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EAERE Magazine

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EAERE Magazine serves as an outlet for new research, projects, and other professional news, featuring articles that can contribute to recent policy discussions and developments in the field of environmental and natural resource economics. It is published quarterly in the Winter, Spring, Summer, and Fall. Contributions from the wider EAERE community, especially senior level researchers and practitioners, and EAERE Country Representatives, are included in the magazine.

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Dear EAERE friends and colleagues,

Welcome to the first issue of the EAERE Magazine in 2019! We have continued with our efforts to collect contributions and insights on recent policy issues and new research developments.

The issue is devoted to the latest climate conference, COP24, that took place in December in Katowice, and more broadly to international agreements and their impacts on ecology, economy, and technological progress. We start with **Robert Stavins** from Harvard University who provides an assessment of the outcome of the COP24 in Katowice. Following this, **Alessandro Tavoni** from the University of Bologna presents research on how the climate negotiators themselves assess the outcomes of past climate conferences and which factors influence their views. **Bård Harstad** from the University of Oslo explains why international treaties are often weak, even when stronger treaties are feasible. **Elena Ojea** from the University of Vigo presents her research project on the effects of climate change on shifting fish stocks in the oceans and what this implies for the regulation of fisheries. Ending the issue on a more positive note, **Eugenie Dugoua** from the London School of Economics describes how the Montreal Protocol was able to stimulate technological progress in replacing ozone-depleting substances.

Enjoy reading!

Astrid Dannenberg

University of Kassel, Germany

The Outcome of COP-24 in Katowice, Poland

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During two weeks of sometimes boisterous plenary sessions and backroom discussions, the 197 Parties of the Twenty-Fourth Conference of the Parties (COP-24) of the United Nations Framework Convention on Climate Change (UNFCCC), meeting in Katowice, Poland, sought to reach consensus on rules and guidelines for implementing the Paris Agreement. That landmark 2015 accord came into force in 2016, and is scheduled to begin operations in earnest in 2020. Hanging over the negotiations was the reality that U.S. President Donald Trump announced in June 2017 that the United States would withdraw from the Paris Agreement (in November, 2020, the soonest that any Party can actually withdraw). Since Trump's announcement, the former co-leadership by the United States and China, which had been critical to the passage of the Paris Agreement, has evolved into something between sole leadership by China and co-leadership by China and the European Union. Not long before midnight on Saturday, December 15th, 2018, a full 24 hours after COP-24 was scheduled to conclude, consensus was reached on the 156-page Rulebook, with considerable credit due to the Polish presidency of the Conference (*not* to be confused with the presidency of the Polish nation), in the person of Michał Kurtyka, Poland's Deputy Minister of Energy. Was COP-24 a Success? A simple "yes" or "no" response to this question would be misleading. There were dozens of aspects of the Paris Agreement on which the delegates to the Katowice meetings wanted to make progress by filling in details in the 29 articles of the skeletal Paris Agreement. Two areas stood out. One is referred to as "transparency," and other is characterized (somewhat inaccurately) as "markets." Combining the achievements and lack thereof on both fronts, I assess the outcome of the Katowice talks to be somewhat more than a half-full glass of water.

Transparency

Transparency refers to the credibility of each nation's measurement of its own performance – in terms of its emissions and its policies. The Paris Agreement gave significant wiggle room to the vast majority of countries – the 154 developing countries – by granting them flexibility in meeting the transparency requirements (which were to be established for the industrialized countries). The U.S. delegation – consisting of civil servants – again worked closely with the Chinese delegation to foster a remarkable consensus that all countries must follow uniform standards for measuring emissions and tracking the achievement of their respect targets (Nationally Determined Contributions or NDCs). This was a significant achievement, and a major step forward toward a level playing field among the countries of the world. Conceivably, it could make it easier for the Trump administration to remain in the Paris Agreement (if the President were to become convinced that such action would be politically advantageous in the run-up to the November 2020 U.S. presidential election). And, likewise, it will make it easier for a future (Democratic or Republican) administration to rejoin the Paris Agreement if the current

President follows through on his promise to withdraw. That is a significant success.

Article 6.2 and Carbon Markets

Turing to the second key set of issues at COP-24, there are two necessary conditions for ultimate success of the Paris Agreement: adequate scope of participation, and adequate ambition of the individual national contributions. The first condition has surely been met, with 97% of global emissions associated with countries taking on responsibilities under Paris, compared with 14% under the current commitment period of the predecessor international agreement, the Kyoto Protocol of 1997. But the factor that brought about such broad participation – namely, that each country's target is anchored in its own national circumstances and colored by its domestic political reality – suggests that the individual contributions will not be collectively sufficient (due to the global commons nature of the problem). Because of this, a key question has been whether there are ways that the Paris Agreement itself, as it is fleshed out, can enable and indeed facilitate increased ambition over time? One answer, on which I have carried out extensive research with colleagues, can be provided by the *linkage* of regional, national, and sub-national policies – connections among policy systems that allow emission reduction efforts to be redistributed across systems.

