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# Trade, Emissions, and Environmental Spillover

## Issue linkages in Regional Trade Agreements

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## Abstract

Reducing trade barriers offers tremendous potential for economic growth and productivity gains. However, higher incomes and increased industrial output can negatively impact the environment. This paper studies the impacts of trade liberalization on the emissions of ozone depleting substances regulated under the Montreal Protocol. While freer trade might challenge the gains achieved by the Montreal Protocol by increasing domestic use of ozone depleting substances, environmental provisions in regional trade agreements linked to Montreal Protocol participation might mitigate such negative environmental outcomes. The paper provides causal evidence that signing a new regional trade agreement leads to increases in consumption of ozone depleting substances relative to Montreal Protocol targets. Environmental provisions aimed at controlling ozone depleting substances offset the increase in consumption of ozone depleting substances observed in regional trade agreements without such provisions. The findings show that the effect is rooted in preventing a "reduction in overcompliance" with the Montreal Protocol observed in regional trade agreements without provisions. The findings also show that cumulative exposure to trade agreements, especially those with ozone depleting substances provisions, increases the speed at which countries ratify the Montreal Protocol amendments.


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# Trade, Emissions, and Environmental Spillovers: Issue linkages in Regional Trade Agreements*

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# 1 Introduction

The Montreal Protocol has been one of the most successful international environmental agreements in history, effectively eliminating the use of ozone depleting substances (ODS) and allowing for the eventual repair of the stratospheric ozone layer (Gonzalez *et al.*, 2015; World Meteorological Organization, 2018; McKenzie *et al.*, 2019). The success of the Montreal Protocol in part stems from its nearly universal set of member countries, including all members of the United Nations and the European Union.[1] The Montreal Protocol incentivizes developing countries to comply by giving them more time than developed countries to phase out substances, offering technical and financial assistance to utilize new substances, and mandating members limit trade with countries not party to the agreement. The Montreal Protocol also features clearly enumerated dispute settlement procedures to address member party noncompliance. However, dispute settlement resolution under the Montreal Protocol focuses on assisting non-conforming countries to move into compliance—punishment mechanisms are limited to extreme cases in which a country loses signatory rights and privileges.[2]

Although widely regarded as a historical success in reducing ozone destruction, the Montreal Protocol remains an important international environmental institution. Over time, the Montreal Protocol has expanded in scope to include regulation of widely used ODS substitutes that have high global warming potential. Consequently, the Montreal Protocol is poised to play a central role in international policy solutions to address global climate change. Furthermore, recent evidence suggests that some countries may be increasing production and consumption of ODS in violation of Montreal Protocol commitments, raising unprecedented challenges to the treaty (Rigby *et al.*, 2019; Western *et al.*, 2022).

In this paper, we study the impacts of linking trade liberalization, in the form of regional trade agreements (RTAs), to the Montreal Protocol and ODS reduction commitments more broadly. RTAs increasingly contain detailed provisions on environmental issues—a phenomenon understood as a type of "issue linkage" in which two unrelated policy areas are tied together (Maggi, 2016). Linking

[1] https://ozone.unep.org/classification-parties.

[2] "Indicative list of measures that might be taken by a Meeting of the Parties in respect of non-compliance with the Protocol:" https://ozone.unep.org/node/2080.

Montreal Protocol and ODS commitments to trade policy under RTAs introduces the potential for additional punitive measures for non-compliance in the form of retaliatory trade policy allowed for under RTA dispute settlement mechanisms. Because these expanded punitive measures fall under the RTA rather than the Montreal Protocol, they potentially cover a broad set of goods and services rather than the narrow focus on ODS-related goods under the Montreal Protocol.

We consider two aspects of issue linkages between trade policy and environmental policy using detailed data on trade agreement content from the World Bank's Deep Trade Agreement database. First, we empirically investigate the use of trade agreements to induce accession to international environmental agreements—a phenomenon referred to as "participation linkage" in the literature. Because the Montreal Protocol limits trade in ODS-related goods with non-member countries, member countries may lobby to include Montreal Protocol accession as a requirement in trade agreements with non-members in order to more effectively open trade while avoiding any barriers under the Montreal Protocol. Second, we consider "enforcement linkage" between trade agreements and reductions in use of ozone depleting substances. In contrast to participation linkages—in which commitments bind via the Montreal Protocol—we also consider ODS commitments directly enumerated in trade agreements themselves that bind via RTA dispute settlement mechanisms. In particular, we study whether such enforcement linkages are effective at mitigating ODS emissions. This is a critical question in light of recent evidence that China has increased production and consumption of CFC-11 in violation of its Montreal Protocol commitments (Rigby *et al.*, 2019).

We also examine the role of substitution in the apparent success of the Montreal Protocol. We study whether reductions in regulated ODS were, in part, accomplished via substitution to other unregulated or less stringently regulated substances. While policy linkage in trade agreements can support commitments prescribed by international environmental agreements, exposure to potential trade remedies may exacerbate or accelerate policy spillovers such as substitution away from regulated substances to potentially harmful alternatives.

We find evidence that RTAs and ODS provisions are effective in promoting participation linkage. While the Montreal Protocol and its amendments have achieved near universal ratification (besides the most recent Kigali Amendment in 2016), many countries—both developed and developing—

took several years to achieve ratification by their national legislatures. We find that participating in RTAs with enumerated clauses regarding ODS and Montreal Protocol commitments is associated with quicker amendment ratification. We also find evidence that RTAs alone, even without ODS clauses, have a significant positive effect on the probability of ratification in a given year, suggesting that countries likely ratified quicker to not endanger gains from trade liberalization under RTAs.

We also find evidence of enforcement linkage effectiveness in RTAs that include ODS provisions. While most countries are in compliance with Montreal Protocol ODS targets, we find that trade liberalization leads to increased use of several ODS groups relative to Montreal Protocol targets, with a *reduction in overcompliance* to the Montreal Protocol. In other words, RTAs induce countries to increase their use of ODS, while still maintaining compliance with the Montreal Protocol. We find evidence that the inclusion of Montreal Protocol and ODS provisions mitigates or entirely reverses these effects for many ODS. We do not find that the effectiveness of these provisions hinges on the enforceability of the provisions under the RTA dispute settlement process, suggesting that linkage to a binding and enforceable international agreement is adequate to generate responses in ODS consumption.

Finally, we find evidence that the signing of RTAs produces spillovers in consumption to less-regulated substances. Consumption of HFC gases—potent greenhouse gases that were not regulated under the Montreal Protocol until 2016—increase as the prescribed target level for its predecessor substance (HCFCs) decreases. RTAs amplify this substitution to HFCs, while the presence of ODS-related provisions do not appear to affect this spillover channel.

This paper makes important, policy-relevant contributions to a number of literatures. First, this paper is one of the first, if not the first, to empirically consider participation linkages in trade agreements. Second, we contribute to the broad literature on the relationship between trade and the environment. A large share of this literature has studied the impacts of trade on pollution (Antweiler *et al.*, 2001; Frankel and Rose, 2005; Managi *et al.*, 2009; Kreickemeier and Richter, 2014; Cherniwchan, 2017) while other work focuses on trade and renewable resource management (Brander and Taylor, 1998; Hotte *et al.*, 2000; Bulte and Barbier, 2005; Copeland and Taylor, 2009; Taylor, 2011; Erhardt, 2018), especially deforestation (Abman and Lundberg, 2020; Barbier and

Rauscher, 1994; Sohngen *et al.*, 1999; Hannesson, 2000; Leblois *et al.*, 2017; López and Galinato, 2005; Barbier *et al.*, 2005; Barbier and Burgess, 2001). Very little of the literature has established causal evidence of the impacts of trade on the environment. Most of these papers rely on either cross-sectional variation or within-country variation in observed trade volumes or trade measures to study this relationship using either pooled ordinary least squares or fixed-effects regressions. We build upon the new, but quickly growing, quasi-experimental literature on the impacts of environmental content in RTAs (e.g. Abman *et al.*, 2021; Abman and Lundberg, 2020)—through both participation linkages as well as the effectiveness of ODS provisions in RTAs on emissions.

We also contribute to a small economics literature exploring aspects of the Montreal Protocol, including country accession (Beron *et al.*, 2003), ODS emissions (Murdoch and Sandler, 1997; Auffhammer *et al.*, 2005), and corruption and emergent black market trade of ODS (Ivanova, 2007). While scientific evidence suggests that the agreement was successful in reducing ODS (Velders *et al.*, 2007; Morgenstern *et al.*, 2008; Fortems-Cheiney *et al.*, 2015; Chipperfield *et al.*, 2015; McKenzie *et al.*, 2019), there is a dearth of rigorous econometric studies using contemporary causal identification strategies on the impacts of the Montreal Protocol. The shortage of economic studies on the Montreal Protocol is a critical gap in the literature, especially in light of the Montreal Protocol's ongoing relevance. The recent Kigali Amendement of 2016 established phaseout schedules for hydrofluorocarbons (HFCs)—powerful greenhouse gases with global warming potentials that dwarf that of carbon dioxide.

The remainder of the paper proceeds as follows. In Section 2 we provide an overview of the institutional setting with a particular focus on the Montreal Protocol and ODS commitments along with our data sources. We discuss our empirical strategy in Section 3. We discuss our findings in Section 4. We offer some concluding remarks in Section 5.

# 2 Background and Data

## 2.1 Regional Trade Agreements

Regional trade agreements, beyond eliminating trade barriers between countries, increasingly address non-trade policy areas in their content such as competition policy, intellectual property, and environmental concerns. Non-trade commitments within RTAs have proliferated in recent decades, both in number and in policy scope—the average RTA in the 1950s covered eight policy areas; in recent years they have averaged 17 (Hofmann *et al.*, 2017). The increasing number of policy commitments has been accompanied by an increase in regulatory and enforcement requirements. The changing nature of RTAs is documented in a new database by the World Bank detailing the content of all RTAs in force and notified to the World Trade Organization (Mattoo *et al.*, 2020). Since the signing of the Montreal Protocol in 1987, many RTAs have included policy commitments tied to the Montreal Protocol and/or ozone-depleting substances in general.

Our data on environmental provisions in RTAs have been collected as part of the broader World Bank project on the content of trade agreements and are described in detail in Monteiro and Trachtman (2020). This is the most extensive effort to date to document environmental provisions in trade agreements. The environmental provisions coded include environmental goals, specific commitments, compliance with multilateral environmental agreements, enforcement mechanisms, and external assistance and collaboration. Within this set of environmental provisions, there are two that address ozone depleting substances:

- Does the agreement require states to control ozone-depleting substances?
- Does the agreement require states to comply with the Montreal Protocol on ozone depleting substances?

Figure 1 displays the frequency of RTAs over time, as well as the inclusion of provisions related to ODS. There are 44 agreements that include at least one of the two provisions related to ODS.[3] The first trade agreements to enter into force that included ODS provisions were the Common Market

[3]The list of trade agreements containing provisions on ODS use is displayed in Appendix Table A.1.

for Eastern and Southern Africa, and the North American Free Trade Agreement, both of which entered into force in 1994. Twenty-five of these agreements include the US, the EU, or Canada. Twenty-nine of the agreements involve at least one South or Central American country. Thirty-six of the agreements contain provisions that are legally binding with dispute settlement mechanisms available under the RTA.

## 2.2 The Montreal Protocol

The consumption and production of ozone depleting substances is regulated by the Montreal Protocol. Signed in 1987, the Montreal Protocol is considered a landmark piece of international policy, as it has 1) achieved universal ratification by members of the United Nations and 2) successfully reduced the use of ODS, beginning the recovery of the stratospheric ozone layer (World Meteorological Organization, 2018).

Originally covering only chloroflurocarbons (CFCs) and halons, the Protocol has been amended five times, increasing in scope to cover carbon tetrachloride (CTC), trichloroethane (TCA) and other fully halogenated CFCs in the London Amendment of 1990; hydrochloroflurocarbons (HCFCs), hydrobromofluorocarbons (HBFCs) and methyl bromide (MB) in the Copenhagen Amendment of 1992; bromochloromethane (BCM) in the Beijing Amendment of 1999; and HFCs in the Kigali Amendment of 2016.[4] While HFCs do not have any ozone depleting potential, they are a potent greenhouse gas.

The phaseout schedules for the consumption and production of ODS dictated in the Montreal Protocol vary by the substance and are based on a country's historical usage. The specific dates and targets for phaseout are determined by a country's status as a developed or developing country. Developing countries, referred to as "Article 5" countries in the Montreal Protocol, are allowed to delay implementation of control provisions and can receive financial and technical assistance to reduce ODS use. Table A.2 in the Appendix lists all non-Article 5 and Article 5 parties.[5] Article 5 designation was determined by a country's consumption of ODS regulated under the original

[4]https://ozone.unep.org/treaties/montreal-protocol-substances-deplete-ozone-layer/the-evolution-of-the-montreal-protocol.

[5]There are 51 non-Article 5 parties and 147 Article 5 parties. Non-Article 5 parties include the European Union, the United States, Canada, Japan, and the Russian Federation; Article 5 countries include China, India, the Republic of Korea, Türkiye, and Brazil.

Montreal Protocol (CFCs and halons—so-called "Annex A" substances) at the time the treaty entered into force in 1989; countries with consumption of less than 0.3 kg per capita were given Article 5 status.

For example, the methyl bromide phaseout schedule for non-Article 5 countries establishes a baseline at a country's total consumption in the year 1991. Annual consumption cannot exceed this baseline by 1995. Annual consumption cannot exceed 75% of its baseline by 1999, 50% of baseline by 2001, 30% of baseline by 2003 and must be completely phased out to 0% of baseline in 2005. For Article 5 countries, the baseline level is set to average yearly consumption over the period 1995–1998. Annual consumption is required to be at or below baseline in 2002, at most 20% of baseline in 2005, and 0% in 2015.

