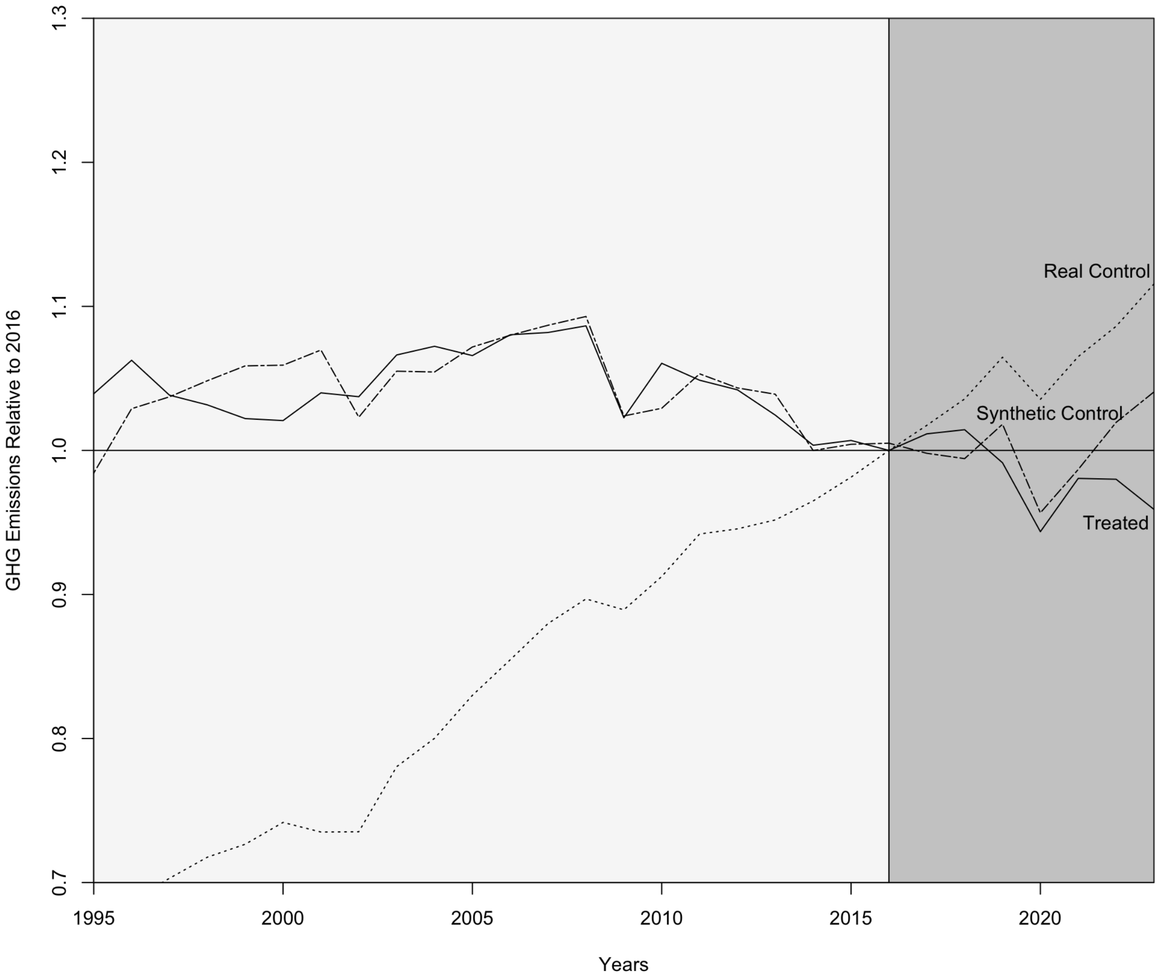
given by a gap between treatment and the synthetic control in later years of the agreement, this gap is not large enough to be statistically significant. Despite the increasing urgency and certainty of climate change mitigation, the depth and breadth of Paris have undercut compliance. Paris participants must weigh the high costs of large pledged emissions cuts against the small likelihood that their own compliance will prove pivotal.

Unlike Kyoto, Paris has not been widely perceived as a failure. Optimism about Paris increases the substantive salience of my null 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 mitigation treaty designs. I argue that this is not the case and too little attention has been given to the structure of reciprocity that these treaties rely on for enforcement. The unchanged design feature that explains the failures of Kyoto and Paris is collective reciprocity. But mitigation treaties could instead be modeled around selective reciprocity, the potential of which I evaluate in Section 3.4.

3.4 Alternative Treaty: Kigali

The Kigali Amendment is omitted from my analysis of comprehensive climate change mitigation treaties thus far for being an extension of the Montreal regime that only covers a single GHG. After the Montreal Protocol (1985) penalized the use of ozone-

Figure 5: 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.

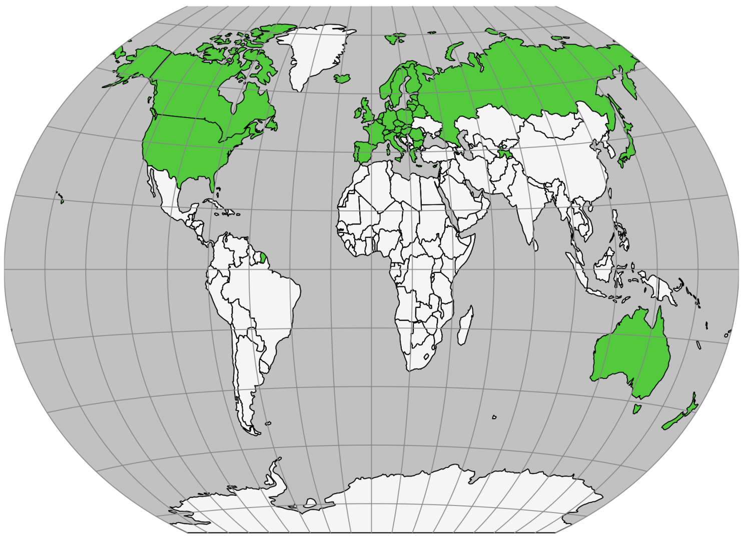
depleting chlorofluorocarbons (CFCs), use of HFCs as substitutes rose steadily. Unlike CFCs, HFCs are not ozone-depleting but are potent GHGs. Kigali extended Montreal's reduction commitments to HFCs so as to limit the treaty's inadvertent harm. Thus, while Kigali is not an agreement to comprehensively 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 and Paris punish non-participation and non-compliance with collective reciprocity, Kigali utilizes Montreal's selective 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 selective 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.

Selective reciprocity has made Kigali more effective in inducing compliance than Kyoto or Paris. Like Kyoto, 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 6 shows the participants of Kigali with stringent commitments in 2023, the latest year of my emissions data.

I describe Kigali participation with two logistic regressions summarized in Table 6. 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 climate resilience

Figure 6: Kigali Stringent Commitment Targets



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

is related in the opposite direction to substantive expectations, reflecting correlation with GDP per capita. As with Kyoto and Paris, Kigali's (stringent) participation is well predicted by wealth and democracy.

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 induced emissions cuts in participating states. This finding supports Hypothesis 3, that Kigali will induce HFC emission reductions among its participants.

I plot this effect in Figure 7, which shows a clear gap between treated states and their synthetic control comparison. Visually, the gap seems to emerge slightly before Kigali gained enough participants to enter force in 2019, reflecting a potential anticipation effect. 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.

The finding that Kigali has successfully caused emissions reductions in states participating with stringent commitments is important for two reasons. First, this finding

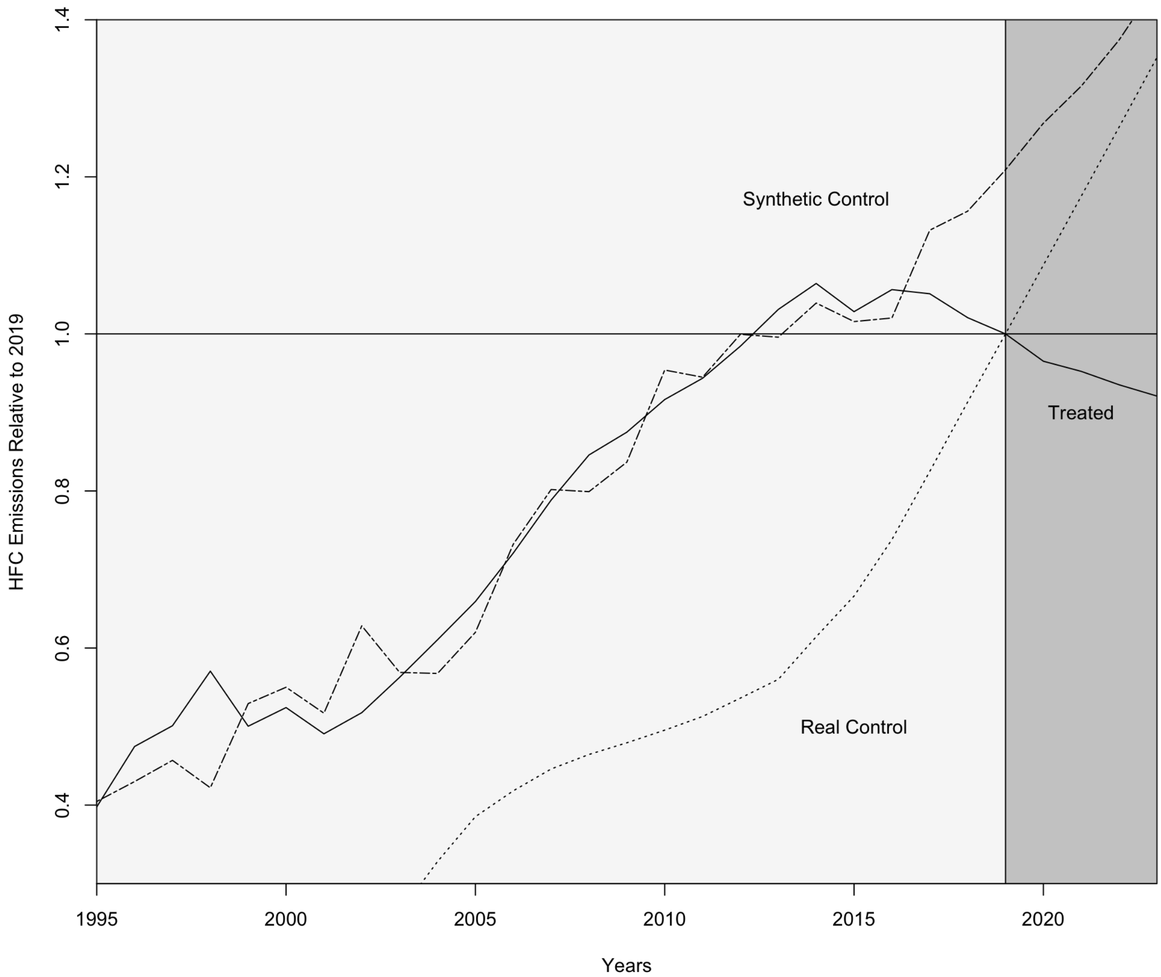
Table 6: Determinants of Kigali Participation

	Dependent Variable: Kigali Participation	
	(1)	(2)
Pre-Kigali HFC Trend	−0.09	−0.14
	(0.09)	(0.10)
Ln GDP	0.06	
	(0.22)	
Ln GDP per Capita	−0.50	1.31***
	(0.62)	(0.33)
Electoral Democracy	3.04*	3.75***
	(1.59)	(1.30)
Climate Resilience Resilience	0.30***	
	(0.09)	
Constant	−15.43***	−14.06***
	(5.62)	(3.49)
Observations	141	141
Log Likelihood	−31.40	−39.82
Akaike Inf. Crit.	74.79	87.64
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 7: Compliance Effect of Kigali

	Dependent Variable: HFC Emissions / 1990 HFC Emissions	
Kigali ATT	-0.203***	-0.408***
	(0.067)	(0.069)
Lag Ln GDP per Capita		0.000
		(0.000)
Electoral Democracy		-0.057
		(0.045)
Treated Observations	37	37
Mean Squared Prediction Error	0.0886	0.0901
Note:	*p<0.1; **p<0.05; ***p<0.01	

Figure 7: 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.

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 and Paris. A crucial distinction between these treaties and Kigali is the latter's use of selective 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 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 selective 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 selective 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 Selective Reciprocity 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 selective reciprocity strategy.

