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. To explore the Montreal Protocol, this paper expands on the commons literature, which focuses mostly on small-scale appropriation problems and applies a similar logic to the matter of large-scale, in this case global, externalities of production. In particular, we apply a social-ecological system framework and common-pool resource theory more broadly to the governance of transboundary pollution. The paper shows how the social and environmental settings that surrounded negotiation of the ozone-depletion problem were particularly conducive to a successful agreement, including a larger set of variables than those previously reported. Our results concur with past studies that focus on the importance of variables such as a limited number of producers, advances in scientific knowledge, and the availability of technological substitutes. However, by applying the social-ecological system framework, we identify other factors of importance that shifted the ozone case from an open-access tragedy to a successful example of global collective action.

Keywords: Social-ecological systems, SES-MAD, common-pool resource theory, ozone, Montreal protocol

1. Introduction

The Montreal Protocol has long been held as an example of a successful global response to a large-scale environmental problem. The protocol that entered into force on January 1, 1989, was designed to gradually reduce and often times eliminate the production of a variety of ozone-depleting substances (ODS) to protect the ozone layer. The Montreal Protocol, initially ratified

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by 21 nations, has been universally ratified since September 2009. Although the environmental effects of the Montreal Protocol, such as the size of the ozone hole and atmospheric concentrations, have continued to worsen, it is expected that the cumulative reductions in the emission of ODS will begin to be felt 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 (SES-MAD) project, explores the Montreal Protocol through the lens of common-pool resource (CPR) theory. It also extends 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, applies 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.

Before turning to the project at hand, we first explore past analyses of the Montreal Protocol using more traditional theoretical approaches. As one of the long-standing successes in international environmental policy, the Montreal Protocol has been the subject of many analyses, largely evaluated through the lens of international relations theory (e.g., Viotti and Kauppi 2012), with a focus on why and how sovereign states agree to be collectively bound to rules in anarchic (i.e., non-hierarchical) contexts. Scholars have studied the Montreal Protocol to understand regime formation and successful environmental governance through specific lenses of agenda-setting (Morrisette 1989), the policy-shaping power of epistemic communities (Haas 1992), discourse analysis (Liftin 1994), and institutionalism (Grundmann 2001). More recently, scholars have evaluated the protocol through the lens of the policy-science interface. For example, Parson (2003) argues that the Montreal Protocol broke through stalled diplomatic negotiations around ozone depletion through the following steps: (1) scientific assessments illustrating the severity and causes of ozone depletion were considered authoritative enough to shape the behaviour of policy actors, (2) the regime itself included novel components such as an assessment process that included regulated industries to evaluate new technological substitutes for chlorofluorocarbons (CFCs), and (3) the ability of the regime to adapt to novel conditions and promote rapid technological change.

With the exception of recent critiques against the neoliberal philosophies or market perspectives that shaped the treaty (Gareau 2013), most studies view the Montreal Protocol as an unprecedented success. Richard Benedick (2009), the past chief negotiator for the United States during deliberations on the formation of the Montreal Protocol, credits the creativity and independence of scientists and scientific assessments in mobilizing nations toward a resolution (2009). In a speech at a celebration of the 20th Anniversary of the Montreal Protocol, Benedick also credited contingencies such as leadership and timing in moving delegates toward a successful pairing of science and politics, institutional arrangements, and scientific knowledge.

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. 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 the appropriation of a good by one individual affects the availability of that good 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 ODS, 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 United States 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 some way by all individuals on the planet. 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, it 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 introduce de facto subtractability, ozone protection 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. 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). Fortunately, atmospheric ozone is produced via natural chemical processes that produce an adequate supply in the absence of external factors (Rowland 2009). Of course, external factors did emerge toward the end of the twentieth century as scientists noticed declining ozone trends and were able to link this trend to growth in the emission of a variety of anthropogenic substances, most notably CFCs. ODS as a public bad tend to be overproduced, not as a purposeful choice but rather as an externality of production and consumption. Many ODS are useful as refrigerants and propellants, and were produced in large quantities to serve these and other purposes. In one of the few analyses of the ozone layer as a CPR, Downie (1999) argues that the ozone layer can be seen as a public good in that it acts as a sink for pollution, provided that it is not destroyed through overappropriation. Seen as a public good, Downie (1999: 103) suggests that the central political question negotiators struggle with relates to "distributional issues" in allocating the production of increasingly smaller allowances of ODS among signatories at each stage of treaty implementation. The problem is thus not one of provision, nor appropriation, but rather in managing the distribution of costs associated with the internalization of the externalities of production.

