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The Origins of Prestige Goods as Honest Signals of Skill and Knowledge

Aimée M. Plourde

Abstract This work addresses the emergence of prestige goods, which appear with fully modern *Homo sapiens* but at different times in different regions. I theorize that such goods came into existence to signal the level of skill held by their owners, in order to gain deference benefits from learning individuals in exchange for access. A game theoretic model demonstrates that a signaling strategy can invade a non-signaling population and can be evolutionarily stable under a set of reasonable parameter values. Increasing competition levels were likely the selective force driving the adoption of this novel strategy. Two changes in the social context in which prestige processes operate are tentatively identified as leading to increased levels of competition for prestige: (1) increasing group sizes and (2) increasing complexity or size of the existing cultural repertoire. Implications for prestige goods' later use in social and political competition are discussed.

Keywords Costly signaling theory · Cultural evolution · Game theory · Prestige goods

This paper explores the evolution of what are commonly referred to as "prestige goods"—material items whose primary function in most contemporary societies is to signal elevated social status as well as to assist in augmenting status. Although the psychology of prestige may be of long duration in the human lineage, what are commonly agreed to constitute prestige *goods* appear relatively late in the archaeological record and thus require separate explanation. I begin by considering the evolutionary history of prestige psychologies and behaviors, and how material goods could come to be involved in prestige processes. It is proposed that prestige goods evolved to function as signals between successful individuals and learning

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A. M. Plourde (✉)
AHRC Centre for the Evolution of Cultural Diversity, Institute of Archaeology,
University College London, 31-34 Gordon Square, London WC1H 0PY, UK
e-mail: aimee.plourde@gmail.com

ones, to help coordinate the exchange of proximity and teaching for the benefits associated with having prestige. This hypothesis is developed in a simple analytical model to assess the viability of such a signaling strategy over multigenerational time scales. Following this, factors favoring the emergence of signaling via material goods and the implications of its emergence for social processes leading to the emergence of permanent, formalized social ranking differences are discussed.

Prestige and the Construction of Social Status

Prestige forms an important component of how people augment their social standing or status relative to other members of their social group (Barkow 1975:554). However, while ranking is ubiquitous in the social species generally and is found in all of our closest primate relatives, prestige is apparently unique to humans; in all other species rank is determined by dominance behaviors alone (Ellis 1995)—in other words, through physical violence, threat of violence, or some other means of coercion. In contrast, prestige consists of the authority and privilege freely given to an individual by others. The source of this admiration of, desire to know, and willingness to defer to the prestigious person commonly derives from her knowledge, expertise, or advanced skill in some valued domain of activity (Henrich and Gil-White 2001:167).

The Origins of Prestige

Following from the idea that prestige psychologies and behaviors arose some time during humans' evolutionary trajectory and have remained a pervasive feature of human psychology and social interaction since that time, it seems likely that they were favored by natural selection to solve an adaptive problem. Recently, Henrich and Gil-White (2001) proposed that this function stemmed from the increasing importance of the social transmission of information to our species' success. They reason that, as culturally transmitted knowledge and skills became increasingly complex, novel psychologies and behaviors that assist in social learning would have been favored. In this particular case, the psychologies of prestige assist in the identification of other individuals in one's group who are successful, and they provide incentive to pay particular attention to the details of their behaviors and opinions, to maintain proximity to them, and to desire their friendship. All of these behaviors should improve one's ability to observe the behavior of a successful person and to interact with her, both of which should contribute to the accurate transmission of beneficial information. Further, such feelings of admiration and respect are linked with desires to please the successful individual, and it is likely that prestigious individuals receive various kinds of social benefits from their admirers, such as leniency after a transgression of group norms or a failure to reciprocate in a dyadic exchange, or support for self and family following injury or illness (see Bateson 1958:91; Hawkes 1991, cited in Henrich and Gil-White 2001:182–183). These benefits in turn provide the incentive to the successful individual to tolerate the presence of an admirer, and also possibly to actively teach or mentor her. Presumably a young and/or learning individual would already have access to parents

and other kin for information without needing to pay such benefits, following the logic of inclusive fitness (Henrich and Gil-White 2001:179; Shennan and Steele 1999; Tehrani and Collard 2009), so the exchange of benefits should only occur for demonstratively superior knowledge and expertise, and only when such skilled individuals do not happen to be close relatives.

