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Governing the invisible commons: Ozone regulation and the Montreal Protocol

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Abstract: The Montreal Protocol is generally credited as a successful example of international cooperation in response to a global environmental problem. As a result, the production and consumption of ozone-depleting substances has declined rapidly, and it is expected that atmospheric ozone concentrations will return to their normal ranges toward the end of this century. This paper applies the social-ecological system framework and common-pool resource theory to explore the congruence between successful resolution of small-scale appropriation problems and ozone regulation, a large-scale pollution problem. The results of our analysis correspond closely to past studies of the Protocol that highlight the importance of attributes such as a limited number of major industrial producers, advances in scientific knowledge, and the availability of technological substitutes. However, in contrast to previous theoretical accounts that focus on one or a few variables, our analysis suggests that its success may have been the result of interactions between a wider range of SES attributes, many of which are associated with successful small-scale environmental governance. Although carefully noting the limitations of drawing conclusions from the analysis of a single case, our analysis reveals the potential for fruitful interplay between common-pool resource theory and large-scale pollution problems.

Keywords: Air pollution, common-pool resource theory, ozone, global collective action, SESMAD, social-ecological systems

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1. Introduction

The Montreal Protocol has long been discussed as one of few examples of a successful global response to a large-scale environmental problem. The protocol, enacted on January 1, 1989, was designed to protect the ozone layer by gradually reducing and, in some cases, eliminating the production of a variety of ozone-depleting substances (ODS). Initially ratified by 21 nations, it is now one of the few truly global agreements having obtained universal acceptance as of September 2009. Although the environmental goals of the Montreal Protocol have not been met, it is expected that the cumulative reductions in the emission of ODS will begin to have an impact on global ozone concentrations toward the middle of the twenty-first century (Ravishankara 2009). The Montreal Protocol has also been the subject of considerable academic and public debate that seeks to understand how, despite a multiplicity of potential impediments including vested industrial interests, a large group of actors with divergent interests and limited knowledge were able to agree upon and subsequently implement a set of rules to resolve a complex collective-action problem.

This paper, as part of the Social-Ecological Systems Meta-Analysis Database (SESMAD) project, explores the Montreal Protocol through the lens of common-pool resource (CPR) theory. SESMAD builds upon earlier meta-analytical efforts such as the CPR database (Ostrom 1990), Regime Effectiveness study (Miles et al. 2002) and the International Regime Database designed by Breitmeier et al. (2006). As described by Cox in the introduction to this special issue, SESMAD is a database broadly based on the Social-Ecological System (SES) framework (Ostrom 2007, 2009; Ostrom and Cox 2010). The SES framework emerged from growing recognition that social-ecological outcomes are the product of complex interactions among diverse actors, institutions, and biophysical systems (Agrawal

2003; Wilson 2006). The framework therefore organizes these components such that scholars can begin to build generalizable knowledge concerning the effects of SES attributes on outcomes such as sustainability in varied SES contexts and using multiple methods of inquiry. The goals of the SESMAD project are twofold: to provide a common framework and measures for cross-case comparisons of theoretically relevant attributes, and to create a systematic approach to analyze individual cases.

Given the breadth and depth of prior studies of the Montreal Protocol, some of which included first-hand accounts (i.e. Benedick 2009), the primary contribution of this investigation is to extend the existing CPR literature into two distinct directions. First, like the other papers in this special issue, it examines the extent to which CPR theory, a stream of collective-action theory developed in mostly small-scale settings, may apply to large, in this case, global collective-action problems. Secondly, it asks whether theories and models developed to understand appropriation externalities at the heart of traditional commons dilemmas apply to a pollution problem or the externalities of production. Thus, the insights generated from this analysis, while not necessarily unique in the context of the Montreal Protocol, provide a potentially valuable starting point for comparative analysis of large-scale environmental governance of pollution problems.

With the exception of recent critiques of the neoliberal philosophies or market perspectives that shaped the treaty (Gareau 2013), most studies view the Montreal Protocol as an unprecedented success. In fact, it is commonly studied through the lens of international relations theory (e.g. Viotti and Kauppi 2012) precisely because it is one of few examples of successful international environmental policy. The international arena is commonly described as anarchic in that no one actor has the legal authority to enlist or sanction other states unless that state has committed itself to some agreement and sacrificed its sovereign authority (Stokke 2011). Thus, international relations theory seeks to understand the conditions under which sovereign states voluntarily bind themselves to bilateral or multilateral agreements. A variety of studies have explored the Montreal Protocol to better understand regime formation and successful environmental governance by focusing on the role of agenda-setting (Morrisette 1989), epistemic communities (Haas 1992), discourses (Liftin 1994), and institutions (Grundmann 2001).

More recently, scholars have turned to the policy-science interface to consider the interaction between knowledge production and the role that it plays in mobilizing and sustaining collective action. For example, Parson (2003) argues that the Montreal Protocol broke through stalled diplomatic negotiations via a three-step process. First, scientific assessments illustrating the severity and causes of ozone depletion were considered authoritative enough to influence policy actors. Second, the regime included novel institutional arrangements, such as an assessment process with industry participants to evaluate new technological substitutes for chlorofluorocarbons (CFCs). Third, the regime allowed for rapid changes in operational rules based on new knowledge and generated incentives for rapid technological change. Richard Benedick (2009), the past chief negotiator for the US, makes a similar claim and credits the creativity and independence of scientists and scientific assessments in mobilizing nations toward a resolution.

