Under What Conditions Will the Paris Process Produce a Cycle of Increasing Ambition Sufficient to Reach the 2°C Goal?

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Abstract

The Paris Agreement establishes a cycle where parties submit their nationally determined contributions (NDCs) every five years. First-round NDCs fail to put emissions on a path consistent with achieving the Agreement's 2°C goal. This article presents a formal, dynamic model of reciprocity-based collective action among states and investigates the conditions under which the Paris process might deliver sufficient ambition ratchet-up to achieve the 2°C goal. The model is run under various assumptions about parties' (1) willingness to increase ambition as a function of what others promise and deliver, (2) compliance with promises, (3) trust in the outcome of the review process, and (4) trust in the outcome of the periodic global stocktake. The results show that the Paris process delivers sufficient ambition ratchet-up to achieve the 2°C goal only under a very restricted set of conditions. At minimum, parties need to increase ambition by 4 percent of global emissions when they submit, confirm, or revise their 2030 targets in 2020.

This article presents a computational model of the Paris Agreement's "ambition mechanism" and investigates under which conditions it facilitates achievement of the 2°C goal. The Paris Agreement (United Nations Framework Convention on Climate Change [UNFCCC] 2015a) contains an ambitious collective goal to limit global warming to "well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C" (Article 2.1[a]). On the other hand, the Agreement contains no targets for individual parties' emissions reductions. Instead, it establishes a cycle in which parties submit their nationally determined contributions (NDCs) every five years. Assessments of the first-round NDCs find that they fail to put emissions on a path consistent with

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achieving the temperature goal (Rogelj et al. 2016; UNFCCC 2015b). Therefore that goal will be achieved only if countries increase ambition over time. How to facilitate a cycle of increasing ambition was a central negotiation topic in Paris. Important outcomes include that parties shall report regularly on the implementation of their NDCs and that those reports will be subject to review. In addition, a "global stocktake" of implementation to assess collective progress every five years, and the outcome of this assessment, shall inform parties in updating and enhancing their NDCs. Finally, the Agreement stipulates that successive NDCs will represent a progression relative to the previous NDC by the same party.

According to Victor (2015), the Paris Agreement offers a way to get started and, over time, build confidence and willingness to do more. However, success is not assured: "It must be earned; confidence must be built" (Victor 2015, 3). Hale (2016) calls the Agreement a turning point in the climate regime's shift from a "regulatory" model to a "catalytic and facilitative" model aiming to create conditions for countries to progressively reduce emissions through coordinated policy shifts. The catalytic logic consists of stimulating first-movers through flexibility, iteration of commitments, and facilitation of positive feedback from prior action to subsequent action (Hale 2018). The review and stocktake are central for creating such positive feedback, but it is currently unclear how catalytic these will be (Hale 2018). Morgan and Northrop (2017) predict that the new paradigm will accelerate the pace of change, arguing that the five-year ratchet cycle creates the clear and predictable pathway that has been missing. Aldy (2016) explains the theory of "mutually reinforcing successive ambition" behind the Paris Agreement, with reference to Schelling (1956): if a party delivers emissions reductions *and* can see that others have also delivered meaningful reductions, then it would be more likely that the party would take a more ambitious second step in reducing emissions. Aldy (2016, 17) argues that "if the implementation of the Paris Agreement can achieve this dynamic over time, then it will succeed in delivering progressively more ambitious emission mitigation." Bang et al. (2016) strike a more cautious note, arguing that to build an effective climate agreement and to strengthen it over time, states rely on two types of mechanisms—norms and incentives. Whereas an ideal agreement would harness both mechanisms, the Paris Agreement relies disproportionately on norms and does little to restructure incentives, they argue. Keohane and Victor (2016) expect that the pledge-and-review approach employed by the Paris Agreement will produce only coordination at a relatively low level, unless review mechanisms are highly effective and designed to engender deeper cooperation. Allan (2019) argues that the ratchet-up mechanism was the one win that could hold promise for those parties wanting an ambitious agreement and a significant consolidation lessening the sting of adopting an insufficient agreement. She also pins hope on NGOs serving as whistleblowers identifying individual laggards to complement the aggregate assessment under the stocktake.

Motivating the current analysis, a key insight by Nyborg (2018) is that viewing the Paris Agreement's framework of voluntary pledges without strong enforcement as a break-through achievement seems to involve an implicit assumption that a cooperative equilibrium exists despite the Prisoners' Dilemma structure of climate cooperation. One rationale for such an assumption is the idea that governments have so-called reciprocal preferences, meaning that their willingness to reduce emissions is increasing with others' willingness to do the same (Nyborg 2018). Using a game-theoretic model, she shows that with such preferences, the system of pledging, reporting, reviewing, and stocktaking makes theoretical sense, because it may enable countries to reach a cooperative equilibrium, rather than the alternative noncooperative equilibrium. Hers is, however, a static model, where countries are homogenous and make a binary choice to pollute or abate; thus it cannot capture the dynamics of increasing ambition over time.

Like Nyborg, this article views the Paris Agreement as a tool for facilitating reciprocity-based collective action among states. Some authors have, however, questioned the dominant conceptualization of climate change mitigation as a collective action problem. Bernstein and Hoffmann (2018) view it instead as primarily a carbon lock-in problem and argue that the Paris Agreement embodies at least the beginning of a shift to this conception. Other authors point to survey results showing strong and robust public support for unilateral mitigation (for a review, see McGrath and Bernauer 2017) as challenging the collective action conceptualization (Mildenberger 2019) and reflecting an emerging global norm where mitigation is the "right thing to do" even if others fail to act (Beiser-McGrath and Bernauer 2019). Furthermore, some see nonstate and substate actors as central to the Paris process (Bernstein and Hoffmann 2018; Hale 2016), while this model limits agency to states only.