A Hypothesis for the Origins of Prestige Goods

The benefits derived from being prestigious, especially in the cumulative sense of being received from multiple admirers, could lead over time to an evolved desire for prestige and of behaviors geared to seeking it out. Further, under the right ratios of skilled to unskilled individuals in a group, it is possible that competition between skilled individuals for prestige "clientele" could occur; Henrich and Gil-White (2001:171, 178–179) suggest that in such a context of competition, skilled individuals might alter their behavior toward potential admirers, being more approachable—essentially, nicer—to them, in order to gain their attentions.

I suggest that, if competition for prestige were sufficiently strong, alternate strategies to attract admirers would also be favored by natural selection. Here I will discuss one such possible strategy, that of behaving in some manner so as to advertise or signal one's level of skills or knowledge to potential admirers, allowing them to more accurately judge one's skill level relative to other possible targets for admiration and deference. Using material goods to signal the degree of skill or knowledge would be one way of accomplishing this, and such items would thus function as "prestige goods." Material goods could indicate the quality of a person's skills and/or spheres of knowledge in numerous ways, essentially by acting as a manifestation of the end product of their operation. For example, the feathers of a rare or elusive bird could demonstrate good hunting skills, weapon crafting, or detailed knowledge of the local environment.

While the ways in which physical goods could reveal success in theory vary as widely as the kinds of skills or knowledge in existence, the actual form that such a signal would need to take must relate back somehow to the skill or knowledge in question in order for the signal to be useful to those interested in augmenting their knowledge and skills. This link between the signal's content and its specific form distinguishes signaling for prestige from other kinds of signals that could have existed (and probably did) aimed at different audiences, including potential mating partners, potential rivals for mating partners, and competitors for other kinds of resources, a point I will return to below.

Another important aspect of the signal is that, because there is a conflict of interest between the signaler and her audience—no doubt the signaler would always prefer to receive prestige benefits while the learning individual should wish to give such benefits only in exchange for superior knowledge and/or skills—the signal needs to be costly in order to maintain its reliability. A substantial literature on signaling theory in animal behavior exists (for a full review, see Maynard Smith and Harper 2003), developed both in economics in the 1960s and independently in evolutionary biology following Zahavi's "handicap principle" for fitness indicators under sexual selection (Zahavi 1975, 1995; Zahavi and Zahavi 1997), which have

explored important issues relating to conflict of interest and signal cost (see, e.g., Godfray 1991; Grafen 1990; Johnstone 1995, 1997, 1998, 1999; Johnstone and Grafen 1993; Maynard Smith 1991).

The general logic behind costly signaling theory (CST) has been employed in a variety of ways in the study of human behavior (a good historical overview is given by Bliege Bird and Smith 2005). Many of the recent applications have centered on issues of sexual selection, focusing on the direct advertisement of personal qualities that would be attractive to mates, such as intelligence (Miller 2000), health, or productive capabilities such as hunting prowess (Aldenderfer 2006; Bliege Bird et al. 2001; Hildebrandt 1994; Smith 2004). Pertinent to the present discussion, some suggest that forms of public generosity, including among other things the punishment of transgressors for violations of group norms (Gintis et al. 2001), hunting of large game animals for public consumption (Bird et al. 2002; Smith et al. 2003), and uploading files in a peer-to-peer file sharing context (Lyle and Sullivan 2007), may constitute costly signals to potential mates and allies, arguing that such generosity both provides an opportunity for demonstrating personal qualities as well leads to gains in status—prestige, in the sense that it is not coerced—that would in itself be an attractive quality to mates and other social interaction partners.

While high status (possibly however it is achieved) is very likely to be attractive to potential mates and allies, and therefore individuals should pay attention to status ranking and all attendant features that demonstrate it, including the display of prestige goods, I would argue that this attention to status overall should not necessarily lead to the emergence of a strategy of displaying rare/difficult-to-produce items (prestige goods). If overall level of success were the salient feature, more straightforward displays—overall amount of food collected, number and health of children, etc.—would seem to be sufficient to the task. In contrast, a learning individual should be more interested in exactly how the successful model accomplishes her level of success, and it is this interest in the details of skill and expertise that would drive the emergence of signaling with finely crafted or rare materials, which in some way demonstrate fineness of skill or degree of expertise in a given realm.[1]