4.2 Selective Reciprocity with Sticks: Carbon Tariffs

No form of stick, or targeted punishment (i.e., the denial of a selective good), has been designed into comprehensive climate change mitigation treaties thus far. But trade restrictions targeting treaty non-participants and non-compliers are a common method of selective reciprocity in treaties as diverse as the WTO and the Montreal Protocol. Carbon tariffs have been widely studied by scholars advocating for "climate clubs" (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 selective 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 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 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 selective goods to climate change mitigation, including financial investment and market access. Rather than supplant the Paris Agreement or begin years of global negotiations anew, selective reciprocity 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 selective reciprocity 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 Compliance Analysis with LULUCF Emissions

Table A.1.1: Compliance Effect of Kyoto with LULUCF Emissions

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Kyoto ATT	0.268	0.346
	(0.175)	(0.100)
Lag Ln GDP per Capita		0.000
		(0.000)
Electoral Democracy		0.015
		(0.167)
Treated Observations	34	34
Mean Squared Prediction Error	0.0634	0.0630
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table A.1.2: Compliance Effect of Paris with LULUCF Emissions

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Paris ATT	0.190	0.177
	(0.153)	(0.269)
Lag Ln GDP per Capita		0.000***
		(0.000)
Electoral Democracy		0.111
		(0.199)
Treated Observations	53	53
Mean Squared Prediction Error	0.0080	0.0085
Note:	*p<0.1; **p<0.05; ***p<0.01	

A.2 Compliance Analysis with CDM Adjustment

Table A.2.1: Compliance Effect of Kyoto with CDM Adjustment

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Kyoto ATT	0.086	0.020
	(0.149)	(0.124)
Lag Ln GDP per Capita		0.000
		(0.000)
Lag Electoral Democracy		0.093
		(0.113)
Treated Observations	34	34
Mean Squared Prediction Error	0.0021	0.0019
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table A.2.2: Compliance Effect of Paris with CDM Adjustment

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Paris ATT	-0.048	0.004
	(0.045)	(0.042)
Lag Ln GDP per Capita		0.000**
		(0.000)
Electoral Democracy		-0.071
		(0.085)
Treated Observations	54	54
Mean Squared Prediction Error	0.0646	0.0041
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table A.2.3: Compliance Effect of Kigali with CDM Adjustment

	Dependent Variable: HFC Emissions/2019 HFC Emissions	
Kigali ATT	-0.304***	-0.400***
	(0.079)	(0.055)
Lag Ln GDP per Capita		0.000
		(0.000)
Electoral Democracy		-0.052
		(0.043)
Treated Observations	37	37
Mean Squared Prediction Error	0.0987	0.0903

Note: *p<0.1; **p<0.05; ***p<0.01

A.3 Compliance Analysis with LULUCF Emissions and CDM Adjustment

Table A.3.1: Compliance Effect of Kyoto with LULUCF Emissions and CDM Adjustment

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Kyoto ATT	0.279	0.355***
	(0.224)	(0.010)
Lag Ln GDP per Capita		0.000
		(0.000)
Lag Electoral Democracy		0.018
		(0.161)
Treated Observations	34	34
Mean Squared Prediction Error	0.0646	0.0608
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table A.3.2: Compliance Effect of Paris with LULUCF Emissions and CDM Adjustment

	Dependent Variable: GHG Emissions/2005 GHG Emissions	
Paris ATT	0.187	0.175
	(0.147)	(0.165)
Lag Ln GDP per Capita		0.000*
		(0.000)
Electoral Democracy		0.108
		(0.196)
Treated Observations	54	54
Mean Squared Prediction Error	0.0080	0.0085
Note:	*p<0.1; **p<0.05; ***p<0.01	

A.4 Weights from the Generalized Synthetic Control

Table A.4.1: Average Weight of Kyoto Control Units

	Avg Weight
ZWE	0.026
SUR	0.024
SGP	0.022
GAB	0.021
NGA	0.018
AZE	0.016
GUY	0.016
SWZ	0.013
JAM	0.012
LBY	0.012
MKD	0.012
USA	0.010
CUB	0.009
BLR	0.009
MNG	0.008
CMR	0.007
UZB	0.007
FJI	0.006
NAM	0.006
PRY	0.005
PHL	0.004
URY	0.004
SLV	0.004
PAN	0.004
PER	0.004
ISR	0.003
ALB	0.003
KOR	0.003
KGZ	0.003
SYR	0.003
DOM	0.002
BOL	0.002
GHA	0.002
CHL	0.002
MLT	0.002
BRA	0.002
ZAF	0.001
CIV	0.001
TJK	0.001
ECU	0.001
BRB	0.0001
ARG	0.0001
CRI	0.00002
MEX	-0.0002
DZA	-0.0003
IDN	-0.001
NIC	-0.002
IRQ	-0.002
GTM	-0.003
BHR	-0.003
TUR	-0.004
TUN	-0.004
THA	-0.004
IND	-0.005
KWT	-0.006
COG	-0.006
JOR	-0.007
ARM	-0.007
MAR	-0.007
PAK	-0.008
SYC	-0.008
HND	-0.009
EGY	-0.010
KEN	-0.010
MYS	-0.011
IRN	-0.011
PNG	-0.011
KAZ	-0.012
SAU	-0.012
QAT	-0.012
TKM	-0.013
MUS	-0.016
VNM	-0.016
ARE	-0.016
BIH	-0.016
OMN	-0.017
CHN	-0.019
TTO	-0.020

Table A.4.2: Average Weight of Kyoto Control Units After Including LULUCF Emissions

	Avg Weight
FJI	0.128
CIV	0.070
JAM	0.026
SUR	0.025
IDN	0.025
ZWE	0.018
SGP	0.018
MNG	0.016
CMR	0.016
GUY	0.016
BOL	0.014
MEX	0.012
GAB	0.012
AZE	0.012
NGA	0.010
SWZ	0.009
MKD	0.008
NAM	0.008
ALB	0.008
PNG	0.006
UZB	0.006
PER	0.006
CHL	0.006
CRI	0.006
SYR	0.006
ECU	0.005
THA	0.004
BHR	0.004
USA	0.003
CUB	0.003
BLR	0.002
TUR	0.002
KOR	0.002
PHL	0.002
PAN	0.001
BRB	-0.0002
ISR	-0.0003
LBY	-0.0003
DZA	-0.0005
GTM	-0.001
ZAF	-0.001
COG	-0.002
SLV	-0.002
KGZ	-0.002
TUN	-0.003
TJK	-0.004
PRY	-0.004
MLT	-0.004
HND	-0.005
URY	-0.007
KWT	-0.007
ARM	-0.008
BIH	-0.009
BRA	-0.010
PAK	-0.010
EGY	-0.011
IRN	-0.011
JOR	-0.012
QAT	-0.012
ARE	-0.012
IND	-0.012
MAR	-0.012
KAZ	-0.012
ARG	-0.013
NIC	-0.014
SYC	-0.014
TKM	-0.015
DOM	-0.016
OMN	-0.017
CHN	-0.017
SAU	-0.018
MUS	-0.020
MYS	-0.021
TTO	-0.023
IRQ	-0.024
KEN	-0.029
GHA	-0.042
VNM	-0.055

Table A.4.3: Average Weight of Kyoto Control Units After CDM Adjustment

Correlation with CDM allocations: −0.2101612

	Avg Weight
ZWE	0.027
SUR	0.026
SGP	0.022
GAB	0.020
NGA	0.018
AZE	0.017
GUY	0.016
SWZ	0.013
MKD	0.013
LBY	0.012
JAM	0.012
USA	0.010
BLR	0.009
CUB	0.009
MNG	0.009
CMR	0.008
UZB	0.007
NAM	0.006
FJI	0.006
PRY	0.005
URY	0.005
PHL	0.004
PER	0.004
PAN	0.004
SLV	0.004
SYR	0.004
KGZ	0.003
ISR	0.003
GHA	0.003
DOM	0.002
ALB	0.002
BOL	0.002
ZAF	0.002
CHL	0.002
KOR	0.002
MLT	0.002
TJK	0.002
CIV	0.001
BRA	0.001
ECU	0.001
CRI	0.001
ARG	0.0003
BRB	0.0002
MEX	-0.00005
DZA	-0.0004
IDN	-0.0004
BHR	-0.002
NIC	-0.003
IRQ	-0.003
TUR	-0.004
GTM	-0.004
TUN	-0.004
THA	-0.004
IND	-0.005
COG	-0.006
KWT	-0.006
ARM	-0.007
MAR	-0.007
JOR	-0.008
PAK	-0.008
SYC	-0.009
KEN	-0.009
HND	-0.010
EGY	-0.010
MYS	-0.011
IRN	-0.011
KAZ	-0.012
PNG	-0.012
QAT	-0.013
TKM	-0.013
SAU	-0.013
MUS	-0.016
ARE	-0.017
VNM	-0.017
BIH	-0.017
OMN	-0.018
CHN	-0.019
TTO	-0.021

Table A.4.4: Average Weight of Kyoto Control Units After Including LULUCF Emissions and CDM Adjustment

Correlation with CDM allocations: -0.1077

	Avg Weight
FJI	0.122
CIV	0.067
JAM	0.025
SUR	0.023
IDN	0.023
SGP	0.017
ZWE	0.016
CMR	0.015
MNG	0.015
GUY	0.015
BOL	0.013
MEX	0.011
GAB	0.011
AZE	0.011
NGA	0.009
SWZ	0.009
MKD	0.007
NAM	0.007
ALB	0.007
UZB	0.006
PNG	0.006
PER	0.006
CHL	0.006
CRI	0.006
SYR	0.005
ECU	0.004
USA	0.003
THA	0.003
BHR	0.003
CUB	0.003
BLR	0.002
TUR	0.002
PHL	0.002
KOR	0.001
PAN	0.001
ISR	-0.0001
BRB	-0.0001
LBY	-0.0002
DZA	-0.001
GTM	-0.001
ZAF	-0.001
SLV	-0.002
COG	-0.002
KGZ	-0.002
TUN	-0.003
TJK	-0.004
PRY	-0.004
MLT	-0.004
HND	-0.005
URY	-0.007
KWT	-0.007
ARM	-0.007
BIH	-0.009
BRA	-0.009
PAK	-0.010
EGY	-0.010
IRN	-0.010
QAT	-0.010
JOR	-0.011
IND	-0.011
MAR	-0.011
KAZ	-0.012
ARE	-0.012
ARG	-0.012
NIC	-0.013
SYC	-0.014
TKM	-0.014
DOM	-0.015
CHN	-0.016
OMN	-0.016
SAU	-0.017
MUS	-0.019
MYS	-0.020
TTO	-0.022
IRQ	-0.022
KEN	-0.027
GHA	-0.039
VNM	-0.051

Table A.4.5: Average Weight of Paris Control Units

	Avg Weight
JAM	0.018
BRB	0.014
CUB	0.014
MKD	0.013
ZWE	0.012
FJI	0.010
SWZ	0.010
ZAF	0.009
TTO	0.008
SLV	0.007
AZE	0.007
NGA	0.007
NAM	0.006
UZB	0.006
ALB	0.006
MEX	0.006
ECU	0.003
CHL	0.003
THA	0.002
CMR	0.002
SUR	0.002
SYR	0.001
DOM	0.001
LBY	0.0004
PAN	0.0001
LKA	-0.0001
TUN	-0.0002
PRY	-0.0004
TKM	-0.001
MUS	-0.001
BOL	-0.001
COG	-0.001
NIC	-0.002
BHR	-0.002
CIV	-0.002
JOR	-0.002
ARM	-0.002
IRN	-0.003
HND	-0.003
EGY	-0.003
GUY	-0.003
PNG	-0.003
TUR	-0.003
MAR	-0.004
SYC	-0.004
DZA	-0.004
PHL	-0.005
PAK	-0.005
CHN	-0.005
KWT	-0.005
MYS	-0.005
GTM	-0.005
KGZ	-0.005
QAT	-0.006
SAU	-0.006
IND	-0.006
KEN	-0.007
IRQ	-0.007
OMN	-0.008
IDN	-0.009
GHA	-0.011
MNG	-0.015
VNM	-0.016

Table A.4.6: Average Weight of Paris Control Units After Including LULUCF Emissions

	Avg Weight
JAM	0.024
BRB	0.013
NGA	0.013
LBY	0.012
MKD	0.011
TTO	0.009
CHL	0.009
COG	0.009
SWZ	0.008
IRQ	0.008
ALB	0.008
CUB	0.008
ZAF	0.007
BOL	0.006
IDN	0.006
UZB	0.005
MNG	0.005
PNG	0.005
ECU	0.004
SYR	0.004
PRY	0.004
ZWE	0.004
CMR	0.004
AZE	0.003
SLV	0.003
JOR	0.003
TKM	0.003
CIV	0.003
NAM	0.002
THA	0.002
PAN	0.002
GTM	0.002
GUY	0.002
DOM	0.002
NIC	0.002
ARM	0.001
MUS	0.001
MYS	0.001
MEX	0.001
SUR	0.001
KWT	0.001
SAU	0.0004
HND	-0.00001
IRN	-0.0003
PHL	-0.001
LKA	-0.001
TUN	-0.002
EGY	-0.002
BHR	-0.002
SYC	-0.002
MAR	-0.003
DZA	-0.003
PAK	-0.003
TUR	-0.003
CHN	-0.005
QAT	-0.006
IND	-0.006
OMN	-0.006
KGZ	-0.007
VNM	-0.013
KEN	-0.014
GHA	-0.025
FJI	-0.114

