Social norms and groups structure safe operating spaces in renewable resource use in a social-ecological multi-layer network model

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Final authors' response

Reply on RC2

This study describes a novel approach to modelling social norms in the context of resource extraction in World-Earth modelling. The authors implement a new model in the existing copan:CORE framework that consists of different layers: a biophysical layer, a layer representing individual agents and their interactions, and a novel layer that represents group processes. By adding the additional group level layer, the authors can model the effects of social norms more realistically by representing the effects of both descriptive and injunctive norms simultaneously. This advances the current representation of social norms in agent based models and World-Earth modelling.

I think this paper is well thought out and well-written, and represents a worthwhile addition to the existing literature and methodology for modelling social norms. Yet, I wonder whether the authors can make more explicit in this paper how the current approach compares to and relates to previous efforts to represent social norms in modelling efforts. I also think the authors can be more explicit about their assumptions regarding the dynamics of social norms and which processes they decided to model and how. I expand on my points below.

We are happy to read that the referee finds our work to be a worthwhile addition to the existing literature and methodology for modelling social norms. We realize that the manuscript could be more explicit in relating our modelling efforts to previous ones and in the assumptions that led to certain modelling decisions.
We will further attempt to respond to the points made, below.

First, I think that the representation of both descriptive and injunctive norms using a group level layer represents a clear step forward for representing social norm effects in agent based models. As I was reading the paper, I however found it difficult to establish how this approach builds upon and differs from other approaches to modelling social norms. I believe a game theory/commons dilemma approach is the main theoretical lens through which decision-making surrounding resource extraction is analyzed and modelled, but the authors do not discuss how their approach relates to this.

We realize that we should better explain the particular gap that we aim to fill with our model and how it differs from previous research in the introduction, section 1. We will attempt to reformulate and include the argumentation below, such that our point of modelling dynamic endogenous descriptive and injunctive norms in a coupled resource use becomes clearer:
We see a twofold addition where our work differs from existing literature. First, to our knowledge, informed by a systematic review (in preparation), there have been few attempts

to model injunctive norms endogenously, i.e. arising from within the model processes, as compared to exogenous, prescribed parametric pressures (e.g. Nøstbakken 2013). Second, to our knowledge, there have been few attempts to include processes similar to descriptive and injunctive norms both endogenously, a) Suzuki & Iwasa, 2009, b) Franceschetti et al. 2022 and c) Lin et al. 2022. We believe to differ from all these approaches within explicitly distinguishing, defining and putting our focus on descriptive and injunctive norms and then compute them as a dynamic complex contagion process.

We also suggest to extend section 2 with a discussion of how our approach relates to already existing approaches for modelling social norms coupled to ecological systems in general. Our approach draws from different modelling efforts with the main goal to have a dynamic endogenous representation of both descriptive and injunctive norms. For this, we include game theoretical elements, namely for the general shape of the decision-making function and influence of harvesting success on individual learning within this decision making. For the social norm component, we rather apply a complex contagion approach in an agent-based model, i.e. the uptake of behaviour governed by social norms. Since we apply a private-pool setting (e.g. each agent has access to their own piece of land or, if the agents are thought to represent villages, each village has access to its own fishing pond) we do not see our approach to be an actual commons dilemma. The choice of a private-pool setting leads to information on the harvesting behaviour of other agents to be purely retrieved via social interaction. We do this to explicitly put the focus of the model specifically on processes in the socio-cultural domain, highlighting group- and norm-influenced spreading of behaviour. Additionally, the private-pool setting keeps the results comparable to former works whose setup for the resource growth and harvesting dynamics we built upon (e.g. Wiedermann et al. 2015). Such a comparison is touched upon in the discussion section 3. 5.. We realize that the private-pool setting can be seen as a limitation of the model and that a common pool setting could be a worthwhile expansion and will additionally discuss this in the conclusion.

Importantly, the commons dilemma framework suggests at least two additional processes related to social norm effects, which are already commonly included in agent based models but which are not represented in this paper. First, if there is a norm to cooperate (i.e., act sustainably), this increases the payoff associated with defecting (i.e., acting unsustainably), which could be a motivating force to shift behaviour to defect in order to maximize personal gains (i.e., freeriding) (e.g., (Tavoni et al., 2012; Tu et al., 2024).

As mentioned above, we view our approach with the social norms alone to be closer to a complex contagion problem than a commons dilemma. We still agree that the above-mentioned process can be an important mechanism in norm conformation, but would argue that it does not exactly fit into the storyline of this work: Since there is no common pool resource, none of the behaviours necessarily represents a cooperation or defection. We opt for another mechanism to represent the payoff of sticking to a sustainable strategy, i.e. the individual learning of the personal harvesting yield. This puts the focus more on temporal scales, i.e. unsustainable behaviour increases short-term yield but decreases long-term yields, with sustainable behaviour leading to the opposite effect. This is also motivated by previous work within the exploit modelling family, where timescales were important to the dynamics. We confirm this in our model, even though the temporal dependence is not as large.

Second, the power of social norms lies in their enforcement, i.e., the fact that there are social punishments associated with not acting in line with the norm (e.g., (Nhim et al., 2019; Tavoni et al., 2012)). I was wondering whether the authors could expand upon why they did not

choose to incorporate such dynamics into the current representation. I realize that making models overly complex is not desirable, but I also think it is important that modelling efforts are cumulative and thus clearly connect to and build upon existing works rather than developing separate approaches that are not integrated.

