



Modeling abrupt cultural regime shifts during the Palaeolithic and Stone Age



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ARTICLE INFO

Article history:

Received 23 September 2014

Available online 7 December 2014

Keywords:

Catastrophic bifurcation
Innovation
Carrying capacity
Creative explosion
Toolkit diversity
Neural hypothesis

ABSTRACT

The coupled dynamics of the size and the mean cultural/technological level of a population, with positive feedback between these two variables, is modeled in the Malthusian–Boserupian framework. Bifurcation diagrams, with innovativeness or the cultureless carrying capacity as the parameter, show that abrupt transitions in the mean cultural level are possible. For example, a gradual evolutionary change toward greater innate innovativeness would produce an associated gradual increase in mean cultural level, until a threshold is crossed that triggers an abrupt cultural regime shift. Hence, the model may help explain the apparently sudden and dramatic efflorescences of Palaeolithic/Stone Age culture during the Late Pleistocene, without having to invoke major contemporaneous genetic changes in cognition. The results of statistical studies on the association between population size and toolkit diversity among ethnographic societies are also discussed.

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1. Introduction

There are two contrasting views on how population size and culture/technology are causally related. For Malthus, “population [size] equilibrates with resources at some level mediated by technology”, whereas for Boserup, “technological change is itself spurred by increases in population [size]” (Lee, 1986, p. 96). In other words, the Malthusian position is that population size is limited by the available technology, and the Boserupian one is that technological change is dependent on population size. In fact, “the two theories are not contradictory, but rather complementary” (Lee, 1986, p. 96), and a theory of cultural/technological change should incorporate the reciprocal effects of population size on culture/technology, and vice versa.

Many Palaeolithic archaeologists and anthropologists currently emphasize the Boserupian perspective in interpreting “sudden” and “dramatic” changes in stone tools or other cultural artifacts during the Late Pleistocene, in particular the “creative explosions” (Kuhn, 2012) of the African late Middle Stone Age and the European Upper Palaeolithic (e.g. Shennan, 2001; Henrich, 2004; Kline and Boyd, 2010; Zilhão et al., 2010; Mesoudi, 2011; Clark, 2011 and Kuhn, 2013). I take the liberty here and below – consistent with Lee (1986, p. 97) – of using the rubric “Boserupian” to indicate the directionality of the arrow of causation noted above,

without distinguishing among the various possible mechanisms or processes. In fact, theoretical studies have repeatedly shown that population size can have a large effect on cultural evolutionary rate and cultural diversity (e.g. Shennan, 2001; Henrich, 2004; Strimling et al., 2009; Mesoudi, 2011; Lehmann et al., 2011; Aoki et al., 2011; Kobayashi and Aoki, 2012; Aoki, 2013 and Fogarty et al., 2015), as can interconnectedness of subpopulations (e.g. Powell et al., 2009; Perreault and Brantingham, 2011 and Premo, 2015). Transmission chain experiments conducted in the laboratory also provide some support for a link between population size and cultural complexity (e.g. Derex et al., 2013; Muthukrishna et al., 2014 and Kempe and Mesoudi, 2014; but see Caldwell and Millen, 2010).

However, archaeological evidence on the role of demographic factors in cultural evolution is inconclusive or even contradictory. Two recent studies of Late Pleistocene South Africa are particularly relevant. Clark (2011) looked for signatures of population growth/demographic stress in an increase of diet breadth (e.g. the use of non-preferred prey animals), obtaining some support for an association with the heightened creativity of Howieson’s Poort. But, as Clark (2011) is careful to note, this association is open to an alternative interpretation, namely that rapid cultural change produced new tools, which were used to exploit novel resources. Klein and Steele (2013) (see also Klein, 2008, Box 1) observed that edible shellfish remains from Middle Stone Age middens are significantly larger than those from Later Stone Age middens. If shellfish size reflects human collection intensity, then this finding suggests that the precocious appearance of modern behaviors in the Still Bay and

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Howieson's Poort may not have been associated with population growth.

In addition, statistical analyses of ethnographic hunter-gatherers have failed to show an association between population size and the number of food-getting tool types (e.g. Collard et al., 2005 and Read, 2006). However, ethnographic food-producing societies (e.g. small-scale farmers and herders) do conform to the theoretical prediction that population size and toolkit diversity should be positively correlated (Kline and Boyd, 2010; Collard et al., 2013). Details are given later. Possible explanations for these contrasting results have been suggested, including higher degrees of specialization in the latter societies.

A fundamental problem in human evolution is how to account for an apparently abrupt cultural change, without invoking a major genetic change in cognition (e.g. innovativeness), for which there is at present no strong evidence (Klein, 2008). In spite of the negative results of some empirical studies, it is clearly worthwhile to investigate theoretically the joint dynamics of culture and population size. However, it is difficult to discern what their explicit mathematical form might be. In a paper that presages the recent archaeological/anthropological discussions, Lee (1986) presents a semi-quantitative graphic model for population size and technology that synthesizes the contrasting viewpoints of Malthus and Boserup. He demonstrates the existence of alternative stable equilibria and/or regimes – a small population with a low technology and a large population with a high technology – and the possibility of transitions between them.