Whereas most prior accounts of the Montreal Protocol tend to explore the effects of variable dyads such as knowledge and motivation or authority and knowledge, our analysis and the SESMAD project in general considers configurations of mostly institutional attributes that jointly affect social and environmental outcomes. One of the strengths of the SESMAD approach is to take complementary and sometimes competing narratives of collective action problems and place them into a diagnostic framework. This facilitates analysis of the context in which collective action occurs, and allows us to dig deeper than single variables such as leadership or technological innovation to explore factors or contingent variables that are not necessarily predictable across cases. Therefore it is precisely because the Montreal Protocol is well-studied that we chose it for our analysis to consider the multiple possible sources of successful large-scale environmental governance.

1.1. Background on common-pool resource theory

CPR theory, as the name implies, is a theory borne out of the study of a particular type of good – common goods (i.e. fish, many forests, wildlife). Types of goods are generally distinguished from one another on the basis of two characteristics: the subtractability of use and difficulty in excluding potential beneficiaries (Ostrom et al. 1994; Ostrom and Ostrom 1999). Subtractability of a good refers to the extent to which appropriation by one individual affects the supply for other individuals. Exclusion, on the other hand, refers to the feasibility of excluding potential recipients from the benefits or costs of a good. Public goods, like ozone protection, are similar to common goods in that exclusion is difficult. Likewise, exclusion is difficult in the context of public bads, such as the emission of pollutants, at least within the geographic range of environmental effects. For instance, the environmental effects or costs of sulfur emissions from coal-fired power generators are felt at a large regional scale (i.e. eastern US and Canada) (Stavins 1998), while particulates often introduce health-related costs at a more limited, local scale (Schwartz 1994; Katsouyanni et al. 1997). The costs associated with a decline in ozone concentrations are felt at a global scale, meaning that the loss of ozone protection is shared in part by the entire global population. Unlike common goods, however, the use of pure public goods (and bads) is not subtractable. Put simply, when an individual takes advantage of ozone protection, a public good, or incurs costs from its absence, their use of that good does not in any way affect the supply available to others. While there are few examples of pure public goods, in that they are often subject to congestion and thereby lead to de facto subtractability, ozone protection that is produced via natural chemical processes is very nearly, if not fully, a pure public good.

The link between CPR theory and the case of pollution is not, however, based on the characteristics of a good per se but rather on the effects of those characteristics on the incentive structure surrounding choices related to the production or appropriation of goods. In other words, we do not make the claim that pollution or the ozone layer is in some manner a common-pool resource. Rather, the same logic that theoretically drives overappropriation of CPRs also provides insights about factors driving global ozone depletion. The tragedy of the commons (Hardin 1968), for instance, showed how the underlying incentive structure of ungoverned common goods leads to overappropriation given that benefits are privately owned and costs are shared. A similar logic applies to the provision of public goods that tend to be underproduced as a result of private costs and shared benefits (Wit and Wilke 1998; Hansen et al. 2005).

Broadly speaking, overappropriation of a common good, underprovision of public goods, and overproduction of public bads present remarkably similar choice environments in that they describe situations of interdependent choice and an incentive structure resembling the Prisoner's Dilemma. Furthermore, the core analytical question in these situations is how to structure institutions to favor more beneficial and efficient social outcomes. While most institutional studies that broadly constitute CPR theory have focused on problems surrounding common goods and problems of appropriation, some have applied similar methods to pollution problems (Ostrom et al. 1961; Lo and Tang 1994; Gardner et al. 2000; Lundqvist 2001; Ostrom 2010). In their now-classic introduction to polycentric metropolitan governance, Ostrom et al. (1961, 835) identified the importance of organizing institutions at a scale that "can encompass the problem." In this way, the institutions are better able to align the costs and benefits of a public good or regulation of a public bad such as pollution.

In the context of the Montreal Protocol, atmospheric ozone and ODS represent two distinct goods. Atmospheric ozone is a public good that generates shared benefits in the form of ozone protection, and private costs in the form of abatement. For much of human history, however, ozone protection was effectively freely provided by natural chemical processes. It was not until ODS, a public bad, was released into the atmosphere in sufficiently large concentrations to disrupt natural generative processes (Rowland 2009) that the situation was transformed into a social dilemma. Similar to common goods, when individuals or groups choose to produce or consume ODS, the underlying incentive structure of that choice reflects only the private benefits from selling or using that product as a refrigerant or propellant – neglecting the collective costs associated with their use. Therefore, despite important differences in the properties of common goods and public bads, the similarity of the choice environment suggests the possibility of correspondence with CPR theory.

In the sections that follow, we first provide a brief background concerning the methodological approach of this study. Next, we apply the SES framework to identify the critical components of the system, present the primary results of our research – the timeline and structure of the case as well as the key variables that emerged during our diagnostic analysis. Our results are presented in two parts. First we set the stage by considering attributes of the resources and actors at the outset of the case that theoretically affect prospects for collective action. Next we consider a subset of social, technological and institutional attributes drawn from the CPR literature and prior studies of the Montreal protocol to identify factors that may have contributed to its success. This also allows us to generate insights concerning the extent to which attributes associated with successful small-scale CPR governance are associated with successful global governance of pollutants.

2. Methods

As described above, this study, like others described in this special issue, draws upon methods that were developed collaboratively as part of the SESMAD project. Secondary data was collected by the authors and used to code data into a relational database hosted at Dartmouth College based on Ostrom's SES framework (Ostrom 2007, 2009) as modified by Cox (2014). The database contains approximately 200 variables of relevance to the study of SESs. These are stored in tables describing the SES itself, its components, and the interactions among these components, as follows.