Heterogeneous Linkage

Linkage is typically framed as between cap-and-trade systems, but regional, national, and sub-national policies will be highly heterogeneous, including a variety of types of emissions trading systems, carbon taxes, and conventional performance and technology standards. As my research in this area with Michael Mehling (M.I.T.) and Gilbert Metcalf (Tufts University) has found, linkage among such heterogeneous policies is not trivial, but is – in many cases – feasible. This is important because linkage fosters: cost savings by allowing firms to take advantage of lower cost abatement opportunities in other jurisdictions; improved functioning of markets by reducing market power and price volatility; political benefits to linking parties; administrative economies of scale; and – perhaps most important – the possibility of satisfying the UNFCCC's key criterion of distributional equity – "common but differentiated responsibilities" – without sacrificing cost-effectiveness. Fortunately, such linkage can be consistent with the Paris Agreement, under the authority of its Article 6, focused on international cooperation. In particular, Article 6.2 provides for cooperative approaches among Parties, with Internationally Transferred Mitigation Outcomes (ITMOs) potentially serving as an accounting mechanism to ensure that international linkages do not result in double-counting or other errors when comparing each country's emissions to its stated target.

Progress in Fits and Starts in Katowice

In Katowice, the delegates sought to write guidelines for Article 6 that could make its promise a reality. Negotiators had an opportunity to define clear and consistent guidance for the accounting of emissions transfers under Article 6.2. My view in advance of the Katowice talks was that a robust accounting framework for ITMO transfers could foster better linkage of climate policies across jurisdictions, but that if the guidance extended much beyond basic accounting rules, restrictive requirements could actually impede effective linkage, and be counter-productive. In precisely this regard, two potential impediments arose in Katowice. Proposals were introduced to place an explicit tax on ITMO transfers under the rubric of "Share of Proceeds," meaning a payment by the transferring parties to a fund intended to help vulnerable developing countries meet their costs of adaptation to climate change. Whereas the objective of financing adaptation has great merit, it is well covered and belongs in other parts of the Paris Agreement, not as a tax on trading. The other potential impediment was in the form of proposals for an implicit tax on transfers, known as "Overall Mitigation in Global Emissions," meaning that each transfer must result in a net reduction in overall emissions. Again, increasing ambition over time is important, but

that is dealt with appropriately in other parts of the Agreement, not by making it an implicit tax on market activity.

As the end of the second week of negotiations approached, it appeared that both of these potential impediments might be finessed, if not completely avoided. But then a single country – Brazil – decided to hold up the talks all night on the final Friday by insisting that it would not let there be any progress on rules for Article 6.2 unless the Conference agreed to state – under Article 6.4, viewed by most as an extension of the Kyoto Protocol's Clean Development Mechanism (CDM) – that it could use its large surplus of CDM credits (of questionable credibility) to help meet its Paris commitments in a manner that would have resulted in double-counting. The Brazilian delegation refused to budge, and the result was that Article 6 was not included in the Katowice decision. Rather, it was punted to COP-25, to be held next year in Santiago, Chile. So, the outcome with this second issue was clearly not a great success, but was it a complete failure, or was it something in between? On first blush, a lack of agreement on the rules of the road for Article 6.2 would seem to render ITMO transfers impossible – and hence reduce the scope for bilateral international linkages. But, as Nathaniel Keohane (Environmental Defense Fund) has pointed out, countries can move ahead with international transfers even without guidance under Article 6.2, because that article is explicit that countries may use transferred mitigation outcomes toward meeting their national targets *whether or not* additional rules have been written. The crucial phrase is that any transfer must be "consistent with guidance," meaning that if guidance exists, it must be followed, but meaningful action does *not* depend on the existence of guidance. Keohane indicates that this language was intentionally written into the Paris Agreement precisely because the United States and others feared that Brazil would try to hold Article 6.2 hostage to Article 6.4 — exactly as they did in Katowice. I hope very much that Dr. Keohane's interpretation is correct. My lingering concern, however, is that in the absence of knowing what some potential future guidance and rules might bring, Parties may be very hesitant to pursue bilateral linkages (and try to justify those in the context of their national targets via ITMO transfers). Only time will tell.

The Bottom Line

Any sound judgment of the ultimate success or failure of the Katowice climate talks – and more important, the success or failure of the Paris Agreement – will depend upon future climate negotiations and upon the domestic policy actions of the key countries of the world. For that, it remains too soon to observe or even predict the long-term outcome.

Some Additional References:

For a much more succinct assessment of the Katowice climate negotiations, see my column in The Conversation: "An Economist's Take on the Poland Climate Conference." For a summary of the outcomes of the Katowice meetings, see this report from the Center for Climate and Energy Solutions. For a detailed summary and assessment of the Katowice outcome, see Axel Michaelowa's slide deck. For an assessment that focuses on the process and outcome of the Katowice negotiations with regard to the role of carbon markets, see the COP24 Summary Report of the International Emissions Trading Association (IETA).

Expert Judgments on the Success of Climate Negotiations

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COP 24 in Katowice, Poland, has recently concluded and the perennial question looms large: has this round of negotiations been successful? Did the parties reach a meaningful consensus on the all-important fine print for implementing the Paris agreement? Of course, we cannot answer such questions objectively, at least not for another few decades, when we will have observed global emission trajectories for long enough to have a clearer view about progress. But even then, the evaluation task involves a lot of guesswork, due to the issue of the elusive counterfactual: what would have happened in the absence of the Kyoto protocol? And what if COP 21 in Paris had been a political failure like the Copenhagen COP?

Luckily, we can do better than doing the guessing ourselves, we can ask experts. That is precisely what Sonja Zitzelsberger, Astrid Dannenberg and I did in a recently published survey (REF 1). We polled about seven hundred experts in an online worldwide survey (addressed to both parties to COPs 3 to 20, and IPCC scientists), to get their views on the degree of success of past and current negotiation architectures. We asked the experts for a wide range of assessments, but all questions fit in one of two camps, specific and general. The latter allowed interviewees to set their own criteria for evaluation, while specific questions left little wiggle room for discretion. To fix ideas, here are examples of specific questions taken from the questionnaire, which took place prior to COP 21 in Paris: How confident are you that:

- The INDCs will be consistent with the 2C target?
- Countries will increase their INDCs if they fall short of the 2C target?
- The increased INDCs will be consistent with the 2C target?
- The majority of countries will fulfil their INDCs?