Table 1 displays the ozone depleting substances regulated under the Montreal Protocol, along with the amendment that introduced their phaseout, specified dates for 0% consumption and production for Article 5 and non-Article 5 countries, and common uses of the substance. The Montreal Protocol groups ODS types into "Annexes" based on introduction date and phaseout schedule.

CFCs, HCFCs and HFCs all have common applications as refrigerants in both commercial and residential systems. They also can be used as aerosol propellants, solvents, and cleaners (Brack, 2017). HCFCs were developed as an alternative to CFCs with lower ozone depleting potential, but were quickly subject to control measures themselves with the Copenhagen Amendment in 1992. HFCs were developed as alternatives to HCFCs and have zero ozone depleting potential. They, however, are very potent greenhouse gases—the most common HFC emitted, HFC-134a, has a 100-year global warming potential 1,300 times higher than $CO_2$. Currently, alternatives to commonly used HFCs include the creation of HFCs with lower global warming potential, natural refrigerants, and hydrofluoroolefins (HFOs).[6] Figure A.1 in the Appendix displays the total emissions of the aggregated HFC measure for Article 5 countries and non-Article 5 countries. Displayed with the emission paths are the CFC and HCFC phaseout schedules for Article 5 and non-Article 5 countries. From 1990–2018 HFC emissions increased dramatically for both country groups. All Annex A and B gases (CFCs, halons, other CFCs, CTCs, and TCA) were phased out for developed countries by

[6]https://ec.europa.eu/clima/eu-action/fluorinated-greenhouse-gases/climate-friendly-alternatives-hfcs en.

1996, while Article 5 countries had until 2010 to complete their phaseouts (2015 for TCA). Unlike the other substances regulated under the Montreal Protocol, methyl bromide has applications in the agricultural sector as a fumigant and pesticide. While Montreal Protocol control measures specified phaseout for Article 5 and non-Article 5 countries in 2010 and 2015, respectively, the substance has been frequently given essential use exemptions in numerous agricultural applications past the phaseout date (Holmes *et al.*, 2020).

Broadly, the Montreal Protocol has succeeded at reducing ODS consumption in both Article 5 and non-Article 5 countries. Throughout most of the phaseout schedule timelines, countries are on average below their consumption limits with Article 5 countries in particular exhibiting reductions in ODS consumption before the start of their phaseout schedules. Figures A.2 – A.15 in the Appendix display the phaseout schedules for non-Article 5 and Article 5 countries with consumption averages over time. However, there are a few instances in which countries are non-compliant on average. For Annex A substances, most Annex B substances and methyl bromide, non-Article 5 countries struggled to reach zero consumption in the first few years in which the substance was supposed to be completely phased out. This is most likely due to parties agreeing to the existence of essential-use exemptions for select industries with applications in which suitable substitutes were not yet available.

The Montreal Protocol's procedures on non-compliance are simple. Non-compliance includes when a country's consumption or production exceeds the level allowed by its phaseout schedule. Examples of non-compliance also include failure to report data to the Ozone Secretariat or failure to implement a licensing system for ODS by the mandated date. The treaty outlines three measures that might be taken in the event of non-compliance: 1) appropriate assistance in data collection, data reporting, technology transfer, or funding, 2) issuing cautions, and 3) suspension "in accordance with the applicable rules of international law concerning the suspension of the operation of a treaty" Brack (2003). Suspension would imply loss of trade privileges in ODS-related goods with countries party to the Protocol or loss of financial assistance. As of 2022, no party has ever been suspended.

## 2.3 Data Set Construction

Our data on country accession to the Montreal Protocol and its amendments, including dates of accession, are taken from the United Nations Environment Programme (UNEP) website.[7] In addition, data on ODS consumption are taken from the United Nations Environment Programme (UNEP) database.[8] The data are self-reported at the country-year level in ozone-depleting tonnes. We target seven of the ten substances regulated by the Montreal Protocol reported by UNEP: CFCs, halons, other CFCs, CTC, TCA, HCFCs, and MB. We omit HBFC and BCM as data are only available for a handful of countries. Note that these data reflect net consumption levels—the data record negative values if net destruction of ODS exceed consumption levels.

For the last group of substances regulated by the Montreal Protocol, HFCs we use data on emissions from the Emissions Database for Global Atmospheric Research (EDGAR) (Crippa *et al.*, 2021).[9] Emissions are given at the yearly level in kilotons from 1990-2018. For our study, we focus on five HFCs that have been common substitutes for CFCs and HCFCs – 23, 32, 125, 134a, and 152. We convert emission kilotons to CO2 equivalent tons and aggregate the five HFCs together.

Since ODS consumption is bound by the phaseout schedules set by the Montreal Protocol, a country's ODS consumption from UNEP needs to be normalized by the country's baseline in order to determine the degree to which the country is in or out of compliance, as well as how trade agreements impact compliance. The Montreal Protocol does not specify yearly targets, only dates for key reduction targets. For example, for Article 5 countries, 2007 CFC consumption can be no more than 15% of base level, and 2010 consumption can be no more than 0% of base level. We construct yearly consumption targets for each country and substance, based on the phaseout schedules dictated by the Montreal Protocol. For each substance, for years in between specific target dates, we linearly interpolate consumption targets. For the example above, the 2008 target would be 10% of base level, and the 2009 target would be 5% of base level. We then take the difference between each country's substance consumption and target value. If the value is positive, the country is consuming at a level

[7]https://ozone.unep.org/all-ratifications.

[8]https://ozone.unep.org/countries/data.

[9]https://edgar.jrc.ec.europa.eu/datasetghg60; also https://data.jrc.ec.europa.eu/dataset/97a67d67-c62e-4826-b873-9d972c4f670b.

above the interpolated target, and an increase represents an increase in substance consumption. If the value is negative, the country is "in compliance." [10]

We merge these country-year emissions data to our data on RTAs and RTA content and construct a "stacked" country-level panel with a ±3 year event window around signature of any RTAs. We consider every RTA that a country signs and include three years before and three years after. If a country signs multiple RTAs in adjacent years, each of ±3 year event windows enter into the analysis data set separately and are stacked or pooled. The resulting panel consists of 265 RTAs and 874 individual seven-year country sequences. We only consider RTAs signed after the Montreal Protocol was signed in 1987, which also corresponds with the start of ODS consumption reporting in most countries.

# 3 Empirical Strategy

We consider two types of linkages between RTAs and the Montreal Protocol. First, we investigate "participation linkages," referring to the potential for trade agreement content to induce accession to the Montreal Protocol or its Amendments. Because the Montreal Protocol bans trade in ODS-related products with countries not party to the Protocol, countries may include provisions in trade agreements to ensure their trading partner's status with the Protocol to maximize gains from trade liberalization.

The Montreal Protocol is made up of the original 1987 treaty and five amendments introducing new substances (1990, 1992, 1997, 1999, and 2016), each of which needs to be ratified by a country's legislature. Figures A.16 – A.18 in the Appendix display histograms of the years in which the original treaty and its amendments were ratified. Besides the most recent amendment in 2016, all five amendments and the original treaty exhibit near-universal ratification. If a country has not ratified an amendment, it is considered a non-party for the substances included in that amendment (Brack, 2017). For example, TCA was introduced in the London Amendment of 1990. If a country had ratified the Montreal Protocol but not the London Amendment, it could trade CFC-

[10] Results using non-interpolated targets are quite similar to reported results and are available upon request.

and halon-related goods with Protocol members but not TCA-related goods.

Despite these trade restrictions, ratification rarely occurs immediately after the treaty signing—across Article 5 and non-Article 5 groups there are countries that take decades to ratify the treaty (as displayed in Figures A.16 – A.18). It took until 2012 to achieve universal ratification of the 1990 and 1992 amendments, and 2014 for the 1997 and 1999 amendments. Dozens of countries have yet to ratify the Kigali Amendment of 2016. It took non-Article 5 countries and Article 5 countries on average 4.67 and 6.93 years, respectively, to ratify the Montreal Protocol. For the London Amendment, it took on average 4.42 and 7.83 years, and for the Copenhagen Amendment it took 5.43 and 7.92 years. These years of noncompliance could have endangered trade relations with countries that had already ratified the treaty, potentially inducing countries to include specific language in trade agreements mandating accession.

To investigate the role that ODS-related provisions play in inducing accession and ratification, we estimate hazard models. We estimate proportional hazard rates on the ratification of four agreements—the London Amendment (1990), the Copenhagen Amendment (1992), the Montreal Amendment (1997), and the Beijing Amendment (1999). We forgo estimating the original Montreal Protocol (1987) as the majority of country accessions occurs before the passage of RTAs with ODS provisions. The outcome in each specification can be interpreted as the inverse of the waiting time until ratification conditional on the covariates. We estimate the following Cox proportional hazard model:

$$\lambda(t|\mathbf{X_{it}}) = \gamma_0(t)exp(\beta_1 cumulRTA_{it} + \beta_2 cumulODS_{it} + \boldsymbol{\beta}\mathbf{X_i}) \quad (1)$$

where $i$ indexes countries and $t$ indexes years. $\lambda(t|\mathbf{X_{it}})$ is the so-called hazard rate—the rate of ratification at time $t$ conditional on not having already ratified by $t$. $\gamma_0(t)$ is the baseline hazard and represents the hazard when all of the predictors are equal to zero. $cumulRTA_{it}$ is the total number of RTAs country $i$ is party to in year $t$. $cumulODS_{it}$ is the total number of ODS clauses within RTAs country $i$ is party to in year $t$. $\boldsymbol{\beta}\mathbf{X_i}$ are time-invariant country-level controls including a country's status as an Article 5 or non-Article 5 country and World Bank income status and regional categorization. We also estimate the hazard rate with Poisson regressions via pseudo-maximum likelihood (PPML) with time and country fixed effects. For each regression, we only include observation years that follow the establishment of the relevant amendment. For all models, we report two-way, cluster-robust standard errors clustered at the country—to account for within-country autocorrelation—and at the year—to account for correlation across countries within a given year.

The second type of issue linkage we consider is that of enforcement linkage—referring to the possibility that ODS-related provisions (in particular, explicit linkages to the Montreal Protocol itself) in RTAs may function as a punitive mechanism through which countries might be able to discipline counterparties through trade retaliation allowed for under the RTA when counterparties are not abiding by their ODS-related obligations under the Montreal Protocol. We identify both the effects of trade liberalization on our emissions outcomes as well as the impact of ODS provisions in RTAs with the following triple-difference model on our stacked country panel:

$$ihs(dev_{igt}) = \beta_1 RTA_{igt} + \beta_2 RTA_{igt} * ODS_{ig} + \alpha_{ig} + \varepsilon_{igt} \tag{2}$$

where $i$ indexes countries, $t$ indexes years, and $g$ indexes RTAs with $ihs(dev_{igt})$ the inverse hyperbolic sine of deviation in consumption of ODS from the target levels under the Montreal Protocol. $RTA_{igt} = 1$ if year $t$ is later than the year that RTA $g$ is signed and zero prior, and $ODS_{ig} = 1$ if RTA $g$ includes the Montreal Protocol or ODS provisions. $\alpha_{ig}$ is a country-RTA fixed effect that ensures that estimated treatment effects are relative to the preperiod for each country and each RTA. Country characteristics such as political, legal and religious institutions, persistent demographic profiles, and time-invariant comparative advantages (e.g. driven by population size or geography) are accounted for via the inclusion of $\alpha_{ig}$. This fixed effect specification also controls for all RTA-level factors that might lead to endogenous content formation like signatory countries' baseline ODS consumption levels, accession to the Montreal Protocol and subsequent Amendments, as well as political economy factors between signatories like relative bargaining power or industry lobbying pressures. We note that since our event window is fixed in time for each RTA, our country-RTA fixed effects does provide for some control of time in our model. We also note that our target deviation outcomes also account for time and ODS drawdown schedules. Untabulated results that include year fixed effects are quite similar and event study specifications in Figures 5–8 largely support our preferred specifications.

In Model (2), $\beta_1$ captures the changes in country outcomes after the signature of an RTA without ODS provisions while $\beta_2$ captures the differential effect from RTAs with relevant provisions. Thus, signature of RTAs that include ODS provisions will lead to an estimated $\beta_1 + \beta_2$ increase in the outcome variable.

We also consider an additional differencing dimension (i.e. a quadruple difference model) on whether the provisions are enforceable via dispute settlement mechanisms:

$$ihs(dev_{igt}) = \beta_1 RTA_{igt} + \beta_2 RTA_{igt} * ODS_{ig} + \beta_3 RTA_{igt} * ODS_{ig} * DS_{ig} + \alpha_{ig} + \varepsilon_{igt} \quad (3)$$

where $DS_{ig} = 1$ if agreement $g$ for country $i$ features ODS provisions that are enforceable via dispute settlement.

We focus on signature, rather than entry into force of RTAs, because countries are already faced with targets under the Montreal Protocol. By signing an RTA linked to the Montreal Protocol, countries are exposed to potential RTA disputes related to Montreal Protocol noncompliance whenever the RTA enters into force. Abman and Lundberg (2020) present evidence of considerable uncertainty in the RTA negotiation process. The negotiation phase of RTAs is typically lengthy and requires multilateral assent to the negotiated treaty content—countries are not able to unilaterally conclude the negotiation phase.[11] We argue that these institutional features of RTAs create plausibly exogenous timing in the signature and, hence exposure to finalized RTA content. Note that our strategy here differs from Abman and Lundberg (2020) and Abman *et al.* (2021) which consider entry into force rather than signature of RTAs. Those studies focus on commitments exclusively enumerated in trade agreements rather than linkage to international environmental agreements as we consider here. For robustness, we also include in the Appendix triple-difference estimates around

[11]More specifically, countries are not able to *successfully* conclude the negotiation phase unilaterally. Countries can unilaterally withdraw from negotiations which can, in many circumstances, terminate the negotiation phase and future prospects for the RTA.

entry into force rather than signature.