When individuals or groups choose to produce or consume ODS, the underlying incentive structure of that choice reflects only the benefits from selling or using that product and not the shared environmental costs. In any case, overappropriation of a common good, underprovision of public goods, and overprovision of public bads are remarkably similar in that they describe situations of interdependent choice and an incentive structure that resembles the classic Prisoner's Dilemma (Ostrom 2005). Furthermore, the core question in many academic inquiries of these situations is how to structure institutions to favor more beneficial and efficient social outcomes. Here we focus on the applicability of CPR theory and the social-ecological system (SES) framework to help structure our understanding of the Montreal Protocol and more generally the applicability of the framework for the study of public bads and pollution.

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 (Gardner et al. 2000; Lo and Tang 1994; Lundqvist 2001; Ostrom 2010; Ostrom et al. 1961). In their now-classic introduction to polycentric metropolitan governance, Ostrom et al. (1961) identified the importance of organizing institutions at a scale that "can encompass the problem." In this way, the institutions are better able to account for the costs of pollution, while capturing the benefits that are produced from lower emissions – in this case, leading to a global governance arrangement.

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, followed by 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. The discussion considers the Montreal Protocol in light of the configuration of key variables that led to mostly successful governance as well as assesses the potential shortcomings of a diagnostic framework approach. Finally, we conclude by comparing the set of variables of interest in a SES analysis with those of previous analyses.

2. Methods

This case, like the others in this special issue, follows the methods that were developed collaboratively as part of the Social-Ecological Systems Meta-Analysis Database (SES-MAD) project, and are described in greater detail by Cox (this issue). SES-MAD collects systematic information on the social and ecological attributes of large-scale social-ecological systems (SESs), the basic unit of analysis, through content analysis of published studies. In particular, this paper relies upon a mixture of peer-reviewed articles and book chapters, as well as unedited books and the so-called "gray literature," to enter data into the SES-MAD database, a relational database hosted at Dartmouth College. The case was coded based on intersubjective agreement after the authors independently evaluated multiple studies of the case. While this approach proscribes measurements of the reliability of coding, it is consistent with prior studies of the commons (Wertime et al. 2007; Ostrom 1990; Cox et al. 2010), and could be said to 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.

The SES-MAD database contains information on approximately 200 variables of relevance to the study of SESs, stored in four main tables and associated linking tables. The structure of the database is based on Ostrom's (2007, 2009) SES framework as modified by Cox (this issue). The main table, the SES table, is used to collect general information on the SES, which is defined as a system containing at least one resource, at least one governance system, and one or more actor groups that relate to the resource within the context of the governance system. A governance system (GS) is a set of institutional arrangements (such as rules, policies, and governance activities) that are used by one or more actor groups to interact with and govern a resource. 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. A resource (R) is an environmental phenomenon or pollutant that can be subjected to human use, production, and governance. Within the relational database, information on relationships between these components is stored in linking tables. The most important linking tables connect the governance system to the resource (GS-R) and then connect this relationship to individual actors (GSR-A), allowing the coder to capture relationships between multiple resources, actors, and governance systems. The database also includes a table connecting the governance of one resource to another resource (GSR-R). Figure 2 shows how this framework was operationalized for this case for two separate time periods (snapshots): the boxes in the figure refer to the actual tables in the relational database. Time periods were defined using regime formation as a turning point between one steady state (in terms of problemsolving) in international affairs and another (see Haydu 1998). Figure 3 shows key variables analyzed in this case in the context of the database structure.

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 1).

<<FIGURE 1 ABOUT HERE>>

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 of the independent variables. The first of these snapshots lasts from the mid-1970s, when the 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 modified SES framework outlined in the introductory article of this special issue (Cox, this issue), 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 with article 12 of the Montreal Protocol, and its duties include administration, monitoring implementation, collection and processing 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 via the Montreal Protocol. Figure 2 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 behaviour 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.