Table A.4.7: Average Weight of Paris Control Units After CDM Adjustment

Correlation with CDM allocations: -0.1074

	Avg Weight
JAM	0.017
CUB	0.014
BRB	0.014
MKD	0.013
ZWE	0.012
SWZ	0.010
FJI	0.010
TTO	0.009
ZAF	0.009
NAM	0.008
SLV	0.007
NGA	0.007
AZE	0.006
UZB	0.006
ALB	0.006
MEX	0.006
ECU	0.004
THA	0.003
CHL	0.003
SUR	0.003
CMR	0.002
SYR	0.002
LBY	0.001
DOM	0.0004
TUN	-0.0001
PAN	-0.0002
PRY	-0.0002
TKM	-0.0004
LKA	-0.0004
MUS	-0.001
BOL	-0.001
COG	-0.001
BHR	-0.001
JOR	-0.001
CIV	-0.002
ARM	-0.002
NIC	-0.002
IRN	-0.003
EGY	-0.003
HND	-0.003
TUR	-0.003
GUY	-0.003
MAR	-0.004
PNG	-0.004
CHN	-0.004
DZA	-0.005
SYC	-0.005
MYS	-0.005
KWT	-0.005
PHL	-0.005
PAK	-0.005
KGZ	-0.005
IND	-0.005
SAU	-0.005
GTM	-0.006
QAT	-0.006
KEN	-0.007
IRQ	-0.008
OMN	-0.008
IDN	-0.009
GHA	-0.011
MNG	-0.015
VNM	-0.016

Table A.4.8: Average Weight of Paris Control Units After Including LULUCF Emissions and CDM Adjustment

Correlation with CDM allocations: -0.0428

	Avg Weight
JAM	0.024
BRB	0.014
NGA	0.013
LBY	0.012
MKD	0.010
CHL	0.010
TTO	0.010
IRQ	0.010
COG	0.009
ALB	0.008
CUB	0.008
SWZ	0.008
ZAF	0.007
BOL	0.006
SYR	0.005
UZB	0.005
IDN	0.005
ECU	0.005
PNG	0.005
MNG	0.005
ZWE	0.004
CMR	0.004
PRY	0.004
JOR	0.003
AZE	0.003
CIV	0.003
TKM	0.003
SLV	0.003
DOM	0.003
THA	0.002
MYS	0.002
NAM	0.002
GTM	0.002
NIC	0.002
GUY	0.002
ARM	0.002
MUS	0.001
SAU	0.001
KWT	0.001
MEX	0.001
PAN	0.0004
IRN	0.0003
SUR	0.0002
PHL	-0.0005
HND	-0.001
LKA	-0.001
TUN	-0.002
EGY	-0.002
SYC	-0.002
BHR	-0.002
MAR	-0.002
DZA	-0.003
TUR	-0.003
PAK	-0.003
CHN	-0.005
OMN	-0.006
IND	-0.006
KGZ	-0.007
QAT	-0.007
VNM	-0.014
KEN	-0.016
GHA	-0.027
FJI	-0.119

Table A.4.9: Average Weight of Kigali Control Units

	Avg Weight
KOR	0.037
MLT	0.031
UZB	0.031
CHN	0.030
TUR	0.024
BOL	0.022
IND	0.021
CHL	0.021
ISR	0.020
BRA	0.018
MKD	0.014
KEN	0.013
MUS	0.011
MEX	0.010
UKR	0.007
AZE	0.006
MYS	0.005
KAZ	0.002
JAM	-0.0003
IRQ	-0.001
LBY	-0.003
THA	-0.003
CIV	-0.003
QAT	-0.003
SYR	-0.004
COG	-0.004
COL	-0.004
PHL	-0.004
NIC	-0.004
PAK	-0.004
ARG	-0.004
SAU	-0.004
LKA	-0.004
ZWE	-0.004
GAB	-0.004
EGY	-0.004
PAN	-0.004
TUN	-0.004
JOR	-0.004
TKM	-0.004
SLV	-0.004
MNE	-0.004
PRY	-0.004
CMR	-0.004
CUB	-0.004
DZA	-0.004
VNM	-0.004
NAM	-0.004
IRN	-0.004
MAR	-0.004
HND	-0.004
CRI	-0.004
OMN	-0.004
ECU	-0.005
GHA	-0.005
GTM	-0.005
FJI	-0.005
ARE	-0.005
ZAF	-0.005
BHR	-0.005
NGA	-0.005
ALB	-0.005
DOM	-0.005
ARM	-0.005
TTO	-0.005
KWT	-0.005
IDN	-0.005
SGP	-0.005
PER	-0.005
MNG	-0.008
URY	-0.048
GEO	-0.059

Table A.4.10: Average Weight of Kigali Control Units After CDM Adjustment

Correlation with CDM allocations: 0.4688

	Avg Weight
MLT	0.034
CHN	0.032
IND	0.028
KOR	0.023
UZB	0.021
TUR	0.020
MEX	0.018
CHL	0.015
MUS	0.015
BRA	0.014
BOL	0.013
ISR	0.012
KEN	0.011
MKD	0.011
UKR	0.008
MYS	0.006
AZE	0.004
KAZ	0.003
ARG	0.001
JAM	0.001
IRQ	-0.001
LBY	-0.002
QAT	-0.003
MNE	-0.003
CIV	-0.004
LKA	-0.004
COL	-0.004
THA	-0.004
PAK	-0.004
TUN	-0.004
SGP	-0.004
PAN	-0.004
PHL	-0.004
TKM	-0.004
TTO	-0.004
SLV	-0.004
CUB	-0.004
SAU	-0.004
COG	-0.004
PRY	-0.004
JOR	-0.005
EGY	-0.005
OMN	-0.005
SYR	-0.005
GAB	-0.005
CRI	-0.005
ZWE	-0.005
CMR	-0.005
ALB	-0.005
MAR	-0.005
GHA	-0.005
NAM	-0.005
DZA	-0.005
NIC	-0.005
VNM	-0.005
ZAF	-0.005
GTM	-0.005
NGA	-0.005
IRN	-0.005
PER	-0.005
BHR	-0.005
DOM	-0.005
ECU	-0.005
HND	-0.005
IDN	-0.005
ARM	-0.005
KWT	-0.005
FJI	-0.005
ARE	-0.005
MNG	-0.014
URY	-0.028
GEO	-0.032

