



Reply to Thomas: Diffusion of military technologies is a plausible explanation for the evolution of social complexity, 1500 BCE–AD 1500

We thank Thomas for his comments (1) on our recent paper, in which we show that a very simple model can explain a remarkably high proportion of variance in historical data on the origins and spread of macrostates in Afroeurasian history (2). The core of Thomas's critique is that our model is "too simple and too abstract" (1). We, however, see model simplicity as a desirable feature in developing theory that is both grounded in sociological mechanisms and tested with historical data. Too many previous attempts at theory building in the social sciences have foundered as a result of being highly complex and including in them too many mechanisms. The ability of our simple model to accurately predict data speaks for itself.

We lack space to address all specific points raised by Thomas (1), so we will focus on the most important ones. First, ultrasocial traits are not just any assets or resources that endow a region with power. In our model (and in real life) these cultural traits yield benefits at the collective level, but impose significant costs at lower levels of social organization. Why they spread, despite these costs, remains a central puzzle of social evolution. Similarly, the process we label as "warfare" is not simply any "accretion" process because it involves the relative power (a function of size and ultrasocial traits) of the polities involved.

Second, we actually consider the independent spread of five military technology traits. Although investigating the effect of timing

of different innovations is an interesting question (and one that we are pursuing), this requires introducing several additional parameters and assumptions.

Third, it is not clear why elevation is a "poor surrogate" (1). Our results indicated that elevation was not a strong predictor of imperial density, and other variables related to it are unlikely to add greatly to the explanatory power of the model. A measure of ruggedness as a proxy for defensibility is actually not as straightforward as it may seem: Because of some measure of gradient, or variability in elevation, its interpretation will depend on the spatial scale over which it is calculated.

In summary, none of the specific criticisms advanced by Thomas (1) undermine the main findings of our report (2). The process of model building is iterative and cumulative, and as we state in the report our model is not in any way a final word in explaining the evolution of complex human societies. The current model builds upon our previous modeling efforts (3), and as we discuss in the *Supporting Information* of our report (2), we continue to work on extending the current modeling results in several directions, including exploring alternative causal pathways. Indeed, there are many opportunities for those interested in the evolution of social complexity to join this burgeoning modeling discipline.

Until a credible model is developed, based on an alternative—and historically attested—

mechanism that can explain at least as high proportion of variance in data, our main conclusion must stand. Diffusion of horse-related military technologies is a plausible explanation for the spatiotemporal patterns of social complexity 1500 BCE–AD 1500.

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1 Thomas RC (2014) Does diffusion of horse-related military technologies explain spatiotemporal patterns of social complexity 1500 BCE–AD 1500? *Proc Natl Acad Sci USA* 111:E414.

2 Turchin P, Currie TE, Turner EAL, Gavrilets S (2013) War, space, and the evolution of Old World complex societies. *Proc Natl Acad Sci USA* 110(41):16384–16389.

3 Gavrilets S, Anderson D, Turchin P (2010) Cycling in the complexity of early societies. *Cliodynamics* 1:58–80.

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The authors declare no conflict of interest.

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