A SES is defined as a unit possessing at least one environmental commons (i.e. resources, ecosystem, pollutants), governance system, and actor group. Basic information about these components is recorded in the case table that provides the most general depiction of the SES. An environmental commons (EC) is an environmental resource or pollutant that can be subjected to human use, production, and/or governance. A governance system (GS) is a set of institutional arrangements (such as rules, policies, and governance activities) that affect interactions between one or more actor groups and an environmental commons (EC). Finally, an actor group (A) can be comprised of individuals, organizations, or nations that have developed a set of institutional arrangements in order to manage human interactions in a specific environmental system, or who alter resource characteristics through extraction or emission. Within the relational database, interactions between these components are stored as records in the interactions (I) table. There are two main types of interactions; governance interactions that record information about interactions between one or more actor groups, multiple governance systems and a single environmental commons, and biophysical interactions that record information about interactions between two or more environmental commons. Different interactions are also used to represent different "snapshots" within the same case reflecting important changes in the components or their attributes that affect interactions in a case (Haydu 1998).

Figure 1 shows how this framework was operationalized for the Montreal Protocol to code two distinct snapshots. In the context of the Montreal Protocol, the pre- and post-1989 period were selected as they mark an important shift in international affairs regarding the ways in which nations approached the problem of ozone depletion and emission of ODS. The most notable changes are the addition of a governance system, the Montreal Protocol, and an actor group, the Ozone Secretariat. The first snapshot is denoted open access, while the second is

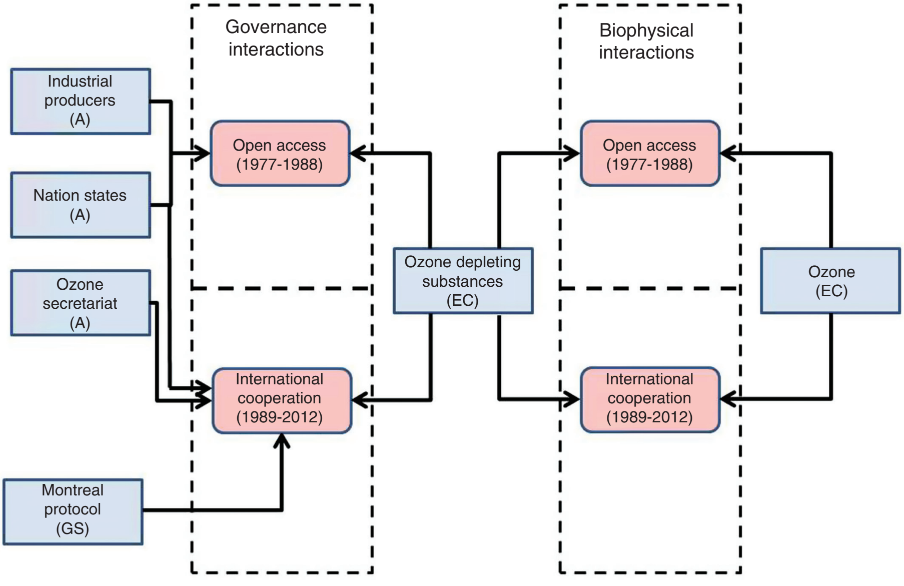

Figure 1: Diagram of the two snapshots (open access conditions at top and Post-Montreal Protocol below) coded for analysis of the Montreal Protocol and the control of ozone-depleting substances (ODS). (Blue square boxes: core components coded into SESMAD database. Red curved boxes: governance and biophysical interactions among core components).

referred to as international cooperation. The boxes in the figure refer to the actual tables in the relational database. Finally, interactions between environmental commons are coded in a separate interactions table, which is why two distinct sets of interactions are shown for each snapshot.

This paper relies upon a mixture of peer-reviewed articles and book chapters, as well as unedited books, grey literature published by the Secretariat and data from the Ozone Secretariat's internet archives to enter data into the SESMAD database. The case was coded based on intersubjective agreement after the authors independently evaluated multiple studies of the case. While this approach limits estimates concerning the reliability of coding, it is consistent with prior studies of the commons (Ostrom 1990; Wertime et al. 2007; Cox et al. 2010), and may enhance the prospects for validity of measurement. Furthermore, given that this analysis of a single case relies upon multiple accounts using different theoretical perspectives and a certain degree of topical overlap, intersubjective agreement allows us to average over the evidence where the nature of a variable is uncertain, or alternatively make an informed choice from among the evidence where one account is more reliable than another.

As discussed in the introduction, a goal of this paper is to generate insights for future study of large-scale pollution problems by considering theories developed in the context of small-scale appropriation dilemmas. While the database contains more than 200 potentially influential variables, a much smaller subset of these is considered in this paper. In Sections 4.1 and 4.2, we consider attributes of the resource (ozone and ODS) and actors that theoretically affect prospects for collective action and successful environmental governance. These attributes structure the incentives that actors face as they seek to resolve collective action problems, and allow us to make general theoretical predictions regarding the likelihood of successful self-organization. For instance, small groups with common interests are likely to face fewer challenges for self-organization than a large group with divergent interests. Next, Section 4.3 explores factors that may have contributed to the transition from an open-access system to successful international regulation of ODS by comparing a subset of social, technological and institutional attributes across the two snapshots. Most of these attributes, such as participation of affected parties, and monitoring were drawn from CPR theory and the related SES framework, while we also include a small subset of attributes such as technological substitutes that were particularly prominent in the reviewed literature. The paper thus seeks to balance the goals of evaluating CPR theory through a meta-analytic structure with an attempt to capture the idiosyncratic details of the case. Neither activity obviates the importance of the other, nor do we see this as evidence of shortcomings in the framework. Similar context-specific variables emerge in every case analyzed in this special issue, in spite of the depth of analysis provided by the framework.