A.5 Diagnostic Plots from the Generalized Synthetic Control

Figure A.5.1: Latent Factors Estimated for Kyoto

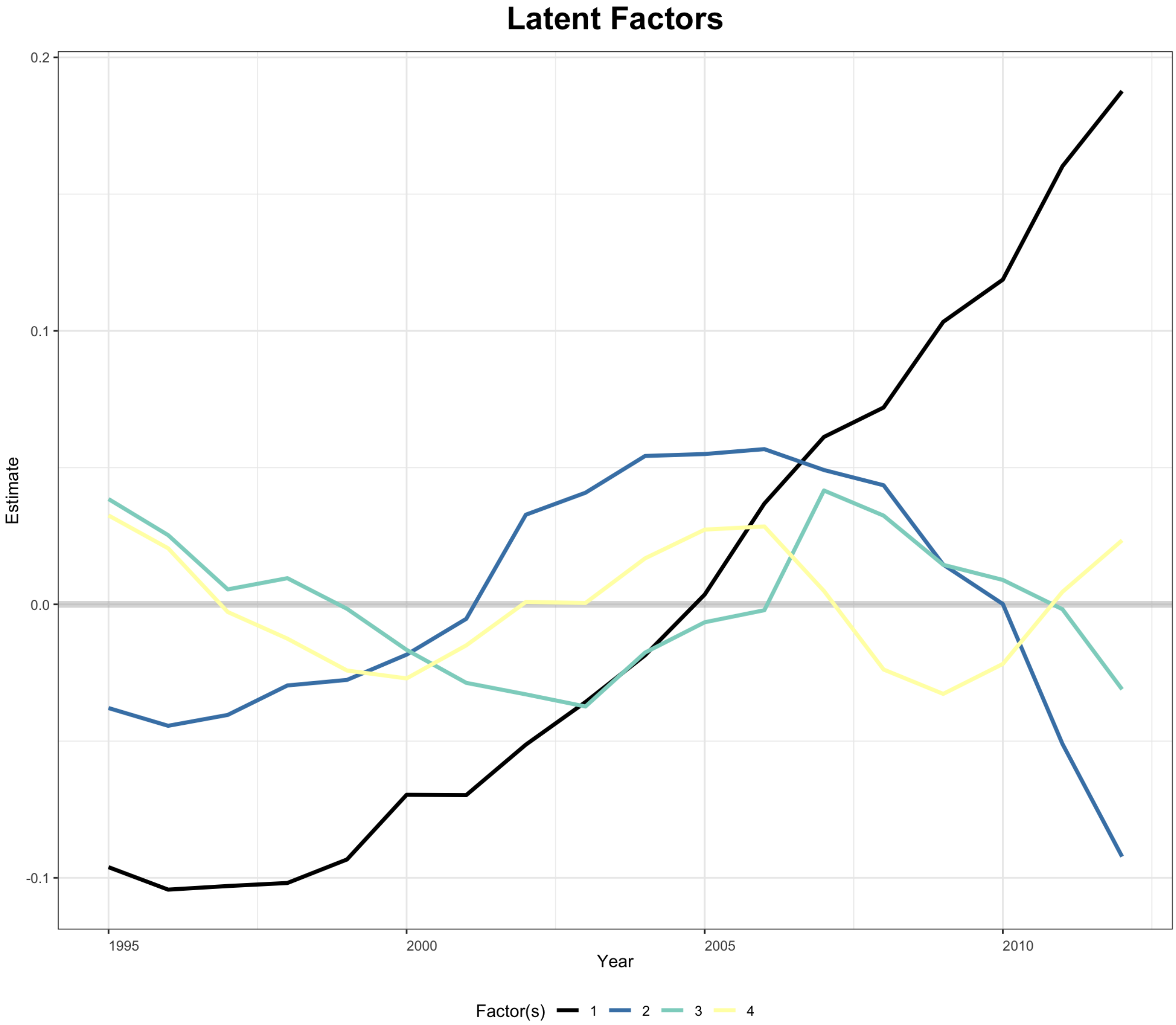

Figure A.5.2: Factor Loadings Estimated for Kyoto

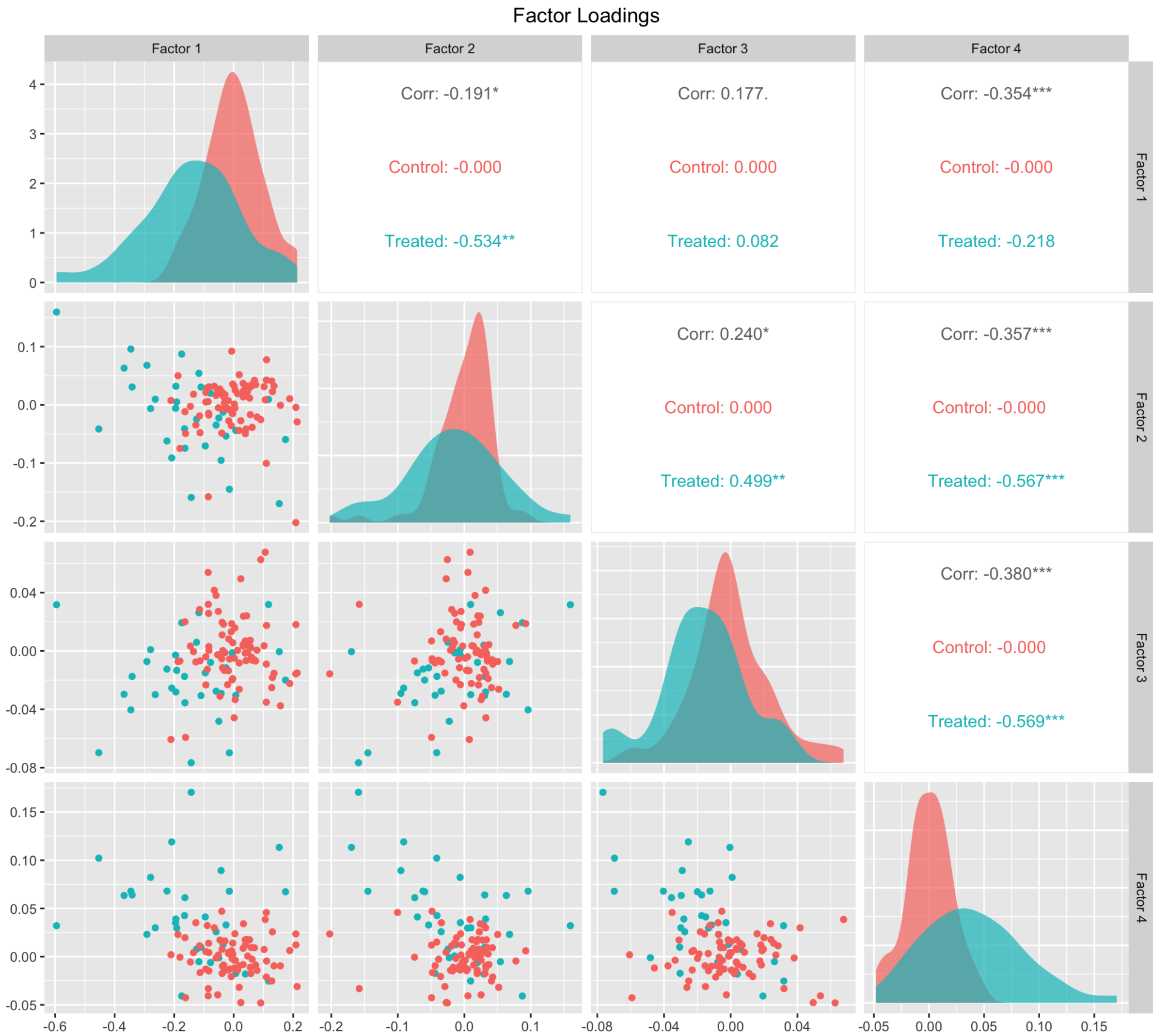

Figure A.5.3: Latent Factors Estimated for Kyoto with LULUCF Emissions

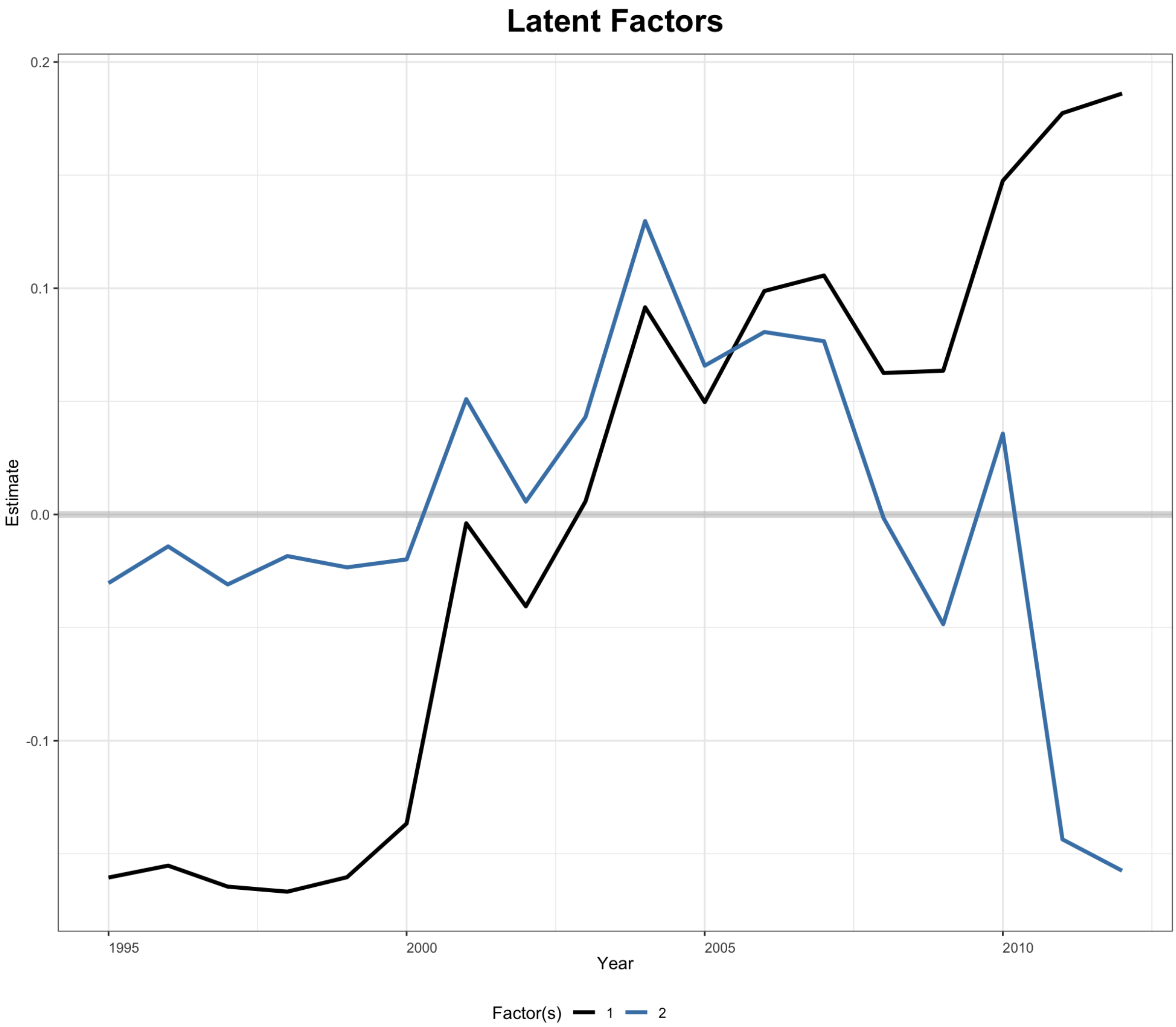

Figure A.5.4: Latent Factors Estimated for Kyoto with LULUCF Emissions

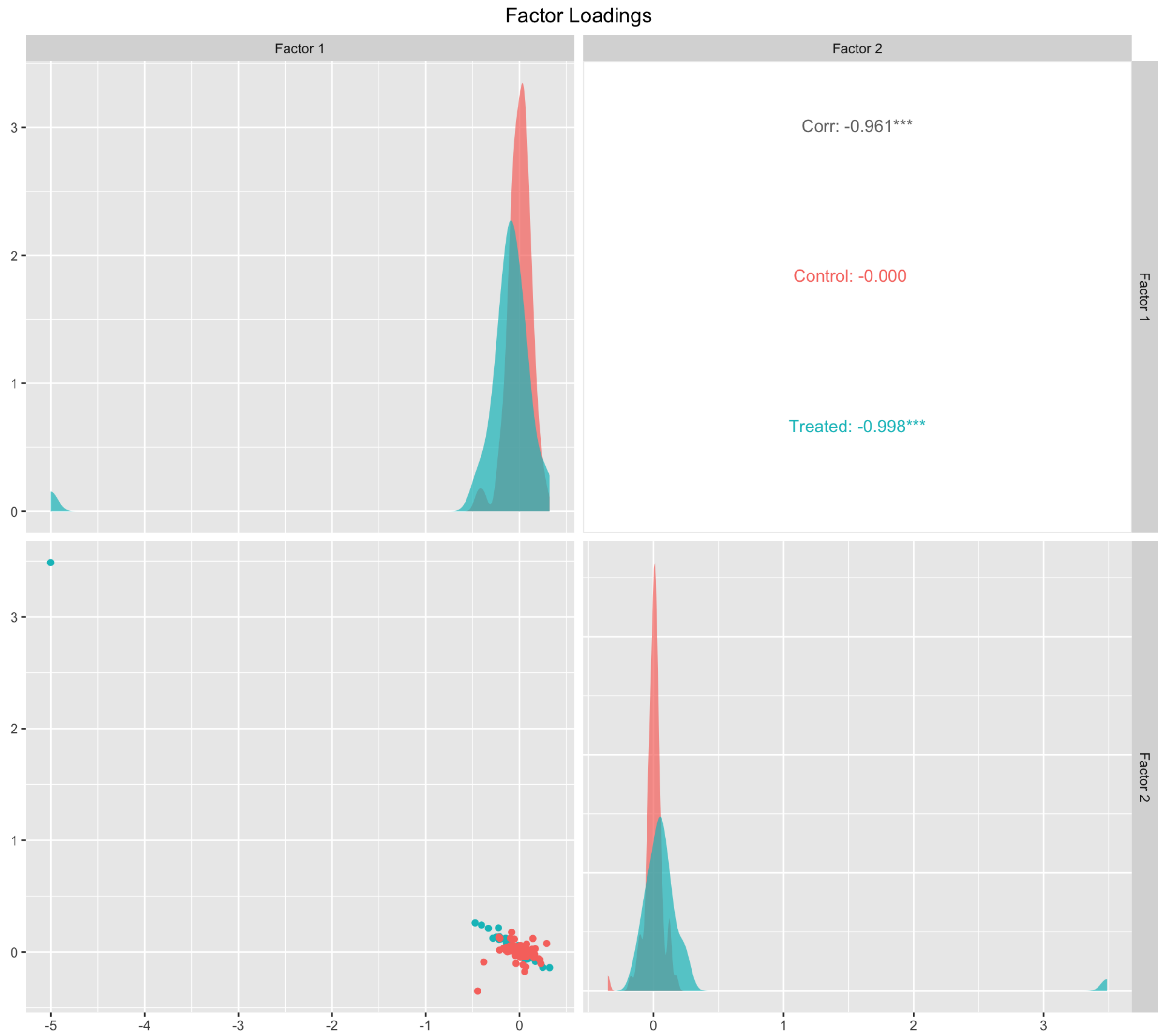