Others, particularly archaeologists, have also suggested that costly signals could be used in the quest for increased social status (Boone 1998, 2000; Boone and Kessler 1999; Neiman 1997; Trigger 1990), but here an important distinction is that in the majority the envisioned social context is one that already includes aspects of formalized social ranking—inheritance of wealth, family/lineage rights to resources, formalized offices of leadership and the like. There is no doubt that competition for increased social status in the Veblenian (1998) sense of conspicuous or wasteful consumption and display is a common feature of societies with such ranking, but this

[1] A related issue is whether the production of any kind of item not directly related to a "utilitarian" function may constitute a signal, though not one of skill. Decorative items, for example, even if made of local material and requiring no great skills to produce, could nonetheless function as signals of the extra time an individual has above and beyond that spent engaged in making a living. Alternatively, it may not be correct to consider items as signals in themselves if their main function is to enhance or draw attention to other features, such as cosmetics or material decorations worn on the body that draw attention to physical indicators or indices of symmetry, fertility, youth, etc. Further discussion of this point is given elsewhere (Plourde 2006, 2009).

provides little insight into how goods inspire feelings of admiration and respect linked with prestige, and how they might play an active role in the emergence of such social ranking, particularly the social infrastructures that support it.

Humans have undoubtedly used signaling as a strategy to advertise different kinds of qualities or information, targeting different audiences, and this "multi-vocality" results in considerable complexity that acts as a barrier to understanding. Clarifying issues related to costs of signaling and benefits received as a result of it should be one step toward elucidating this subject. As Johnstone and Grafen (1992:215) have noted, mathematical models are useful when it would be difficult to evaluate the expectations from differing verbal models. In the present case, it is this issue of cost that makes assessment of the viability of a signaling strategy difficult for longer time scales than are captured by experimentally derived observation and ethnographic data. In the following section, I develop an analytical model of the costly signaling argument presented above, formulated using a game-theoretic framework, which allows its internal logic to be more rigorously evaluated over such longer, "evolutionary" time scales.

The Model

To build a model of the operation of prestige goods as honest signals of skill and expertise, let us assume a population composed of individuals that vary in their degree of a given skill. To simplify the model, assume that skill level has only two states, high or low. Let p represent the frequency of highly skilled individuals in the population. Individuals are aware of their own level of skill but do not know that of others in the population. For a given round of interaction, two individuals are selected at random from the population. One individual is randomly assigned the role of "signaler," S, and the other the role of "responder," R. The round of interaction begins with the signaler deciding whether or not to produce a signal, purportedly to indicate to her interaction partner the possession of a high degree of skill. The signaler makes this decision using one of three possible strategies: always signal (AS) regardless of actual personal skill level; "honestly" signal (HS), meaning signal only when skill level is in fact high; and never signal (NS). A fourth possible strategy, signal only when skill level is low, need not be considered as it is highly unlikely to occur. Let c represent the cost of producing the signal if highly skilled, and c' if unskilled, assuming that $0<c<c'$. Following the action of the signaler, the responder then chooses whether or not to pay attention to a signal and whether to respond to it with deference, based on one of three possible strategies: always "respond" with deference to the signaler, regardless of the production of a signal or not (AR); "honestly" respond, meaning in this case respond with deference behaviors only when a signal is produced by the signaler (HR); and never respond (NR). Response takes the form of paying a benefit, b, to the signaler, which is a cost to the responder and causes a reduction in her fitness.[2] However, interacting with a

[2] The use of a single parameter to represent both the costs paid by admirers, which may take may different forms, and the benefit from such deference to the signaler, is meant to capture the fact that the transaction is a transfer from the learner to the signaler/teacher, and follows models of costly signaling by offspring to parents, where the transfer of resources from the parent to the offspring is in a common currency, although the cost of the signal for the offspring is distinct.

signaler who is highly skilled allows the responder to increase her own skill level, which in turn raises her fitness by an amount s. After this interaction and the possible subsequent opportunities for learning that follow from it, the individuals are returned to the population. The decision tree shown in Fig. 1 illustrates the payoffs to signalers and responders from a given interaction, depending on the level of skill possessed by the signaler. In future rounds of the game, pairs of individuals are again drawn at random from the population to interact with one another.