<<TABLE 1 ABOUT HERE>>

<<FIGURE 2 ABOUT HERE>>

4. Results

Our synthesis of prior studies as captured in the SES-MAD database suggests that 26 variables from the framework are potentially relevant to understand the observed decline in ODS production (Table 2). As seen in Figure 3, 11 of these variables are commonly associated with CPR theory (Cox, this issue), while 16 are variables more commonly associated with the SES framework. The remaining variables are those that experts in the Montreal Protocol have highlighted as relevant to understand the outcomes of this case study, but are not mentioned in either the CPR or SES literatures. Below, we describe these variables aggregated into categories of resource and actor attributes and institutional features, and explore their role in explaining outcomes. Figure 3 captures these variables as they are found in the SES-MAD database, and simply identifies whether they are seen as influential or not, while Table 2 adds additional details concerning the state of these variables across snapshots.

<<TABLE 2 ABOUT HERE>>

<<FIGURE 3 ABOUT HERE>>

4.1. Resource attributes

The expected return to normal atmospheric concentrations of ozone as a result of the Montreal Protocol can at least in part be linked to attributes of the resources that facilitated regulation. In our analysis, we considered both ODS (the regulated externalities) and the atmospheric ozone layer (the public good) as "resources" governed by the Montreal Protocol. This distinction stems from the structure of the case and the differences between institutions aimed at governing resource production (or emissions), as in atmospheric deposition of pollution, and institutions that govern provisioning of a public good, such as the ozone layer. Among the resource attributes highlighted as key by the CPR and SES literature, we distinguished the ones that help us to understand how international cooperation was arranged to avoid the ozone destruction by ODS, as well to distinguish our case from more classical CPR case studies. These differences come mostly from the difference in studying a global air pollution case instead of a small-scale appropriation problem.

At the outset, the characteristics of ODS and ozone appear ill-suited to CPR governance. Both are small (effectively invisible), highly mobile substances whose only boundary corresponds to the whole of planet Earth. 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 United States and Europe would produce 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. Surprisingly, in the case of the Montreal Protocol, these variables, when combined with the general sense of looming crisis that surrounded negotiations, seem to have motivated participants to develop regulations to control ODS emissions.

Grouping all ODS into a single category for coding purposes alludes to certain underlying characteristics of this type of pollutant that greatly facilitated regulation. ODS that include a wide range of anthropogenic chemicals such as CFCs, HCFCs, and carbon tetrachloride all interact with ozone in the atmosphere and ultimately lead to its dissociation and the loss of ozone protection (Isaken 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 (ODP), 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).

4.2. Actor attributes

The literature on collective action generally suggests that small groups with homogeneous interests (Olson 1965) and groups with shared norms (Ostrom 1990, 2009) are more likely to successfully resolve collective-action problems. However, empirical studies show that while group characteristics may influence aspects of collective action, their effects are often mediated by other aspects of the social, institutional and ecological environment (Agrawal and Yadama 1997; Vedeld 2000; Poteete and Ostrom 2004). For instance, Olson (1965) suggests that groups may be privileged and therefore more likely to succeed if they possess one or a small number of individuals capable of independently resolving a collective action problem given an appropriate incentive structure. This has been applied to the case of greenhouse gas production to suggest that the United States and China working as a pair could have a significant effect on curbing climate change, even without cooperation of many signatories to the Kyoto Protocol.

Of the three actors included in this study, the industrial group of producers appears best suited to engage in collective action in mobilizing against a treaty. They were composed of relatively few companies and concentrated mostly in the United States and Europe, and also stood to absorb much of the costs associated with abatement. While the small size and concentration would ultimately facilitate external monitoring of abatement, the underlying incentive structure of the group would suggest that they would be able to come together to oppose environmental regulations in one or more of the national parties. Early on the industrial group appeared to leverage their interests via the American and European governments, but this rapidly fell apart when DuPont broke with the group to take a leadership position in favor of regulation. On the other hand, the nation-states, composed of a large number of actors with what can be safely assumed as 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, the fact that they were able to eventually organize successfully, and in the presence of an industry group whose composition made them more likely to be able to successfully oppose regulation, suggests that actor attributes are, at best, part of a more complex story.