Extant literature, be it theoretical or empirical, provides little grounds for assessing the likelihood that the Paris process will actually foster a dynamic that builds trust and delivers increasing ambition, and at the pace needed to reach the temperature goal. The assessments of first-round NDCs relative to the temperature targets (Rogelj et al. 2016; UNFCCC 2015b) are sensitive to assumptions about emissions post-2030; however, because the assessments focus on current NDCs, limited effort is devoted to developing post-2030 trajectories. Raftery et al. (2017) provide coherent emissions trajectories until 2100, using United Nations projections for population growth combined with a statistical model for GDP per capita and carbon intensity. They estimate a 5 percent probability of limiting warming to less than 2°C. However, these are "projections assuming that the general range of trends of the past 50 years continues into the future" (638) and hence do not explicitly include future policies, not even current NDCs.

This article addresses the identified knowledge gap by developing a formal, dynamic, agent-based model and investigates the conditions under which the Paris process delivers sufficient ambition ratchet-up.

Method

The envisioned ambition cycle is a dynamic process in which parties adjust their ambition in response to the observed and promised behavior of others. For modeling such adaptive systems, agent-based modeling is a suitable method (Miller and Page 2009). Such models can be defined as "computerized simulations of a number of decision-makers (agents) and institutions that interact through predescribed rules" (Farmer and Foley 2009). In the current model, the agents are states, and the institutions are interpretations of the Paris Agreement.

Model Institutions

The Paris Agreement and the accompanying decisions established the basic elements of a contribution cycle, with more detailed rules and procedures adopted at COP24 in 2018.

Article 4.9 requires parties to communicate an NDC every five years. The first NDCs were communicated in 2015, and new ones are due in 2020 and then every five years thereafter (Decisions 23 and 24). Parties have yet to agree on the end date of each NDC. Most first-round NDCs contain goals for 2030, while some contain goals for 2025. Parties with 2030 targets are requested to confirm or revise them in 2020 (Decision 24). From 2031, there will be common time frames, but their length has not yet been agreed (UNFCCC 2019a, 17). The model assumes a common time frame of five years. Hence NDCs submitted in year t address emissions in year $t + 6$ until and including year $t + 10$. Those five years are termed a *contribution period*; see Figure 1.

Article 13 establishes a transparency framework. Parties shall report their emissions and information necessary to track progress in their NDC implementation and achievement biennially starting from 2024 (UNFCCC 2019b, 18). In the UNFCCC accounting framework, emissions reports typically contain data

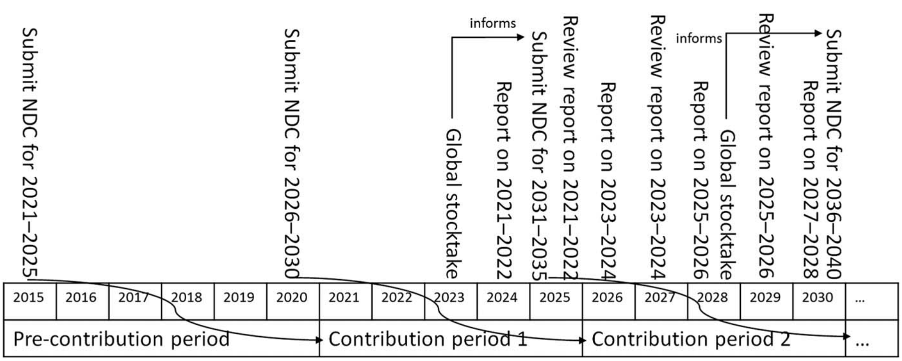

Figure 1
Interpretation of the Process Established by the Paris Agreement

for the year $t - 2$ or earlier (Briner and Moarif 2016). In the model, the 2024 report thus contains data on the first two years of implementation (2021 and 2022), and so forth. Article 13 also states that reports shall undergo a multilateral review. It will consist of a technical expert review followed by a multilateral consideration of progress (UNFCCC 2019b). The secretariat shall commence preparation of the review immediately after a transparency report has been submitted (UNFCCC 2019b). The model assumes that the review will be completed the year after report submission, so the first review is completed in 2025 and will provide information on whether parties' actions and emissions in 2021 ($t - 4$) and 2022 ($t - 3$) were consistent with their NDCs.

The transparency framework is focused on individual parties and will not be sufficient for assessing aggregate progress (Briner and Moarif 2016; Rajamani 2016). Collective progress toward achieving the Agreement's goals will be assessed as countries take stock of implementation of the Agreement every five years starting in 2023 (Article 14). In preparation of their next NDC, parties shall explain how it has been informed by the outcomes of the stocktake (UNFCCC 2019a). Notably, the stocktake is not mandated to assess individual parties, because this was opposed by some parties during Paris negotiations (see Brun 2016; Rajamani 2016). The model assumes that the first stocktake assesses progress in the first two years of implementation and that subsequent stocktakes assess the progress during the five years since the previous stocktake. As the model starts in 2020, when implementation of the Agreement itself begins, it excludes the 2018 Facilitative Dialogue, which was envisioned as a "pre-stocktake" but failed to explicitly encourage countries to raise ambition.

The model specifies NDCs as emissions reductions within a five-year contribution period, expressed as percentage points (pp) of the given party's emissions in 2020. Estimation of 2020 emissions is explained in the next section. To illustrate, if a party with initial emissions of 100 Mt pledges to reduce emissions to 95 Mt by 2025 and to 87.5 Mt by 2030, its first NDC takes the value 5 pp, and the second takes the value 7.5 pp. NDCs are translated into annual contributions for the five-year contribution period, assuming a linear trend. In the example, annual contributions are 1 pp in the first period and 1.5 pp in the second.

Each new NDC "will represent a progression beyond the Party's then current [NDC]" (Article 4.3). While this formulation leaves some room for interpretation, the model implements it as a requirement that each party's NDC be no less ambitious than its previous NDC, measured in annual emissions reductions (percentage points of 2020 emissions). Hence a party pledging to reduce emissions 2 pp below 2020 levels by 2025 must pledge to reduce them by at least *another* 2 pp by 2030. This is a strict and probably overly optimistic interpretation of this "progression principle." Furthermore, it is unclear whether this Article is legally binding and, if it is binding, whether it could be enforced. For these reasons, we run the model under two different assumptions, one where the parties respect the progression principle and one where they ignore it.