The following were instead framed in general terms: To what degree do you think the climate summits (COPs 1−20) have been useful on their own (apart from the official outcome)? Do you think that overall the Kyoto Protocol has been a success or a failure?

One of the most striking results of the analysis is that the nature of the question significantly affects the degree of optimism about the success of the negotiations. With few exceptions, respondents appeared to be more positive when questions were asked in general terms, but such enthusiasm was curbed when the criteria for success were explicitly mentioned in question. This is more evident for climate negotiators, especially when they were involved as party in COPs that were instrumental to reach an agreement under evaluation. Specifically, we find that negotiators who were more involved in the making of the Kyoto protocol (those who were parties to multiple conferences between 1997, when COP 3 in Kyoto took place, and 2001 which marked COP 7 in Marrakech) were more likely to see the Kyoto protocol as a success than those who attended fewer such conferences. Conversely, specific assessments such as those related to confidence in the Paris agreement's INDCs elicit a significantly lower probability of being optimistic, independent of how many relevant COPs the respondents attended as party to the delegation.

Three reasons are likely to rationalize such behavior, and probably all of

them play a role in explaining the positive effect of involvement on general views (only): self-serving bias, information asymmetry and selection effect. Let's look at them in turns.

Self-serving bias hinges on our desire to maintain or enhance self-esteem. It has long been known in psychology that perceptions of success are not only influenced by objective evidence, but also by subjective impressions and needs. Accordingly, we often tend to see our own performance and achievements in an overly favorable light. This tendency can lead to an actor-observer asymmetry in the perceptions of an outcome, since only the actor's (and not the observer's) self-esteem is at stake. Humans have developed many ways of processing information about own achievements that allow them to indulge in favorable judgments (REF 2-4). Research in psychology has shown that self-serving bias is likely to appear when the assessment context is ambiguous and allows room for choosing the evaluation criteria, or weighing them differently (REF 5). An important reason for this is that a subjective assessment cannot be wrong. Indeed, according to their own criteria for success, respondents' assessments may be accurate. In any case, it is impossible to prove that such an assessment is wrong, which arguably reduces the psychological "costs" of taking an overly optimistic stance. Selecting suitable criteria is a convenient way to repress information that would dampen the optimism. Questions that specify the criteria for success, in contrast, make repression difficult and "expensive," since optimistic answers may prove wrong and unveil the erroneousness of the illusion at a later stage. High costs of information repression thus decrease the likelihood of self-serving answers (REF 6). In the context of climate negotiations, more involved negotiators have greater responsibility for the outcome and may thus be more inclined to evaluate the negotiations more positively.

The second explanation for the greater optimism of more involved parties is information asymmetry between the more involved and the less involved negotiators. Experienced delegates are more exposed to confidential information; they have the opportunity to interact directly with other negotiators and to accumulate personal knowledge which requires repeated interactions and social networks; and they have a broader perspective on the achievements of past negotiations, historical shifts in positions and attitudes, and the difficulties that come up in the course of the negotiations. Experienced negotiators might therefore be optimistic for reasons that escape those who have attended fewer COPs.

The last channel which is likely to bias the responses of the experts is selection out of the sample: perhaps more optimistic negotiators are more inclined to stay in the game, while those who have lost faith in the UNFCCC platform drop out of the negotiations over time, skewing the results towards positive assessments. The survey data suggest that such self-selection effect is indeed present. Specifically, negotiators who attended the latest conferences are more optimistic than negotiators who attended earlier conferences and later dropped out from the negotiations. Interestingly, this applies to both general and specific assessments. Note that, in addition to the above explanations relating to psychological processes, information asymmetry and selection bias, there are also material incentives for the negotiators to assess (and praise) the outcome as success, such as social status and career prospects.

Ultimately, whichever the channels at work are, the views of experts involved in the climate negotiations are highly consequential for the implementation of current agreements, and the negotiation of future ones. If negotiators lose faith in a given architecture, such as the one laid out in Paris in December 2015, it is likely they will invest less in future meetings, or even oppose it to pave the way for alternative proposals. The experts surveyed in REF1 appear to have little hope that countries will comply with the INDCs pledged in the run-up to COP 21; furthermore, they are also relatively pessimistic about the prospects for increased ambition in (then) future negotiations.

Meanwhile, three more rounds of conferences have taken place, and the messages from COP 24 in Katowice are mixed (REF 7). At the outset of the summit, its president Michal Kurtyka said that delegates were gathering against a much more subdued backdrop. "The appetite for multilateral solutions is not as it was in 2015," he said. "The general mood is different." (REF 8). The election of Mr Trump in the U.S. and Mr Bolsonaro in Brazil, and more broadly the rise of populism and nationalism worldwide pose a serious threat to the Paris agreement, which relies on voluntary effort by sovereign states. Christiana Figueres, the former head of the UN climate secretariat, sums it up as follows: "Climate, that should not be a partisan issue, has become bound up in that ideological camp, mostly because of the allergy I think to the role of government, and the role of multilateral agreements. So climate ends up being one of the sacrificial lambs." (REF 8). Jerry Taylor, president of a U.S. think-tank called Niskanen Centre, echoes such concerns: "I don't know what more you could do to appease concerns on the right than an international agreement that allows you to set your own targets". "While Paris was a necessary step, it was not at all sufficient. It was a rather anaemic and unambitious step, and the fact that even an anaemic and unambitious step can be this problematic should be alarming to climate realists." (REF 8) Eliciting the expectations of the involved actors appears to be ever more important given today's increasingly uncertain political landscape.