4.3. Changes across snapshots

This section identifies changes in social, economic, and political conditions across the two snapshots in our analysis that correspond to the shift from an open-access system to successful regulation of an atmospheric pollutant.

Political participation and governance-resource mismatch: The CPR literature clearly suggests that the participation of affected parties (Ostrom 1990) and the fit between institutions and SES conditions (Folke et al. 2007) are important determinants of success. Our case study starts with a situation of anarchy at the international level with different approaches taken by the United States and others, and ends with international cooperation. This shift corresponds to matching the scale of political participation and environmental impacts to the governance system. Furthermore, the Montreal Protocol provided mechanisms for participation by a multiplicity of actors, including developing nations and key industrial actors like DuPont.

Proportionality: In terms of natural resource commons, proportionality describes a state in which the benefits that actors accrue from the commons are proportional to the amount of inputs required to sustain the commons in the form of labor or resources, as determined by the rules in force (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 good provision and the extent of emission cuts. For the Montreal Protocol and the production of ODS, 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 of rule provision 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 permanently institutionalized to assist countries with low per capita production and consumption of ODS to achieve phase-outs by offering compensation in the form of direct aid and technology transfers (Parson 2003). The financial assistance mechanism and delayed implementation for the developing world helped to ensure global implementation with proportional distributions of costs and benefits.

Leadership, economic dependence, and technological substitute: The political leadership of key industrial actors like DuPont, with its role in pushing the production of ODS alternatives, greatly facilitated eventual agreement. Among our coded actors, the nation-states were led by a group of states concerned about the potential impact of the loss of ozone protection on human health through increased UV radiation. The industrialized world was similarly situated in terms of economic dependence upon ODS production for key industrial uses, but as negotiations developed, countries with lower per capita consumption and production of ODS argued for the necessity of economic aid in transitioning away from what they saw as critical technology for modernizing their economies (Downie 1999). Likewise, research efforts by DuPont and their breakthroughs with respect to technological substitution played a major role in shifting industry and national positions toward regulation, although there has been argument over the direction of the cause-effect relationship.

Group size, group heterogeneity, and flexible rights: The main negotiating body was composed of a relatively small number of rich countries (i.e., United States, European Community, United Kingdom) 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). Negotiations began with a few relatively homogeneous countries but ended in a global agreement with more heterogeneous participants that nonetheless shared a common interest in avoiding the consequences of ozone depletion. 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. This incentive structure 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; some of the costs for developing nations would be offset by direct contributions from privileged members. Parson (2003) also suggests that the strong leadership of US negotiators privileged the group involved in negotiating the Montreal Protocol in the years shortly before an agreement was finally reached. Their proposals, which were initially conceived as so extreme and at odds with important domestic policymakers that they would never be considered, actually ended up constituting the basis of the agreement once DuPont came out in support of the measures.

Environmental monitoring, visibility of feedbacks and the role of science: Concern with the ozone layer originated from scientific study. During the first snapshot, up until the 1980s, visibility of the problem was non-existent. However, scientific knowledge improved rapidly with growing concern for the issue and, as a result, environmental monitoring and feedback on the resource improved rapidly. Scientific consensus on the consequences of ODS production and its effects on ozone emerged quickly. The combination of scientific consensus and the quick build-up of the monitoring base rapidly improved the visibility of feedback between the polluters and the SES, stressing the urgency for action, creating a sense of crisis and resolve.

Social monitoring: In addition to environmental monitoring, 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. As a result, the Secretariat is seen as an independent facilitator for social monitoring between convention parties.

Social pressure: Social pressure is an external factor to our system that provoked a rapid response in governments and other actors. Social pressure grew through several environmental and health NGOs in the years before and after the adoption of the Montreal Protocol, the important media attention that the ozone hole had, as well as the sense of crisis in moving toward action.

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.

A number of variables highlighted in Table 2 and Figure 3 seem to be important in explaining the outcomes of ozone regulation and parallel those from CPR theory. In addition, a number of other well-established CPR variables did not prove to be important in our case study, most notably: well-defined physical boundaries, the use of graduated sanctions, conflict-resolution mechanisms and rights to organize, and nested/multilevel governance arrangements. Physical boundaries of the resource does not appear important in this case because in both snapshots, ozone and ODS are distributed globally and, in a general sense, are independent of the locus of emissions. Graduated sanctions, the rights of affected parties to organize for the purposes of rule making, and nested governance are also absent across snapshots. As a whole, the highly centralized and restrictive nature of governance in the Montreal Protocol case differs substantially from the flexible, decentralized regimes in which CPR theory was developed. 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 producers.

