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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Endogenous technological and population change under increasing water scarcity" *by* S. Pande et al.

Anonymous Referee #1

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Review of Pande et al. "Endogenous technological and population change under increasing water scarcity"

Summary. This paper presents a novel model developed to explore the dynamics of coupled human – hydrological systems, and namely to explore development in a context that is constrained by natural resource availability and endogenously-determined production technology. In making a connection between endogenous growth theory (in economics) and ideas related to the limits to growth, the paper represents an important step forward for those interested in the complex dynamics of these and similar coupled systems, and therefore should be published. Nonetheless, the paper would be much stronger if it better explained how it is informed and draws on the prior literature on such economic models, and would benefits from more self-critical reflection. Typical

readers of a journal like HESS will want to understand such issues to better put the paper's results into a wider context. A variety of other general and specific comments follow in the more detailed review below.

HESS Review questions. Does the paper address relevant scientific questions within the scope of HESS? Yes. Does the paper present novel concepts, ideas, tools, or data? Yes, it presents novel concepts and tools. Are substantial conclusions reached? Somewhat. It is difficult to understand how robust the results are to structural model and parameter assumptions. Are the scientific methods and assumptions valid and clearly outlined? In general, yes. Are the results sufficient to support the interpretations and conclusions? Not sure. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? Should be. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes. Does the title clearly reflect the contents of the paper? Yes. Does the abstract provide a concise and complete summary? The abstract is not concise and clear, and should be rewritten. Is the overall presentation well structured and clear? Mostly, although copy-editing is warranted. Is the language fluent and precise? Mostly. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Yes. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? No. Are the number and quality of references appropriate? Yes, except that more discussion and description of the strengths and weaknesses of endogenous growth models is needed. Is the amount and quality of supplementary material appropriate? No; I would suggest that the authors expand this to include sensitivity analysis on parameters and key model assumptions.

General comments. 1. My first main concern has to do with framing the results in the context of endogenous growth models that are commonly used in economics (e.g. Romer). I doubt that most readers will have much familiarity with such models and their strengths, weaknesses, and realism vis-à-vis the dynamics of societal develop-

ment. While a thorough review of such models is clearly beyond the scope of this article, I would suggest that the authors clarify some of these aspects by including an additional short section that describes such models and where they differ from the Limits of Growth models to which the paper's model results are compared. 2. Like many papers relying on highly stylized models, it is difficult for the reader to fully understand the implications of modeling assumptions for the results that are obtained. I was somewhat dismayed to see very little critical self-reflection and discussion in this paper on such issues, and the remainder of my general comments touch on some of the main issues I would have concerns about (though obviously these should not be considered exhaustive). The discussion closes with a single paragraph on extensions and next steps, but the reader is left to wonder just how robust the results are to changes in underlying assumptions. This is important because the predictions from the model are rather dire outside of the technological singularity case which the authors deem to be unlikely. Is a growth stabilization trajectory really outside the realm of possibility? And if so, why? 3. The model does not account for endogenous migration in the face of declining consumption per capita. While this may not seem critical as it could be considered to be embedded in the population growth rate, it suggests that the characterization of scarcity-induced and the model as "a credible predictor of upcoming population decline" may be misleading. Seen another way, the much-cited decline in the Murrumbidgee basin may as much be part of a story of comparative advantage and out-migration (of population, agricultural and other production towards other more water rich areas). In this sense, the observed decline can hardly be considered catastrophic. 4. Building on this point, the authors seem to imply that there is equivalence between population and the success of a society, but population change is itself endogenous (as well documented in the demography literature) and will respond to declining resource availability, productivity changes, and the extent of human capital development (and this may stave off declines in consumption). The fact that population growth is tied to consumption thresholds (rather than change) is therefore problematic. 5. Related to point 1 above, the paper's focus and reliance on the concept of endoge-