Using the payoffs to the different signaling and responding strategies, which vary according with the pairing of different strategies, the relative fitnesses of signaling and responding strategy combinations can be assessed. The fitness (V) of the Honest Signaling (HS) strategy when paired with an "Honest" Response (HR) strategy, and the reverse, is given by Eqs. 1 and 2, respectively.

$$V_{\mathrm{S}}(\mathrm{HS}|\mathrm{HR}) = p(b - c) \tag{1}$$

$$V_{\mathrm{R}}\ (\mathrm{HR}|\mathrm{HS}) = p(s - b) \tag{2}$$

A population of individuals using the combination of the HS and HR strategies can resist invasion by other signaling and responding variants, particularly Always Signal and Never Respond, when the cost of signaling when unskilled (c') is higher than both the cost of signaling when highly skilled (c) and the benefit to be gained

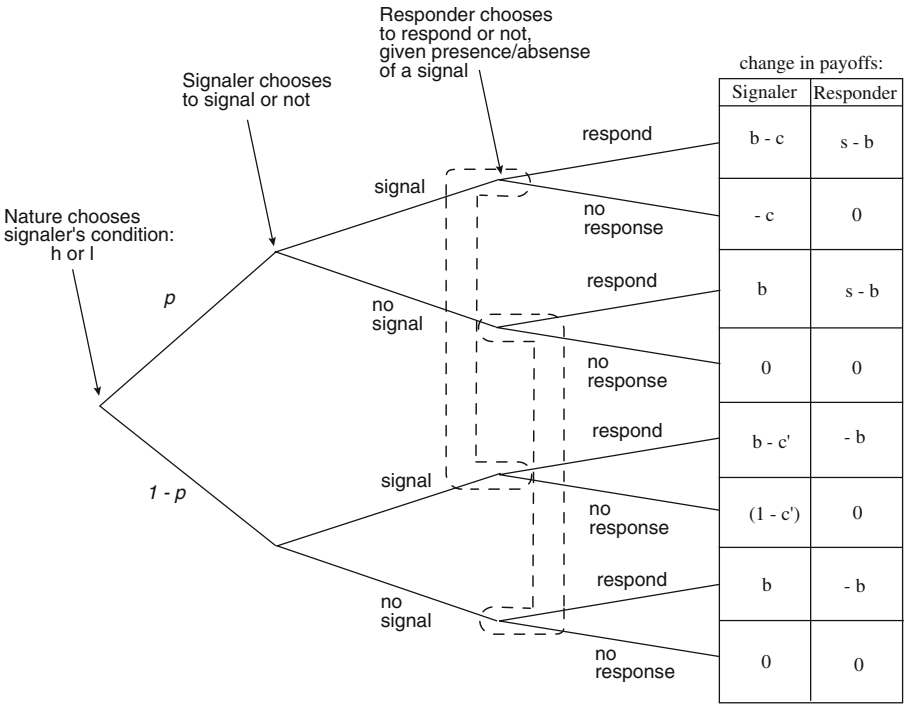

Fig. 1 Decision tree showing all payoffs to signalers and responders, depending on signalers' degree of skill/expertise

from signaling (b), and when the benefit to responders in terms of learning new skills (s) is greater than the deference costs paid the signaler (b). These conditions are summarized in Eq. 3.

$$0 > c > b > c',\ s \tag{3}$$

Further, the combination of the Honest Signaling and Responding strategies can also enter a population where Never Signal and Never Respond are the default strategies. This is due to the fact that the fitnesses of both the Honest Signaling and Honest Response strategies are neutral when compared with the fitnesses of the Non-Signaling and Non-Responding strategies played against their own type—in other words, both are zero.

Further, as seen elsewhere with other kinds of cooperative behaviors, kin selection could help lower the threshold for invasion by the Honest Signal and Respond pair of strategies. When one takes into account the effect of relatedness between the rare invading HS+HR individuals, invasion is possible when the benefit (s) to the responder multiplied by the degree of relatedness to the signaler (r) is greater than the cost (c) to the highly skilled individual of producing a signal, as shown in Eq. 4.

$$rs > c \tag{4}$$

Unsurprisingly, this result is an instantiation of Hamilton's rule of inclusive fitness. The calculation of this result is provided in Appendix 1.