Figure A.5.5: Latent Factors Estimated for Kyoto with LULUCF Emissions

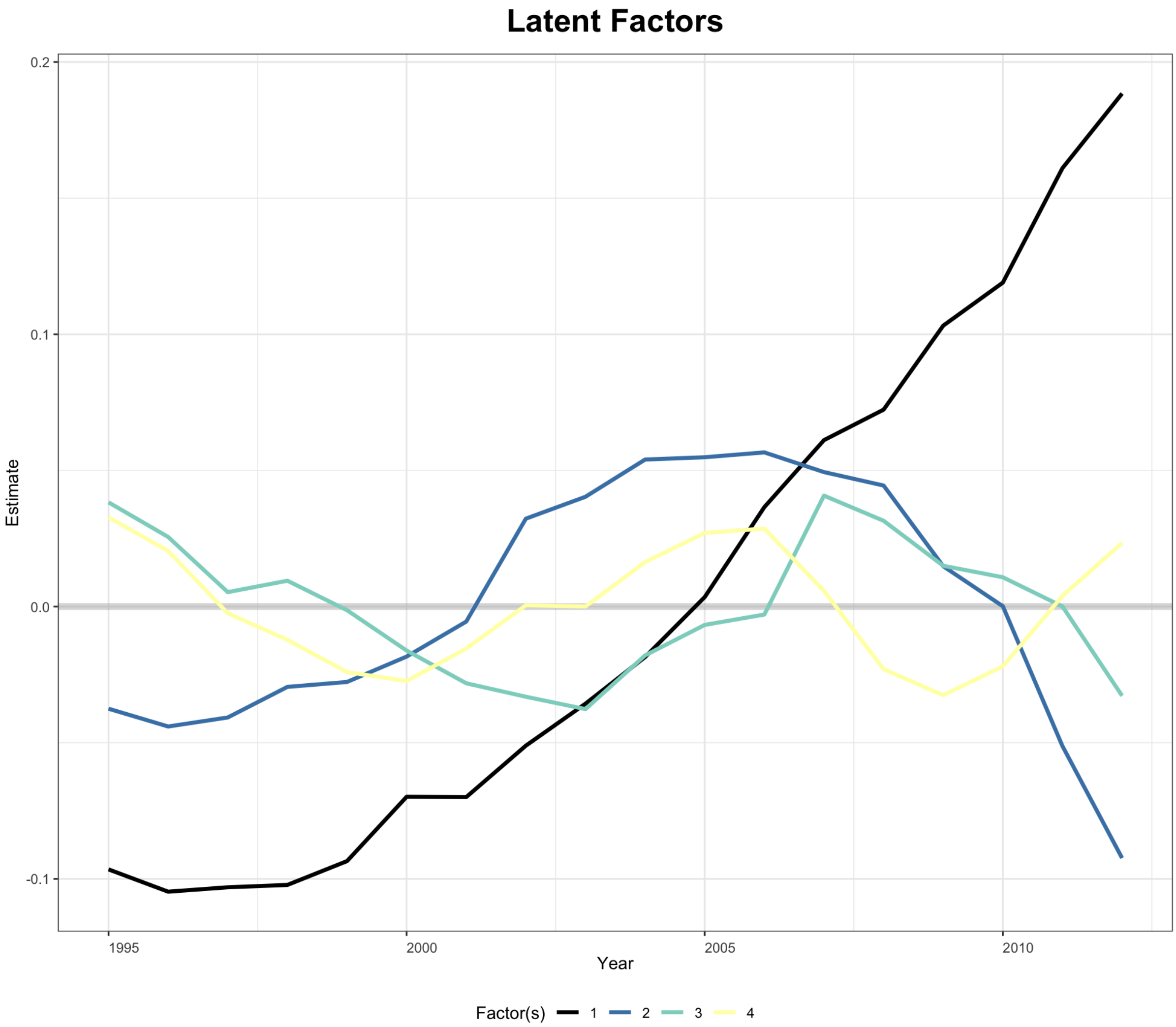

Figure A.5.6: Factor Loadings Estimated for Kyoto with CDM Adjustment

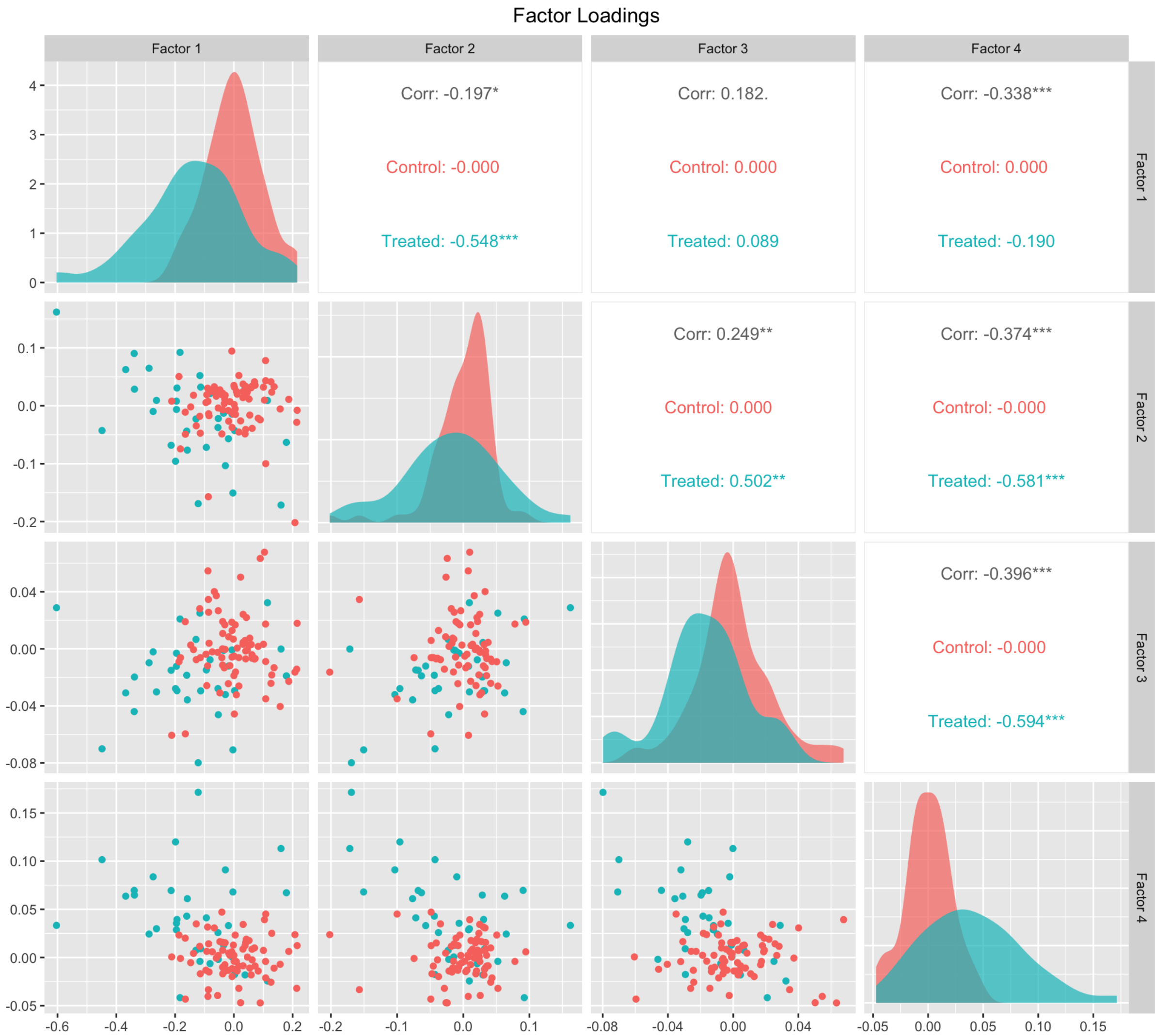

Figure A.5.7: Latent Factors Estimated for Kyoto with LULUCF Emissions and CDM Adjustment

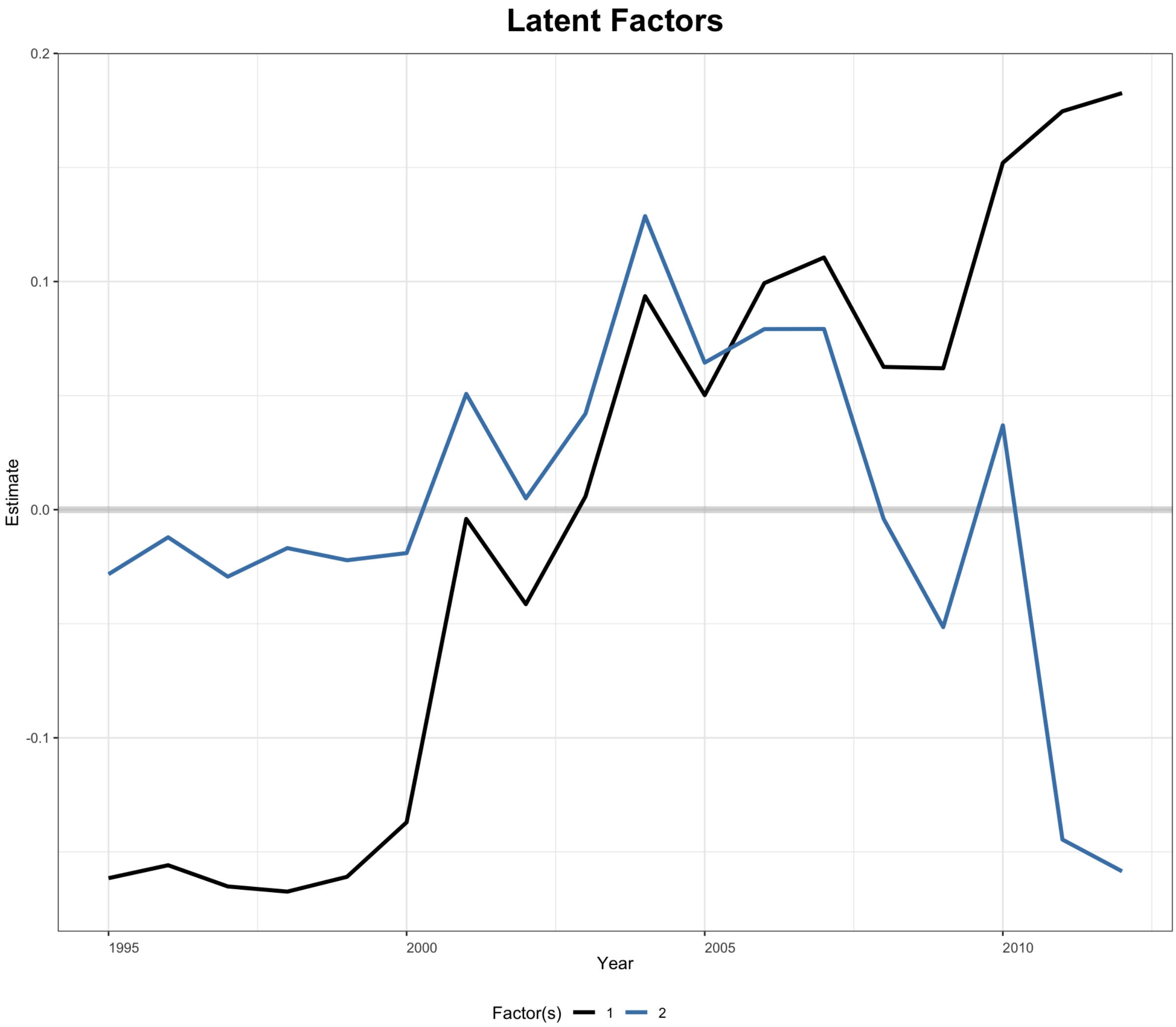

Figure A.5.8: Latent Factors Estimated for Kyoto with LULUCF Emissions and CDM Adjustment