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Treaties are Weak – For Political Economy Reasons?

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How should we explain to our students that real-world treaties are so different from the first-best ones? A recent answer is provocative.

When many of us teach environmental economics, we often emphasize the normative and the first-best policy solutions. We all know off many papers that analyze and derive the "best" international agreement, for example.

To be honest, I find it almost a bit embarrassing to teach such papers since we as well as our students know very well that the reality is quite different.

At the least, our students deserve a thorough discussion of why our ideal solutions have not yet been implemented globally. Personally, the need for such a discussion has motivated my research on rainforest conservation (Harstad, 2016) and on why Pigou taxes are rarely observed (Austen-Smith et al., 2019).

To focus on another example, most international environmental agreements are very weak in that they are not enforced or backed up by sanctions. The Kyoto Protocol said that, if a country emitted more than promised, it had to make up for it (+1/3 penalty) in the next period. That punishment, however, would just make future noncompliance even more tempting. The Paris Agreement gives up on such sanctions completely.

It does not have to be this way. After all, it is possible to use trade sanctions to deter noncompliance. The Montreal Protocol permitted such measures, and that protocol has been celebrated as one of our most successful international environmental agreements.

It is also not difficult to find theoretical arguments in favor of "strong" treaties that are fully enforced (by trade sanctions or other sanctions): See Nordhaus (2015), for example. Or, consider the following simple model (for details, see Battaglini and Harstad, 2019). Suppose a foreign country (F) benefits if the home country (H) abates more. Although such abatement gives both costs and benefits to H, the net cost to individuals in H vary across voters and political parties. For example, the net cost to a relatively green party (G) may be smaller than the perceived cost for a relatively brown party (B), while most voters may face costs that are in between these two extremes.

Suppose now that F and the policy incumbent in H negotiate a treaty. The policy incumbent is either G or B. The treaty species whether H should abate and the consequence if H does not. This consequence may be represented by the level of the sanction. It is natural to refer to the treaty as "strong" if the sanction is so high that every party, brown and green, prefer to comply rather than to face the sanction. A treaty is instead "weak" if the sanction is so small that the brown party prefers to not comply ex post, although the green party will. Thus, a weak treaty may or may not be complied with, depending on who will be in power at the time when compliance is decided on.

Both the first-period incumbent and the foreign country dislike the uncertainty characterizing a weak treaty. Furthermore, a first-period incumbent may want to tie the hands of the future policy maker. Thus, under a few standard assumptions,

it is possible to prove that the best treaty, signed by F and H's first period incumbent, is either a strong treaty or (if F benefits little from H's abatement) no treaty at all. A weak treaty is always dominated. (This result is referred to as Proposition 0 in Battaglini and Harstad, 2019).

The reason for why the first-period incumbent might be replaced is that there may be an election between the negotiation stage and the compliance stage. It is always difficult to predict elections, and thus it is natural to use so-called probabilistic voting models to analyze them (see Persson and Tabellini, 2000). In these models, it is common to assume that a policy maker receives the office rent "R" if being elected, in addition to the benefit that the election winner can decide on the policy in the future.

When the electoral uncertainty and the office rent R are added to the model, we arrive at a result that is in stark contrast to the benchmark discussed above (i.e, to Proposition 0): If the office rent R is sufficiently large, *the equilibrium treaty is always weak*! That is, the first-period incumbent and F intentionally agree on a sanction level that is so small that the brown party will not comply, if the brown party is elected. Only the green party will find it optimal to comply, given this small sanction level. Furthermore, such a weak treaty is negotiated regardless of whether the first-period incumbent is green or brown. (This result is referred to as Proposition 1 in Battaglini and Harstad, 2019). The results may be surprising: Even if the first-best treaty is a strong treaty (with a large sanction) and even if a strong treaty is feasible, the policy makers will always prefer a weak treaty as long as it is sufficiently important to win the next election.

To understand the result, note that with a strong treaty, the voters are indifferent between electing G and B: either party will find it optimal to abate in the future, given that the sanction level is high. With a weak treaty, in contrast, the parties are quite different: while G will comply, if elected, B will not. If the median voter prefers compliance (i.e., if the sanction level is larger than the median voter's cost of compliance), then G is more likely to be elected. If the sanction level is smaller, the voters might not find it worthwhile to comply only to avoid the sanction, and thus B, who will not comply, will be more likely to win. Consequently, regardless of whether the first-period incumbent is B or G, some type of weak treaty maximizes the incumbent's probability for being reelected.

The model is sufficiently simple to be taught to undergraduate students. For the same reason, it can also be extended and generalized in various directions. The paper discusses the role of technology, size and depths of treaties, and it allows for many electoral periods.

Since elections are characteristics of democracies, the theory predicts that democratic countries are more likely than others to sign international treaties, but that these treaties are rather weak and not necessarily effective. A first look at the data supports these predictions. In the paper, we also discuss a number of real-world cases. For example, Al Gore negotiated a very ambitious climate treaty on behalf of the US in the 1990s. As is consistent with our theory, the treaty was weak and could not be expected to be complied with if the republicans won the 2000 election (which they did).