Another consideration regarding the stability of the combined Honest Signaling and Responding strategy concerns changes over time in the proportion of highly skilled individuals in the population. It could be argued, for instance, that if unskilled individuals continue to learn from highly skilled ones as a result of the interaction with them, eventually the entire population would become highly skilled, rendering the utility of a signaling strategy useless. However, in reality this eventuality should not occur for a number of reasons. First, it can reasonably be assumed that learning new skills is a relatively difficult process, even with the help of proximity and teaching; while those unskilled individuals who have access to a highly skilled mentor are more likely to increase their own level of skill than those without, it is nevertheless likely to be the case that most unskilled individuals will fail to become highly skilled. Further, some rate of attrition of highly skilled individuals from the population should be assumed, following senescence and death of highly skilled group members or their migration from the population. It is also possible that a given skill may become "unfashionable" or no longer useful, rendering the person with a high degree of skill in the defunct domain no longer in demand as a model. Similarly, unskilled individuals should be assumed to enter the group regularly through birth or migration. To capture these differing sources of change in the proportions of highly skilled and unskilled individuals in the population in our model, let α represent the frequency at which unskilled individuals become highly skilled, and let the rate at which the proportion of individuals in the population switch from highly skilled to unskilled be represented as a mutation rate μ. Now, instead of allowing nature to "choose" the proportion of highly skilled individuals in the population, p, we can allow it to evolve. In this case, we find that the proportion of highly skilled to unskilled individuals in the population will reach an equilibrium,

which is a function of both α and μ. This function is given in Eq. 5. The calculations demonstrating this are fully presented in Appendix 2.

$$\left(1-\hat{p}\right)=\frac{\mu}{\alpha(1-\mu)} \tag{5}$$

Discussion

The model suggests that as a strategy, the use of material goods to signal skill and expertise levels to potential admirers could be a successful one over long time scales. The model is, of course, a very simplified one in many ways, particularly in that signaling in a given episode is restricted to only one other individual in the group, and also in that the value of the signal is fixed as belonging to one of only two states, present or absent. Work is currently underway to investigate how (1) changing the model to include signaling to a number of people, in a group with up to *n* number of members,[3] and (2) making the signal cost a continuous variable will affect the results. Such "simple" models are nevertheless useful in that they can provide insight into the nature of the relations between causal variables that more realistic, and thus more complex, models often cannot show as clearly. The present model has value in identifying the relevant variables involved in such a signaling interaction, and in explicating the nature of the costs and benefits involved that must exist for such a strategy of signaling to emerge and succeed.

Prestige Goods and Deference Benefits

The model suggests that under the right conditions, signaling a high level of skill and expertise using material goods could be repaid through the benefits derived from being cultivated as a tutor by admiring learners. Do data exist that support this prediction? Extant data are suggestive but not conclusive. Henrich and Gil-White (2001:180–187) cite a substantial body of data from diverse ethnographic sources and social psychology experiments indicating that people who are considered to be highly skilled within their community are preferentially copied, have higher status, and receive deference and privileges, and are excused from social obligations. However, it is not often specified in these cases how competence, and how prestige, were assessed by subjects—was the display of prestige goods an influential factor? And if so, can it be demonstrated that the goods are linked to skill? In contemporary, complexly organized societies it is ubiquitous for prestige goods to signal degree of wealth and social position, possibly in addition to whatever skill and expertise signal value they may have. However, I theorize that signaling skill and expertise as a strategy should have come into existence prior to the emergence of permanent and

[3] Gintis et al. (2001) used an *n*-person framework to examine a similar costly signaling scenario. Results of their model suggested that there was no significant difference between the results of dyadic and *n*-person setups. However, I feel it necessary to confirm these findings when sampling from the deme occurs with replacement after each round of interaction, a variation that essentially makes it more difficult for a signaling strategy to invade a non-signaling population.

formalized social ranking and inheritable wealth, following from the fact that skill level was likely increasingly important as cultural complexity and cognitive capacities themselves increased. This suggests that wasteful signaling of wealth and social status (*sensu* Veblen) probably tapped into signaling psychologies and behaviors already in place. But first it returns us to the question of the original nature of the social context within which prestige competition was operating in the past that could have permitted or favored a signaling strategy to emerge and succeed.

Why Begin to Signal for Prestige from Skill and Expertise?