Opening up for "the use of internationally transferred mitigation outcomes towards [NDCs]," Article 6 suggests that a party may finance emissions reductions in another party's territory and count them as part of the fulfillment of its own NDC. Negotiations on the rules and procedures could not be agreed as scheduled in 2018 and are still ongoing (UNFCCC 2019a). The model also allows for transfers and does not distinguish such mitigation arrangements from strictly domestic mitigation. It follows that a party's total contribution is not capped at 100 percent of its own (2020) emissions.

Model Actors

The Paris Agreement has been signed by 195 countries, all of which have submitted a NDC. The EU has a joint NDC and is therefore modeled as a single actor. Owing to data problems, six small countries are excluded from the analysis, which means the model contains 162 actors, who are responsible for virtually all global anthropogenic emissions, excluding international aviation and shipping.

Actors' initial emissions are calibrated on data from 2015 (Güthschow et al. 2018). For emissions from land use, the average over 2011–2015 is used, to limit the effect of interannual volatility. The model assumes emissions stay unchanged until 2020, when implementation of the Paris Agreement starts. Thus pre-2020 emissions, covered by the Kyoto Protocol and the Cancun Agreements, are exogenous.

Because NDCs take a variety of formats and are described ambiguously, translating them into emissions is no trivial task. The analysis builds on three different sources for quantifications of first-round NDCs (Holz et al. 2018; Meinshausen and Alexander 2016; PBL 2017). Each source provides a high-emissions estimate and a low-emissions estimate for some parties. There are three reasons for such ranges. Some parties, like the United States, have explicitly stated their target as a range. For other parties, the range is due to uncertainty in translating the NDC into emissions. For a third group, the high-emissions estimate refers to unconditional elements in the NDC, while the low-emissions estimate includes also elements that are conditional on foreign financial support. The model will be run for both the high-emissions and the low-emissions scenarios. Each scenario is compiled by taking the mean across those of the three sources covering a given party. In the high-emissions scenario, emissions in the period 2020–2025 increase by 2 percent, while in the low-emissions scenario, they decrease by 2 percent. However, this range does not capture all uncertainty. Rogelj et al. (2017) find that projected 2030 emissions range between −10 percent and +20 percent around the median. The source of greatest uncertainty are the variations in socioeconomic baseline development. Thus it is possible that 2030 emissions will lie outside the range considered in this model while still being consistent with NDCs. The ambiguity in NDCs also illustrates a weakness of the Paris Agreement, which is sparse in formatting requirements for NDCs. The additional guidelines agreed in 2018 (UNFCCC 2019a) will, it is hoped, reduce ambiguity of future NDCs.

Most parties submitted NDCs with targets for 2030 and are thus required to confirm or revise them in 2020. The model assumes such updates affect annual contributions in the second half of the next decade, while contributions until 2025 are determined by the NDCs already submitted, by taking the midpoint between current emissions and current 2030 targets.

First-round NDCs indicate parties' initial willingness to contribute (**IWTC**)[1] and are thus central inputs to the model. The model defines a party's **IWTC** as the percentage reduction in emissions in 2025 implied by its NDC relative to 2020 levels. For parties whose NDCs imply increasing emissions, this parameter will be negative. Because behavior pre-2020 is exogenous to the model, the revision of NDCs in 2020 is not modeled as a regular pledging event informed by others' behavior in the preceding years. Instead, the model allows for **IWTC** to be boosted in 2020, through the input parameter **Boost2020**, applied uniformly to all parties. This means that it is possible to make assumptions about behavior when implementation formally begins post-2020 independent of what countries put on the table in 2020.

The analysis assumes parties would continue the trend set by their **IWTC+Boost2020** absent any international process. Global emissions would thus increase from 2020 to 2100 by 38 percent in the high-emissions scenario and decrease by 27 percent in the low-emissions scenario, given that **Boost2020** is zero. These baseline scenarios imply lower emissions than the no-policy baseline scenarios included in the IPCC AR5 (Figure 6.5), where, in the median scenario, 2100 emissions are 70 percent higher than 2020 emissions, while in the most optimistic scenario, they are roughly equal to 2020 emissions. This assumption is consistent with the conclusion that current NDCs "with continued action" reduce emissions below AR5 no-policy baselines (Rogelj et al. 2017).

For the Paris process to result in a positive cycle of ambition, parties must be willing to increase their contributions in response to others' contributions. The model varies the strength of this influence through a **Reciprocity Parameter** (**RP**), which takes values from 0 to 1. A value of, for example, 0.5 means that when party A's perception of other parties' contributions increases by 1 pp, its own willingness to contribute increases by 0.5 pp. Because this parameter is not observed and hence cannot be empirically calibrated, it will be varied systematically across model runs. It will also vary stochastically across parties within each run.

This type of reciprocity would be counter to basic economic models of climate cooperation, which predict that one country's unilateral ambition increase will lead other countries to lower their ambitions, implying negative **RP** (e.g., Hoel 1991; Konrad and Thum 2014). On the other hand, the observed behavior of individuals implies positive **RP** (e.g., Bardsley and Moffatt 2007; Fischbacher and Gächter 2010; Fischbacher et al. 2001). Transposing these observations

1. Input parameters to the model are denoted in bold.

from behavioral economics onto states can reverse the pessimistic prediction from models of cooperation (Buchholz and Sandler 2017). Hafner-Burton et al. (2014) provide reasons for why patterns observed in cooperation among individuals can shed light on decisions by international negotiators. Furthermore, if reciprocity is widespread in the general population, a government aiming at reelection may act as if it had such preferences (Nyborg 2018).