Recently, Richerson and Boyd (2013) discussed the importance of adopting such an interactive approach in understanding progressive and regressive cultural changes during the Palaeolithic. “Perhaps toolkit complexity waxed and waned with the demographic fortunes of populations subject to highly variable conditions.... Perhaps ... human populations were bistable. A high population density equilibrium would generate a fancy technology and ... it could maintain high population density. A small population ... would have a simple toolkit and a slow response to variation and hence would remain small”. (pp. 290–291). Richerson and Boyd (2013) also note the possibility of hysteresis, whereby forward and backward transitions between alternative stable regimes occur under different exogenous conditions. See also Richerson et al. (2009).

In a paper that predates Richerson and Boyd (2013), Ghirlanda and Enquist (2007) posit a highly specific functional form for the endogenous effect of population size on the “amount of culture”, and vice versa. In particular, innovations are assumed to be produced in proportion to population size, and the carrying capacity is proportional to the amount of culture. Their model predicts either a stable equilibrium in the two variables, population size and amount of culture, or an explosive increase of both. The outcome is determined by three parameters, one of which can be regarded as a measure of innovativeness. However, their model does not yield bistability, for the reason explained later.

The goal of the present paper is to describe and analyze a minimal dynamical model – in the spirit of Ghirlanda and Enquist (2007) – for population size and cultural level (or cultural complexity) that instantiates the verbal model of Richerson and Boyd (2013). In the interest of simplicity, the model makes arbitrary assumptions without empirical foundation, except perhaps in a qualitative sense. But even so it is not amenable to the kind of thorough treatment that is possible, say, for the spruce budworm model (e.g. Murray, 1989, pp. 4–8). Hence, we resort to numerical examples to demonstrate the possibility of bistability, “catastrophic bifurcations”, and hysteresis (Scheffer and Carpenter, 2003). These numerical examples are selective, since my purpose is to demonstrate the possibility, not the likelihood, of their occurrence. Nevertheless, the analyses suggest that bistability is observed only

within a limited range of parameter values. Within such a limited parametric range, we have two regimes – a small population at a low cultural level and a large population at a high cultural level – and the forward and backward shifts between these locally stable regimes follow different paths. Importantly, transitions between alternative stable equilibria may be sudden on an archaeological timescale.

Theoretical results are obtained that may help in interpreting the creative explosions of the Palaeolithic/Stone Age. Of particular interest is the prediction that a gradual evolutionary increase of innovativeness can eventually trigger a saltational increase in cultural level. The threshold for innovativeness would depend on other conditions such as environmental productivity. This scenario is not inconsistent with the “neural hypothesis”, a recent version of which invokes “a neural change that promoted the extraordinary modern human ability to innovate” (Klein, 2008, p. 271). However, the neural change would not, we argue, be attributable to just one “fortuitous mutation” in a major gene 50,000 years ago.

2. Model

Assume the Henrich (2004) model of directly-biased cultural transmission, with the cultural level of an individual given by z – for example, a quantitative measure of skill or cultural trait diversity – and the mean cultural level of the population given by \bar{z} . In this discrete-generations model, each of the N newborns simultaneously and independently tries to copy the individual of the parental generation with the maximal value of z , which we write as z_{\max} . The actual z value acquired by each newborn follows the Gumbel distribution. We modify the Henrich model, as done by Mesoudi (2011), so that the negative deviation of the mode of this Gumbel distribution from z_{\max} is a function of \bar{z} , specifically $-\alpha\bar{z}$, where $\alpha > 0$. In other words, we are assuming that it becomes increasingly more difficult for a newborn to improve on the cultural level of its exemplar as the mean cultural level of the population increases. This requires us to set $\bar{z} > 0$. Then, approximating the original difference equation (Mesoudi, 2011, Eq. (2)) by a differential equation, we have

$$\frac{d\bar{z}}{dt} = -\alpha\bar{z} + \beta(\varepsilon + \log N), \quad (1)$$

where $\beta > 0$ is a measure of the dispersion of the Gumbel distribution and $\varepsilon \approx 0.577$ is Euler's constant.

The Henrich (2004) model and its extensions (e.g. Powell et al., 2009; Mesoudi, 2011 and Kobayashi and Aoki, 2012) are widely used as representations of cultural evolution among hunter-gatherers, and that is my reason for adopting it. Eq. (1) entails that $\frac{d\bar{z}}{dt}$ is more likely to be positive when N is large. A larger population facilitates an increase in mean cultural level, because the maximal value of z in the offspring generation is then probabilistically more likely to exceed that of the parental generation, z_{\max} . Hence, the mechanism by which population size drives cultural change may not be what Boserup had in mind (e.g. Lee, 1986 and Shennan, 2002), but the arrow of causation points in the same direction.

Next, assume the logistic model of population growth, where the carrying capacity, $M(\bar{z})$, is a sigmoid function of \bar{z} with an inflection point at $z^* > 0$. Specifically,

$$\frac{dN}{dt} = rN \left\{ 1 - \frac{N}{M(\bar{z})} \right\}, \quad (2a)$$

where

$$M(\bar{z}) = K + D \frac{e^{c(\bar{z}-z^*)}}{1 + e^{c(\bar{z}-z^*)}}. \quad (2b)$$

We can regard K as representing the carrying capacity of the “cultureless” state ($\bar{z} \rightarrow 0$), provided cz^* is sufficiently large. On

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