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Interactive Comment

Interactive comment on “Endogenous change: on cooperation and water in ancient history” *by* S. Pande and M. Ertsen

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Response to Van der Zaag by Saket Pande and Maurits Ertsen

We are grateful to Van der Zaag for providing such an honest and constructive criticism of our paper. In response to his first remarks about the theory, our aim is to qualitatively test the regularities predicted by the theory (the causality) based on limited data set that we have for the case studies. We agree with Van der Zaag that the available data is limited to quantitatively test the theory of endogenous change in context of water that we have introduced in this paper. The aim of the paper is to find qualitative evidence of conditions under which cooperative patterns emerge or collapse as suggested by the theory of endogenous change. This is also linked to the issue of scale, another

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comment of Van der Zaag. The spatial and temporal scale that is required to study the emergence and/or disappearance of patterns of cooperation in human societies is the scale of a civilization, from its genesis to dispersal.

We chose the two case studies as these were two civilizations that flourished and dispersed in mid to late Holocene and have been well studies both by paleoclimatologists and anthropologists/archeologists alike. Water in both Holocene societies played a dominant role, as has been extensively documented by several researchers. Just as increasing scarcity exacts costs on a society (in the Indus case), increased variability in the occurrence of wet and dry periods even if average conditions are not so dry (Hohokam) also exact costs. The latter has been shown by Pande and Mckee (2007) and several others.

By suggesting that increasing scarcity conditions or increasing variability of wet and dry periods exacts costs on a society we do not suggest a linear relationship (and hence we do not suggest a correlation) between the evolution of societies and scarcity (or increased variability) conditions. In fact our theory of endogenous change suggests the contrary. Our theory suggests that it is not just the time series of scarcity condition that matter; it is also its spatial and/or statistical pattern. It suggests that a civilization can mature even under increasing scarcity conditions at regional scale provided the spatial or statistical pattern is favorable for regional scale cooperation. Complex societies cannot rise under resource constraints or uncertainty (such as water scarcity) unless societies efficiently allocate and use resources.

Technological innovation plays the role of providing higher production per unit input. In context of ancient societies it may for example mean higher agricultural production per unit water. Thus a 'positive' population growth rate can be sustained even under increasing scarcity condition. But then specialization is necessary, if not sufficient, for technological innovation and it often appears when resources are efficiently used. The scale of cooperation, be it in the form of infrastructural development, trade linkage or emergence of a state with a strong central authority matters. Gains in efficiency that are realized are based on allocation of resources that is agreeable to all within a region. That means a cooperative structure of some sort at that scale.

In order to retain the general flavor of the theory that we have introduced, we refrained from naming the particular form of technological innovations, cooperative structures, or water scarcity conditions. The ambition of the paper is to present the theory and present qualitative evidence to support the regularities predicted by the theory. In our opinion, the data used is a first step to do so; more detail would not make the evidence stronger. It would obviously clarify the particular shapes of cooperation and technological change. Both the authors are working on understanding change in ancient societies in much more detail, especially the second author. For the approach in the current paper, a modeling exercise based on the presented theory is a natural next step which we are currently undertaking. We, by no means, intend to suggest that our theory is the only one that can explain rise and dispersal of ancient societies. But it appears to be a major one putting paleoclimatological records in perspective of water and evolution of societies.

Regarding the Hohokam case, we used reconstructed annual (October to July) rainfall and temperature data for the Southern Colorado plateau. We assumed annual evapotranspiration a linear function of annual mean-maximum temperature (Blaney-Criddle type method). A runoff proxy is then defined as a linear function of the difference between annual rainfall and annual evapotranspiration. Since normalization (subtracting the mean and dividing by the standard deviation) of a linear function of a variable is the same as the normalization of the variable itself, we obtain a normalized runoff proxy as the difference between normalized annual rainfall and normalized annual-mean temperature. A normalized value of the proxy measures the deviation from mean in units of standard deviation (variation).

If the annual runoff proxy can be assumed to be normally distributed, a normalized runoff proxy value of -1.5 is a relatively rare negative deviation with a probability of non-exceedence around 7%. This can be contrasted with conditions around 1175AD

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when runoff had an approximate probability of non-exceedence of around 15%. We acknowledge that the assumption that rainfall and temperature is normally distributed may be strict. Further the reconstruction data used in this Figure is for southern Colorado plateau that is different from the reconstruction data in fig 12. The southern Colorado plateau reconstruction data is used since it dates back till 570 AD for both precipitation and temperature. While it is not a local historical hydro-climatic record of the Hohokam area, it does provide us with a credible reconstruction of the regional hydroclimatology. This is in no way different from the use of reconstructed historical data of regional hydroclimatology in the Indus case study.

Our analysis based on figures 13 and 14, though proximate in nature, relies on increased stochasticity of scarcity as a result of demographic change and population pressure that increased partly due to the success of a maturing civilization. A cursory look at the regional hydro-climatic variations before 1000 AD may appear to support Van der Zaag's argument that the hydro-climatology was equally variable before the sedentary period, acclimatizing the society to such stochasticity. However, a careful analysis rebuts Van der Zaag's argument and supports (a causal regularity predicted by) the theory of endogenous change proposed in this paper, just as in the case of Indus river basin. Following a major departure from hydro-climatic variation around 700 AD, the Hohokam area had relatively low scarcity and low rainfall variance between 700-1000AD. This relatively calm period of hydro-climatic determinism might have led to a transition from food gathering to sedentary life.

As in the Indus, we find the Hohokam civilization maturing to a quasi-statehood during times of increasing scarcity (that depends on both exogenous climate and endogenous societal complexity such as population growth) around 1150AD (the beginning of early classic era). This provides evidence of the departure of the evolution of Hohokam society from hydro-climatic determinism. However, the premium to avoid 'apparent' stochasticity might still have been relatively low. This might have resulted in a cooperative structure that scaled the entire study area. The Hohokam witnessed its dispersal

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around the peak of scarcity. The willingness to avoid the 'apparent' stochasticity might have been larger than the gains from cooperation. This might have led to dispersal of population centers as they sought better areas to populate. Thus, in both cases, cooperative structures appeared at the scale of the study area (the rise to maturity or quasi-statehood) under increasing scarcity conditions. In both the cases the cooperative structures collapsed under relatively extreme water scarce conditions. Thus, we claim that we find evidence the supports the regularities predicted by the theory in both the cases.

We will incorporate almost all the minor comments by the referee. On changing the title of the paper, we have clarified above that hydro-climatic determinism doesn't necessarily drive the evolution of a society. The change described in the paper is indeed endogenous at hydrological scales.

References: Pande, S., and M. McKee (2007), Valuing certainty in a consensus-based water allocation mechanism, Water Resour. Res., 43, W02427.

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