nous technical change is useful, I think, but the authors are surprisingly non-committal about its relevance. (e.g. p. 13510 says that "we acknowledge that fierce debates may still take place on the nature of technological change"). Why not take a position? What types of dynamics can be explained if technological change is assumed to be endogenous rather than exogenous, and why do these make the theory more credible in the context of water? 6. How realistic is the assumption that "the water resources available at any time are entirely consumed by the production activity that the society engages in." Does this mean that there is no possibility of long-term storage of water resources, either naturally (large existing groundwater aquifers, forests, etc.) or as influenced by human innovation and technology? What are the implications of this? 7. How sensitive are the model results to various assumptions other than the rate of success of innovation (the issue explored in Section 3.2), such as: a) relative productivity of different types of labor and water; b) assumptions about population growth relative to consumption levels (e.g., what about declining population growth when consumption increases, as seen across many rich societies); c) rate of return (should be intuitive); and d) assumptions about ever-declining water availability.

Specific comments / technical corrections – In general a serious copy-editing effort is required to improve the readability of the manuscript. I have only commented on some of the issues on which I stumbled below. 1. The abstract is rambling, long, and hard to follow. I would suggest that it be significantly streamlined in order to motivate the reader to read on. 2. What is meant by "existing, historically grown sets of water related technologies" (p.13509)? This seems a long-winded way of saying "existing water related technologies". I am not sure what is important about "sets" of such technologies. 3. P. 13513, line 21 should read: "The parameter. . .represents how she weighs her future consumption relative to present consumption." And later: "Thus the larger the $\beta 0$, the larger the propensity to save." 4. P.13515, line 23 should be "feed back" (verb) not "feedback" (noun). Also in line 25 "higher surpluses" should be referred to as "they" not "it". The first comment applies in other places in the manuscript, where it should be "feeds back" not "feedbacks" (lines 18 and 26 on p.13521) 5. P.13515,

the last sentence does not make sense; what is: “the balance of funds for borrowing and savings by surplus”? 6. Without additional explanation of the notion of “scale of cooperation” described on p. 13516, the reader cannot understand the paragraph between lines 7 and 19. Perhaps the authors expect the reader to consult Pande and Ertsen, but this is unfair given that the term seems critical to the arguments about the importance of endogenous technological change. I would suggest better explaining what this means. 7. P. 13518, lines 15-17: I think what is meant is: “Note that the rate of technological change is never negative, i.e. technology never deteriorates but rather builds upon previously generated technology, in addition to other factors. 8. P. 13520, lines 6-8 do not read correctly. Please revise. Also line 25 the correct verb form should be “falls”. 9. P.13521, there is a contradiction in the sentences between lines 9 and 13, and I am not sure what the authors are trying to say: “However, the increase in production, both due to technological advancement and increasing population that contributes skilled and unskilled workers, is not sufficient to support consumption per capita of an increasing population (Fig. 1d). Note that the consumption per capita of a researcher and an unskilled worker is the same for all t. This leads to an persistent decrease in consumption per capita over time.” 10. In several places, the authors use the word “inturn” which does not exist. It should be “in turn”. Same with “inspite”. 11. P. 13521, line 14: delete the word “condition”. 12. P. 13522, line 3: I suggest using “constraints” rather than “limits” to differentiate from the arbitrary “limit” imposed to end the model simulation. 13. P. 13522, line 6: missing “the” in “the outputs of the Limits to Growth. . .” 14. Can you clarify what is meant by “super-exponential growth”? If this is simply reaching the singularity that is described, best not to introduce a new term that has no precise meaning. 15. P. 13523, line 17 should read: “production is a function of. . .” 16. P. 13524, line 21 should read: “once population reaches its maximum.” Also, I don’t understand what the sentence in lines 23-25 means, specifically what does “endogenously imputing” mean? 17. P. 13524, line 27: I don’t think “asymptote” can be used as a verb. 18. P. 13525, line 5: Replace “till” (not a word) with “until” 19. Discussion: p. 13525, lines 23-25: I don’t think you have assumed that innovation is purely

random, otherwise it cannot be endogenous. Best to not recreate confusion here. 20. P. 13526, line 11: Please rephrase: “the technological advancement led production” which is a mouthful.

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