3. Structure of the case and social-ecological outcomes

The Montreal Protocol on Substances that Deplete the Ozone Layer has now been universally ratified and is considered one of few successful examples of broad-based international cooperation. Since 1989, when the Montreal Protocol entered into force, the production of ODS, most notably CFCs, has rapidly declined and it is expected that atmospheric ozone concentrations will return to their normal ranges toward the end of this century (Figure 2).

We structured the analysis of the system around two snapshots (Table 1) that are generally marked as major changes in the conditions of one or more critical attributes. The first of these snapshots lasts from the mid-1970s, when the potential threat of ozone-depleting substances was first realized, until 1989, when the Montreal Protocol was ratified. The second snapshot runs from the ratification of the Montreal Protocol until its 25th Anniversary (2012).

Using the SESMAD framework (Cox 2014), we see that the major change between the two periods is the creation, development, and implementation of a governance system that manages the production and release of ODS and, in the process, indirectly manages ozone. The second, subsidiary change related to the establishment of a governance system is the introduction of the Ozone Secretariat.

The Ozone Secretariat is based at the United Nations Environment Programme (UNEP) offices in Nairobi (Kenya). The Secretariat functions in accordance

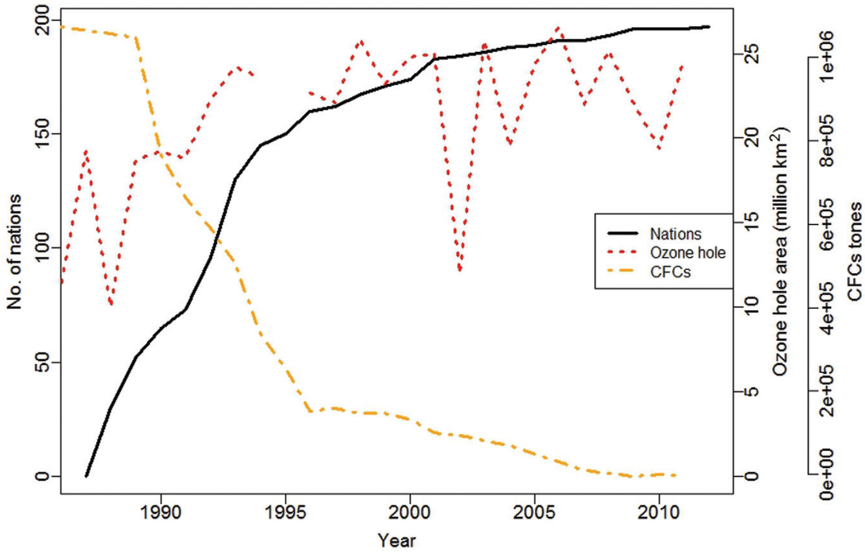

Figure 2: Adoption and performance of the Montreal Protocol reporting the cumulative number of countries ratifying the Montreal Protocol, area of the ozone hole, and production of CFCs. Sources: http://ozone.unep.org/new_site/en/index.php; http://ozonewatch.gsfc.nasa.gov/.

with article 12 of the Montreal Protocol, and its duties include administration, monitoring implementation, collection and processing of ODS data from the parties to the convention, and providing information concerning the ozone layer. Prior to the ratification of the Montreal Protocol, select governments in the industrialized world introduced limited industry regulations regarding substances later restricted by the Montreal Protocol. However, the key shift was the coordination of regulation, monitoring, and, to a lesser extent, enforcement of ODS emissions via the Montreal Protocol. Figure 1 shows the structure we used for the analysis of this SES. Two resources are distinguished in this case: (1) the ODS that are produced by the industrial actors and directly managed by the governance system after the ratification of the Montreal Protocol and (2) the ozone layer that is affected by the concentration of ODS. The main governance system, the Montreal Protocol, seeks to alter the behavior of producers of ODS, the industrial actors, and was designed and implemented by the nation-states that ratified it and the Ozone Secretariat who manages it.

4. Results

The analysis presented in this section draws upon our synthesis of multiple studies using the SESMAD database to explore factors that may have contributed to the observed decline in ODS production (Figure 2). While most of these attributes are

Table 1: Major events relating to the regime formation and subsequent milestones of the Montreal Protocol and the control of ozone-depleting substances (ODS).

Snapshot	Date	Event
	1939	CFCs are invented.
	1973	R. Stolarsky and R. Cicerone indicate that chlorine released into the stratosphere could unleash a complicated chemical process that would continually destroy ozone for several decades (published in 1974).
	1974	M. Molina and S. Rowland discover that, unlike most other gases, CFCs are not chemically broken down or rained out quickly in the lower atmosphere but rather, because of their exceptionally stable chemical structure, persist and migrate slowly up to the stratosphere. They conclude that CFCs are eventually broken down by solar radiation and, in the process, release large quantities of chlorine into the stratosphere.
	1970s	Start of international scientific efforts to begin cooperation on research with an eye toward building a regulatory regime. They begin under conditions of great uncertainty.
Snapshot 1: Open access 1977–1988	1977	International cooperation starts with a conference of experts from 32 countries, convened by the United Nations Environment Programme (UNEP), adoption of the World Plan of Action, and establishing a Coordinating Committee.
	1981	The UNEP Governing Council authorizes negotiations to attempt to create a binding treaty on measures to protect the ozone layer.
	1985	Vienna Convention for the Protection of the Ozone Layer.
	1986	Ozone hole is clearly observed.
	1987	Montreal Protocol on Substances that Deplete the Ozone Layer successfully negotiated and opened for signatures.
	1988	NASA-sponsored Ozone Trends Panel reports that ozone depletion was occurring and that it has human-induced causes.
Snapshot 2: International cooperation 1989–2012	1989	The Montreal Protocol enters into force.
	1990	Second meeting of parties to Montreal Protocol at London. London amendments to the Montreal Protocol.
	1992	Copenhagen amendments to the Montreal Protocol permanently establish the Multilateral Fund.
	1997	Montreal amendments to the Montreal Protocol.
	1999	Beijing amendments to the Montreal Protocol.
	2007	Montreal Declaration.
	2012	25th Anniversary of the Montreal Protocol.