In addition to reflecting a basic preference for conditional cooperation, the **RP** could also capture the positive reinforcement mechanisms outlined by Urpelainen (2013): enacted climate policy may have dynamic effects that alter the payoffs of the international cooperation game, either by spurring technological advances to reduce mitigation costs or by creating new political constituencies. Hale (2018) discusses two additional reinforcement mechanisms: policy learning through experimentation and diffusion; norm change. The key common feature of these mechanisms is that mitigation becomes more attractive for each country the more global emissions are reduced. An observed example is provided by Dimitrov et al. (2019), who argues that social learning is an important explanation for the agreement in Paris and for the spate of INDCs launched just beforehand.

Although the model can accommodate both positive and negative **RP**, the current analysis excludes negative values, because—given the model structure—it is trivial to predict that such values are not compatible with the Paris Agreement's goals. Conversely, the average value across actors cannot be larger than 1, because then equilibrium willingness to contribute would tend to infinity, and such an average would be unrealistic in light of empirical evidence on individuals (Fischbacher and Gächter, 2010)

Perceptions of others' behavior include both what is promised and what has been delivered, with equal weight given to each. A party's promise is weighted by its *credibility*, (*cred*)[2], and by its share of emissions, (*e*).[3] Variable $cred_{it}$ captures other parties' confidence that i will comply with its new NDC, operating as a discount factor. The variable is updated through the review process described below. Perceptions of past aggregate contributions are derived from the outcome of the previous stocktake (termed *stock*),[4] also explained below. These assumptions result in a target function for NDC formulation:

$$NDC_{it} = \mathbf{IWTC}_i + \mathrm{RP}_i\left(\sum\nolimits_{j\neq i}^{N-1} NDC_{jt} \times cred_{jt} \times \mathbf{e}_{j2020} + stock_{it}\right)/2. \qquad (1)^5$$

2. Endogenous variables are denoted in italics. The subscript t here refers to the most recent review available at time t.
3. Because NDCs are measured as percentage point reductions from 2020 emissions levels, they are weighed by emissions shares in 2020. Party i's emissions are excluded from the calculations of others' emissions shares so that the weights sum to 1.
4. The subscript t here refers to the most recent stocktake available at time t.
5. This is a simplified equation that assumes NDCs are positive. The more general equation is found in the technical appendix.

Because the target function for party i's NDC for period t includes others' NDCs for period t, the target functions are interdependent. The model contains an idealized process of NDC formulation in which indicative NDCs are adjusted iteratively until no party wants to change its NDC given all others' NDCs, at which point they are finalized.[6] The model converts the NDC into annual emission reduction pledges, annotated *ndc*, assuming a linear trend over the five-year period.

Furthermore, it is assumed that parties intend to achieve what they pledge, abiding by an obligation set in Article 4.2. They nevertheless sometimes fail to comply perfectly with their pledges, for unforeseen reasons. The probability of compliance varies across parties and is not directly observable by others. In year t, party i will reduce emissions by ndc_{it} (i.e., $contribution_{it} = ndc_{it}$) with probability **Compliance Rate**$_i$; otherwise, it will keep emissions constant from year $t - 1$ (i.e., $contribution_{it} = 0$). If ndc_{it} is negative, and i happens not to comply, it will emit 1 pp more than pledged (i.e., $contribution_{it} = ndc_{it} - 1$).

The review process assesses whether parties comply with their NDCs, and the review outcome affects their credibility ($cred_i$). Each review covers two years, and compliance in each year is binary, so that the possible outcomes are compliance in zero, one, or two years. The review process is unlikely to be perfect, and therefore parties might not feel completely certain of others' compliance, even though the review uncovered no defection. Hence a positive review is discounted by the parameter **Confidence in Review (CiR)**, which, in this analysis, takes values from 0 to 1. The weight given to the last review relative to i's credibility at $t - 1$ is determined by the **Learning Parameter** (**LP**), which in the current analysis is kept constant at 0.5. After each review, a party's credibility is updated according to the following formula:

$$cred_{it} = \frac{years\ \ in\ \ compliance}{2} \times \mathbf{CiR} \times \mathbf{LP} + cred_{it-2} \times (1 - \mathbf{LP}) \qquad (2)$$

Credibility is defined to be zero from the start, so that until parties see verified actions by others, their *NDCs* will simply equal their **IWTC+Boost2020**. The extent to which the Paris process builds trust among parties will be captured by increases in credibility. Over time, $cred_i$ converges toward $compliance\ rate_i$ × **CiR**. Note that when **CiR** is less than 1, credibility cannot reach 1 even if compliance is perfect. If parties reduce emissions by more than promised or if they believe the review underestimates emissions reductions delivered (**CiR** > 1), credibility could in theory increase above 1, but the current analysis will not consider such scenarios.

6. To limit computation time, NDCs are finalized when no party would want to change its indicative NDC by more than 0.1 ppt. This simplification has a negligible effect on results.

Perceptions about aggregate progress in the past are informed by the global stocktake. Again, parties will unlikely feel completely certain that others have actually contributed as much as indicated by the stocktake, so they discount the outcome by the parameter **Confidence in Stocktake** (**CiS**), which in this analysis takes values from 0 to 1.[7] The perception by party i at time t is given by

$$stock_{it} = \sum_{j \neq i}^{N-1} \sum_{n=t-5}^{t-1} contribution_{jn} \times \mathbf{e}_j \times \mathbf{CiS} \tag{3}$$

Parties hence consider the sum of other parties' contributions over the previous five years[8] measured in pp of 2020 emissions. Note that because the stocktake is not mandated by the Paris Agreement to assess individual parties, the outcome does not affect parties' credibility.

The model excludes information produced by other sources than the Paris institutions. In reality, nonstate actors will likely contribute significantly to enhancing transparency (Van Asselt 2016). A notable complementary source is *Global Carbon Budget*, published annually during the COP. However, this analysis uses UNFCCC national inventories where available, because "we assess these to be the most accurate estimates because they are compiled by experts within countries that have access to detailed energy data, and they are periodically reviewed" (Le Quéré et al. 2018, 2145). Therefore the quality of other sources partly derives from the official reporting and review system, justifying the model's focus on the latter.