Finally, we consider the role that trade liberalization via RTAs—and ODS-related commitments therein—might play in exacerbating spillovers from regulated ODS to other environmentally-harmful substances. To do so, we extend our triple-difference model in Equation (2) with target commitments under the Montreal Protocol in substitute substances. We consider two main substitution channels: from CFCs to HCFCs and from HCFCs to HFCs:

$$ihs(y_{igt}) = \beta_1 RTA_{igt} + \beta_2 RTA_{igt} * ODS_{ig} + \beta_3 target_{it} + \alpha_{ig} + \varepsilon_{igt} \tag{4}$$

where $y_{igt}$ either refers to the country-year consumption of HCFCs as reported by UNEP or the country-year aggregated HFC emissions generated from EDGAR data. $target_{it}$ refers to the specified target level under the Montreal Protocol for the substance being substituted away from—for the HCFCs regressions the previous substance is CFCs, and for the HFCs regressions the previous substance is HCFCs. We also include some specifications in which we interact $target_{it}$ with our trade liberalization variables to measure changes in the spillover channel around trade liberalization.

Recall that HCFCs became subject to phaseout schedules under the Copenhagen Amendment in 1992, with 0% dates in 2020 and 2030 for non-Article 5 and Article 5 countries, respectively. HFCs became subject to phaseout schedules under the Kigali Amendment in 2016, with 15% dates in 2036 and 2045. Note that the RTA signatures in our database all occur before the passage of Kigali in 2016.

For all of our enforcement linkage specifications, as well as our spillover specifications, we report two-way, cluster-robust standard errors clustered at the country-RTA level—to account for temporal autocorrelation within treatment units—and at the country-year level—to account for correlation across RTA "stacks" that might arise from overlapping, adjacent RTA treatment at the country level.

# 4 Results

We report our participation linkage estimates from Equation (1) in Table 2. Positive coefficients correspond to increases in the probability of ratification in a given year, while negative coefficients correspond to decreases in the probability of ratification. For each Montreal Protocol amendment, we estimate a Cox proportional hazard regression (first column) and a Poisson regression via pseudo-maximum likelihood (second column).

For the London and Copenhagen Amendments, being party to an RTA is associated with an approximately 36%–45% and 14%–33% increase in the probability of amendment ratification in a given year, respectively. The existence of ODS clauses increases the probability of acceptance by approximately 22%–30% and 34%–180%, respectively. Given that the first ODS clauses in RTAs appeared in 1994, after the signing of both amendments, the coefficients are most likely picking up "late ratifiers" signing the Protocol after engaging in RTAs with ODS clauses. All coefficient estimates for the effect of cumulative RTAs are highly significant, the estimates for ODS provisions are highly significant under the PPML model—our preferred specification as the inclusion of both year and country fixed effects account for time-varying baseline hazard rates, as the Cox model does, but also all time-invariant country-level factors that may affect ratification rates.

The results for the Montreal and Beijing Amendments are qualitatively similar. These later amendments do not introduce as many new substances as the previous two (only BCM, which was not widely used at the time) but include important updates to HCFC regulations. For the Montreal and Beijing Amendments, being party to an RTA is associated with an approximate 5%-61% and 8%-48% increase in the probability of amendment ratification in a given year, respectively. The existence of ODS clauses increases the probability of ratification by 10%-112% and 16%-77%, respectively. Most coefficient estimates for the effect of cumulative RTAs are highly significant with ODS provision estimates highly significant in PPML specifications.

On the whole, we find evidence that trade liberalization itself is associated with an increased rate of ratification of Montreal Protocol Amendments. As mentioned, the institutional details of the Montreal Protocol—particularly prohibited trade in ODS-related goods with non-members—

suggest that gains from trade liberalization are maximized when all RTA parties have ratified Montreal Protocol Amendments thereby avoiding any trade frictions that might otherwise arise. Notably, we find that RTA linkage to the Montreal Protocol can dramatically increase the ratification rate of Montreal Protocol Amendments above and beyond the effect of trade liberalization itself.

We turn our attention to enforcement linkages in Table 3 in which we report estimates of our triple-difference model in Equation (2). We find that trade liberalization significantly increases deviations from targets for Annex A gases. However, the mean level of our outcome variable is negative, indicating overcompliance in Montreal Protocol commitments. CFC deviation from target increases by approximately 70% after RTA signature, which corresponds to a reduction in overcompliance of approximately 980 tonnes of ODP. On average, this corresponds to an increase in

100-year global warming potential (GWP) equivalent to 7.7 million tons of carbon dioxide.[12] Halon deviation from target increases by approximately 37% after RTA signature, which corresponds to a reduction in overcompliance of approximately 97 tonnes of ODP (approximately equivalent to an increase in 100-year GWP of 25,000 tons of carbon dioxide).[13] We reiterate that, on average, countries are still in compliance with Montreal Protocol targets following signature of RTAs, the targets are simply less slack than they were before an RTA. We estimate positive coefficients on target deviations of Annex B (other fully halogenated CFCs, CTC, and TCA) gases after RTA signature, however none of these coefficients is statistically differentiable from zero. We estimate a negative responses in target deviations for HCFCs and Methyl Bromide after RTA signature, although only the HCFC effect is significant.

We find fairly broad evidence that the inclusion of ODS and Montreal Protocol provisions in RTAs lead to significantly negative response on target deviations for both Annex A gases (CFCs and halons) and from most Annex B gases (CTC and TCA). Negative point estimates here correspond to *increases* in overcompliance, i.e. the Montreal Protocol targets become even more slack with the inclusion of the provisions. For CFCs, CTC, and TCA, the provision magnitude is such that in

[12]UNEP CFC data does not differentiate CFC gases in ODS consumption data. Different CFC gases have different global warming potential. Our calculation here is based on the average GWP across all CFCs.

[13]As above, individual halon gas consumption quantities are not separately reported in the UNEP data. This number is based on average ODP and GWP for halons and aggregated halon consumption data.

RTAs with these provisions the net effect of signature is negative—overcompliance increases after signature for all three gases. For halons the inclusion of the provisions offsets the RTA signature effect such that in RTAs with the provisions there is no net change in compliance after signature. We report event study coefficients with 95% confidence intervals for these triple-difference regression in Figures 2–8.

Our results in Table 3 suggest that the provisions do indeed appear to be effective for many of the substances in our study. We explore this effectiveness further by considering provisions that are binding and enforceable with access to dispute settlement mechanisms under the RTA. We report estimates of Equation (3) in Table 4. Notably, the mitigating effects of ODS provisions on Annex A emissions do not hinge on the enforceability of such provisions via RTA dispute settlement. We attribute this finding to two features of our experimental setting. First, most countries are in compliance with Montreal Protocol obligations. Because emissions targets are slack, the enforceability of provisions would also be slack, i.e. the threat of disputes under the RTA are not binding since most countries are not in violation of the provisions and/or the Montreal Protocol. Second, because the Montreal Protocol is a binding and enforceable international agreement, linking trade policy to it may not require enforceability of commitments via RTA dispute settlement channels since enforceability already binds under the Montreal Protocol.

Despite these findings, linking ODS and Montreal Protocol commitments to trade agreements with dispute settlement mechanisms that fall under the RTA might become more important in the future. Recent evidence suggests that China has increased production and consumption of CFC-11—an Annex A prohibited substance (Rigby *et al.*, 2019). There are also detections of increased HCFC production (Western *et al.*, 2022). However, punitive measures in the Montreal Protocol are limited. Linking ODS commitments to potentially punitive trade policy via RTA dispute settlement channels may create opportunities to apply binding policy pressures on non-compliant Montreal Protocol members.

Finally, we report estimates of our spillover model from Equation (4) in Table 5. We find consistent evidence of substitution spillovers from CFCs to HCFCs—a one percent drop in CFC consumption targets under the Montreal Protocol phaseout schedule (i.e. an obligated reduction in CFC consumption) is associated with an .8–.10 percent increase in HCFC consumption (findings significant at the 1% level). Exposure to RTAs that include ODS-related provisions reverses this spillover channel, however. Following signature of RTAs with ODS provisions, a 1 percent reduction in CFC consumption targets is associated with a decrease in HCFC consumption of approximately 0.07 percent. Notably, HCFCs are themselves regulated under the Copenhagen Amendment to the Montreal Protocol, hence exposure to ODS provisions is likely to directly impact HCFC consumption regardless of this spillover channel.

Similarly, we find strong evidence of substitution spillovers from HCFCs to HFCs—a 1 percent drop in HCFC consumption targets under phaseout schedules set by Montreal Protocol Amendments (i.e. obligated reductions in HCFC consumption) is associated with an approximately .19–.25 percent increase in HFC consumption (findings again significant at the 1% level). Unlike the CFC-HCFC spillover channel, HFCs do not yet have binding phaseout schedules under Montreal Protocol Amendments. HFC regulation was only recently introduced in the 2016 Kigali Amendment which many countries have not yet ratified. Furthermore, the reduction schedule has not yet started for HFCs, even among Kigali Amendment signatories[14] Consistent with this observation, trade liberalization exacerbates spillovers from HCFCs to HFCs with an additional .042 percent increase in HFC consumption in response to HCFC target reductions. Notably, the presence of ODS-related provisions does not significantly affect this spillover channel.

# 5 Concluding Remarks

The past 30 years have seen an unprecedented push for trade liberalization, with 262 regional trade agreements (RTAs) involving 188 countries entering into force over this period. This coincides with the signing of the Montreal Protocol in 1987, a landmark international agreement that has achieved a near universal membership and is reported to have successfully prevented catastrophic damage to the planet's ozone layer.

Few studies in the economics literature have addressed the empirical effects of the Montreal

[14]85% target reduction is to occur by 2036 for non-Article 5 countries and 2045 for Article-5 countries.

Protocol, including how its control measures interact with trade and trade agreements. Our paper considers two types of issue linkages between trade agreements and the consumption of ozone-depleting substances—participation linkage and issue linkage. The Protocol bans trade in ODS-related goods with non-parties, so engagement in trade agreements can threaten a country's Protocol compliance if their trading partner is not a party. We find evidence of participation linkage—countries engaged in RTAs with ODS provisions exhibit quicker ratification of Montreal Protocol Amendments, as do countries engaged in RTAs in general.

While reducing trade barriers offers tremendous potential for economic growth and productivity gains, higher incomes and increased industrial output could challenge the gains achieved by the Montreal Protocol by increasing domestic use of CFCs and other ozone depleting substances. Indeed, we find that trade liberalization increases consumption of Annex A gases—CFCs and halons. However, average deviation from Montreal Protocol targets remains negative, meaning RTAs "reduce overcompliance" to the Montreal Protocol. We find that environmental provisions prevent this reduction in overcompliance for CFCs and halons, suggesting that trade pressure and further technology transfer, most likely from developed to developing nations, helped countries phaseout CFCs and halons quicker.

We also find that RTAs linked to international environmental agreements can potentially exacerbate leakage and spillovers present in the environmental agreements themselves—potentially punitive actions available under the RTA can increase spillover pressures. In particular, we find that both Montreal Protocol targets and trade liberalization increase substitution away from HCFCs to HFCs. This is a significant environmental policy leakage as HFCs have significantly higher GWP than HCFCs. Our findings suggest that linking trade policy to international environmental agreements has the potential to increase the efficacy of international environmental policy but can also increase leakage in environmental policy due to the threat of punitive trade policy.

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# 6 Tables and Figures

Table 1: Montreal Protocol Substances

| Gas | Introduction | 0% Date: nonArticle 5 | 0% Date: Article 5 | Common Uses |
|---|---|---|---|---|
| | | **Annex A** | | |
| CFCs | Montreal Protocol (1987) | 1996 | 2010 | Refrigerant, propellant |
| halons | Montreal Protocol (1987) | 1994 | 2010 | Fire extinguishants |
| | | **Annex B** | | |
| "other" CFCs* | London Amendment (1990) | 1996 | 2010 | Not in Wide Use |
| CTC | London Amendment (1990) | 1996 | 2010 | Feedstock, solvent |
| TCA | London Amendment (1990) | 1996 | 2015 | Solvent |
| | | **Annex C** | | |
| HCFCs | Copenhagen Amendment (1992) | 2020 | 2030 | CFC Replacement |
| HBFCs | Copenhagen Amendment (1992) | 1996 | 1996 | Not in Wide Use |
| BCM | Beijing Amendment (1999) | 2002 | 2002 | Not in Wide Use |
| | | **Annex E** | | |
| MB | Copenhagen Amendment (1992) | 2005 | 2015 | Fumigant, Pesticide |
| | | **Annex F** | | |
| HFCs | Kigali Amendment (2016) | 2036 (85%) | 2045 (85%) | HCFC Replacement |

Table 2: Hazard Models of Montreal Protocol Amendment Ratification

| | *Dependent variable: Ratification Hazard Rate* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | London | | Copenhagen | | Montreal | | Beijing | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Cumulative RTAs | $0.307^{***}$ | $0.376^{***}$ | $0.130^{**}$ | $0.286^{***}$ | $0.046^{*}$ | $0.475^{***}$ | $0.075^{***}$ | $0.395^{***}$ |
| | (0.098) | (0.022) | (0.056) | (0.018) | (0.027) | (0.017) | (0.024) | (0.015) |
| Cumulative MP/ODS Prov | 0.260 | $0.203^{***}$ | 0.292 | $1.032^{***}$ | 0.096 | $0.752^{***}$ | 0.150 | $0.571^{***}$ |
| | (0.279) | (0.059) | (0.338) | (0.054) | (0.138) | (0.040) | (0.224) | (0.034) |
| Observations | 1,313 | 1,313 | 1,443 | 1,443 | 1,289 | 1,289 | 1,319 | 1,319 |
| Model | Cox | PPML | Cox | PPML | Cox | PPML | Cox | PPML |
| Baseline Hazard | year | country, year | year | country, year | year | country, year | year | country, year |

Hazard model coefficient estimates of Montreal Protocol and Montreal Protocol amendment ratification. Cumulative RTAs is the time-varying cumulative number of RTAs that a country has signed. Cumulative MP/ODS Provisions are the cumulative number of signed RTAs that include our study provisions on ODS and/or Montreal Protocol compliance. Cox proportional hazard models include time-invariant World Bank country income categories (high, low, upper middle, lower middle), region categories (EAS, ECS, EU28, LCN, MEA, NAC, SAS, SSF), and Montreal Protocol Article 5 membership status. Censored psuedo-poisson maximum likelihood (PPML) models estimate Poisson-equivalent regressions and include linear country and year fixed effects which are equivalent to country-specific baseline hazard functions. We report two-way cluster-robust standard errors clustered at the country and year level for all regressions. Statistical significance from two-sided $t$ tests are denoted by $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01.