Sources: Benedick (1998); http://ozone.unep.org.

commonly associated with CPR theory and the SES framework, we also consider a small subset of case-specific attributes. These attributes are not included in the SESMAD database, but were highlighted as particularly important by several of the reviewed studies. Thus it is also possible to evaluate the general diagnostic potential of the SESMAD database for large-scale pollution cases by considering whether the omission of these attributes would critically undermine our analysis of the Montreal Protocol or alternatively whether they would be necessary additions to the database for future analyses of large-scale pollution. The analysis proceeds by first setting the stage in terms of resource and actor attributes during the first snapshot that theoretically affect prospects for successful collective action. It then continues by exploring changes (or the lack thereof) in the social, technological and institutional environment across the two snapshots.

4.1. Resource attributes

Resource attributes are often neglected in the literature on the commons (Agrawal 2003; Epstein et al. 2013); which tends instead to focus on the institutional and social aspects of successful environmental governance. Nonetheless, a small subset of resource attributes have received considerable attention as they structure the incentives and challenges that actors face as they seek to resolve collective action problems. These include the clarity of resource boundaries, mobility of resource units, and the rate at which management efforts can feasibly improve resource conditions (Schlager et al. 1994; Basurto and Ostrom 2009).

At the outset, the characteristics of ODS and ozone appear ill-suited to CPR governance as outlined in Table 2. Both are small (effectively invisible), highly mobile substances that are distributed throughout the earth's atmosphere. Resource mobility across institutional boundaries has long been held as a challenging and sometimes insurmountable problem for CPR governance (Schlager et al. 1994; Giordano 2003) as it tends to increase uncertainties regarding the ability of groups to capture the benefits of their management efforts. For instance, cutbacks in the production and consumption of ODS in the US and Europe would yield few benefits if emissions simply shifted to other countries. Thus, regulation of ODS effectively demanded global participation and mechanisms to ensure that participants could not simply offshore their emissions to a few non-participating nations. A further challenge for collective action was the long atmospheric residence time of ODS. This meant that even with a rapid halt to ODS emissions that most, if not all, of the participants to negotiations would not live to enjoy the benefits of their efforts (although they could limit further costs). Moreover, vote-seeking political actors would have to justify the costs of a policy that would yield few observable benefits for their constituents. Surprisingly, in the case of

Table 2: Resource attributes.

Attribute	**Resource**	
	Ozone	**ODS**
Spatial extent	Global	Global
Physical boundaries	Clear boundaries	Unclear boundaries
Speed of feedback	Slow (decades)	Emissions: rapid Atmospheric concentrations: slow
Size of units	Small	Small
Mobility	High	High
*Residence time	–	Variable, but generally high (2–550 years)
Source of emissions	–	Primarily point source

*Attribute is not recorded in the SESMAD database.

the Montreal Protocol, these attributes, when combined with the general sense of looming crisis that surrounded negotiations, seems to have motivated participants to develop global regulations to control ODS emissions.

Finally, there was an additional resource attribute that greatly facilitated regulation, which is alluded to by our choice to group all ODS into a single category. ODS include a wide range of anthropogenic chemicals such as CFCs, HCFCs, and carbon tetrachloride that interact with ozone in the atmosphere and ultimately lead to its dissociation and the loss of ozone protection (Isaksen et al. 2009). However, their effects vary as a result of chemical differences that affect their level of reactivity and atmospheric residence time (Pyle et al. 1992). Fortunately, growing knowledge of the underlying chemical processes allowed regulators to develop a standardized metric, ozone-depletion potential, to regulate emissions such that the most damaging compounds were replaced by less-damaging compounds, followed by a phase-out or ban for most purposes (Parson 2003). In other words, negotiators were able to devise effective regulations for ODS by considering a single attribute, ozone-depletion potential, and then focusing early efforts on the most damaging compounds.

4.2. Actor attributes

The literature on collective action generally suggests that small groups with homogeneous interests (Olson 1965), and shared norms (Ostrom 1990, 2009) are more likely to successfully resolve collective-action problems. More specifically, the proportional benefits of collective action are larger in shared groups, increasing the likelihood that this exceeds the private costs of collective action. Homogenous interests, on the other hand, increase prospects for successful collective action by reducing the costs associated with reaching agreement regarding the purpose of collective activities. In contrast with accounts based on shared interests, several scholars have noted that prospects for successful collective action may increase dramatically when the individual benefits of collective action for one or a small subset of actors within a group exceed the total costs of self-organization (Olson 1965; Hardin 1982; Baland and Platteau 1999). Hardin (1982) labels such groups as privileged because even if other actors fail to contribute (i.e. act as free-riders), the smaller subset still stands to benefit from the provision of a public good. This has been applied to the case of greenhouse gas production to suggest that the US and China working as a pair could have a significant impact on carbon emissions, even without cooperation of many signatories to the Kyoto Protocol.

Of the two actors included in the first snapshot of the Montreal Protocol case, the industrial group of producers appears best suited to engage in collective action to successfully mobilize against a treaty as outlined in Table 3. Although there were a fairly large number of industrial CFC producers around the world, a comparatively smaller number of these concentrated in the US and Europe, were responsible for a considerable fraction of emissions, and also stood to absorb much of the costs associated with abatement. Thus CPR theory would generally

Table 3: Actor attributes.