Additional differences between this case study and CPR theory, as described in the previous section, come from other variables that help us to understand our case but are not key variables in CPR theory, as well as variables that are important for this specific case but were not considered in the SES-MAD database (Table 2, Figure 3). Many of these differences arise from moving up to a global scale, which makes some of the boundary concepts irrelevant and distorts the meaning of other variables (e.g., heterogeneity between actors). Other differences stem from applying natural resource management ideas to the realm of pollution abatement.

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, subtractability is effectively the polar opposite of CPRs with concerns about overproduction rather than overappropriation. As a result, governance had to recognize a three-step causal process: from the production of goods (1st) that resulted in the release of ODS (2nd) that in turn destroyed ozone in the atmosphere (3rd). This analysis revealed that the SES framework may have a broader range of applicability than CPRs, and ability to identify many of the variables associated with successful governance of a pollutant. However, it also showed that some aspects of CPR theory, particularly those that relate to appropriation and associated activities such as monitoring and sanctioning, do not directly correspond to pollution cases. Nonetheless, CPR theory directs specific attention to resource users; and with slight modifications, many of the factors associated with overappropriation can be applied to the study of the externalities of production.

While CPR theory, in some ways, makes for an unusual candidate for exploration of the Montreal Protocol, the shift from theory to a framework provides a broader perspective to explore potential hypotheses for its success in a wider universe of cases (Schlager 1999). As described earlier, a number of scholars studying the Montreal Protocol draw on particular theoretical foundations to understand the case and its successes (e.g., Benedick 1998, Litfin 1994, and Parson 2003). Rather than contest these studies or their more nuanced discussions, we drew on them to help study the case through the SES framework. In so doing, we identified the homogeneity of national interests in resolving the problem, the political participation of key industrial actors like DuPont, and the role of science in increasing the visibility of feedback between the polluters and the SES as key variables to explain the success of the Montreal Protocol. These, in addition to the variables of choice in the other studies, all combine to create the social and ecological outcomes that we now see.

5.2. Shortcomings and interesting analytical complexities

Drawing upon multiple studies of the case in question and applying these to the database coding form raised two main issues. First, a number of important variables identified as important went uncoded, as they had no direct analogues in the database. These include a sense of crisis in mobilizing actors despite uncertainty in the scientific knowledge base, the role of media attention in provoking a response, and the similar role of NGO pressure. Similarly, the complexity of issues means that, in the process of coding, we likely oversimplified, averaged out variation, or missed additional complexities. This often had to do with reducing a multifaceted issue to a binary (or categorical) variable. The authors also occasionally did not have the information to address some questions. In short, this analysis helps to simplify the high degree of complexity of the case and provides answers to some questions, while opening up the possibility of comparison with other cases. Other, more nuanced, case-specific questions are better addressed by testing detailed theories and developing focused case studies such as those used in this analysis.

The research also 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 overstudied, alternative perspectives can illuminate important features of the individual case and benefit from its inclusion in a broader study. 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 this study, we explore the complexity and importance of a large set of variables instrumental in creating the context that led to the unparalleled successes of the Montreal Protocol. We also note our success in applying key variables from the CPR and SES literatures to the study of large-scale systems. 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 a function of 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 SES-MAD 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 towards more sustainable large-scale environmental governance.

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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 in 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.

Table 2. Important variables explaining outcomes relating to the governance of ozone-depleting substances (ODS).