Table 3: Deviation from Montreal Protocol Targets after RTA Signature

| | *Dependent variable: IHS Target Deviation* | | | | | | |
|---|---|---|---|---|---|---|---|
| | CFCs | Halons | CFCs (B) | CTC | TCA | HCFCs | MB |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Post Sig | $0.696^{***}$ | $0.371^{***}$ | 0.021 | 0.139 | 0.022 | $-0.396^{***}$ | $-0.024$ |
| | (0.154) | (0.094) | (0.039) | (0.102) | (0.052) | (0.083) | (0.106) |
| Post × ODS | $-1.401^{***}$ | $-0.381^{**}$ | $-0.043$ | $-0.434^{*}$ | $-0.287^{*}$ | $-0.005$ | 0.023 |
| | (0.381) | (0.190) | (0.078) | (0.251) | (0.170) | (0.212) | (0.280) |
| Observations | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 |
| $R^2$ | 0.526 | 0.551 | 0.390 | 0.484 | 0.602 | 0.642 | 0.528 |
| Mean (ODP tons) | -1402 | -261 | -3 | -551 | -30 | -116 | 14 |

FE triple-difference regressions on a stacked country-level panel with a ±3 year event window around RTA signature. All outcomes are the inverse hyperbolic sine of the difference between ODS emissions and emissions targets under the Montreal Protocol. All models include country-event fixed effects. Robust standard errors are (two-way) clustered at the country-event and country-year levels. We report the mean deviation from target across the entire sample in tons of ozone depletion potential (ODP). Statistical significance from two-sided $t$ tests are denoted by $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01.

Table 4: Deviation from Montreal Protocol Targets after RTA Signature

| | *Dependent variable: IHS Target Deviation* | | | | | | |
|---|---|---|---|---|---|---|---|
| | CFCs | Halons | CFCs (B) | CTC | TCA | HCFCs | MB |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Post Sig | 0.698*** | 0.370*** | 0.022 | 0.139 | 0.021 | −0.393*** | −0.028 |
| | (0.154) | (0.094) | (0.039) | (0.103) | (0.052) | (0.083) | (0.106) |
| Post × ODS | −1.280*** | −0.482** | 0.093 | −0.401 | −0.319 | 0.322*** | −0.406 |
| | (0.370) | (0.220) | (0.127) | (0.274) | (0.231) | (0.100) | (0.462) |
| Post × ODS × DS | −0.171 | 0.142 | −0.191 | −0.045 | 0.044 | −0.460* | 0.603 |
| | (0.501) | (0.255) | (0.144) | (0.269) | (0.272) | (0.248) | (0.500) |
| Observations | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 |
| $R^2$ | 0.527 | 0.551 | 0.390 | 0.484 | 0.602 | 0.643 | 0.528 |
| Mean (ODP tons) | -1402 | -261 | -3 | -551 | -30 | -116 | 14 |

FE triple-difference regressions on a stacked country-level panel with a ±3 year event window around RTA signature. All outcomes are the inverse hyperbolic sine of the difference between ODS emissions and emissions targets under the Montreal Protocol. DS is an indicator equal to 1 if the the ODS provisions are binding with dispute settlement under the RTA. All models include country-event fixed effects. Robust standard errors are (two-way) clustered at the country-event and country-year levels. We report the mean deviation from target across the entire sample in tons of ozone depletion potential (ODP). Statistical significance from two-sided $t$ tests are denoted by $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01.

Table 5: Montreal Protocol Spillovers in Consumption of Environmentally Harmful Emissions

| | *Dependent variable:* | | | |
|---|---|---|---|---|
| | HCFCs (ihs) | | HFCs (ihs) | |
| | (1) | (2) | (3) | (4) |
| Post RTA | $-0.322^{***}$ | $-0.577^{***}$ | $0.074^{***}$ | $0.334^{***}$ |
| | (0.088) | (0.116) | (0.025) | (0.040) |
| Post × ODS | $-0.387^{**}$ | $-0.409^{**}$ | $-0.113^{***}$ | $-0.128$ |
| | (0.178) | (0.206) | (0.037) | (0.144) |
| CFC target (ihs) | $-0.083^{***}$ | $-0.105^{***}$ | | |
| | (0.016) | (0.018) | | |
| Post × CFC targ | | $0.116^{***}$ | | |
| | | (0.017) | | |
| Post × ODS × CFC targ | | $0.064^{*}$ | | |
| | | (0.036) | | |
| HCFC target (ihs) | | | $-0.257^{***}$ | $-0.189^{***}$ |
| | | | (0.039) | (0.034) |
| Post × HCFC targ | | | | $-0.042^{***}$ |
| | | | | (0.006) |
| Post × ODS × HCFC targ | | | | 0.012 |
| | | | | (0.019) |
| Observations | 4,616 | 4,616 | 1,022 | 1,022 |
| $R^2$ | 0.910 | 0.914 | 0.998 | 0.998 |
| Mean | 658 | 658 | 28.8m | 28.8m |

Regressions on a stacked country-level panel with a ±3 year event window around RTA signature. The HCFC outcome is the inverse hyperbolic sine of aggregated HCFC consumption in ODP units. The HFC outcome is the inverse hyperbolic sine of the sum of HFC 134a, HFC 125, HFC 32, HFC 152a, and HFC 23 in 100-year GWP units. All models include country-event fixed effects. Robust standard errors are (two-way) clustered at the country-event and country-year levels. We report mean consumption in tons of ODP (for HCFCs) and tons of 100-year GWP (for HFCs). Statistical significance from two-sided $t$ tests are denoted by $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01.

Figure 1: Regional Trade Agreements and ODS Provisions by Year Agreement Entered Into Force

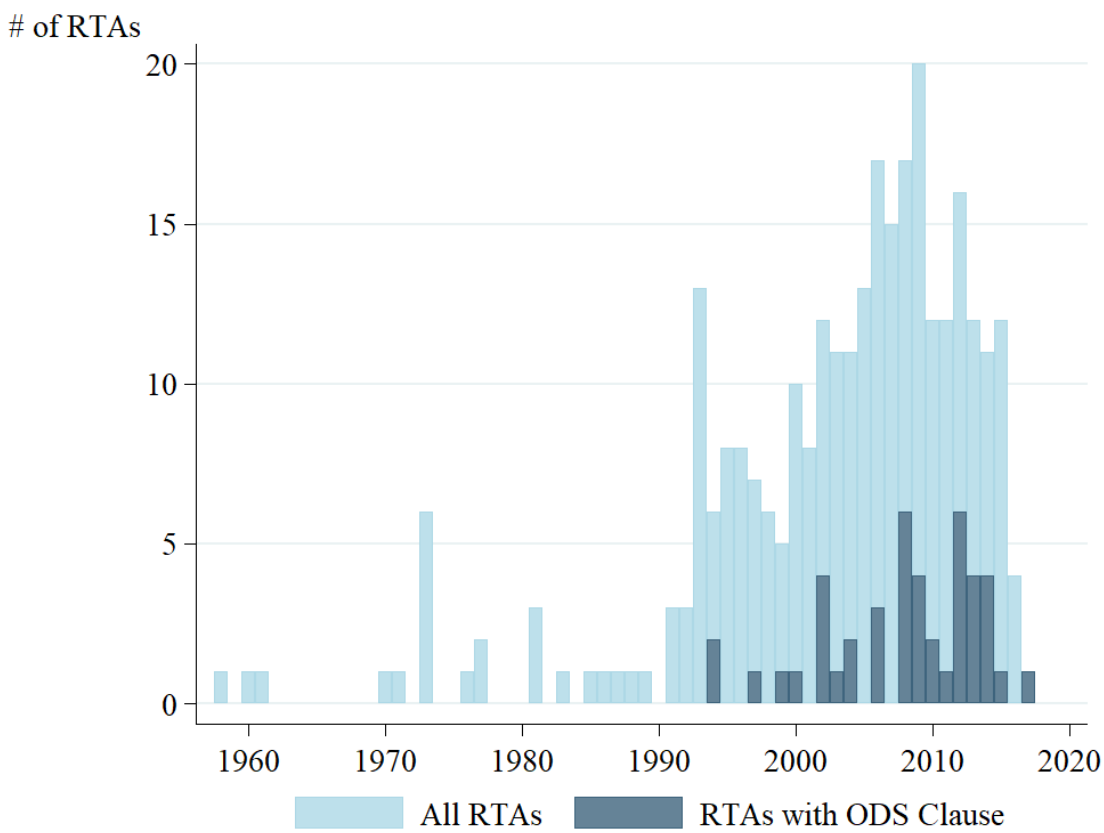
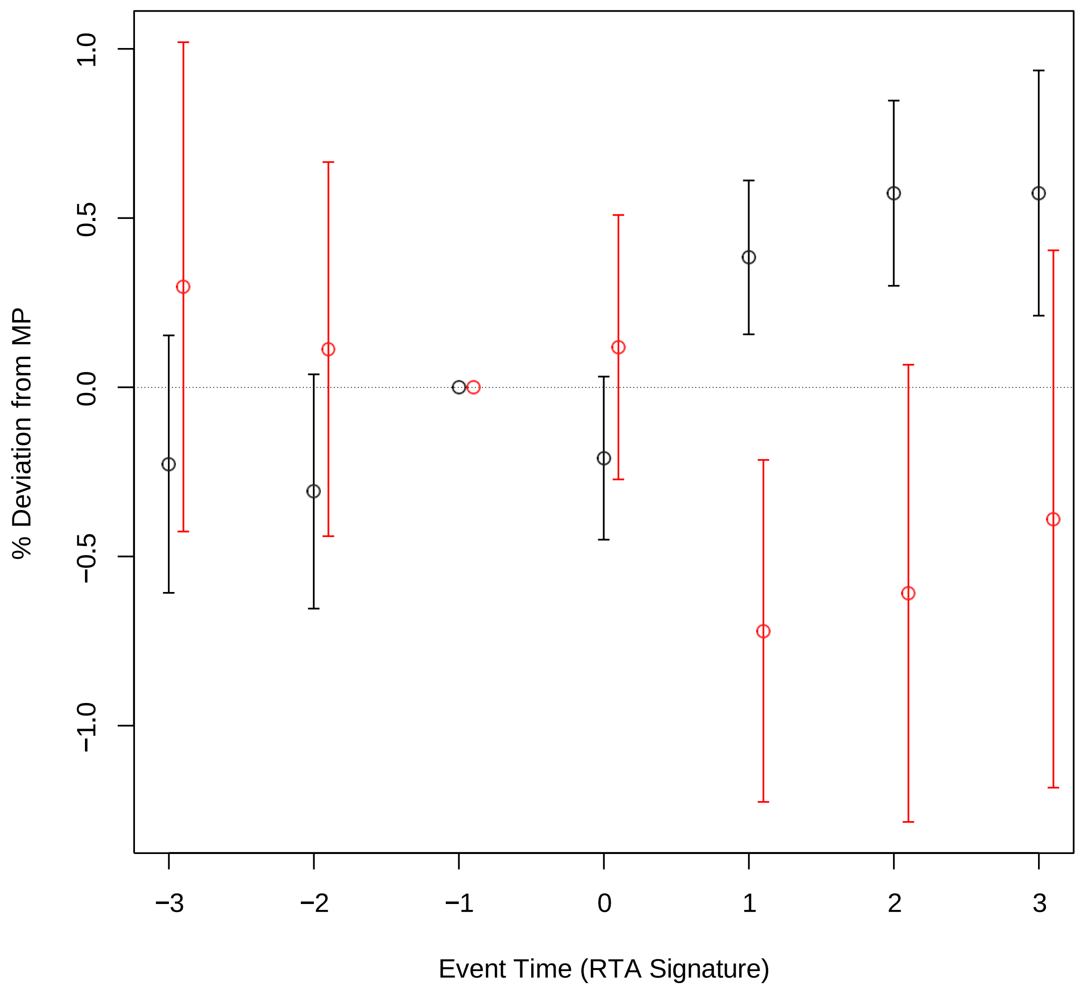
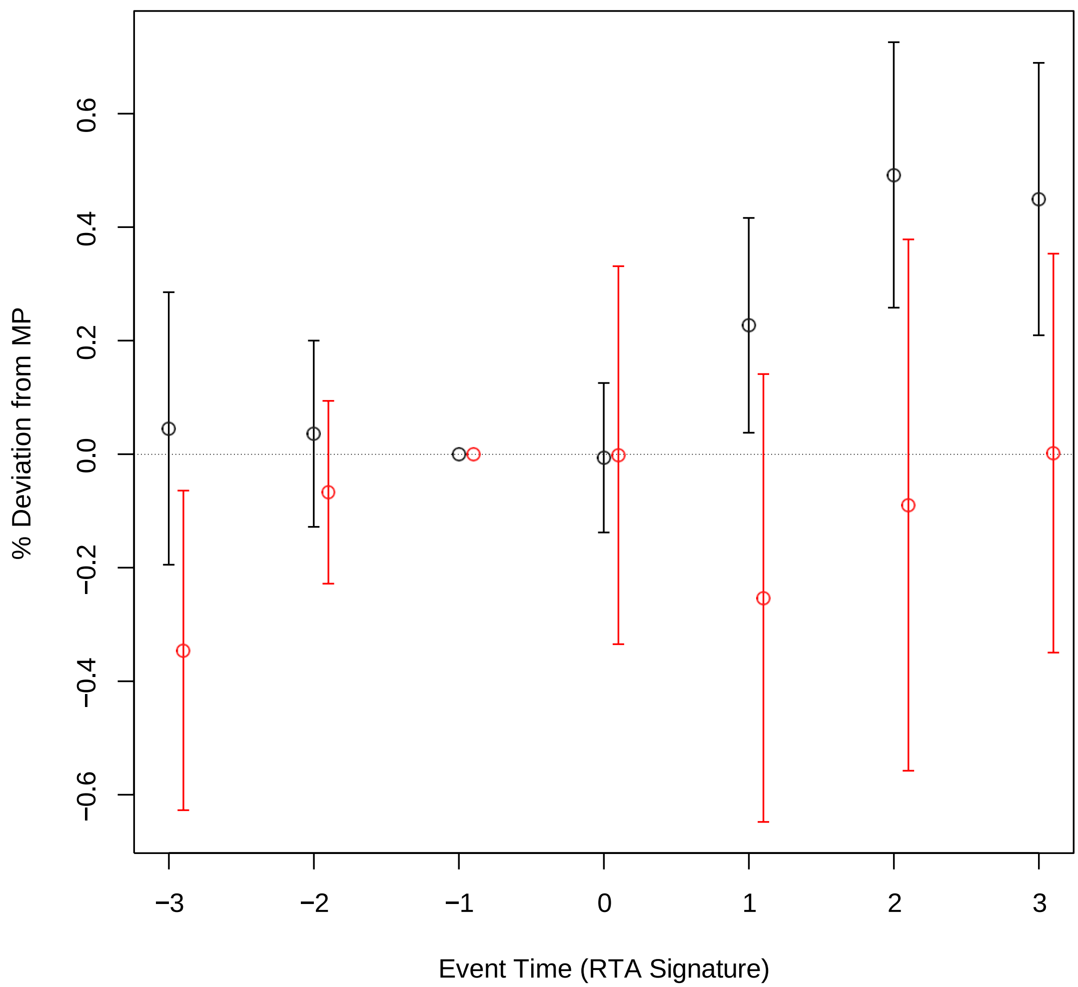