Attribute	Actors	
	Industry	**Nation-states**
Group size	Large, but fewer major producers	Large
Heterogeneity of interests	Low	High
*Users concentration	High	–
Privileged members	Yes	Yes

*Attribute is not recorded in the SESMAD database.

predict that this group would be able to successfully oppose environmental regulations through self-organization or the individual lobbying efforts of large-scale producers such as DuPont. On the other hand, the nation-states, composed of a large number of actors with heterogeneous norms, and interests that varied along at least two dimensions – their status as a producer nation and their ability to pay for more expensive substitutes – is not suggestive of a group likely to resolve a collective-action problem. Nonetheless, they did eventually manage to organize successfully, which is surprising given the favorable attributes of the industrial group. As a whole, the results suggest that actor attributes are, at best, part of a more complex story that is mediated by other aspects of the social, institutional, and ecological environment (Agrawal and Yadama 1997; Vedeld 2000; Poteete and Ostrom 2004).

4.3. Changes across snapshots

Given the challenges associated with governing ODS emissions for global ozone recovery, as well as actor characteristics that favored collective action against regulation, the prospects for successful implementation of the Montreal protocol seemed dim. Nonetheless, CPR theory is characterized by an optimistic assertion that most, if not all, environmental problems can be resolved provided that actors identify and implement the "right institutions" for a given context (Young 2002; Ostrom 2007). This section therefore considers changes in the social, institutional, and political landscape across the two snapshots that coincide with the shift from an open-access system to successful regulation of an atmospheric pollutant (Table 4). Although specific institutions associated with successful environmental governance vary considerably, certain attributes of those institutions such as participation of affected parties, spatial fit, proportionality and monitoring have been shown to apply to a wide range of circumstances (Ostrom 1990; Cox et al. 2010).

Political participation and institutional fit: The CPR literature clearly suggests that the participation of affected parties (Ostrom 1990) and the fit between institutions and environmental problems (Young 2002; Folke et al. 2007) are

Table 4: Changes across snapshots.

Attribute	First snapshot	Second snapshot
Political participation	Limited	High
Spatial fit	Misfit	Fit
Proportionality	Absent	Present
Leadership	Present	Present
Technological substitute	Absent	Present
Economic dependence	High	Low
Nested governance	Absent at start, informal at end of snapshot	Formalized
Flexible institutions	Yes, but uncoordinated	Yes, coordinated
Scientific knowledge	Limited but growing	Strong
Scientific consensus	Absent	Present
Graduated sanctions	Absent	Absent
Social monitoring	Limited	Present
*Social pressure	Present, but uncoordinated	Present and coordinated

*Attribute is not recorded in the SESMAD database.

important drivers of successful environmental governance. Our case study begins with anarchy at the international level (Milner 1991), consisting of uncoordinated regulation by the US and other nation states. By the end of the second snapshot, however, the case is characterized by international cooperation and universal agreement on a set of common and relatively strict ODS production and trade policies. This shift stems from a dramatic change in collective-choice institutions and processes after enactment of the agreement and aligns the governance system with the scale of environmental impacts. Furthermore, the Montreal Protocol provided mechanisms for participation by a multiplicity of actors, including developing nations and key industrial actors like DuPont. An argument could be made that prior to adoption of the protocol that ODS was governed at the international level by markets for ODS products. However, as the market did not internalize externalities of production, the use of national-level regulations to resolve externalities manifested at the global scale generated a spatial mismatch between institutions and ODS emissions.

Proportionality: In terms of natural resource commons, proportionality describes a state in which the benefits that actors accrue from a good are proportional to the amount of inputs required to sustain that good in the form of labor or resources, as determined by the rules in use (Ostrom 1990). For pollutants, the logic of proportionality is somewhat different, and speaks to congruence between past emissions, or the introduction of negative externalities, and the level of contributions in terms of public goods provision and the extent of emission cuts. While the whole world stood to gain from cutbacks in emissions, the problem itself originated quite clearly in the developed world. These same countries were also better situated to incur the costs to provide public goods and abatement given their economic conditions. After the Copenhagen Amendments in 1992, a financing scheme – the Multilateral Fund for the Implementation of the Montreal Protocol – was created to assist countries with low per capita production and consumption of ODS. This fund provided developing countries with direct aid and technology transfers to compensate them for the costs of ODS substitutes (Parson 2003). The financial assistance mechanism, combined with a delayed timetable for the developing world helped to ensure global implementation with proportional distributions of costs and benefits.

Leadership, economic dependence, and technological substitute: Leadership in favor of regulation by key industrial actors, most notably DuPont is often identified as a critical change that facilitated agreement on and rapid implementation of the Montreal Protocol (Parson 2003; Benedick 2009). DuPont's shift from an antagonistic stance, however, was far from an act of altruism as their investments in research and development had led to the production of ODS substitutes. This lessened their own, as well as society's dependence on ODS products; and also provided selective incentives for DuPont to encourage strict and rapid implementation of the Montreal Protocol since they would initially dominate the market for ODS substitutes. Leadership by UNEP, on behalf of developing nations was also seen as a crucial factor that reduced transaction costs and sustained pressure for developed nations that had created the problem to compensate them for the costs of ODS regulation (Benedick 2009). Finally, Richard Benedick, the chief US negotiator was a leading figure throughout negotiations and helped to ensure that negotiations did not fall apart (Parson 2003).

Nested governance and flexible institutions: At the outset of the negotiations, the main negotiating body was composed of a relatively small number of rich countries (i.e. US, European Community, UK) responsible for most of the production of ODS and a large number of mostly poorer countries that produced little ODS, but who would be disproportionately affected by the (potentially) high costs of alternatives (Downie 1999). As negotiations progressed, however, the groups began to self-organize into subgroups according to their interests, capacities, and resources and enabled a global agreement among a large number of heterogeneous participants that nonetheless shared one common interest in avoiding the consequences of ozone depletion. This nested structure is now formalized with the Multilateral fund, whose executive committee is comprised of seven members from each of the developing and developed countries that are party to the protocol.