As discussed previously, competition for prestige could arise when the number of potential admirers were in short supply relative to the number of would-be prestigious individuals, a threshold also affected by the amount of benefit gained from each additional admirer, and the cost of their presence in terms of the amount of time lost to interacting with them at the expense of more profitable activities. The variation in the timing of the appearance of prestige goods demonstrated by the archaeological record implies that levels of competition for prestige may have varied substantially among groups.[4] What factors could cause prestige competition to escalate, as would favor advertising degree of skill and expertise with costly goods? Two things suggest themselves: (1) increasing group size, and (2) increasing complexity and/or number of skills and domains of cultural information.

An increase in the number of group members could lead to increased prestige competition and favor signaling in that as group size increases the number of people in the group with some degree of success should also increase, although the number of the most highly skilled individuals (the best models) should actually be smaller relative to the group as a whole. As the number of successful people in a group rises, learning individuals and recent migrants would have more choices from which to select a model, leading the level of competition between successful individuals for admirers to rise. Further, as the number of skilled individuals rises, it should also become more difficult for learning individuals to determine which individual is the most successful and therefore the best choice of model.

The expansion in skill and knowledge sets available and important to success could also favor a strategy of advertising. As new skills are added to the repertoire of ways of making a living and existing skills and bodies of knowledge are expanded and become more complex, the difficulty of learning everything necessary to be successful will concomitantly increase. This in turn should make it more important for learning individuals to have access to a good model, and thus be willing to invest more energy in evaluating potential models and to increase the amount of social benefits bestowed on their potential prestige "patrons." Such increases in the benefits

[4] Here again I am specifically referring to goods whose primary function is to signal to learning individuals, who desire access to a highly skilled model and are willing to be deferent to that person in exchange. Such goods should be distinct from other kinds of physical items used as signals, specifically ones used to signal to mates and allies the amount extra time (general success levels), or items used to attract attention to salient physical qualities. It seems likely, however, that prestige goods could have *derived* from these. So for instance, the earliest forms of decorative items, such as beads, may not have begun as prestige goods, but when made of an exotic material or made in a particularly complex way, they would be taking on a signal content now aimed at learning individuals.

received from having prestige could then compensate for increased costs incurred to win prestige competition, including those involved in procuring or creating prestige goods.

Prestige Goods and the Emergence of Sociopolitical Ranking

It is worth reiterating that this model for the origins of prestige goods does not include or require the presence of sociopolitical hierarchy, or the kinds of competition for offices of leadership and elevated status categories that it involves. However, the factors just discussed as promoting increases in levels of competition for prestige could very well result from other, overarching factors that are also often implicated in the emergence of social inequality, including increases in population size, increasing group circumscription, and technological innovation. Bliege Bird and Smith (2005:234) observe that signaling for prestige via food production and the development of prestige hierarchies are constrained in part by productive capability, both in general and specifically with regard to "the relation between productive resources and producers' skill differentials," observations that resonate with much archaeological theory on the emergence of social hierarchy. Thus, while this model contains no causal arrow directly between the emergence of prestige goods and social ranking, it could well be the case that the stimuli for both lay in these overarching forces. Although archaeological data may not be able to capture the dynamics of signaling "in action," they do provide the means to examine the timing of the appearance of prestige goods in the archaeological record in relation to increases in group size, group interaction levels, and technological innovation, as well as other indicators of the presence of social ranking, including differences in diet, health, house size, burial elaboration, and the like. Evaluation of these with a case study drawn from the south-central Andes (Plourde 2006; Plourde and Stanish 2006) reveals that prestige goods do in fact appear in the archaeological record prior to other indicators of social ranking, suggesting that the production of such items did indeed predate the existence of heritable rank and wealth differences, and thus could have been involved in their creation. A careful review of other cases of autochthonous development of social complexity from around the world (now underway) is needed to bolster this finding.

But beyond predictions about the timing of the emergence of prestige goods, the model presented here provides a basis for understanding *how* it is that prestige goods display and distribution could in fact play an active role in the emergence of sociopolitical complexity. Admiration of and desire for prestige goods are often cited as the reasons why prestige goods' display and distribution were important in the emergence of sociopolitical hierarchy, but the source of these desires is also often left unexplained or underspecified. This model provides an explanation for why people should admire those who possess prestige goods, and why they should also desire to possess such goods themselves, particularly in a context where storable or inherited wealth is nonexistent and thus cannot be the source of their value. Drawing on ethnographic observations of how leaders are chosen in contemporary egalitarian societies,[5] I suggest that prestige would have played an important part in who is