Figure 2 illustrates the model's relationships in a simplified version containing only two parties—Blue and Red. Input parameters are displayed in bold and endogenous variables in italics. Global processes and variables are shown in black. Solid arrows show effects of parameters on variables or of one variable on another. Dashed arrows denote effects on other relationships (interactions). *NDC ambition* in Red has a direct effect on *NDC ambition* in Blue, and the strength of this relationship is determined by Red's *credibility*. Red's contributions also have indirect effects on Blue's *NDC ambition* (through the global stocktake) and on Red's own *credibility* (through the review). The effectiveness of global stocktakes and reviews is determined by the global parameters **CiS** and **CiR**, respectively, which are not included in the figure. The Technical Appendix (https://www.mitpressjournals.org/doi/suppl/10.1162/glep_a_00548) provides a complete explanation.

As noted, first-round NDCs are estimated to keep global emissions roughly constant in 2020–2025. However, compared to a scenario derived from policies in place before the NDCs were announced, unconditional NDCs reduce emissions

7. In theory, **CiS** could be above 1 if parties believe the stocktake overestimates global emissions, but such scenarios are not included in the current analysis.
8. An exception occurs for the first stocktake in 2023, which assesses only the years 2021 and 2022.

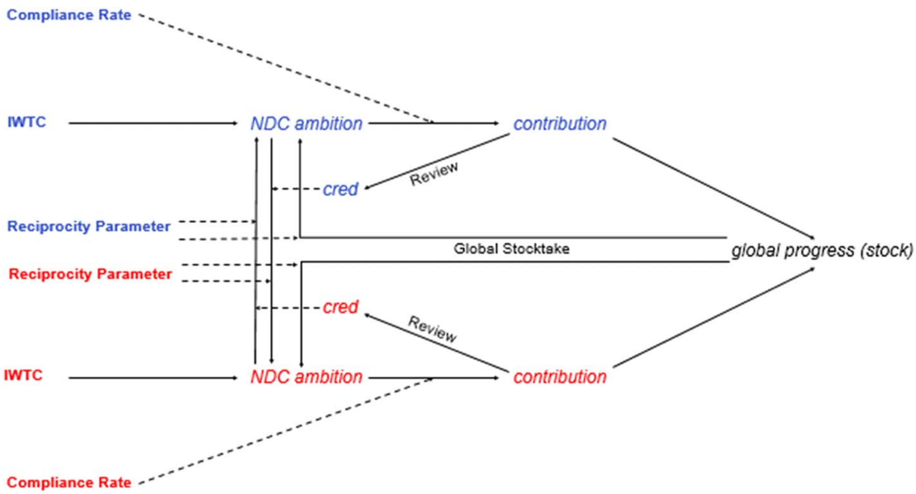

Figure 2
Simplified Model Cycle

by around 3.5 percent (Rogelj et al. 2016; Table A5 in Technical Appendix).[9] Progress in the first contribution period is assessed against this pre-NDC scenario. Subsequent stocktakes measure progress over and above the previous contribution period.

US Withdrawal

On June 1, 2017, President Trump announced that the United States would leave the Paris Agreement and immediately stop implementing it. Using a sector-by-sector review, Galik et al. (2017) estimate that emissions under the Trump administration will remain approximately constant at 2015 levels, whether the administration holds power for four or eight years. Climate Action Tracker (Höhne et al. 2017) similarly concludes that the Trump administration's climate policies will result in US emissions flatlining instead of continuing the recent downward trend, if they are fully implemented and not compensated by other actors. The current analysis assumes Trump serves a single term and that the subsequent president immediately reenters the Paris Agreement and reverts to the ambition levels signaled by the Obama administration, measured in annual emissions reductions. Hence Obama's targets will be postponed by four years. The effect of one or two terms with Trump is analyzed in depth using the same model as the current article by Sælen et al. (2020).

9. Unconditional NDCs correspond to the high-emissions NDC scenario. Conditional NDCs reduce emissions further by around 3.5 percent according to the data used in this model. Which of the two figures is used in the model depends on whether the high-emissions or low-emissions scenario is chosen.

Carbon Budget Remaining Given the Paris Agreement's Temperature Goal

How much greenhouse gas can be emitted without exceeding the Paris Agreement's temperature goal is subject to considerable uncertainty and debate. A recent analysis (Goodwin et al. 2018) uses a novel approach to reducing the uncertainty and estimates that meeting the 2°C target in 66 percent of scenarios implies that the budget remaining from the beginning of 2017 is 35–41 times current annual emissions. (The equivalent figure for the 1.5°C target is 17–18.) This budget is somewhat larger than most earlier estimates (e.g., Global Carbon Project 2016; International Energy Agency 2016). Because the model assumes emissions remain at constant levels until the beginning of 2021, the remaining 2°C budget is thus assumed to be 31–37 times current annual emissions.

Results and Discussion

Many of the model's input parameters are uncertain. It is therefore run for multiple values of those parameters (Table 1, first two columns). In total, the analysis reported here examines 351,384 different parameter configurations.[10] Moreover, the probability distributions for the parameters are also unknown, so probabilities cannot be assigned to different model runs. Figures 3 and 4 show the emissions trajectories in a small selection of these runs. Both figures isolate the effect of two binary input parameters, high-emissions versus low-emissions interpretations of first-round NDCs, and the progression principle. The top row uses the high-emissions estimate (**High**), whereas the bottom row uses the low-emissions estimate (**Low**). The right-hand column assumes that the progression principle is respected (**Prog**), while the left-hand column assumes that it is ignored (**No prog**). In Figure 3, all remaining parameters are set at the midpoint of the examined range (see Table 1, column 2). Under these settings, the Paris process fails to produce increasing ambition over time. Instead, global emissions increase for the entire time period considered. The difference between the **High** and **Low** scenarios is large and increasing over time. Hence, in this model, the initial ambition level is highly influential for cumulative future emissions. The difference due to the progression principle is more limited, but when respected, it does limit the emissions increase.