Figure 2: CFC Event Study Around Signature of RTA



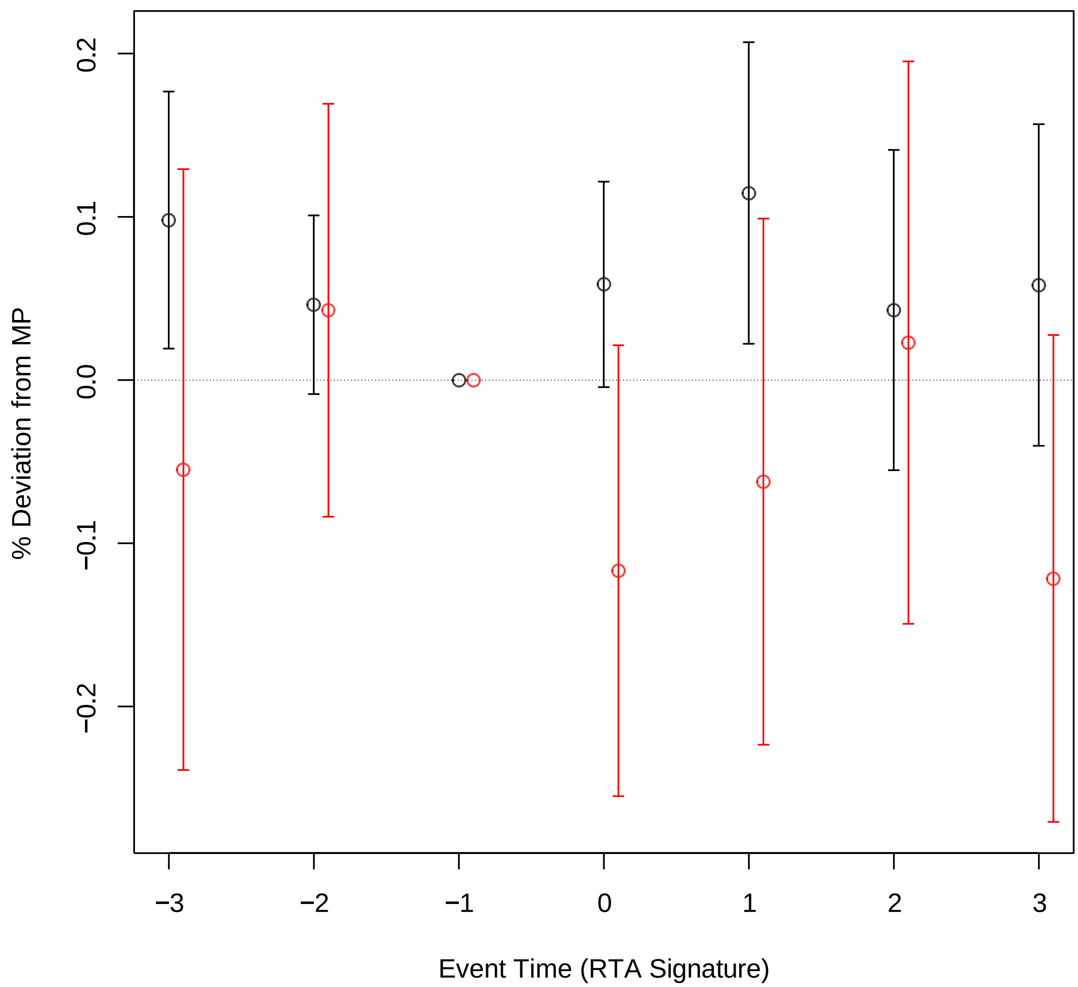

**Notes:** This figure presents event study coefficients for CFC emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 3: Halon Event Study Around Signature of RTA



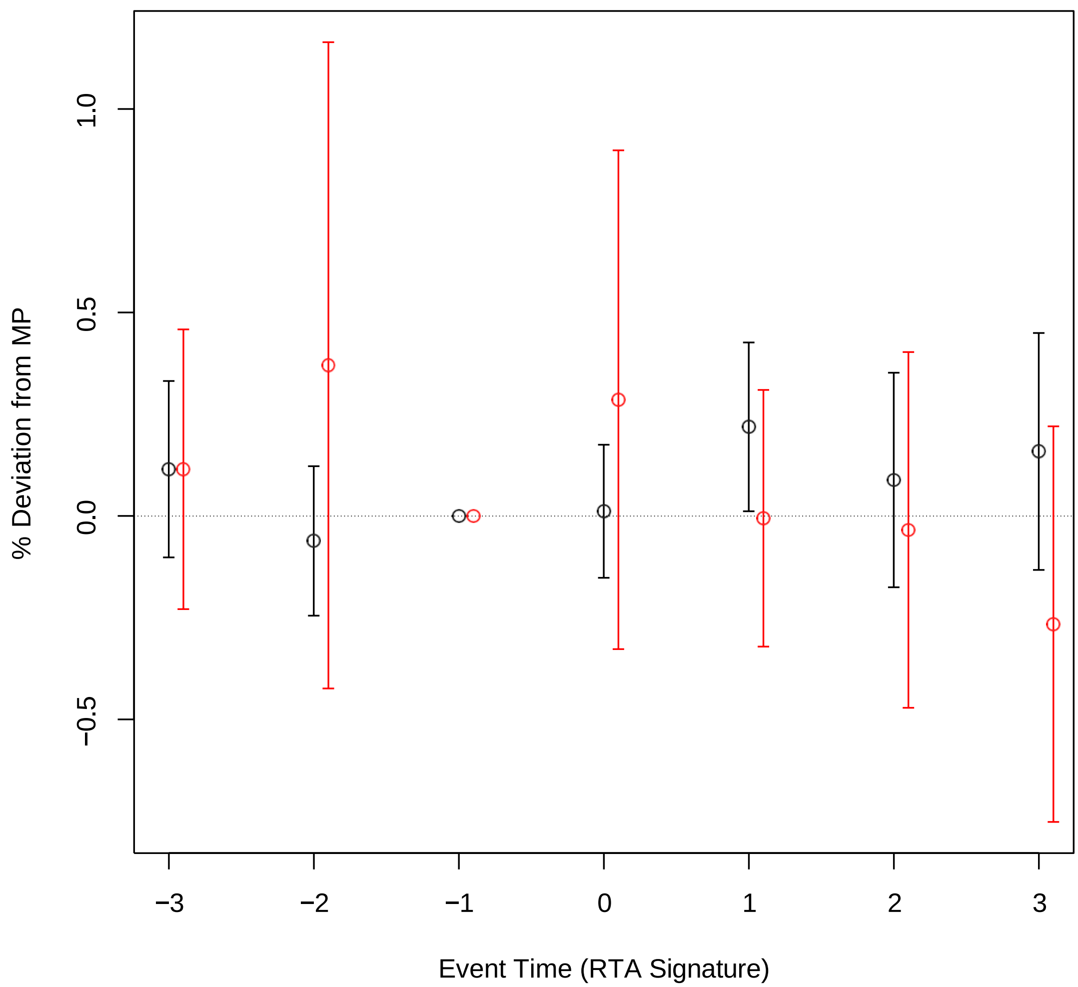

**Notes:** This figure presents event study coefficients for Halon emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 4: Annex B CFC Event Study Around Signature of RTA



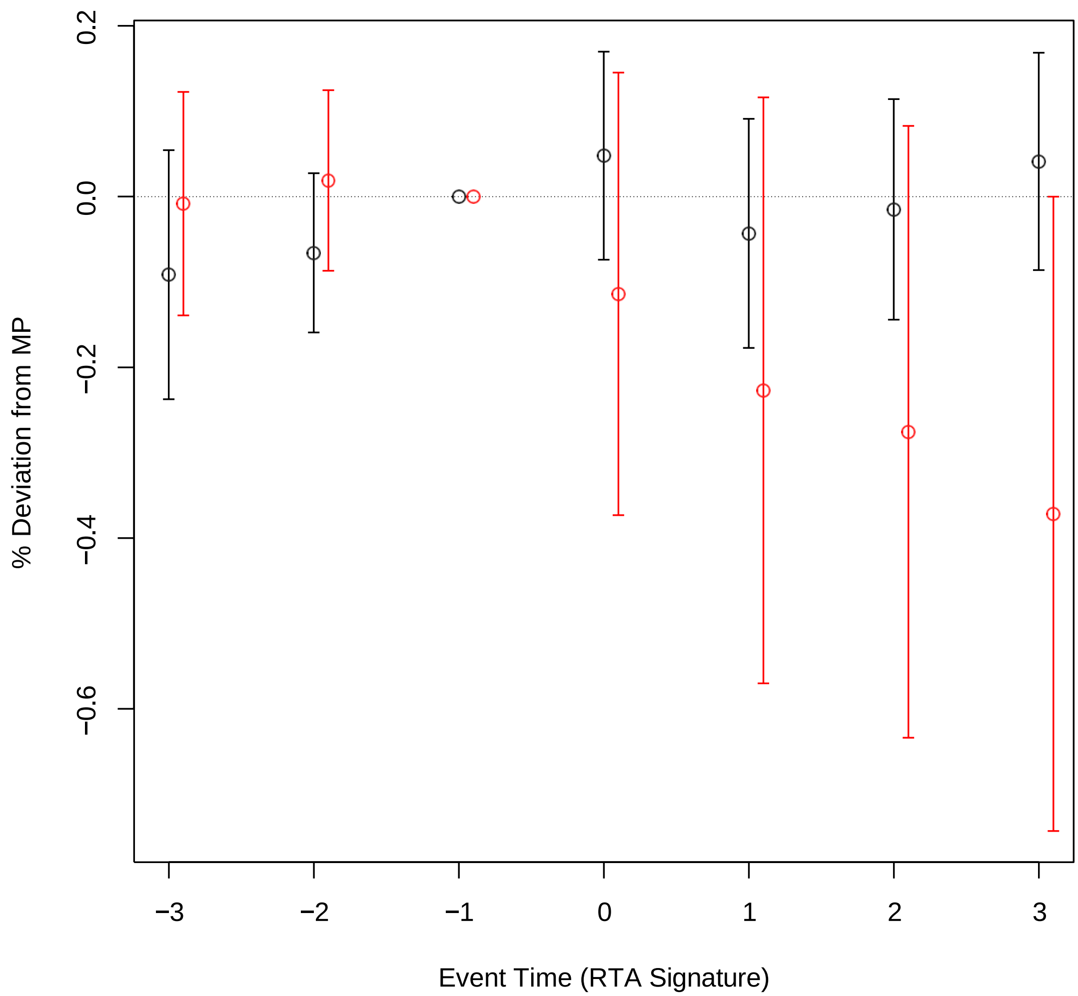

**Notes:** This figure presents event study coefficients for CFC emissions from Annex B countries (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 5: CTC Event Study Around Signature of RTA