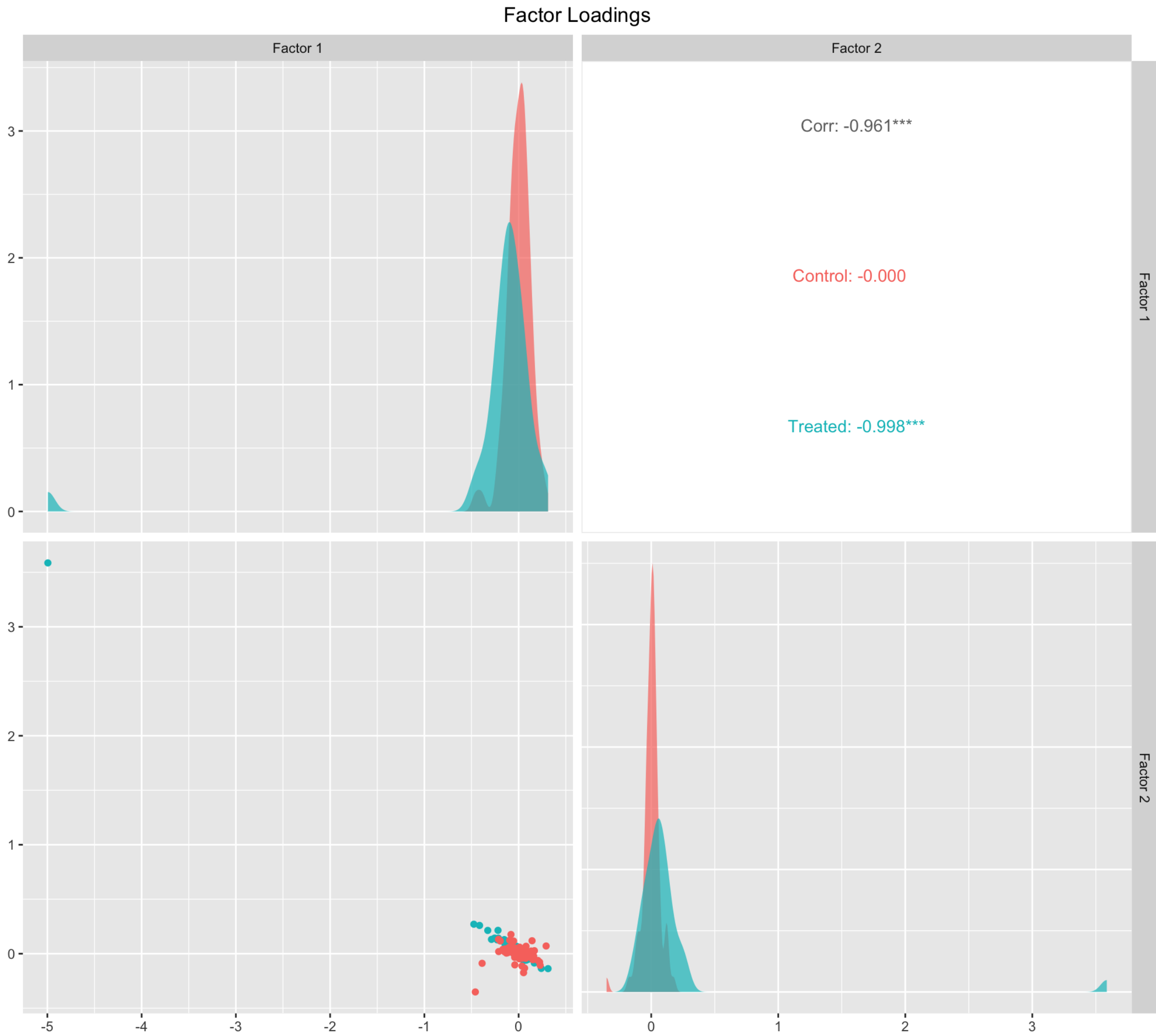

Figure A.5.9: Latent Factors Estimated for Paris

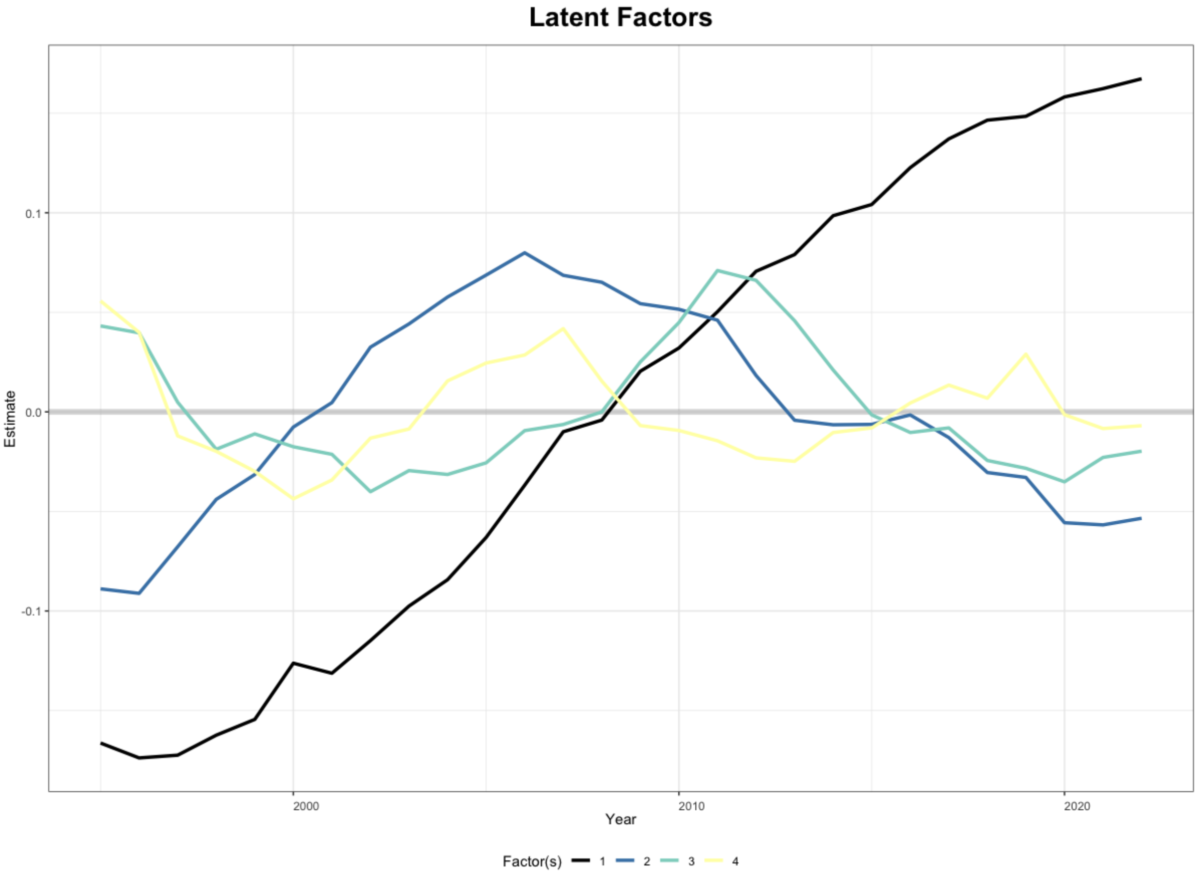

Figure A.5.10: Factor Loadings Estimated for Paris

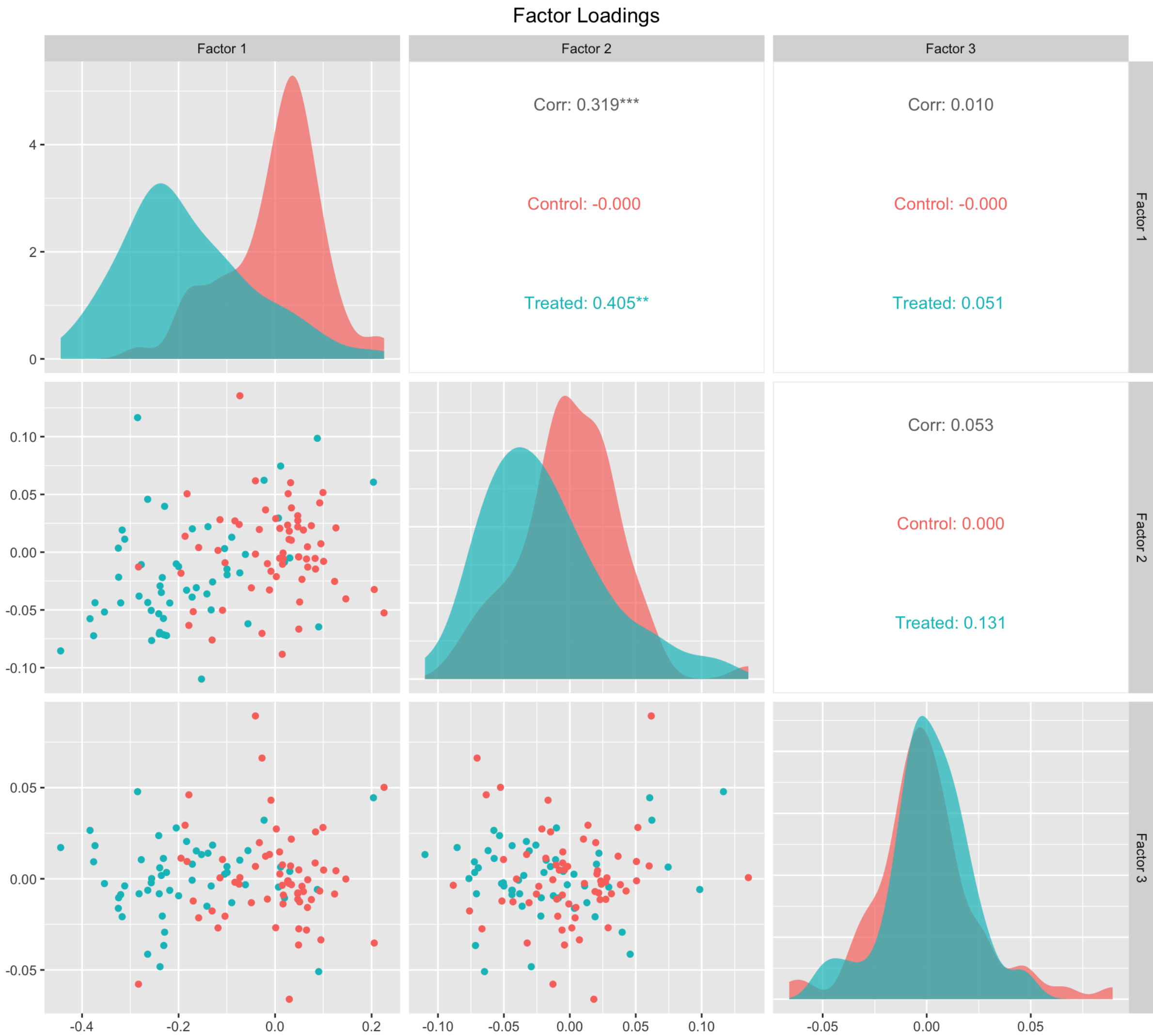

Figure A.5.11: Latent Factors Estimated for Paris with LULUCF Emissions

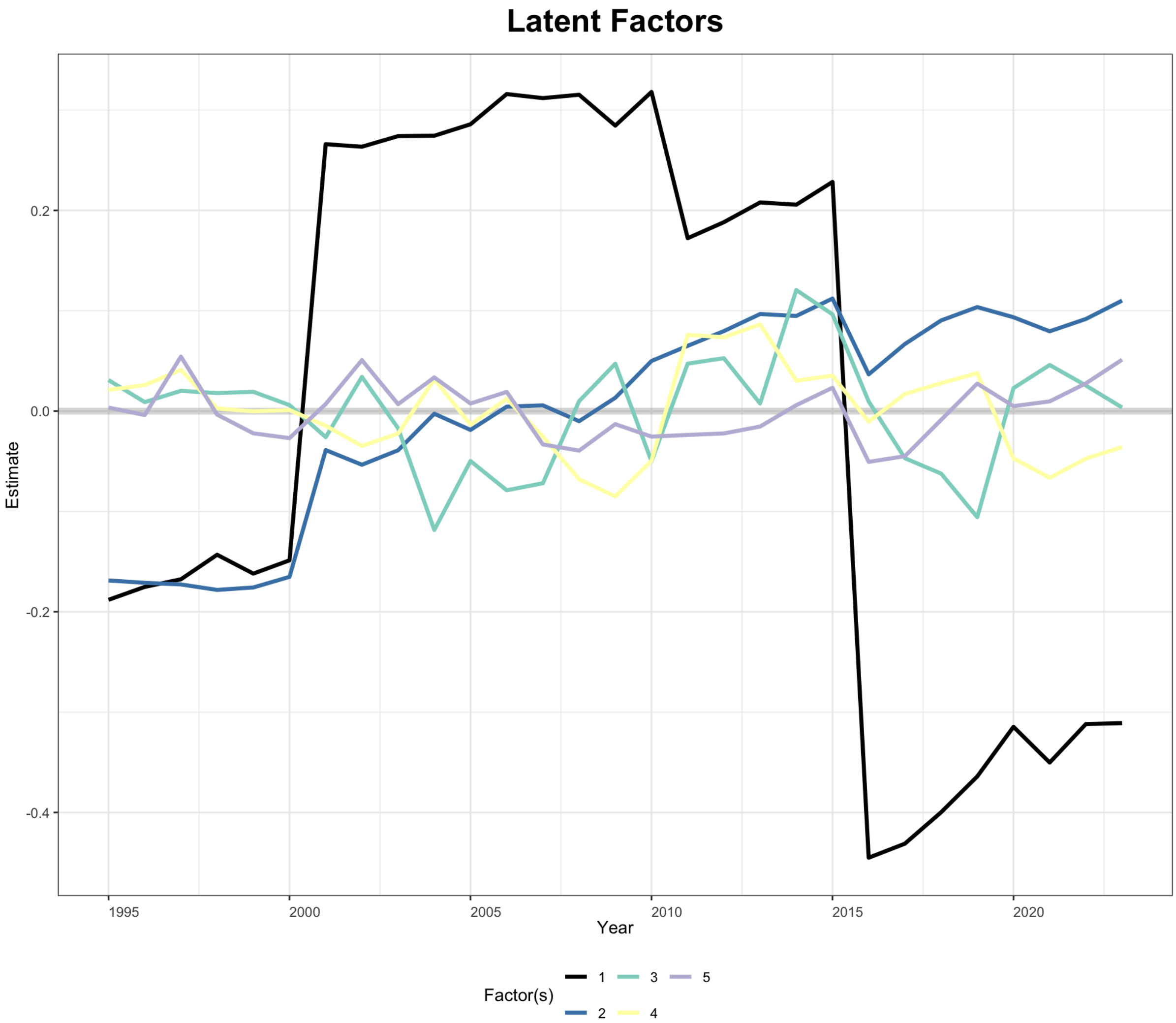

Figure A.5.12: Factor Loadings Estimated for Paris with CDM Adjustment