The self-organization of countries into groups with similar interests helped to reduce a variety of transaction costs associated with designing and implementing the protocol. Developing countries, mostly through their unofficial representative (UNEP), were able to negotiate a financial and technical assistance package in addition to the previously established delayed implementation that provided for better alignment between the benefits and costs of abatement given past patterns of emissions. These incentives moved the otherwise heterogeneous parties closer to their operational goals. Developed nations benefited from greater participation in the Montreal Protocol, which increased the likelihood that their efforts would lead to the desired results. Similarly developing nations would be able to offset some of their costs with direct contributions from privileged members. Thus, institutional flexibility according to the heterogeneous capacities and interests of groups greatly facilitated successful negotiation and implementation of the Montreal Protocol (Barratt-Brown 1991; Downie 1999).

Scientific knowledge and consensus: Concern with the ozone layer originated from scientific investigations of atmospheric processes. During much of the first snapshot, the visibility of ozone depletion was effectively non-existent, and where knowledge existed it was often highly contested. However, scientific knowledge improved rapidly with increased attention on issues concerning ozone depletion and as a result of investments in environmental monitoring the visibility of the relationship between ozone depletion and ODS became clear to most, if not all, participants. Scientific consensus and the development of a strong environmental monitoring system therefore allowed the participants to justify rapid implementation of ODS regulations by stressing the urgency for action, creating a sense of crisis and resolve.

Social monitoring and graduated sanctions: In addition to environmental monitoring, information about users' behavior fostered cooperation (Ostrom et al. 1994). The Ozone Secretariat played a leadership role as a bridging agent both in brokering agreements concerning north-south financial arrangements and as a social monitor and compiler of national and aggregate ODS emission data (Barratt-Brown 1991). As a result, the Secretariat is seen as an independent facilitator for social monitoring between convention parties. In contrast, graduated sanctions an important element of successful small-scale collective action (McKean 1982; Ostrom 1990) is absent across the two snapshots. Given the generally positive performance of the Protocol and the absence of any form of sanctioning at the international level, it would seem that graduated sanctions may be less applicable for successful collective action among nations.

Social pressure: Social pressure is an external factor to our system as defined in the case that provoked a rapid response from governments and other stakeholders after a long period of inaction. Although environmental NGOs had been pressuring individual governments for many years, it was not until groups in the US, Europe, and the developing world met in London and coordinated around a specific proposal that these efforts translated into policy in the form of strict regulations and short timetables for ODS reductions (Barratt-Brown 1991). Drawing upon recent scientific evidence, these groups were able to influence previously hesitant parties to agree to these stringent regulations, and move toward a system that met the needs of developing countries.

4.4. Similarities and differences with CPR theory

The study of the commons and SESs has oriented itself around questions of when groups will be able to successfully resolve collective-action problems (Ostrom 1990; Wade 1994; Baland and Platteau 1999). While there is general consensus around a core set of design principles, the effects of variables are often presumed to be mediated by the state of other variables in complex SESs. In this section, we consider the similarities and differences of the key variables found in our case study with those key variables proposed in the CPR theory while making note of the two most significant sources of variations in our case from traditional CPR theory: the nature of the good and global nature of the system.

A number of variables highlighted in Table 4 seem to conform to the expectations of CPR theory and likely contributed to the successful regulation of ODS. Proportionality relative to historical emissions and heterogeneous levels of development appears to have made a major contribution in moving the Montreal Protocol from a largely western to a global governance system (Sarma and Taddonio 2009). This, in turn, was facilitated by the self-organization of developing nations under the unofficial leadership of UNEP as an informal type of nested governance that lowered transaction costs associated with negotiations. However, other CPR attributes failed to enjoy the same level of support, most notably: well-defined physical boundaries and graduated sanctions. In fact, the absence of relevant resource boundaries seems to have motivated action by generating a global sense of crisis. Graduated sanctions are also absent, but appear to have little impact on either the level of compliance or overall emissions. It is not entirely clear if size, the nature of the good, or some other combination of attributes limit the influence of its absence, but what is clear is that compliance has remained high despite the fact that protocol sanctions have never been used (Sarma and Taddonio 2009). Finally, although the protocol incorporated a measure of flexibility to account for its heterogeneous parties, the operational rules that governed ODS production limited national-level regulatory diversity to a "two-sizes-fits-all" approach. This limited diversity differs substantially from the higher levels of institutional diversity observed in many CPR settings (Ostrom et al. 1994). Nonetheless, as CPR theory progressed, the focus on local governance shifted to emphasize the fit between institutions and SES environments (Acheson 2006), and it is not necessarily surprising that a centralized regime successfully resolved what amounts to a global problem with a small number of major producers.

5. Discussion

The story of the Montreal Protocol often reads as a monumental achievement, against considerable odds, that promised to provide a starting point for future international responses to global environmental problems. Certainly, the speed at which a large number of interested parties were able to overcome their differences stands in contrast to conventional predictions that transaction costs in large groups substantially reduce the likelihood of voluntary provision of public goods. Nevertheless, the Montreal Protocol, while not predestined for success, had several factors in its favor that substantially increased these odds. In what follows, we highlight three ways in which the research program described in this special issue, and this study in particular, draws fresh insight on a well-studied case. We also address key shortcomings that arose in the process.