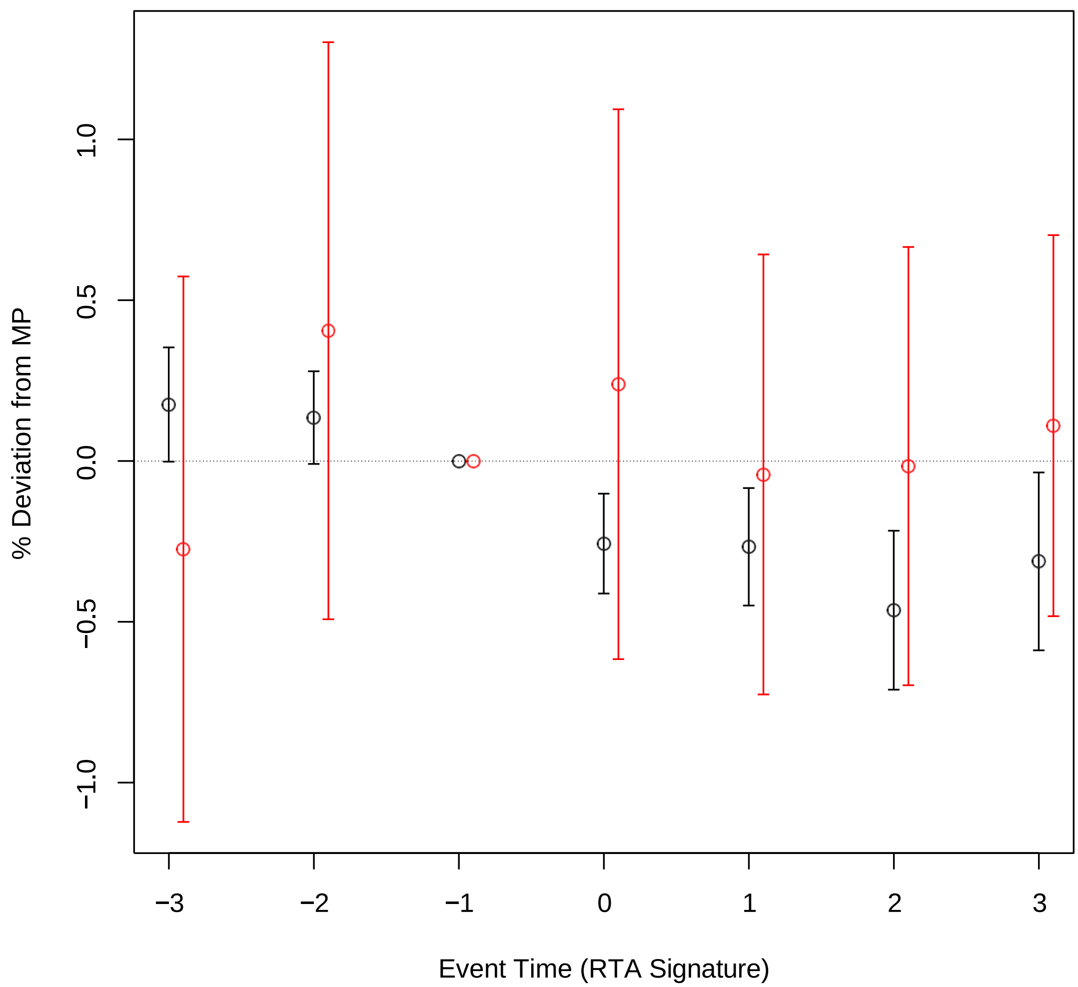

**Notes:** This figure presents event study coefficients for CTC emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 6: TCA Event Study Around Signature of RTA



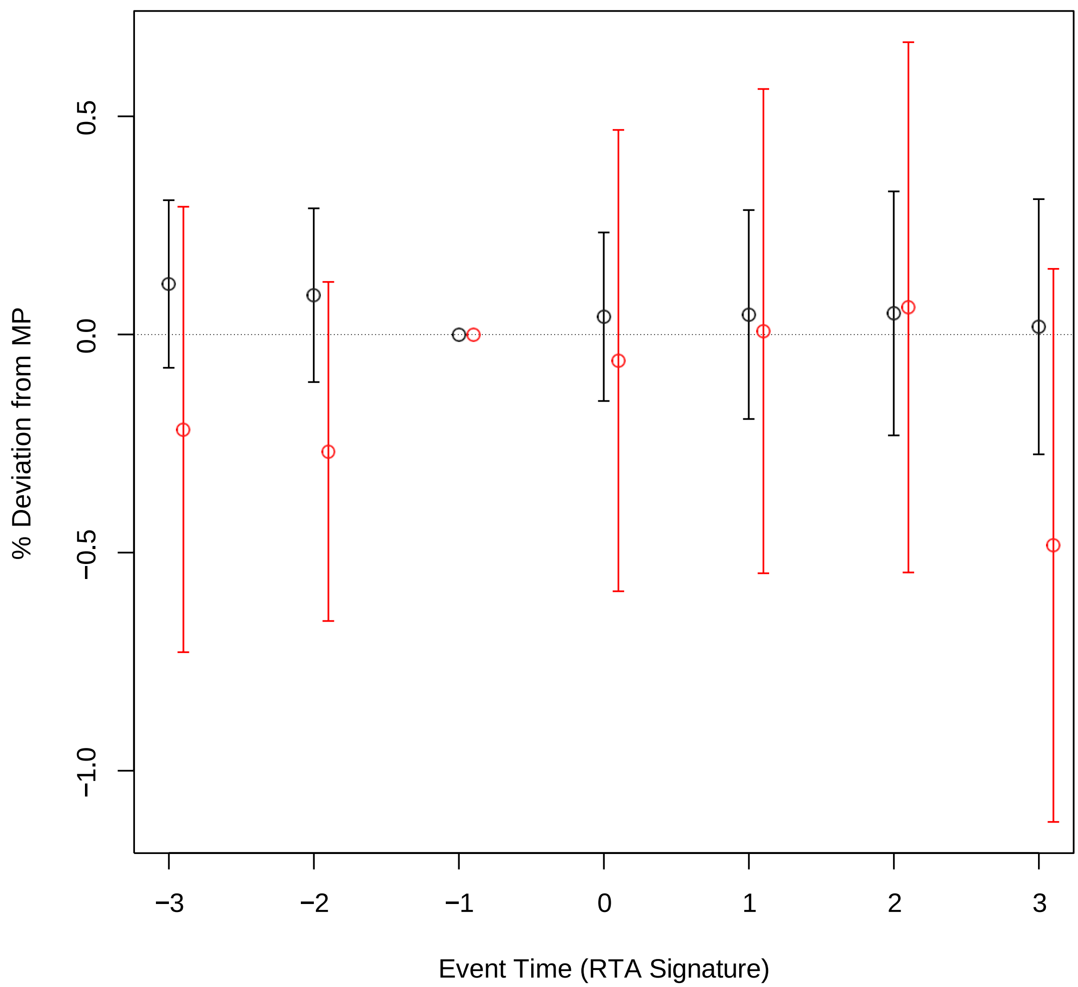

**Notes:** This figure presents event study coefficients for TCA emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 7: HCFC Event Study Around Signature of RTA




**Notes:** This figure presents event study coefficients for HCFC emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

Figure 8: Methyl Bromide Event Study Around Signature of RTA




**Notes:** This figure presents event study coefficients for Methyl Bromide emissions (represented as percent deviations from target). Black lines correspond to coefficient estimates and 95% confidence intervals for RTAs without ODS provisions, red lines correspond to coefficient estimates and 95% confidence intervals for RTAs with ODS provisions.

# A Appendix: Supplemental Tables and Figures

Table A.1: Regional Trade Agreements with ODS Provisions

| Agreement | Entry into Force | Supplemental Dispute Settlement |
|---|---|---|
| Common Market for Eastern and Southern Africa (COMESA) | 1994 | 0 |
| North American Free Trade Agreement (NAFTA) | 1994 | 1 |
| Canada - Chile | 1997 | 1 |
| Chile - Mexico | 1999 | 1 |
| East African Community (EAC) | 2000 | 1 |
| EU - San Marino | 2002 | 0 |
| Chile - El Salvador (Chile - Central America) | 2002 | 1 |
| Canada - Costa Rica | 2002 | 1 |
| Chile - Costa Rica (Chile - Central America) | 2002 | 0 |
| Panama - El Salvador (Panama - Central America) | 2003 | 1 |
| US - Chile | 2004 | 1 |
| Panama - Chinese Taipei | 2004 | 1 |
| US - Bahrain | 2006 | 1 |
| Japan - Malaysia | 2006 | 1 |
| Guatemala - Chinese Taipei | 2006 | 1 |
| EU - Bosnia and Herzegovina | 2008 | 0 |
| EU - Montenegro | 2008 | 0 |
| El Salvador - Honduras - Chinese Taipei | 2008 | 1 |
| Chile - Honduras (Chile - Central America) | 2008 | 1 |
| Nicaragua - Chinese Taipei | 2008 | 1 |
| Panama - Costa Rica (Panama - Central America) | 2008 | 1 |
| Panama - Guatemala (Panama - Central America) | 2009 | 0 |
| Canada - Peru | 2009 | 1 |
| US - Peru | 2009 | 1 |
| Panama - Honduras (Panama - Central America) | 2009 | 1 |
| Chile - Guatemala (Chile - Central America) | 2010 | 1 |
| EU - Serbia | 2010 | 0 |
| Canada - Colombia | 2011 | 1 |
| Korea, Republic of - US | 2012 | 1 |
| US - Colombia | 2012 | 1 |
| Canada - Jordan | 2012 | 1 |
| US - Panama | 2012 | 1 |
| Chile - Malaysia | 2012 | 1 |
| Chile - Nicaragua (Chile - Central America) | 2012 | 1 |
| Canada - Panama | 2013 | 1 |
| EU - Central America | 2013 | 1 |
| New Zealand - Chinese Taipei | 2013 | 0 |
| EU - Colombia and Peru | 2013 | 1 |
| EU - Ukraine | 2014 | 1 |
| EU - Georgia | 2014 | 1 |
| EU - Rep. of Moldova | 2014 | 1 |
| Canada - Honduras | 2014 | 1 |
| Canada - Korea, Republic of | 2015 | 1 |
| Trans-Pacific Partnership | 2017 | 1 |

Table A.2: Montreal Protocol Parties

| Party | Article 5? | Party | Article 5? | Party | Article 5? |
|---|---|---|---|---|---|
| Afghanistan | Yes | Costa Rica | Yes | India | Yes |
| Albania | Yes | Croatia | No | Indonesia | Yes |
| Algeria | Yes | Cuba | Yes | Iran, Islamic Rep. | Yes |
| Andorra | No | Cyprus | No | Iraq | Yes |
| Angola | Yes | Czech Republic | No | Ireland | No |
| Antigua and Barbuda | Yes | Cˆote d'Ivoire | Yes | Israel | No |
| Argentina | Yes | Korea, Dem. People's Rep. | Yes | Italy | No |
| Armenia | Yes | Congo, Dem. Rep. | Yes | Jamaica | Yes |
| Australia | No | Denmark | No | Japan | No |
| Austria | No | Djibouti | Yes | Jordan | Yes |
| Azerbaijan | No | Dominica | Yes | Kazakhstan | No |
| Bahamas | Yes | Dominican Republic | Yes | Kenya | Yes |
| Bahrain | Yes | Ecuador | Yes | Kiribati | Yes |
| Bangladesh | Yes | Egypt, Arab Rep. | Yes | Kuwait | Yes |
| Barbados | Yes | El Salvador | Yes | Kyrgyzstan | Yes |
| Belarus | No | Equatorial Guinea | Yes | Lao PDR | Yes |
| Belgium | No | Eritrea | Yes | Latvia | No |
| Belize | Yes | Estonia | No | Lebanon | Yes |
| Benin | Yes | Eswatini | Yes | Lesotho | Yes |
| Bhutan | Yes | Ethiopia | Yes | Liberia | Yes |
| Bolivia | Yes | European Union | No | Libya | Yes |
| Bosnia and Herzegovina | Yes | Fiji | Yes | Liechtenstein | No |
| Botswana | Yes | Finland | No | Lithuania | No |
| Brazil | Yes | France | No | Luxembourg | No |
| Brunei Darussalam | Yes | Gabon | Yes | Madagascar | Yes |
| Bulgaria | No | Gambia, The | Yes | Malawi | Yes |
| Burkina Faso | Yes | Georgia | Yes | Malaysia | Yes |
| Burundi | Yes | Germany | No | Maldives | Yes |
| Cabo Verde | Yes | Ghana | Yes | Mali | Yes |
| Cambodia | Yes | Greece | No | Malta | No |
| Cameroon | Yes | Grenada | Yes | Marshall Islands | Yes |
| Canada | No | Guatemala | Yes | Mauritania | Yes |
| Central African Republic | Yes | Guinea | Yes | Mauritius | Yes |
| Chad | Yes | Guinea Bissau | Yes | Mexico | Yes |
| Chile | Yes | Guyana | Yes | Micronesia | Yes |
| China | Yes | Haiti | Yes | Monaco | No |
| Colombia | Yes | Holy See | No | Mongolia | Yes |
| Comoros | Yes | Honduras | Yes | Montenegro | Yes |
| Congo, Rep. | Yes | Hungary | No | Morocco | Yes |
| Cook Islands | Yes | Iceland | No | Mozambique | Yes |