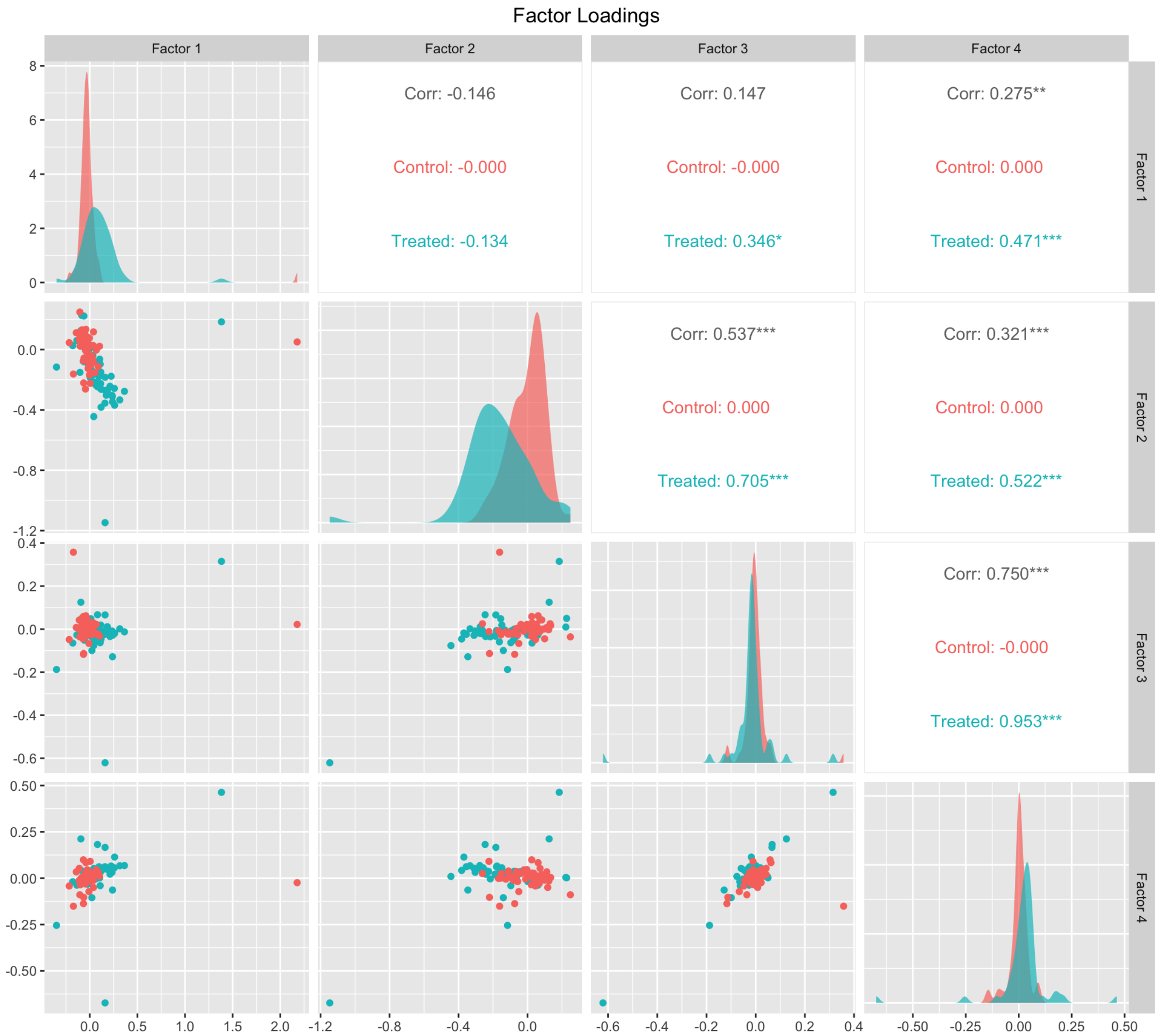

Figure A.5.13: Latent Factors Estimated for Paris with LULUCF Emissions

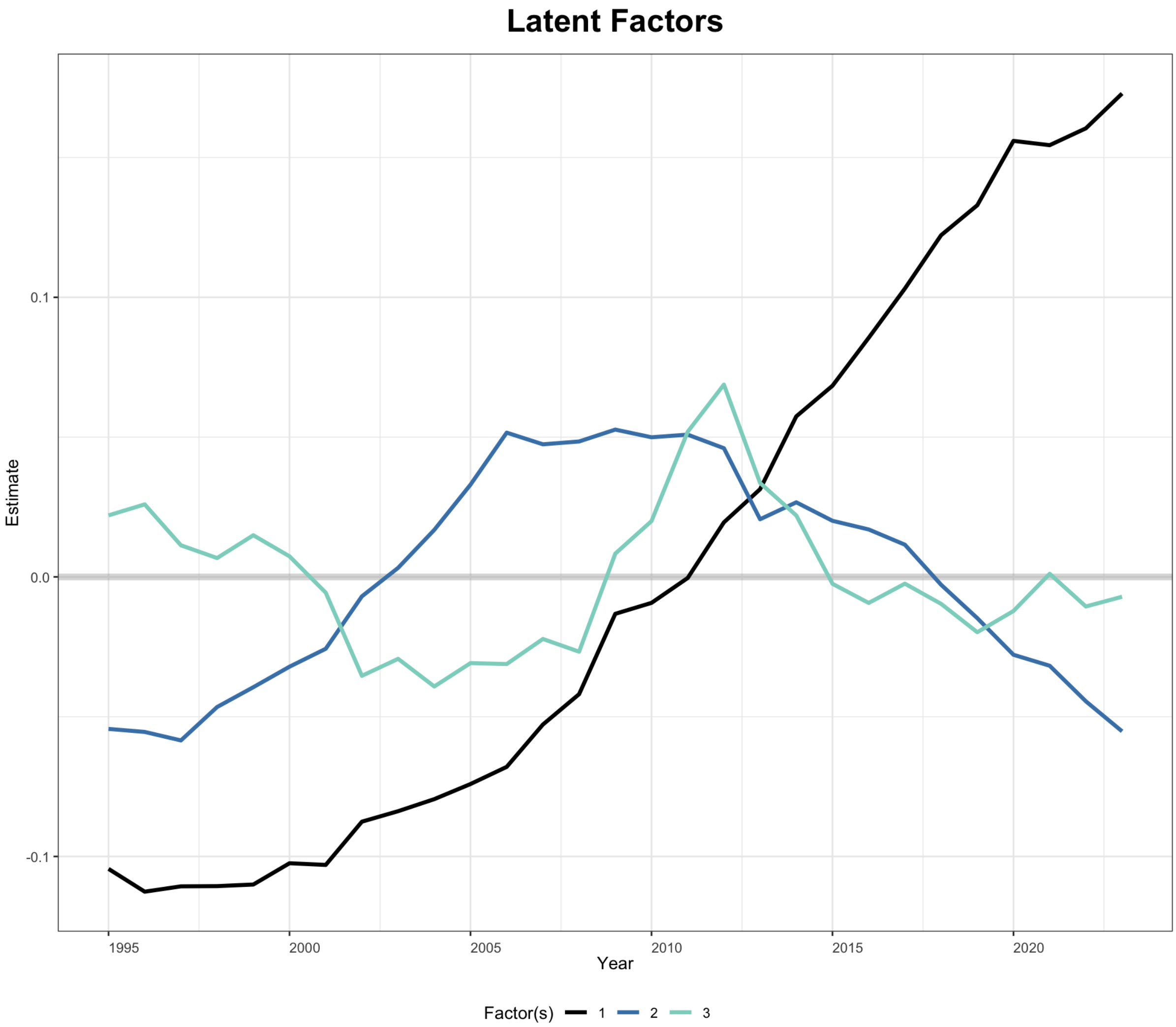

Figure A.5.14: Factor Loadings Estimated for Paris with CDM Adjustment

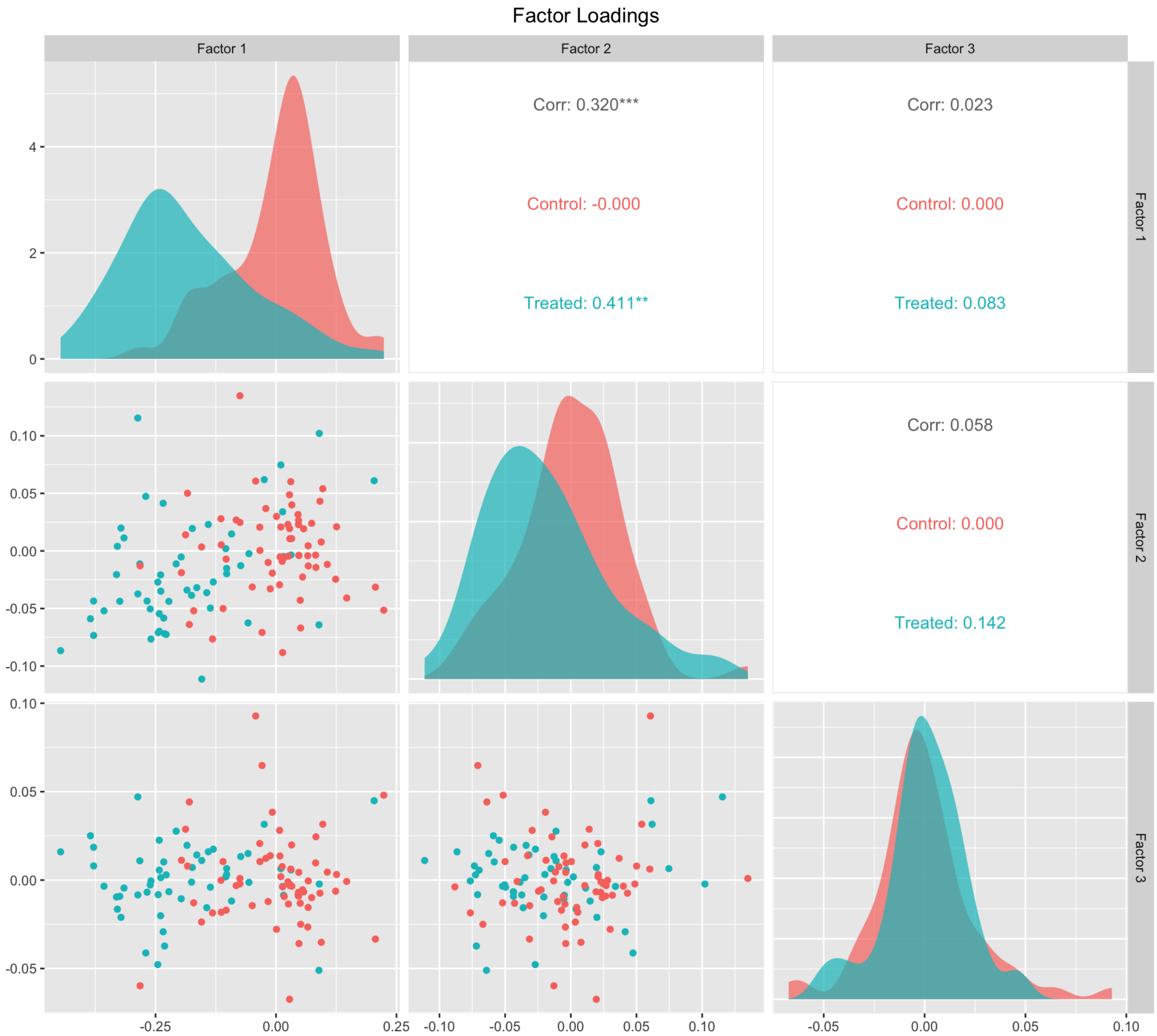

Figure A.5.15: Latent Factors Estimated for Paris with LULUCF Emissions and CDM Adjustment

Figure A.5.16: Latent Factors Estimated for Paris with LULUCF Emissions and CDM Adjustment