5.1. Findings from the SES framework

One of the clear challenges to “scaling-up” CPR theory in this study was the nature of the regulated good, pollution – a classic externality of production rather than a traditional CPR. While difficulty of exclusion is shared, use or consumption of the public bad is not subtractable, and concerns center on overproduction rather than overappropriation. As a result, the governance system had to recognize a three-step causal process: from the production of private goods that (1) resulted in the release of ODS, (2) affected global atmospheric ozone concentrations and (3) generated private costs. This analysis revealed that despite these differences, the SES framework and CPR theory may be relevant for the analysis of other types of goods. However, the results also showed that some aspects of CPR theory, particularly those that relate to resource boundaries and graduated sanctions, do not directly correspond to this and possibly other pollution cases.

Given that the shift from a small-scale CPR to a large-scale public bad alters the conditions in which decisions are made, it is not entirely surprising to find that SES attributes have different effects. For example, Ostrom’s (2007) introduction to the SES framework points out how a change to a single variable, the ability to communicate, has a dramatic effect on individual and aggregate payoffs in CPR experiments. The SES framework builds upon this general premise to include a wide range of potentially influential attributes, and suggests that social-ecological outcomes in particular and human behavior in general are a function of the combination of attributes that collectively structure choice environments. In the case of pollution, a particularly noteworthy change to this structure is that additional units of pollutants clearly imply a loss, while in the context of CPRs; additional cattle in a pasture imply gains. Given that human beings tend to value losses greater than they do gains (Kahneman and Tversky 1979), this may explain, at least in part, why the absence of boundaries motivated action among a large number of parties facing the possibility of substantial individual and collective costs.

While CPR theory, in some ways, makes for an unusual candidate to explore the Montreal Protocol, the shift from theory to a framework provides a broader range of potentially relevant attributes compatible with multiple theories (Schlager 1999). As described earlier, a number of scholars studying the Montreal Protocol draw on particular theoretical foundations to understand the case and its performance (e.g. Litfin 1994; Benedick 1998; Parson 2003). Although this allows them to offer strong explanations of causal processes, it also risks neglecting additional factors that may have facilitated agreement and successful implementation. Therefore, rather than contesting these studies or their more nuanced discussions, we combined them to help study the case through the SES framework. In doing so, we were able to identify a larger set of factors including political participation of key industrial actors like DuPont, nested governance, and scientific knowledge and consensus that increased the visibility of the relationship between ODS emissions and ozone concentrations as key variables, among others that likely contributed to the success of the Montreal Protocol.

5.2. Shortcomings and interesting analytical complexities

The SESMAD database provides a systematic approach to perform within-case analysis using temporally bounded snapshots (or observations) of a case. These snapshots, coded using multiple studies of the Montreal Protocol allowed us to identify important changes in the social and institutional environment that may have contributed to its success. However, this analysis also uncovered several weaknesses associated with the SESMAD approach. First, although snapshots are able to capture some of the complexity of the case, the coding of attributes tended to overlook their multidimensional nature, limited measurement to nominal or ordinal scales, and often required values to be determined by averaging over considerable heterogeneity. For example, the political power of actors is reduced to a single three-point ordinal measure which neglects details about the mechanisms by which that power is exercised, the contexts in which that power is manifested, and heterogeneities within a group of actors. Second, a number of variables identified as important by previous studies are not present in the SESMAD database. These include a sense of crisis in mobilizing actors despite uncertainty in the scientific knowledge base, and the role of media attention and NGO pressure in provoking a response. In short, the SESMAD approach helps to simplify and standardize a case for cross-case comparison, and generates potentially valuable insights by comparing snapshots for within-case analysis. However, other, more nuanced, case-specific questions may be better addressed by alternative approaches such as process tracing.

Finally, the research provides insights for possible future research directions. The intent is to use this study as a starting point for a systematic program of analysis of similar international pollution cases. Coding across a large number of such cases in a comparable manner will allow for hypothesis testing and more generalizable conclusions concerning the role that variables and their interactions play with respect to successful long-enduring institutional arrangements. Eventually, it is hoped that the results will provide policymakers with tools to craft better institutional arrangements for environmental governance – not unlike the role that atmospheric scientists played during the build-up to Montreal in this case. Similarly, we hope to explore the commonalities between pollution cases and other more “typical” CPR dilemmas to determine the extent to which existing knowledge can be used for governance of pollution problems. Thus the aim, broadly put, is to explore the possibility of “design principles” for international public good dilemmas and/or large-scale systems.

6. Conclusion

While the Montreal Protocol is often viewed as over studied, alternative perspectives can illuminate important features of a case. In particular, as highlighted above, we note that previous studies tend to focus on a core set of variables, often in support of a narrow theoretical perspective. In contrast, we explore the complexity and potential importance of a large set of variables instrumental in creating the context that led to the unparalleled successes of the Montreal Protocol. Moreover, the case clearly demonstrates that although resource and actor attributes may pose immense governance challenges that their effects are mediated by regulatory institutions (Agrawal and Yadama 1997; Poteete and Ostrom 2004). In retrospect, the concentration of ODS production among few industrial actors in specific nation-states made the scale issue more manageable from a collective action standpoint by constructing a group that could be described as privileged (Olson 1965; Hardin 1982), although environmental effects remained global in scale.

The analysis presented in this case study suggests that successful governance of ODS for ozone protection was likely a function of a number of attributes including the global nature of environmental costs coupled with a small number of producers, heterogeneous endowments among nation-states, political activities of industrial stakeholders, and increasing scientific knowledge. While much of the knowledge generated in this report can be found in alternative accounts of the protocol, the multiple-methods approach adopted by the SESMAD project leaves open the possibility that additional insights may be gleaned from comparative and large-N analyses that include this case and, hopefully, make contributions toward more sustainable large-scale environmental governance.

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