Although our result and the mechanism behind it may at first appear to be surprising, they are in line with the literature on political economy. Earlier papers have already explained how political incumbents may try to influence future elections by accumulating debt (Aghion and Bolton, 1990), building infrastructure (Robinson and Torvik, 2005), or privatization (Biais and Perotti, 2002). Battaglini and Harstad (2019) follow this tradition and apply the insight to how international treaties will be designed in a political economy context.

So why is the result provocative? Because it suggests that although a better world is possible, policy makers intentionally sacrifice efficiency for reelection.

Future research will show whether the data supports this explanation, or whether there are other plausible theories that better explain the puzzle of why most treaties are weak. In the meanwhile, the theory may provide some food for discussion when students ask us why first-best and real-world treaties are so different.

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Anticipate Socioeconomic Impacts in Oceans for Adaptation

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A wide array of climate change impacts have already occurred in the marine environment, many of which affect fisheries and the livelihoods depending on them[1]. Physical changes in the temperature, chemistry, and currents in the oceans are producing changes in marine species traits that are causing shifts in marine species distributions and seasonality at rates even faster than those observed for terrestrial species[2,3]. These will carry serious consequences for the millions of jobs directly and indirectly depending on fisheries worldwide (43.5 million people in the sector and 200 million people in the processing industry including aquaculture), as well as impacts on the dietary needs for 4 billion people whose protein intake is partially supplied by the oceans, according to the 5th IPCC Assessment Report[4]. Research on climate change socioeconomic impacts and adaptation in fisheries is evolving largely lacking. I argue that **anticipating socioeconomic impacts and adaptation processes is necessary to successfully adapt to climate change in the oceans**. Research in this direction can provide the required insights to understand the range of adaptation pathways that are possible under future climate change scenarios, motivate policy action, and expand the focus from fisheries vulnerability to the adaptation of marine social-ecological systems.

From physical impacts to socioeconomic impacts

Climate change is having a direct impact on ocean chemistry and biophysical processes that has been widely recalled[6]. Researchers are able to project some of these changes into the future to gain insights on future ocean productivity[7] and plan both adaptation and mitigation actions based on

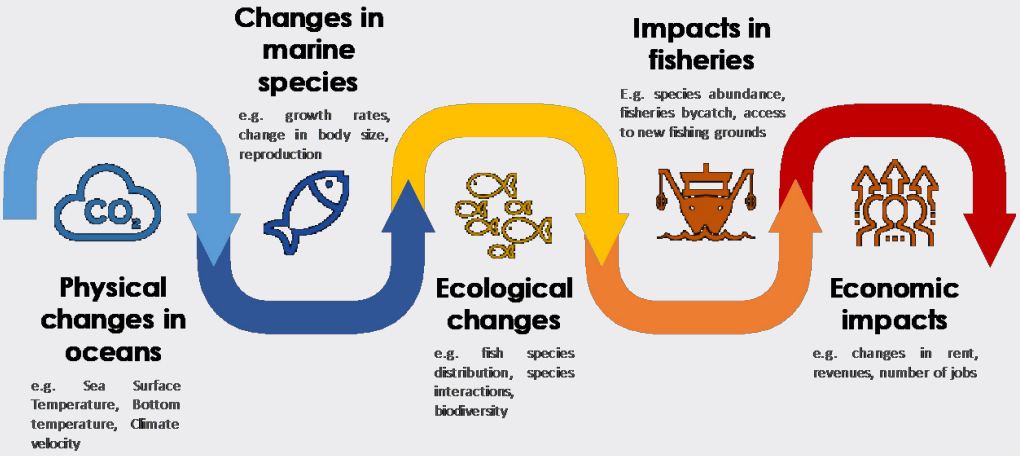

Figure 1. Climate change impact pathway in the oceans

fast, with important theory achievements[5] but empirical evidence on both economic impacts[1] and adaptation processes is the future availability of fish. Despite this knowledge, as we move along the impact pathway shown in Figure 1, we are losing

accuracy in our scientific understanding and ability to anticipate climate change impacts. From biophysical changes to changes in marine species. From changes in marine species to ecological changes. From ecological changes to impacts on the fishing activity, and from impacts on the fishing activity to impacts on the wider society. Every step in our understanding increases the uncertainty about the potential impacts of climate change in the oceans and their magnitude. This is no reason for policy inaction: **a precautionary approach requires governments to address climate change socioeconomic impacts despite the degree of uncertainty associated with them.**

Some of the main climate change impacts observed in marine species are distributional shifts[8]. Distributional shifts refer to changes in the species geographical ranges as a response to warming, where marine species move towards the poles and/or to deeper waters in order to maintain their preferred thermal range. Distribution shift is a great example of an impact pathway in the marine system. While species have only biophysical barriers in the oceans to adapt, fisheries targeting shifting stocks are limited by management areas established in the oceans, such as countries Economic Exclusive Zones (EEZ), areas established within the EU Common Fisheries Policy, or access rights established in international agreements. Recent studies show that, depending on the climate scenario chosen, between 46 and 60 new marine stocks will be shifting to new EEZs in the next decades[8]. At the European level, ICES has reported that highly important commercial species such as hake (*Merluccius merluccius*), or cod (*Gadus Morhua*), among others, have shown to have shifted northwards towards colder waters during the last decades, compromising fishing activities especially for southern countries that can no longer access northern fishing grounds. Our research shows that socioeconomic impacts of shifting stocks are not necessarily higher for the stocks shifting faster, but for the fisheries that are most dependent on a species that is crossing a management area. When a fishery is directed at a stock that is shifting and therefore exiting a country management area, economic theory suggests that countries will overharvest the species at the trailing edge[8,9]. Transboundary problems related to overharvesting species at the trailing edges are a real threat to global conservation and fisheries economic systems, and policies that reverse the effect of overharvesting are very much needed. Our ongoing research shows that agreements on catch shares between countries can compensate some of the costs of shifting stocks. Therefore, **adaptation policy needs to address both ecological and institutional challenges related to the expected shifts in fish stocks.**