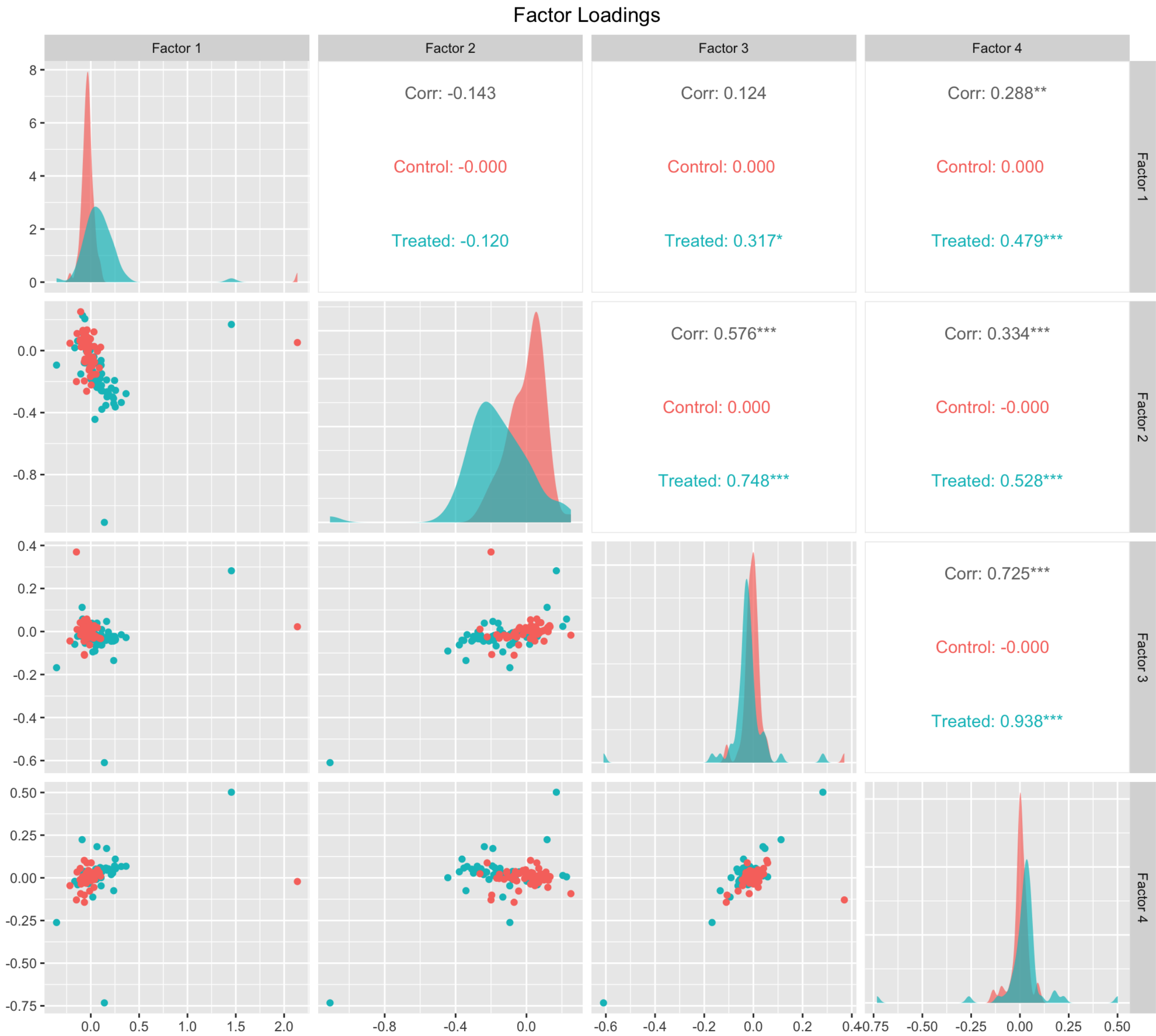

Figure A.5.17: Latent Factors Estimated for Kigali

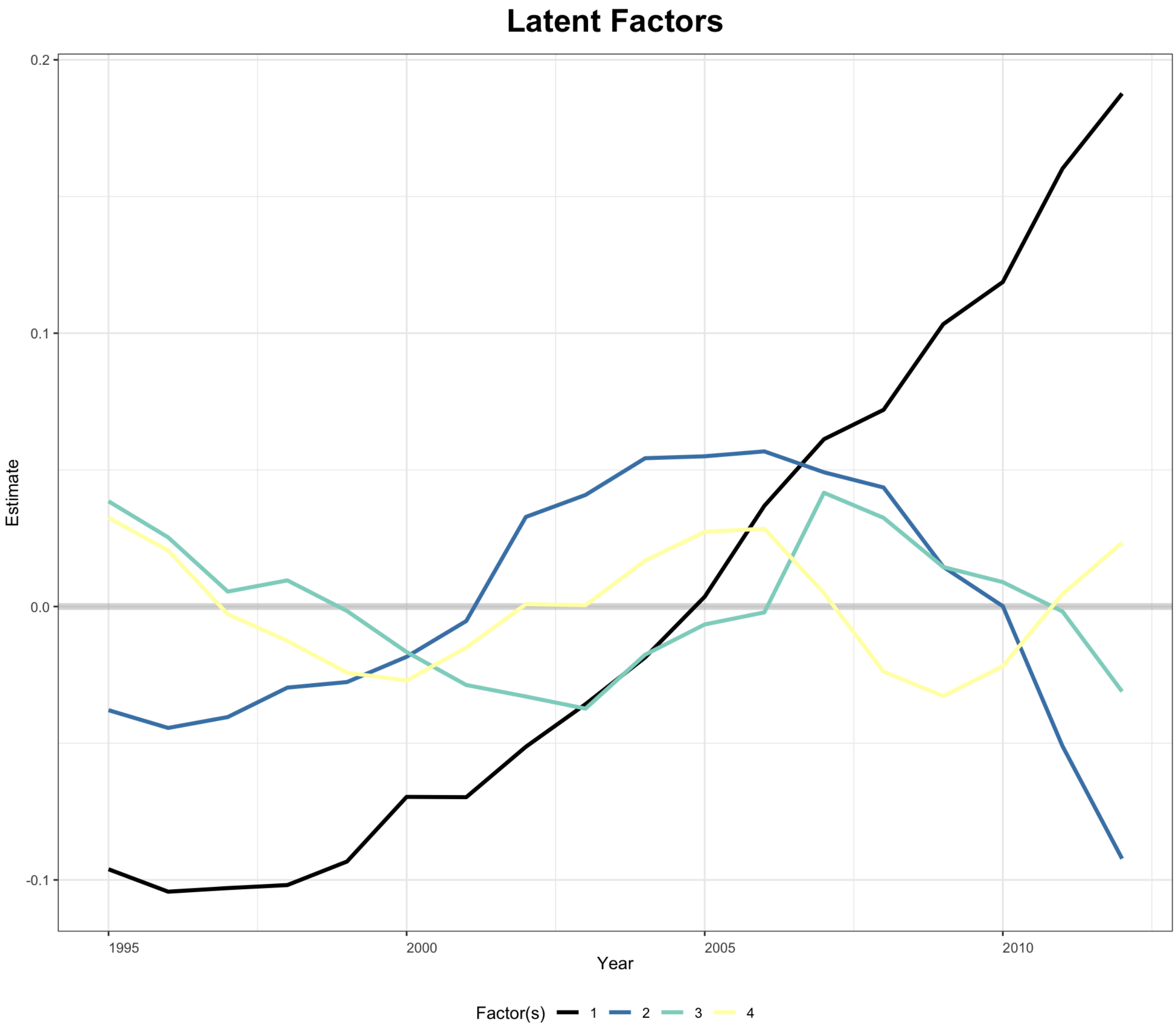

Figure A.5.18: Factor Loadings Estimated for Kigali

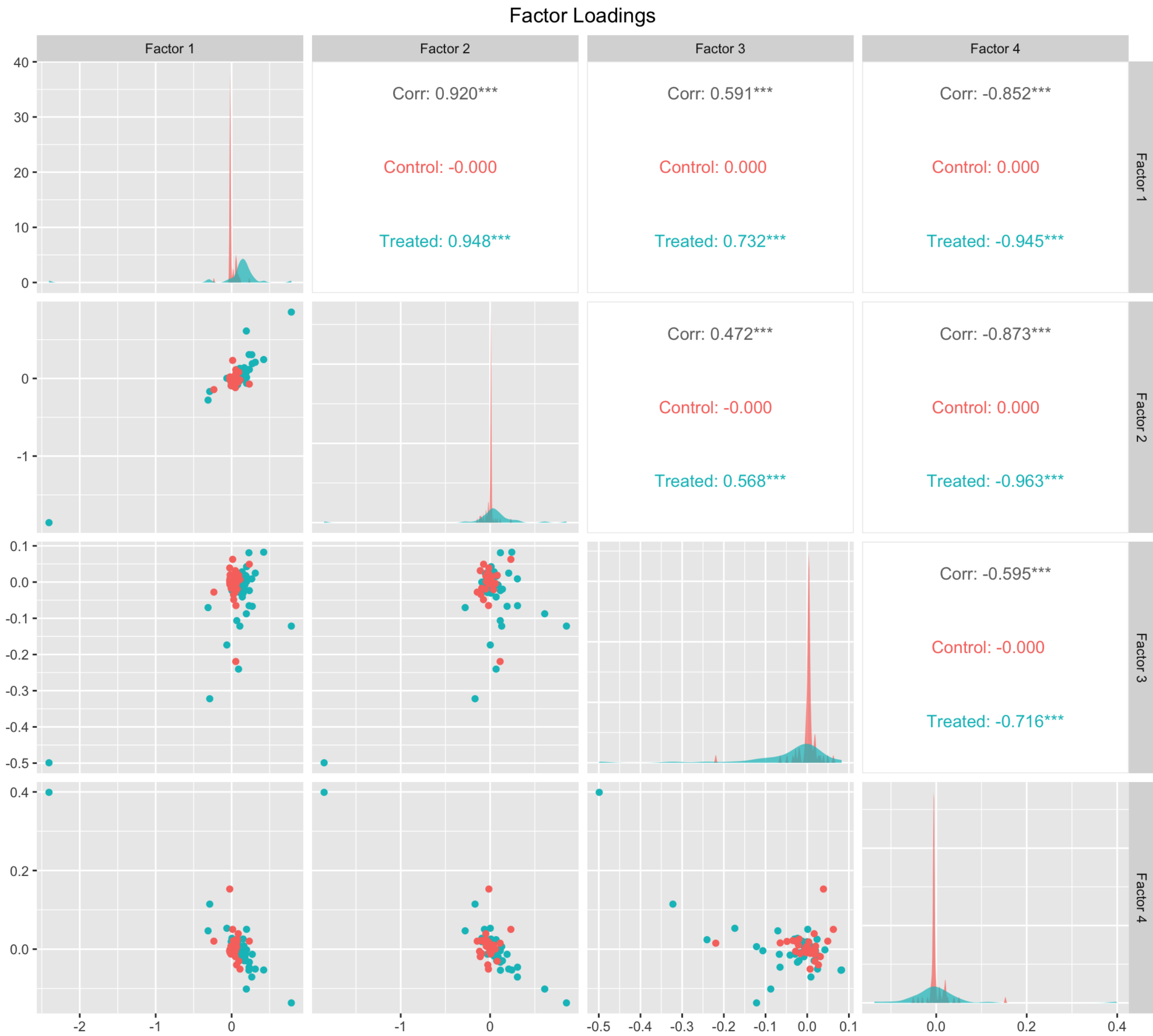

Figure A.5.19: Factor Loadings Estimated for Kigali with CDM Adjustment

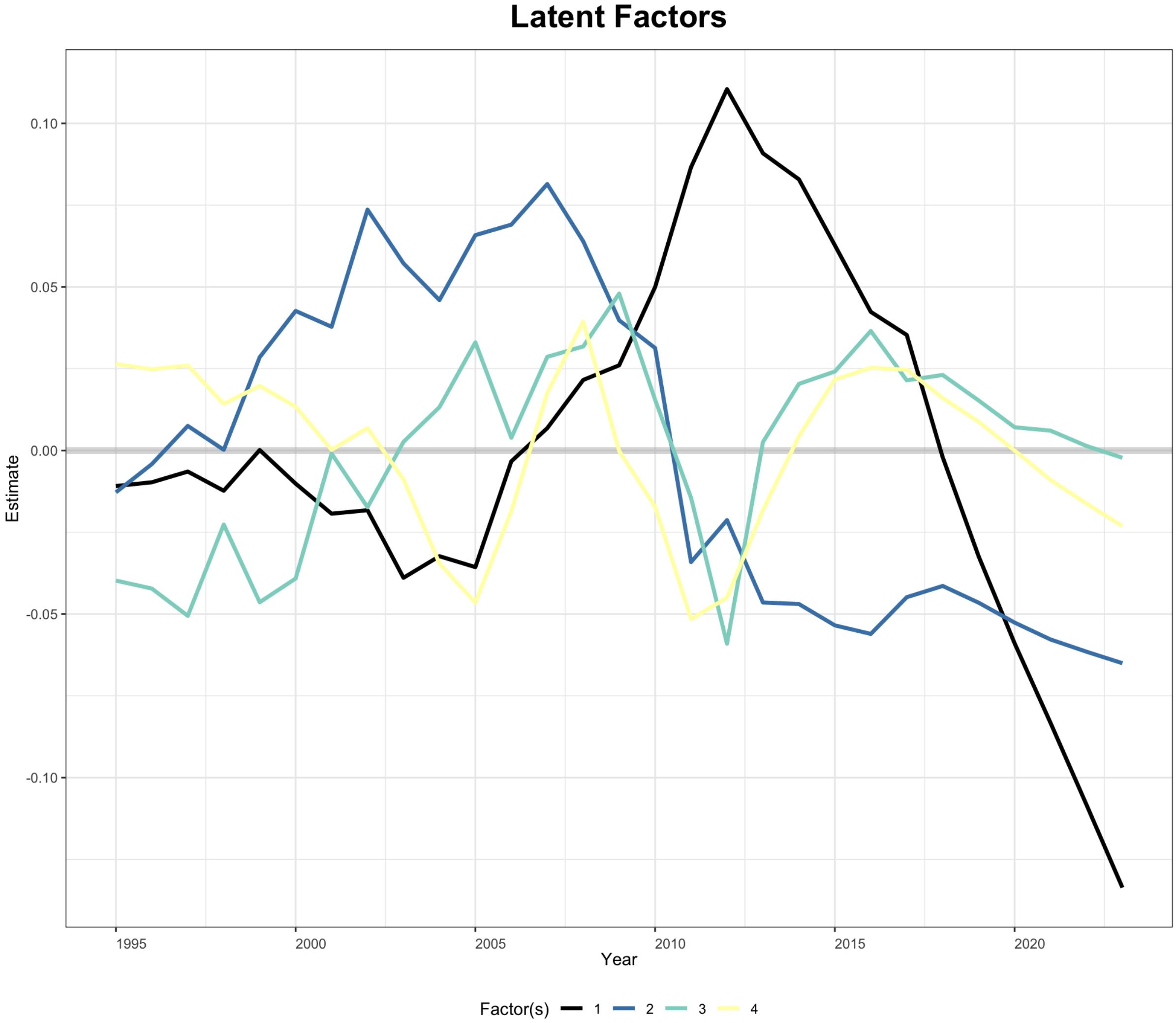

Figure A.5.20: Factor Loadings Estimated for Kigali with CDM Adjustment