Variable	SES component	First snapshot	Second snapshot
RESOURCE PHYSICAL BOUNDARIES	ODS	The ODS does not have boundaries.	
	O	The ozone layer has clear boundaries.	
PROPORTIONALITY	ODS-N, ODS-I	Few countries responsible for most production of ODS, while the rest are affected by the rising cost of alternatives and consequences of ozone destruction.	Proportionality increases due to the financial and technical assistance of developing countries, as well as the delayed implementation for developing countries.
POLITICAL PARTICIPATION	ODS-N	Before the Montreal Protocol, the level of cooperation among nation states was very low.	The nation-states have a high level of political participation in the governance of the production of ODS.
	ODS-S	–	The Ozone Secretariat has a very important role in the governance of the production of ODS.
	ODS-I	ODS producers have a moderate level of political participation in the governance of the production of ODS.	
SOCIAL MONITORING	ODS-N	The nation-states allocate and monitor the ODS emissions within their jurisdiction.	
	ODS-S	–	The Ozone Secretariat monitors the implementation of the convention and receives and processes data from the parties to the convention on ODS.
	ODS-I	The producers are not responsible for monitoring the ODS emissions but likely cooperate with states in joint monitoring.	
GROUP SIZE	N	International cooperation started with a conference of experts from 32 countries.	Universal agreement of the Montreal Protocol.
	I	Many industries are producing ODS.	
RESOURCE RENEWABILITY	O	The atmospheric ozone will need decades to return to its normal concentration range.	
LEADERSHIP	N	There is no leader among the nation-states.	
	I	DuPont (informal leader) pushed the production of ODS alternatives. DuPont has low representativeness, some authority, and low accountability.	
ECONOMIC DEPENDENCE ON RESOURCE	ODS-N, ODS-I	High dependence of nation-states and producers on ODS or ODS substitutes.	Dependence on ODS decreases.
HETEROGENEITY OF INTERESTS	N	High heterogeneity of interest among producers of ODS nations and non-producers' nations.	
	I	Low heterogeneity of interest among producers.	

Scientific knowledge and consensus	ODS, O	Since the 1970s, the scientific knowledge about ODS and their interaction with ozone has grown rapidly.	There is a scientific consensus that ODS are responsible for ozone destruction.
Environmental monitoring	ODS, O	Ineffective system to monitor ODS production and ozone concentration.	Very effective system to monitor ODS production and ozone concentration.
Flexible rights	ODS	–	The Montreal Protocol has flexible rights.
Scientific knowledge	ODS-N, O-N	Initially, the scientific knowledge of nation-states about ODS and O is low.	The scientific knowledge of nation-states about ODS and O is high.
	ODS-S, O-S	–	The scientific knowledge of the Ozone Secretariat about ODS and O is high.
	ODS-I, O-I	The scientific knowledge of industries about ODS and O is low.	The scientific knowledge of industries about ODS and O is medium.
Speed of feedback	ODS-N, ODS-I, O-N	The effects of management interventions of nation-states in ODS and O, and industries in ODS, are slowly seen.	The effects of management interventions of nation-states in ODS and O, and industries in ODS, are seen faster.
	O-I	The effects of management interventions of industries in O are slowly seen.	
Visibility of feedback	ODS-N, ODS-I	The visibility of the effects of management interventions on ODS is medium.	
	O-N, O-I	The visibility of the effects of management interventions on ODS to the O is low.	
	O-S	–	The visibility of the effects of management interventions on ODS to the O is low.
Compliance	ODS-N, ODS-I	–	Yes.
Users' concentration	N, I	The spatial distribution of users is very concentrated.	
Size	ODS, O	ODS and O have very small size (=<mm).	
Mobility	ODS	The ODS produced by industries end in the ozone layer.	
Spatial autocorrelation	ODS	The spatial autocorrelation of ODS is low.	
	O	The spatial autocorrelation of ozone is high.	
Point/Non-point source	ODS	ODS are non-pointsource pollutants.	
Residence time	ODS	The residence time of ODS is very high.	
Technological substitute	ODS	Before the Montreal Protocol was adopted, DuPont found substitutes to ODS.	
Spatial extent	ODS, O	Very large spatial extent.	
Social pressure	External factors	Social pressure about the necessity to avoid the consequences of ozone destruction is very high. This includes the pressure of environmental NGOs, the media attention given to the ozone depletion, and the sense of crisis.	

Variables in caps correspond to important variables highlighted in CPR theory; variables in italic correspond to key variables not mentioned in our SES framework. I=ODS producers, N=nation-states, O=ozone, ODS=ozone-depleting substances, S=Ozone Secretariat.