Fisheries management under climate change

As climate negotiations continue to evolve in a race to counteract the increasing greenhouse gas (GHG) emissions and revert the worst climate change scenarios, adaptation to existing and projected impacts is unavoidable. In marine systems, adaptation to climate change has a short record and quantitative studies analyzing the effectiveness of adaptation options and their implications are still scarce. One of the big research questions in this respect is to understand to what extent existing fisheries management practices are resilient to climate change. In other words: how can current fisheries management adapt to expected climate change impacts? Recent research is addressing this question with exercises on the effects of closing the high seas to fishing, reforming fisheries globally, or creating marine reserve networks that reduce the expected impacts of climate change, and scientific efforts should continue in this direction.

Fisheries management has had numerous historical failures in attempting to limit catches to sustainable levels and this continues in many areas of the world. The failure of many traditional regulating structures to halt this collapse has led economists to propose several property rights- based approaches, arguing that appropriate assignment of rights internalizes externalities and facilitates stewardship, leading to sustainability through a profit motive[10]. Additionally, marine reserves,

defined as ocean areas protected against resource extraction, have also been defended as a solution to fisheries collapse, due to their potential positive spillover effects for adjacent fisheries[11]. **Recent work is incorporating climate change impacts to test these management regulations, suggesting that fisheries reform can have substantial economic gains in the face of climate change**[9]. This literature is still evolving and needs to incorporate more complexity in the consideration of climate change impacts, incorporate equity and social implications of adaptation policies and contrast model results with observed impacts and regulation effectiveness from empiric work.

Adapting the social-ecological systems of fisheries

Previous approaches to fisheries management contrast with the perspectives raised by new conceptual frameworks that tackle reorganization and renewal of communities and institutions[13]. **Most fisheries management strategies ignore or are ill-prepared to enhance resilience to climate change and a change in paradigm is needed for global fisheries to be able to adapt to climate change.**

Very recent work has started to assess the adaptive capacity of fisheries management to confront climate change, and identifies socioeconomic resilience attributes for different fisheries management regimes[13,14]. However, these studies often look at a single dimension of the system (economic, institutional), and no empirical assessments of resilience have been made yet in a comprehensive manner. **More research is needed in order to understand how to integrate the ecological, social an institutional resilience dimensions and operationalize resilience as an adaptation strategy.** For this, we are working on a novel framework where we conceptualize fisheries as social-ecological systems to understand adaptation to climate change (Figure 2). This approach is relevant to small-scale fisheries as well as large-scale fisheries that are associated with a social system (i.e. traditional tuna fleet, artisanal fisheries).

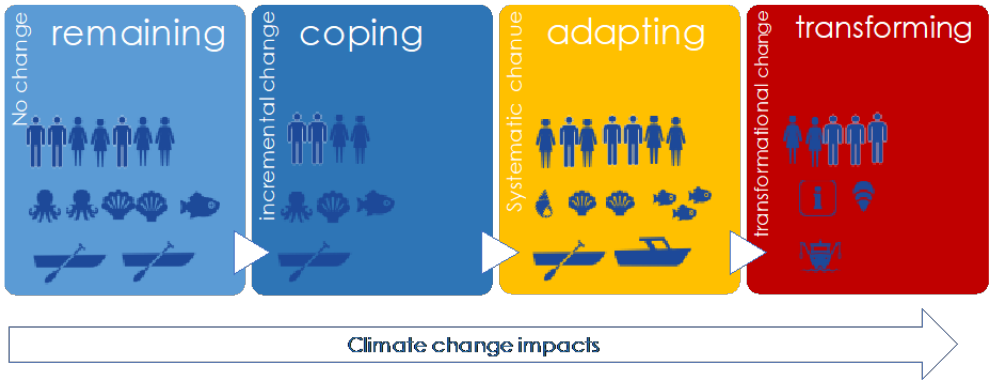

Figure 2. Adaptation levels towards climate change resilience in fisheries social-ecological systems

management from a socio-ecological perspective. The more holistic socio-ecological approach understands fisheries as an intertwined system where ecological and socioeconomic factors interact, by considering not only the resource system (fishing stocks) but also the fishing community, the set of rules and institutions that regulate fishing, and the interactions among these parts. In this context, a resilience perspective is increasingly used for understanding the dynamics of social-ecological systems under climate change[12]. While ecological resilience is traditionally defined as the resistance of ecosystems or species to disturbance, and the speed of recovery following disturbance; in social systems resilience is related to the disturbance,

Under the impacts of climate change, a policy objective would be to adapt the social-ecological system of the fishery to the expected impacts (i.e. shifting stocks). Adaptation can take place at different levels, mostly dependent on the magnitude of the impacts but also on the existing policies and social norms in place. Fisheries can react by remaining the same, coping with the impacts, or adapting to

the impacts with a systematic change (Figure 2). A step further would be a transformational change where the social-ecological system would transform to a different system which can be desired or not (Figure 2). Figure 2 summarizes the adaptation process as an example of where to place the policy objective. **Defining the adaptation objective is important in order to anticipate adaptation processes, develop adaptive capacity and design planned adaptation.**