| Party | Article 5? | Party | Article 5? |
|---|---|---|---|
| Myanmar | Yes | Slovak Republic | No |
| Namibia | Yes | Slovenia | No |
| Nauru | Yes | Solomon Islands | Yes |
| Nepal | Yes | Somalia | Yes |
| Netherlands | No | South Africa | Yes |
| New Zealand | No | South Sudan | Yes |
| Nicaragua | Yes | Spain | No |
| Niger | Yes | Sri Lanka | Yes |
| Nigeria | Yes | West Bank and Gaza | No |
| Niue | Yes | Sudan | Yes |
| North Macedonia | Yes | Suriname | Yes |
| Norway | No | Sweden | No |
| Oman | Yes | Switzerland | No |
| Pakistan | Yes | Syrian Arab Republic | Yes |
| Palau | Yes | Tajikistan | No |
| Panama | Yes | Thailand | Yes |
| Papua New Guinea | Yes | Timor-Leste | Yes |
| Paraguay | Yes | Togo | Yes |
| Peru | Yes | Tonga | Yes |
| Philippines | Yes | Trinidad and Tobago | Yes |
| Poland | No | Tunisia | Yes |
| Portugal | No | Türkiye | Yes |
| Qatar | Yes | Turkmenistan | Yes |
| Korea, Rep. | Yes | Tuvalu | Yes |
| Moldova | Yes | Uganda | Yes |
| Romania | No | Ukraine | No |
| Russian Federation | No | United Arab Emirates | Yes |
| Rwanda | Yes | United Kingdom | No |
| Saint Kitts and Nevis | Yes | Tanzania | Yes |
| Saint Lucia | Yes | United States | No |
| Saint Vincent and the Grenadines | Yes | Uruguay | Yes |
| Samoa | Yes | Uzbekistan | No |
| San Marino | No | Vanuatu | Yes |
| São Tomé and Príncipe | Yes | Venezuela, RB | Yes |
| Saudi Arabia | Yes | Vietnam | Yes |
| Senegal | Yes | Yemen, Rep. | Yes |
| Serbia | Yes | Zambia | Yes |
| Seychelles | Yes | Zimbabwe | Yes |
| Sierra Leone | Yes | | |
| Singapore | Yes | | |

Table A.3: Deviation from Montreal Protocol Targets after Entry into Force of RTA

| | *Dependent variable: IHS Target Deviation* | | | | | | |
|---|---|---|---|---|---|---|---|
| | CFCs | Halons | CFCs (B) | CTC | TCA | HCFCs | MB |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Post RTA | 0.475*** | 0.347*** | 0.016 | 0.115 | 0.028 | −0.403*** | 0.023 |
| | (0.141) | (0.096) | (0.031) | (0.075) | (0.050) | (0.088) | (0.094) |
| Post × ODS | −0.220 | −0.267* | −0.042 | −0.241 | 0.162 | −0.134 | −0.096 |
| | (0.295) | (0.147) | (0.069) | (0.200) | (0.118) | (0.201) | (0.236) |
| Observations | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 |
| $R^2$ | 0.562 | 0.579 | 0.408 | 0.485 | 0.661 | 0.645 | 0.566 |
| Mean (ODP tons) | -821 | -218 | -3 | -472 | -19 | -128 | 10 |

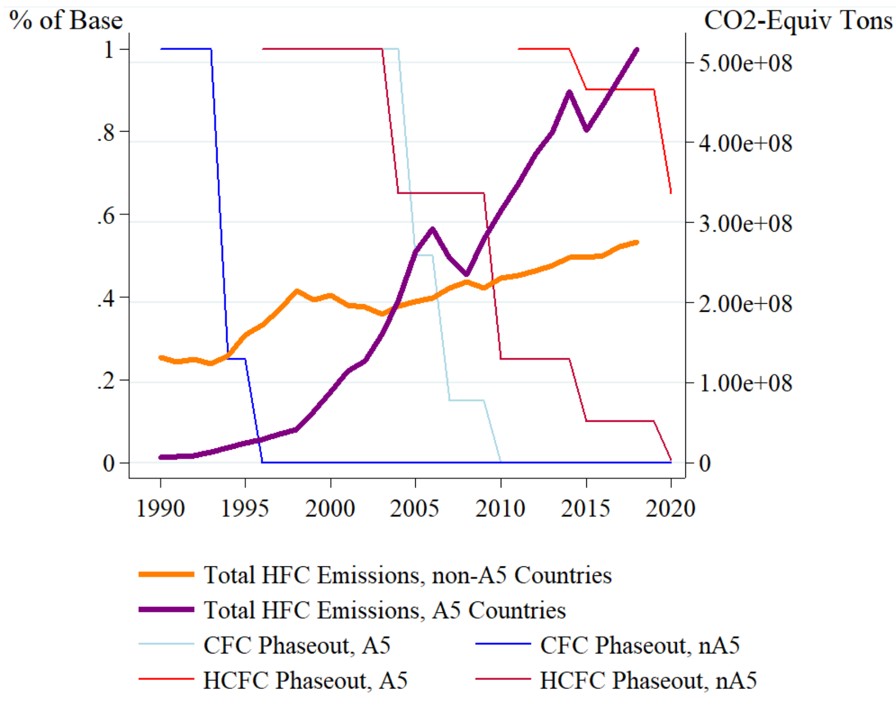
FE triple-difference regressions on a stacked country-level panel with a ±3 year event window around RTA entry into force. All outcomes are the inverse hyperbolic sine of the difference between ODS emissions and emissions targets under the Montreal Protocol. All models include country-event fixed effects. Robust standard errors are (two-way) clustered at the country-event and country-year levels. We report the mean deviation from target across the entire sample in tons of ozone depletion potential (ODP). Statistical significance from two-sided $t$ tests are denoted by
$^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01.

Table A.4: Deviation from Montreal Protocol Targets after Entry into Force of RTA

| | *Dependent variable: IHS Target Deviation* | | | | | | |
|---|---|---|---|---|---|---|---|
| | CFCs | Halons | CFCs (B) | CTC | TCA | HCFCs | MB |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Post RTA | 0.472*** | 0.345*** | 0.014 | 0.118 | 0.027 | −0.401*** | 0.022 |
| | (0.141) | (0.096) | (0.031) | (0.075) | (0.050) | (0.088) | (0.094) |
| Post × ODS | −0.528* | −0.458*** | −0.258 | 0.103 | 0.025 | 0.126 | −0.178 |
| | (0.290) | (0.159) | (0.164) | (0.228) | (0.055) | (0.222) | (0.475) |
| Post × ODS × DS | 0.434 | 0.269 | 0.304* | −0.484 | 0.193 | −0.367 | 0.114 |
| | (0.399) | (0.182) | (0.170) | (0.298) | (0.133) | (0.291) | (0.492) |
| Observations | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 | 6,118 |
| $R^2$ | 0.562 | 0.579 | 0.409 | 0.485 | 0.661 | 0.645 | 0.566 |
| Mean (ODP tons) | -821 | -218 | -3 | -472 | -19 | -128 | 10 |

FE triple-difference regressions on a stacked country-level panel with a ±3 year event window around RTA entry into force. All outcomes are the inverse hyperbolic sine of the difference between ODS emissions and emissions targets under the Montreal Protocol. DS is an indicator equal to 1 if the the ODS provisions are binding with dispute settlement under the RTA. All models include country-event fixed effects. Robust standard errors are (two-way) clustered at the country-event and country-year levels. We report the mean deviation from target across the entire sample in tons of ozone depletion potential (ODP). Statistical significance from two-sided $t$ tests are denoted by
*p<0.1; **p<0.05; ***p<0.01.

Figure A.1: HFC-134a, 125, 32, 152a, 23 aggregated emissions with CFC and HCFC Phaseout Schedules