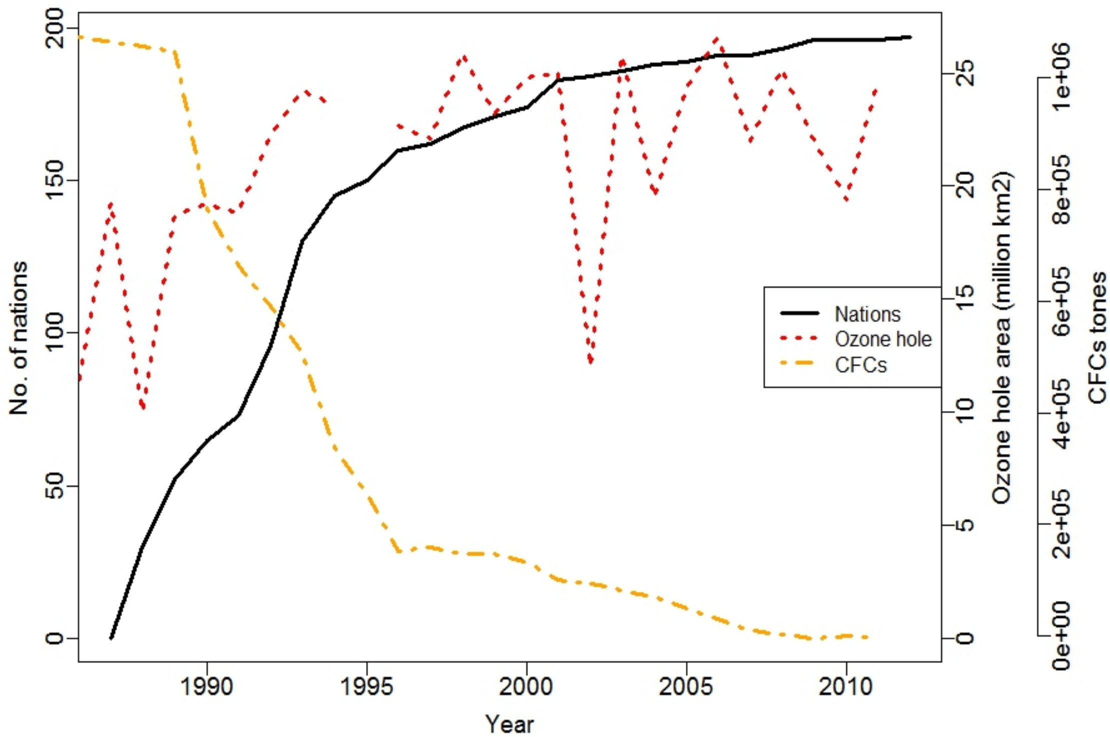

Figure 1: Evolution of the number of countries ratifying the Montreal Protocol (in cumulative values), area of the ozone hole, and production of CFCs.(Sources: http://ozone.unep.org/new_site/en/index.php; http://ozonewatch.gsfc.nasa.gov/).

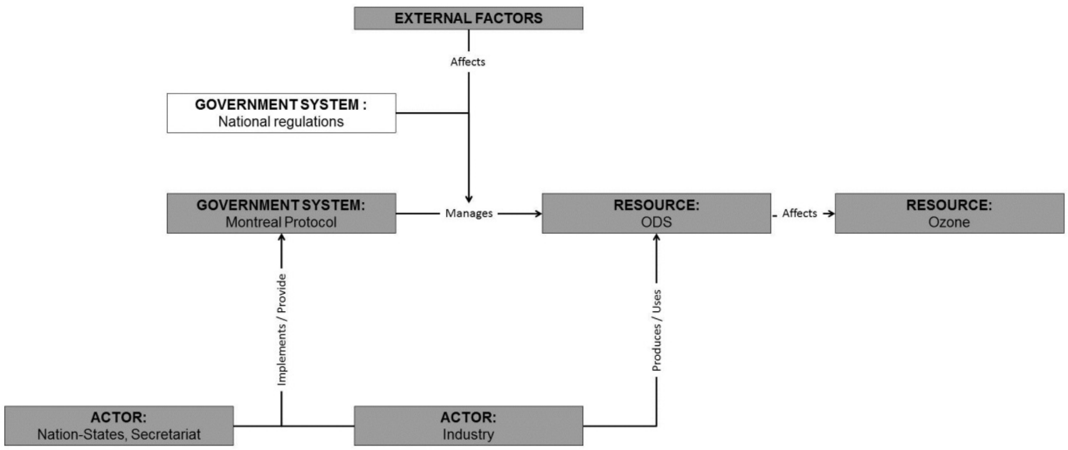

Figure 2: Diagram of the snapshots coded of governance of the Montreal Protocol and the control of ozone-depleting substances (ODS).