Adapting marine livelihoods to the expected impacts of climate change is a complex task. Socioeconomic implications of climate change in the oceans are conditioned both by the accuracy of the observed and predicted impacts, the institutional arrangements and the fisheries management policies in place, and the ability of the society to cope, adapt or transform. I have shown key areas of research and policy innovations that can be further developed to advance adaptation in marine systems. We need to consider both ecological, social and institutional dimensions in fisheries, and improve our understanding of climate change impacts and adaptation processes. For this, we need to continue developing approaches that anticipate impacts and adaptation in marine social-ecological systems. While challenges may differ at the local and regional scales for fisheries adaptation, the science is advancing fast in both directions and soon we will be able to propose resilient adaptation actions for fisheries globally.

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Directing Technological Change to Save the Ozone

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Solving environmental problems often relies on adopting green technologies, but technological change is usually direction-blind. Is it possible to encourage greener innovations? Several studies show that environmental domestic regulations can (Jaffe et al. 2002; Newell et al. 1999; Popp 2010; Popp et al. 2010). However, environmental problems often span several borders, and domestic regulations become insufficient. Countries then must negotiate international agreements. Can such agreements foster the development of green technologies? International cooperation is easier to achieve when economic costs are low. Thus, it is possible that agreements occur only when technological solutions are available and cheap.

In this case, agreements would encourage adoption of existing technologies — as opposed to the development of new ones. In an on-going research paper (Dugoua 2019), I investigate whether international environmental agreements can foster innovation by studying the case of the Montreal Protocol. The protocol stands today as a hallmark of environmental diplomacy. It was signed in 1987 and aimed at protecting the ozone layer. Several kilometers above our head, ozone protects humans and ecosystems by absorbing incoming UV light. But, in 1974, scientists suggested that chlorofluorocarbon (CFC) gases catalyzed the destruction of ozone (Molina et al. 1974).

At the time, many industries used CFCs: foams, refrigeration and air-conditioning, aerosols, fire protection, and solvents. The theory purported that, once released into the atmosphere, CFCs rose to the stratosphere where sunlight broke them up releasing chlorine atoms. In turn, each chlorine atom reacted with ozone molecules, catalyzing their destruction. It took several years to confirm the theory and negotiate an international agreement. But eventually, it happened, in 1987. At the Montreal summit, high-income countries agreed on a CFC phase-out schedule. Since then, the agreement has been hailed as a success, and sometimes even, as the most successful environmental agreement ever negotiated.

For evidence of its success, look no further than the data on CFC consumption over time. In 1985, the world consumed more than a million tonnes of ozone-depleting substances; that number decreased fivefold in about ten years. How did we manage such exploit? We didn't stop using air-conditioning and other CFC-related services — quite the contrary. Instead, industries and consumers found ways of substituting CFCs with other compounds. I investigate whether the Montreal Protocol and its following amendments fostered such technological change.

The literature on the Montreal Protocol is not sparse. The happy ending of the crisis has triggered the curiosity of many scholars. Analyses of the treaty structure using game theory, for example, highlight how Montreal succeeded in overcoming free-rider incentives and induced full participation (Barrett 1999; Murdoch et al. 2009; Wagner 2016). However, opinions on the role of innovation remain mixed. In *Ozone Diplomacy*, for example, Richard Benedick, the head negotiator for the US delegation, argues that `(it) was evident (...) that the protocol was, in fact, moving industry in directions that two years earlier had been considered impossible' (Benedick 2009). Thereby, he claims a causal effect of the protocol on the development of CFC substitutes.

But, an often-heard narrative argues that CFC alternatives were already available in the 1980s. The Protocol then might not have done much to encourage innovation. The New York Times, for example, reported in August 2002 that, at the time of the negotiation, `(...) substitutes for the harmful chemicals were readily available (...)'. There exist several studies describing technological change during the ozone crisis (Gonzalez et al. 2015; Parson 2003; Taddonio et al. 2012). Yet, they have remained qualitative and, so, examining trends over time is not possible.

I analyze data on innovation and science to cast new light on technological change during the ozone crisis. I construct panel datasets of the number of scientific articles and the number of patents on CFC substitutes. Figure 1 shows the trends over time. I find that, before 1987, few patents and articles on CFC substitutes exist. Additionally, the pre-1987 trend is quite flat, especially for patents. The number of patents then increases by more than 500% over the period from 1987 to 2000. Articles increase by close to 200%. These findings are robust to using citation-weighted document counts. Indeed, the most cited patents and articles on CFC substitutes appear after Montreal.