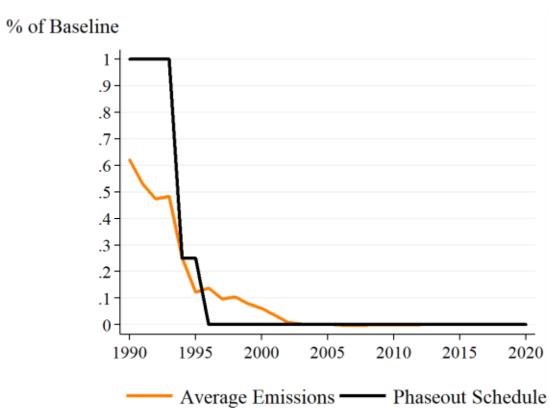




Figure A.2: CFCs non-Article 5
Average Emissions and Phaseout

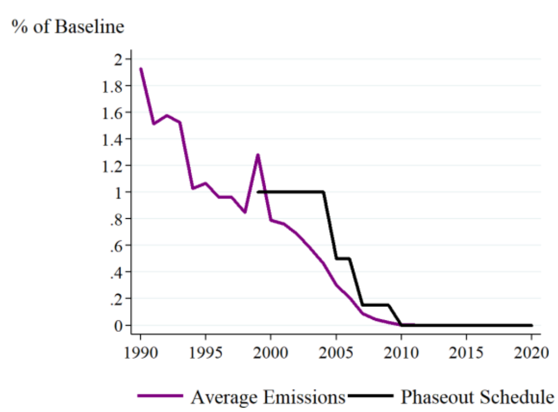



Figure A.3: CFCs Article 5
Average Emissions and Phaseout

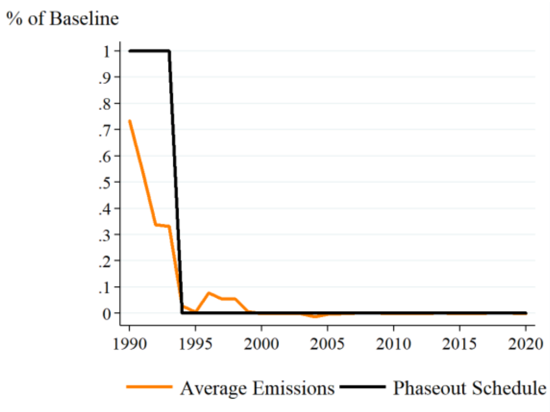



Figure A.4: Halons non-Article 5
Average Emissions and Phaseout

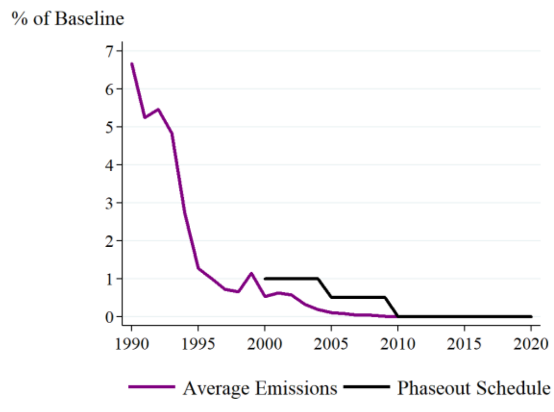



Figure A.5: Halons Article 5
Average Emissions and Phaseout

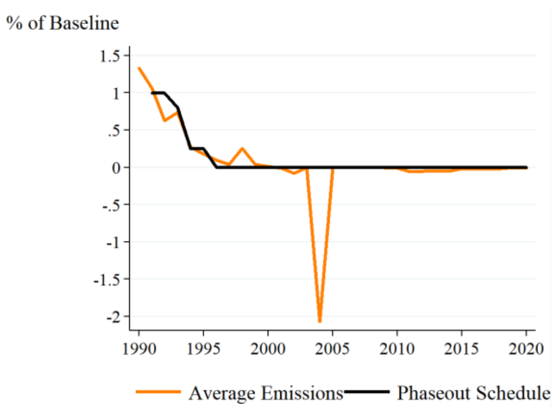



Figure A.6: Other CFCs non-Article 5
Average Emissions and Phaseout

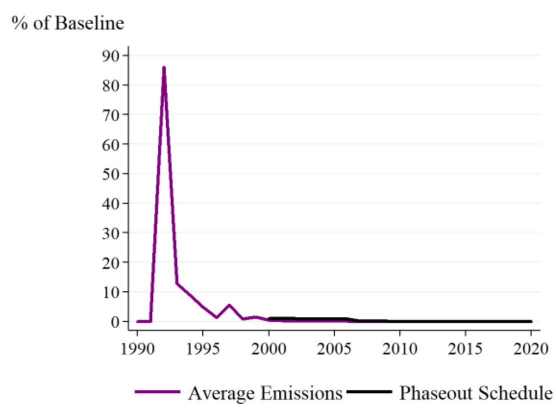



Figure A.7: Other CFCs Article 5
Average Emissions and Phaseout

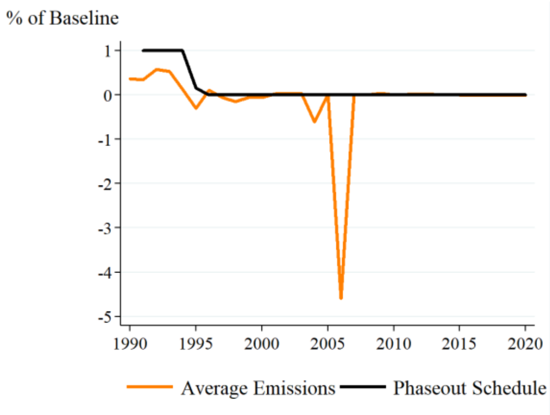



Figure A.8: CTC non-Article 5
Average Emissions and Phaseout

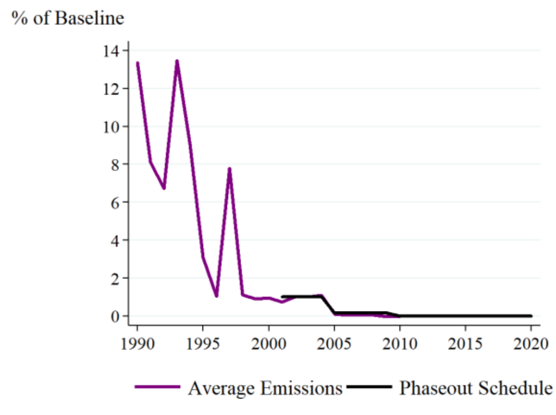



Figure A.9: CTC Article 5
Average Emissions and Phaseout

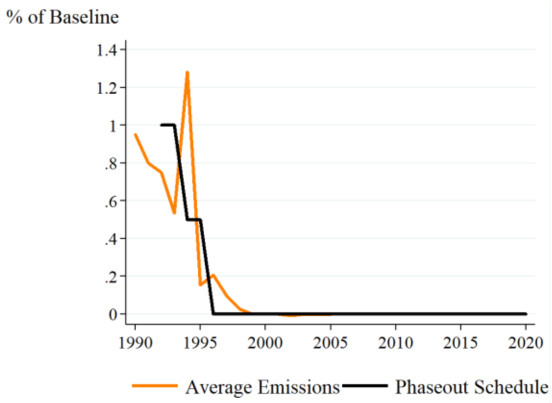



Figure A.10: TCA non-Article 5
Average Emissions and Phaseout

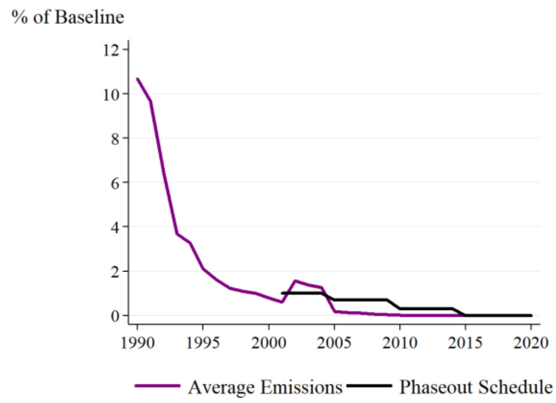



Figure A.11: TCA Article 5
Average Emissions and Phaseout

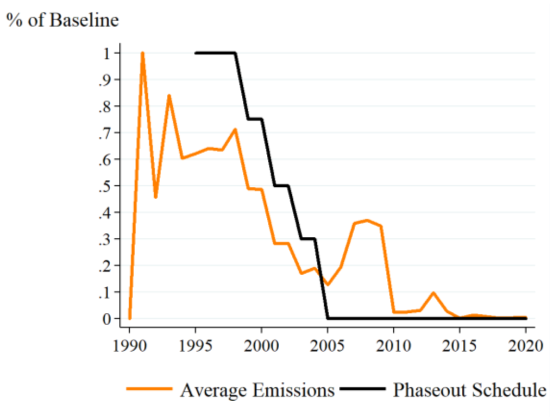



Figure A.12: MB non-Article 5
Average Emissions and Phaseout

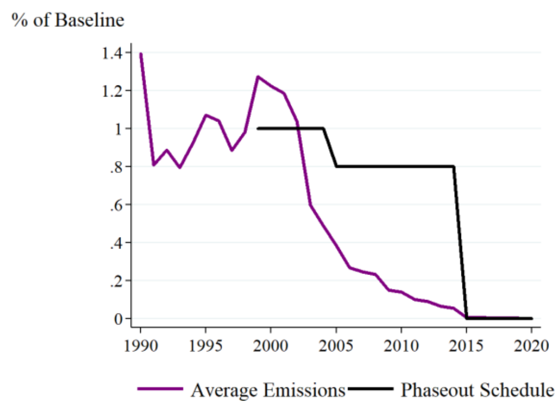



Figure A.13: MB Article 5
Average Emissions and Phaseout

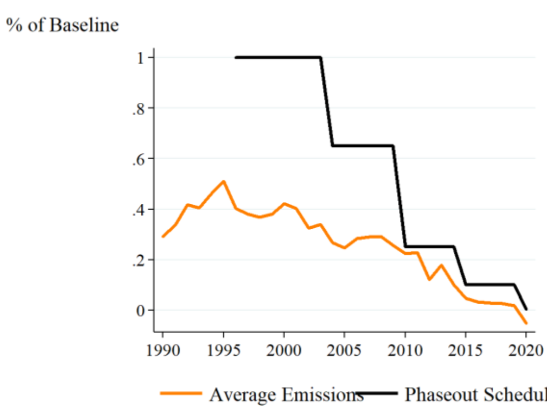



Figure A.14: HCFCs non-Article 5
Average Emissions and Phaseout

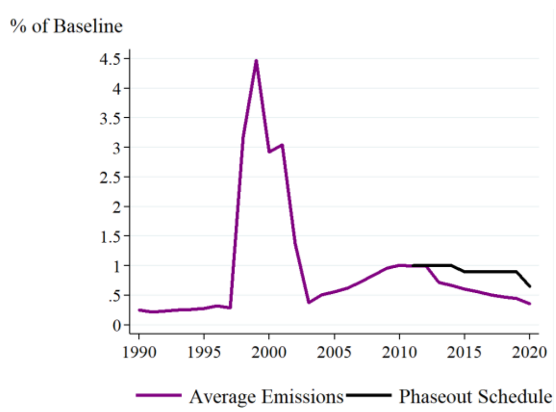
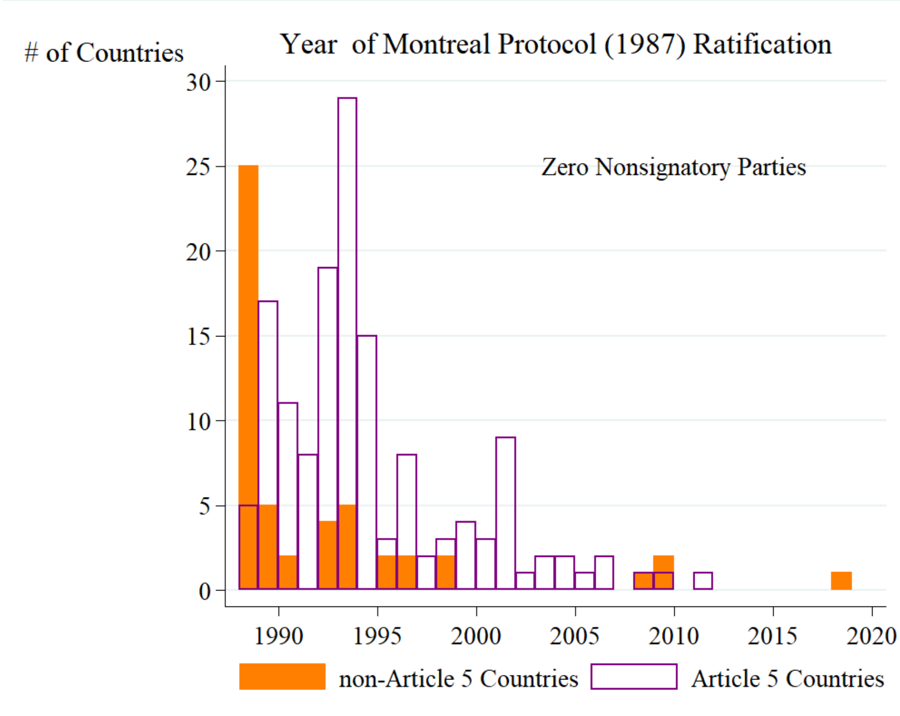



Figure A.15: HCFCs Article 5
Average Emissions and Phaseout

Figure A.16: Montreal Protocol and London Amendment Ratification



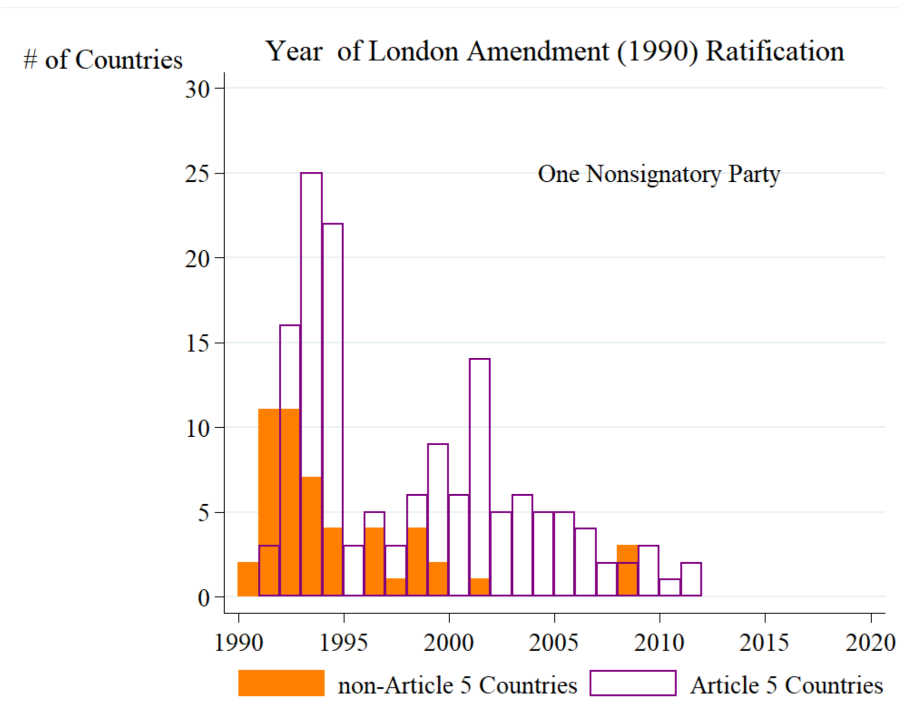



Figure A.17: Copenhagen Amendment and Montreal Amendment Ratification

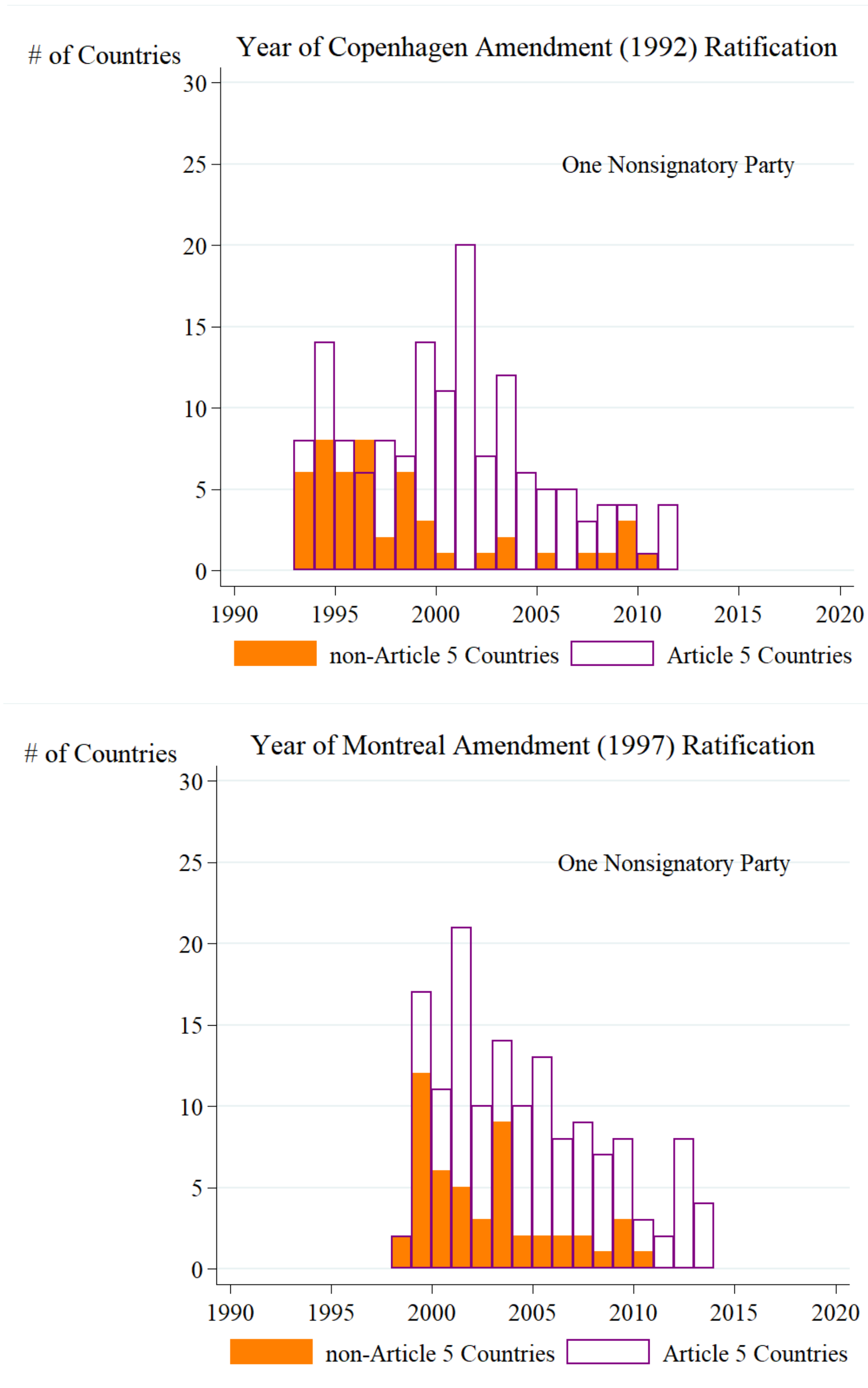


Figure A.18: Beijing Amendment and Kigali Amendment Ratification