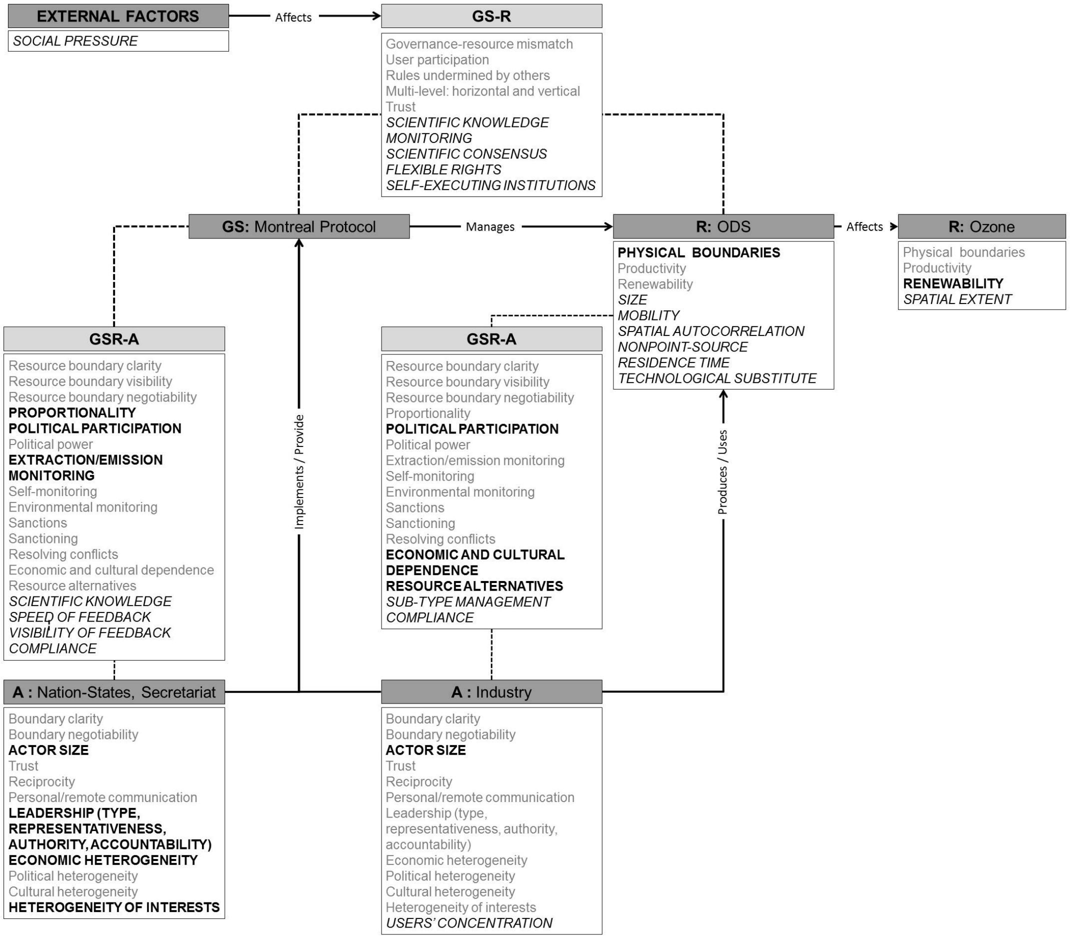

Figure 3. Important variables explaining outcomes of the governance of the Montreal Protocol and the control of ozone-depleting substances (ODS). (Light-gray boxes are links between main components. Variables in caps and bold are important variables identified through CPR theory [and in the coding database]; variables in caps and italic are other important variables identified through this research.)