Figure 4 shows the results for more optimistic scenarios where the other parameters are set at the second-highest value examined (see Table 1, column 2). Now, the Paris process succeeds in generating increasing ambition, at least after some time. In the **Low** scenarios, global emissions reach zero well before 2100, while in the **High** scenarios, 2100 emissions are close to current levels, after initially increasing. The progression principle has greater effect in the **High** scenarios than in the **Low** scenarios, because in the latter, there are few instances where any party would want to decrease its ambition, in any case. Only the

10. Within each scenario, **Compliance Rate**$_i$, and **RP**$_i$ are uniformly distributed across parties with a 0.2 range, except when they are 0 or 1, in which case, there is no variation across parties.

Table 1
Parameter Values Included in the Analysis and Minimum Values Observed in Scenarios that Stay Within the 2°C Carbon Budget

Model Parameter	*Range Examined, min–max (Interval)*	*Absolute Minimum*		*Minimum When Other Variables Are Not at Their Maximum*	
		No prog	*Prog*	*No prog*	*Prog*
Boost2020	0–5 pp (1 pp)	3 pp	1 pp	5 pp	4 pp
Compliance rate mean	0–1 (0.1)	0.8	0.8	1	0.9
Reciprocity parameter mean	0–1 (0.1)	0.3	0.3	–	0.9
Confidence in review	0–1 (0.1)	0.4	0.3	1	0.9
Confidence in global stocktake	0–1 (0.1)	0	0	–	0.8

most optmistic of these scenarios (low-emissions NDCs and progression principle respected, bottom right) limits emissions to within the carbon budget estimated for the 2°C target. In this scenario, cumulative emissions after 2020 total 35 times current emissions, hence within the 31–37 range identified in

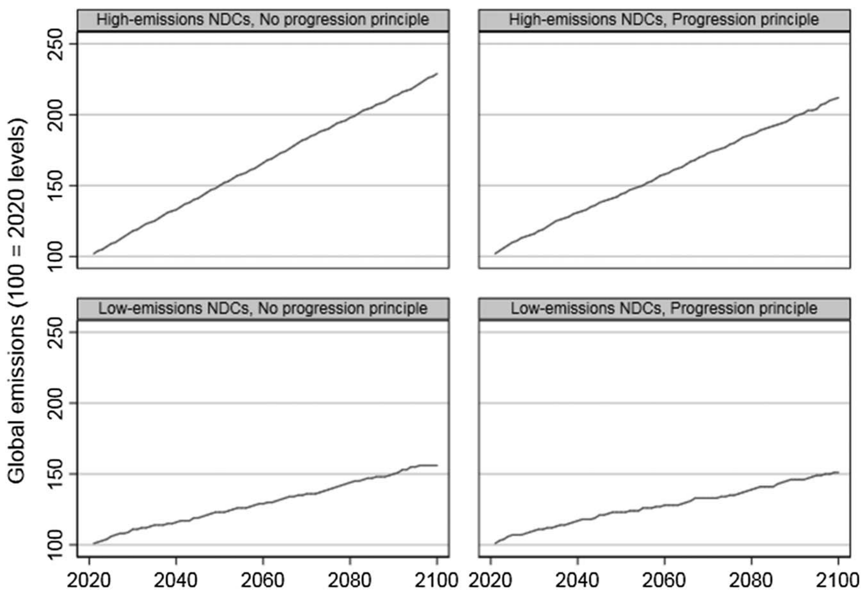

Figure 3
Development of Global Emissions

All other parameters at their midpoints.

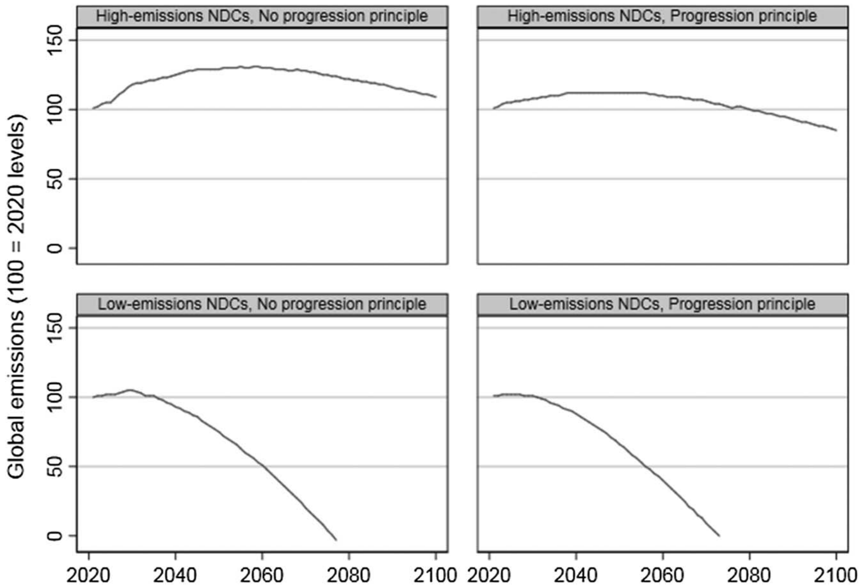

Figure 4
Development of Global Emissions

All other parameters at their second-highest values.

the previous section. In the scenario without the progression principle (bottom left), the figure is 39. As all remaining parameters in the model are set at the second-highest value examined, the analysis so far shows that the model achieves the 2°C target only under only a very restricted set of conditions. The remaining analysis will identify these conditions in more detail.

Overall, only 986 of the examined scenarios stay within the upper bound for the 2°C carbon budget estimate, that is, 37 times current annual emissions. These scenarios amount to less than 0.3 percent of all scenarios examined. Notably, all scenarios starting from the high-emissions ones end up exceeding this budget. Hence, under the most cautious interpretation of first-round NDCs, the model rules out achieving the 2°C target. Among these 986 scenarios that stay within the upper bound for the 2°C carbon budget, the progression principle is respected in 582. This means that the principle increases the share of scenarios staying within this budget from 0.23 percent to 0.33 percent. In other words, while helpful, it is not a necessary condition.