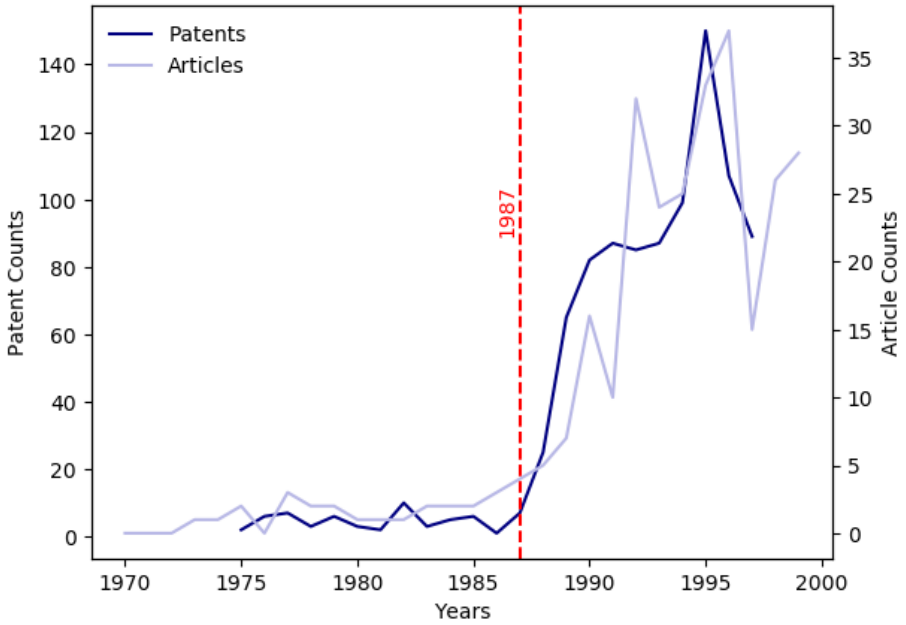

Figure 1. Counts of patents and articles on CFC substitutes

In the paper, I attempt to causally attribute the increase in science and innovation to the Montreal protocol and its following amendments. To do this, I implement a difference-in-differences design and a synthetic control method. I also leverage quantitative text analysis techniques — topic modeling — on the full text of patents and articles to help account for possible confounders. I provide details of these procedures in the paper.

A necessary step of my empirical work consists in tracking articles and patents mentioning CFC substitutes. To this end, I first compile a list of 14 molecules identified as potential substitutes in 1988. In fact, scientists knew which molecules were potential substitutes. Indeed, CFCs have a very specific molecular structure, and substitutes could not be too different. CFCs contain only carbon, chlorine and fluorine atoms: that structure gave them great thermodynamic properties. And these properties rendered them useful in many industrial processes. In the 1930s, CFCs truly embodied the miracle of modern chemistry as they were non-toxic, non-corrosive and cheap to produce.

The connection between molecular structure and industrial properties determined a limited set of potential substitutes. A substitute needed similar carbon chains

but with hydrogen instead of chlorine or fluorine. As a result, developing CFC substitutes was not about `new-to-the-world' compounds, but instead `new-to-the-industry' compounds. The critical technological challenges were about making large-scale production cost-efficient, redesigning processes and equipment already installed. I use patents to capture new process and formula designs for CFC substitutes. On the other hand, I use scientific articles to capture work on thermodynamic properties, toxicity profile, and environmental acceptability.

One might be surprised by the low number of patents and articles before 1987. After all, a strong mobilization around the issue of ozone depletion occurred as early as the late 1970s. For example, the USA unilaterally banned CFC use in aerosols in 1978. But, actually, physical and chemical substitutes for aerosol uses were already commercially available (roll-on stick and alkane mixtures). In any case, the ban affected only one type of CFC use. Aerosols represented about 20% of total CFC consumption and other sectors were unaffected.

In 1978, public awareness of the issue was so acute that even a major CFC manufacturer, DuPont, publicized its commitment to the cause. DuPont announced the investment of \$10 million in research and development (R&D) of CFC substitutes. But the effort was short-lasting. Three years later, DuPont had terminated these initiatives. The early 1980s, indeed, saw drastic demobilization. For one thing, atmospheric models were still unable to converge on precise predictions about the fate of stratospheric ozone. And governments with strong anti-regulatory agendas came to power. Reagan in the USA is one example.

Those accounts are consistent with R&D efforts remaining dormant until 1987. The Montreal Protocol then clarified incentives and signaled that CFC substitutes would be commercially viable. Firms then raced to develop and patent technologies related to CFC substitutes. An alternative narrative contends that such technologies might have already been ready and kept secret until the last moment. Hence, the Montreal Protocol might have provided incentives to patent whatever firms already had in-house, rather than fostered R&D. But the data do not support such a narrative well.

If the signature of Montreal only encouraged the patenting of technologies that already existed, we would observe a peak of applications for new patents soon after Montreal. I observe no such peak for all patentees as well as for the largest two, DuPont and Dow Chemical. Instead, the take-off is progressive consistent with firms ramping up R&D resources and, so, R&D output.

Finally, the timing of the increase seems to indicate that firms were quick to react. It takes only about three years to observe a level of patent applications that is (statistically) significantly higher. Besides, the effort sustains over the ten following years. Such a swift turn around will be surprising to some. How long would redirecting R&D towards CFC substitutes take? The answer might be shorter than you think. Other studies have found similarly short lags. For example, Popp (2002) shows that increases in energy prices induce more energy-related patenting and he observes over half of the effect in just five years.

My empirical analysis complements the literature on Montreal by showing and quantifying its effect on science and innovation. Too often, environmental-friendly technologies remain expensive, and environmental problems inadequately addressed. Decision-makers might prefer to wait for proven and cheaper technologies to arise before negotiating binding commitments. My paper shows that agreements can encourage the development of green technologies, and suggests they are part of the mechanism to obtain better technological solutions. Agreements, then, should be negotiated as early as possible.

Note: The graph plots the yearly number of articles or patents mentioning the names of any of the 14 CFC substitutes. We note a clear increase for both patents and articles after 1987, the year Montreal was signed. For patents, the graph shows any *granted* patent (as opposed to patent applications) between 1976 and 1999. The year on the x-axis, however, corresponds to the application date. For articles, the year on the x-axis corresponds to the year the article was published in the academic journal.

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