We agree with the referee that enforcement and sanctioning of social norms are a key element of social norms. The lack of direct enforcement is an important limitation of the model that we suggest to include in the conclusion of the manuscript, in line with the comment of the other referee. Our model only indirectly includes sanctioning, aggregated within the probabilistic decision-making function, where we assume that there must be some social pressure for agents to adhere to social norms, be it social or non-social sanctions.
We also suggest to explain this particular modelling decision in more detailed in the above-mentioned addition to section 2.
Anticipating the reasoning for this choice, there are two main factors that explain the lack of a sanctioning mechanism: the first one is in fact the computational reason of keeping the model tractable and not overly complex. A guideline for coupled models is that the complexity of submodels should be comparable. In our model this guideline has already been stretched, as the resource growth and harvesting mechanisms are fairly simple, while the social norm component has a larger degree in complexity. This has to be kept in mind when discussing the realism of the social norm component alone.
The second factor lies within the context of the broader modelling choices. Since we apply a private-pool setting, we think that it would be difficult to apply direct sanctioning to the resource, as agents only have access to their own pool of resource. Instead, a nearby sanctioning mechanism in a group setting such as ours might be ostracism. For this, an adaptive network structure would be needed, which in our opinion is already a large extension of the current model. We did not use such a network, since adaptive dynamics could overshadow the local dynamics of the dynamic social norms that we wanted to put a focus on.
We intend to give a more detailed outlook in the conclusion section, mentioning possible future extensions of our framework with an adaptive network and a common pool setting. This would allow for sanctioning through reduction of harvesting yields and ostracism, while additionally largely improving the group dynamics.

Second, I think distinguishing between injunctive and descriptive norms is a great addition to the literature, but I think the current theoretical review and modelling application is still a bit agnostic and simplistic about the different mechanics through which injunctive and descriptive norms influence behaviour. People can conform to social norms because of informational (i.e., assuming that the behaviour most people do will likely be the correct/most effective approach) or normative reasons (i.e., wanting to fit in/not stand out) (e.g., (McDonald & Crandall, 2015)). The latter of these also relies on the sanctioning of norm violations by other group members, as I also identified above as a missing mechanism. Studies also indicate that there are key interactions that occur when descriptive and injunctive norms do or do not align. Specifically, if an injunctive norm is contrasted with a conflicting descriptive norm, its effect on behaviour is minimized (e.g., (Bonan et al., 2020; Smith et al., 2012; Staunton et al., 2014)).

We thank the referee for bringing up these additional mechanics through which injunctive and descriptive norms can influence behaviour. We will include these mechanisms in our discussion of social norms in section 2. Our modelling approach is in fact agnostic to the reason why people conform to social norms (informational or normative).

The effect that, if an injunctive norm is contrasted with a conflicting descriptive norm, its effect on behaviour is minimized, can technically be implemented in the model via the weights in the decision-making function. Since our study aims to represent the general social norm framework as an addition to the copan:CORE framework for future usage, we aimed to stay as general as possible with our assumptions regarding the interdependencies of descriptive and injunctive norms and the reason to conform to them. They can be adjusted when applied to modelling a situation for which such information is given.

I am not asking the authors to implement all these mechanics in the current application of the model, but I do think it this paper could present the full (or at least a fuller) picture of our understanding of the effects of social norms, and then more clearly show which elements are and are not represented in the current modelling representation and why.

We find this remark very important and attempt to give a fuller picture in the above-mentioned additions to the manuscript. We want to emphasize again that the reason for a lack of some of the above-mentioned mechanisms was the aim of this work to design and test a lean and tractable model of endogenously emerging descriptive and injunctive norms for further extension in World-Earth modelling.

Lastly, if I understand correctly, the effect of group membership only matters for injunctive norms and not descriptive norms. I think the model would be more realistic if group membership also affected how people react to the observed behaviour of others. Specifically, there is literature which shows that the effects of social norms differ based on whether this information is received from ingroup or outgroup members ((Spears, 2021). For example, people are more likely to follow the behaviour of other ingroup members compared to outgroup members. Similarly, deviation from a norm is perceived far more negatively for ingroup compared to outgroup members.

We completely agree with the comment that the model would be more realistic if formal group membership more directly affected how people react to the observed behaviour of others in the descriptive norm. In our opinion, a variation of this effect is still indirectly incorporated into the model to some extent: If a neighbouring agent is in the same higher-level group as an original agent, then this will increase the likelihood of the original agent to follow the behaviour of its ingroup neighbour through the injunctive norm mediated by groups, additionally to the descriptive norm. A higher-level outgroup neighbour instead will add less to the likelihood of the original agent to change its behaviour, as it only affects the contribution of the descriptive norm.
This discrepancy between the modeling approach and observations in real-world norm sturdies arises due to the modeling decision of separating descriptive and injunctive norms and attributing both to a different network layer, while both can be heavily entangled in the real world. We decided not to include a direct ingroup/outgroup mechanism into the model to keep complexity of the model low, as to be keep the influences of descriptive and injunctive norms tractable.
The ingroup/outgroup importance could be emphasized in a future work with an adaptive network, which we plan to mention in the outlook, as mentioned above.

We want to thank the referee very much for the helpful comments and remarks to our manuscript, as well as pointing to additional literature.

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