Figure 5 plots all the 582 parameter combinations that lead to cumulative emissions less than 37 times current annual emissions when the progression principle is respected. Each parameter is represented by an axis and each scenario by a line joining the parameter values represented in that scenario. The figure shows that the lines are concentrated toward the upper ranges for all parameters, with only a few lines passing through lower-range values. It hence indicates that

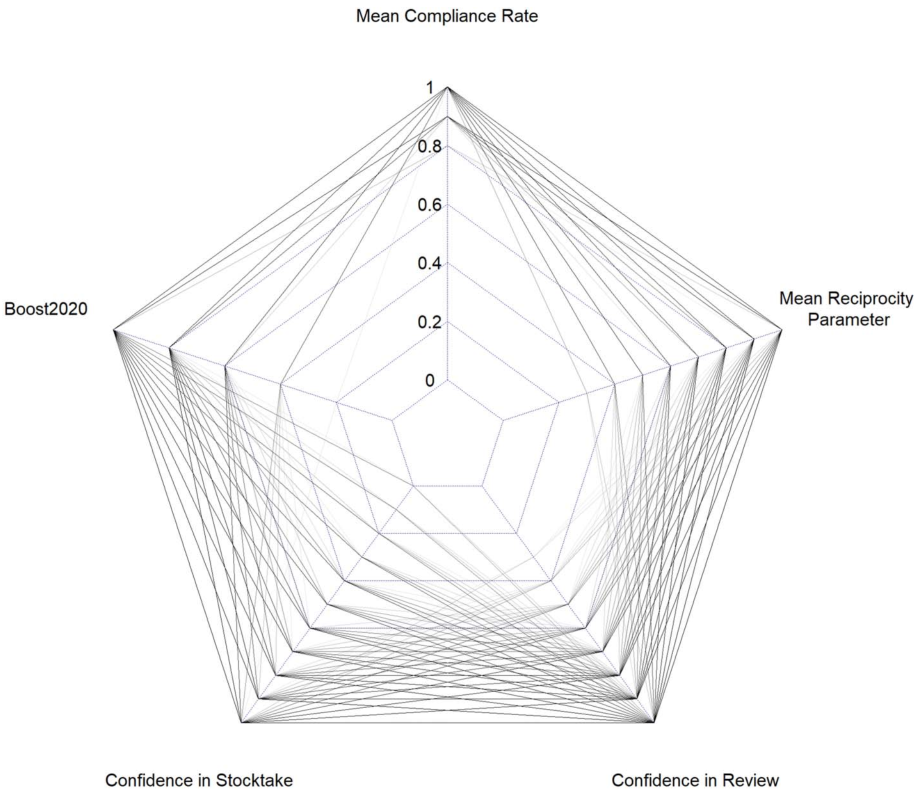

Figure 5
Plot of Parameter Value Combinations in Scenarios that Stay Within the Upper Bound for the 2°C Carbon Budget Estimate

Includes only scenarios where the progression principle is respected. The axis range for Boost2020 is 0–5, while remaining axis ranges are 0–1. Each scenario is represented by a pentagonal line.

optimistic input parameter values are needed for the model to achieve the 2°C goal.

Table 1 presents the minimum values for model parameters in those scenarios that stay within the upper bound for the 2°C carbon budget estimate, conditional on the progression principle. Columns 3 and 4 present the absolute minima, with no restrictions on other parameters. Column 4 thus corresponds to Figure 6. The mean compliance rate must be at least 80 percent, while the conditions placed on other parameters do not appear very limiting. However, these conditions are far from sufficient. Even when simultaneously satisfied, and considering only the low-emissions NDC scenarios, only around 6 percent of scenarios limit emissions to below the upper bound for the estimated 2°C budget (7.2 percent in column 3 and 5.6 percent in column 4). Columns 5 and 6 present the minima under the additional restriction that no other parameter

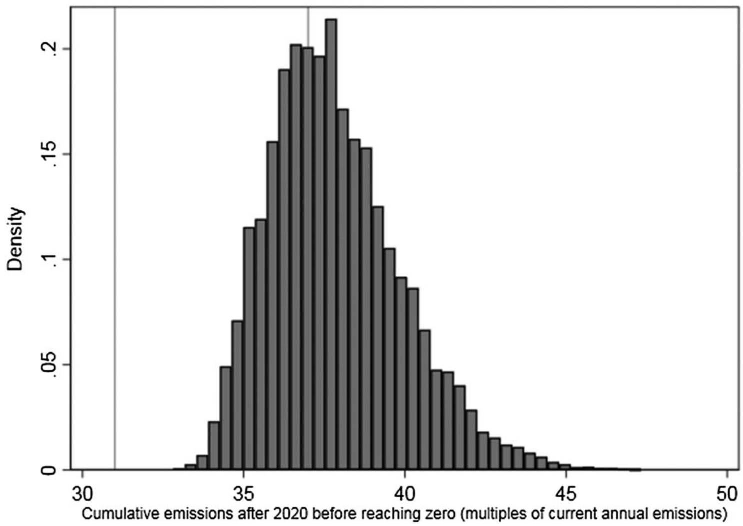

Figure 6
Distribution of Total Cumulative Emissions in Scenarios Specified by Column 6 of Table 1, **Prog**, and **Low**

Vertical reference lines mark upper and lower bounds for the estimated 2°C carbon budget.

take its maximum value, because the absolute maxima, like 100 percent compliance, may not be achievable. Without the progression principle, emissions cannot be limited to below the upper bound of the estimated budget unless at least one parameter is set at its maximum value. Therefore column 5 cannot be completed. With the progression principle respected (column 6), the minimum conditions are now the second-highest values of the ranges examined, except for **CiS**, for which the condition is 80 percent. Rerunning the model 10,000 times with the exact parameter values given in column 6, with low-emissions NDCs and the progression principle respected, results in the distribution of total cumulative emissions shown in Figure 6. The variation in outcomes is due to stochastic elements in the model. Of these outcomes, 38 percent limit emissions to below the upper bound for the estimated 2°C budget. Hence these parameter values are not always sufficient for staying within the most optimistic estimate of a carbon budget that, in turn, gives a 66 percent probability of limiting warming to less than 2°C above preindustrial levels.

The conditions derived in column 6 are rather limiting. First, current NDCs must be boosted by at least 4 pp when targets for 2030 are to be confirmed, revised, or submitted in 2020. In the model, this amounts to an exogenous boost to the process and thus indicates that the process itself is not capable of ratcheting up ambition from current NDCs to achieve the 2°C target, even under the most optimistic interpretation of both current NDCs and the budget available. In the likely case that parties do not abruptly increase ambition in 2020, the 2 °C target might still be achievable, given that a similar boost occurs at a later stage. However, the necessary magnitude increases with time. Second, compliance with NDCs must be over 90 percent, leaving little room for shortfalls. Third, parties must display a mean RP close to 1, responding to an increase in others' average ambition by increasing their own ambition by almost the same amount. In other words, parties must be nearly perfect conditional cooperators. In contrast, experiments show that individuals tend to be highly imperfect conditional cooperators. For example, Fischbacher and Gächter (2010) find an average RP of just over 0.4. Finally, parties must strongly trust both the review and the global stocktake. The last condition implies that the current negotiations must produce strong and trustworthy institutional arrangements to govern these two processes.

Conclusions

This analysis has shown that the Paris process delivers sufficient ambition ratchet-up to achieve the 2 °C goal only under a very restricted set of conditions. To achieve this goal, an ambition boost is needed, for example, when parties are due in 2020 to submit, confirm, or revise their targets for 2030. Global emissions in 2030 should be at least 4 percent lower than the level estimated using the most optimistic interpretation of current NDCs. This result implies that it is insufficient to focus only on means to increase ambition over time; if ambition is not increased from the start of implementation, the model does not produce any scenario that achieves the 2 °C. In a process of gradually increasing ambition, the starting level is highly influential for cumulative future emissions, particularly given a 2 °C budget.

The analysis also underscores the importance of ensuring that the Paris institutions work effectively. Most crucial appears to be a reporting and reviewing system that parties trust. Combined with high compliance rates, such a review system enables parties to trust that others will actually implement their NDCs, and in turn, this trust combined with reciprocity facilitates increasing ambition. Trust in the global stocktake is also needed, although not quite at the level needed for the review. Finally, the analysis included a very strong interpretation of the progression principle and found it helpful for achieving the 2 °C goal, even if not strictly necessary. This principle has a stronger effect when other parameters are set at pessimistic levels, reducing the amount by which the 2 °C budget is exceeded.

The model results show that parties must be highly willing to increase ambition in response to the emissions reductions that others promise and deliver. Such reciprocity would be contrary to standard economic models, and the magnitude needed is also higher than observed in behavioral experiments involving individuals. Because such strong reciprocity seems unrealistic as a pure preference, wider sources of positive reinforcement appear needed, pointing to the mechanisms outlined by Urpelainen (2013) and Hale (2018). Furthermore, compliance rates must be at least 90 percent. Given that NDCs are nonbinding, and the enforcement mechanism explicitly nonpunitive, this finding implies that parties' internal motivation to deliver on their promises must be very high. The reliance on very optimistic assumptions regarding states' normative behavior identified by the model suggests that incentives are needed in addition to norms, supporting Keohane and Victor's (2016) assessment that without new incentives for action, global climate cooperation is stuck on easy coordination with limited gains. One way to create such incentives would be through climate clubs initiated by smaller groups of countries who are willing to enact ambitious policies and to use incentives to motivate others to follow, for example, in the form of side payments (Sælen 2016), preferential market access to members (Hovi et al. 2019) or trade sanctions on nonparticipants (Nordhaus 2015). However, a club including most major emitters would face the same structural impediments that have plagued the UNFCCC (Falkner 2016). To date, alternative fora to the UNFCCC have served merely as discussion clubs (Andresen 2014; Weischer et al. 2012). Given that the Paris Agreement is in place and that it does have the potential to spur increasing ambition under favorable assumptions—albeit unlikely at a rate sufficient for achieving the 2°C goal—an important consideration for club proposals is how to tailor them to complement the Paris Agreement rather than supplant it.

The model simplifies from reality by containing unitary states as the only actors. Domestic politics is included only implicitly as a potential source of reciprocity to international actions. Domestic demand for climate policy independent of action abroad is endogenous to the model. While the widespread support for unilateral action found in surveys has not yet translated into ambitious action by countries (for a discussion, see McGrath and Bernauer 2017), it might in the future. In this model, that would give rise to an increase in countries' *IWTC*, like *Boost2020*. The focus on states also fails to capture the role of subnational climate governance experiments in promoting decarbonization pathways (Bernstein and Hoffmann 2018).

Excluding nonstate actors is also a significant limitation, as the Agreement embraces their actions, and the COP21 decisions set out a larger role for these actors in the future process, including through an annual high-level meeting for announcement and follow-up of commitments (Hale 2016; Morgan and Northrop 2017). In addition to participating directly at the international level, these groups can influence governments' willingness to increase ambition over time (Bäckstrand et al. 2017; Keohane and Oppenheimer 2016). Nonstate actors may also contribute significantly to enhancing transparency, as mentioned in the Method section. However, Allan (2019) warns that nonstate action is not a substitute for state action and argues that states are required as drivers, implementers, and funders. The effect of nonstate action on the likelihood that states will increase NDC ambition is an important question for future research (Hale 2016).

The model's sobering results regarding the ability of multilateral interstate interactions under the Paris Agreement to fulfill the 2°C goal underline the importance of these alternative sources of ambition, that is, smaller groups of countries taking the lead, public demand for unilateral action, and nonstate actors.

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