[5] By the term "egalitarian" I specifically refer to an absence of formalized leadership positions or social ranking: it is likely the case that status differences have always existed in human societies—by age, sex, and level of skill—and prestige differences do exist in contemporary egalitarian societies.

selected—or accepted—as leader, since leaders for a given activity are usually selected from among those who have experience and/or skill relevant to the task at hand, such as combat (Chacon 2004) or inter-group alliance and trade (Johnson and Earle 2000). In other words, they should have prestige in that particular arena, and thus prestige goods should offer a way for group members to evaluate a potential leader's skill and knowledge. In addition to display, the would-be leader who could provide prestige goods to followers would tap into a culturally evolved desire for such goods, offering the enticement so often cited as the basis of people's voluntary participation in emergent elites' activities and schemes. As wealth and differences in social power between lineages emerge and become established, the signal content for prestige goods should then expand to include these new parameters, as first described by Veblen (1998) in the late 1800s—in fact, it seems possible that the very process of prestige competition could create some sort of positive feedback system in which, as would-be leaders draw family and allies to produce such goods, the goods inevitably come to embody these very parameters, as modeled by Boone (1992, 1998, 2000; Boone and Kessler 1999), Neiman (1997), and others.

Conclusions

This work suggests the possibly productive input of evolutionary models of human nature to anthropological and archaeological theories of the evolution of social structures and institutions. The model presented here attempts to contribute to an explanation of how and when prestige goods first appear as a result of social dynamics in early human societies by proposing that they function as costly and therefore honest signals of skill and/or expertise. Results suggest that conditions could have existed in the past under which such a signaling strategy could be evolutionarily stable, and could also invade a population lacking such a strategy. Drawing on work in evolutionary psychology on the nature of prestige itself provides a solid basis from which to theorize about the nature of the psychology of prestige goods and how they came into existence, and how they then could come to be involved in and operate in social ranking. Further modeling will focus on increasing the realism of the model, and on elucidating how signal content could be expanded as a result of changes to social dynamics as social and political ranking emerge.

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Appendix 1

To consider the effect of relatedness between rare Honest Signaling and Responding types on the invasion criterion for the Honest Signaling and Responding strategy HS+HR into the Non-Signaling, Non-Responding (NS+NR) population, assume that

there is a probability r that an HS+HR type meets itself and $(1-r)$ probability that it meets a common NS+NR type. Therefore, we can say that the probability for an individual to be paired with her own type is $[r+(1-r)q]$ and the probability of being paired with the other type is $[(1-r)(1-q)]$, where q represents the frequency of her own type. For the purposes of simplification, let H represent the HS+HR strategy combination and N represent the NS+NR combination. To evaluate the relative fitnesses of the two types, we multiply the fitness of each type against itself and against the other type with the probability of meeting whichever type.

$$V_{SR}(H|H)(\text{prob}H) + V_{SR}(H|N)(\text{prob}N) > V_{SR}(N|H)(\text{prob}H) + V_{SR}(N|N)(\text{prob}N)$$

In the invading scenario, we can assume $q=0$ for the invading type HS+HR, while for the common type NS+NR, the probability of being paired with her own type is 1, and the probability of being paired with the rare type is 0.

$$\left[\underbrace{[p(b-c)]}_{V_S(HS|HR)} + \underbrace{[p(s-b)]}_{V_R(HR|HS)}\right]\underbrace{[r+(1-r)q]}_{Pq} + \left[\underbrace{(-pc)}_{V_S(HS|NR)} + \underbrace{0}_{V_R(HR|NS)}\right]\underbrace{[(1-r)(1-q)]}_{R(1-q)} > \left[\underbrace{[0]}_{V_S(NS|HR)} + \underbrace{[0]}_{V_R(NR|HS)}\right][0] + \left[\underbrace{(0)}_{V_S(NS|NR)} + \underbrace{0}_{V_R(NR|NS)}\right][1]$$

$$\begin{aligned}
[p(b-c)+p(s-b)][r+(1-r)0]+(-pc)[(1-r)(1-0)] &> 0\\
[pb-pc+ps-pb][r]+(-pc)[(1-r)] &> 0\\
(ps-pc)r+(-pc)(1-r) &> 0\\
rps-rpc-pc+rpc &> 0\\
rps-pc &> 0\\
rps &> pc\\
rs &> c\\
rs-c &> 0
\end{aligned}$$

Therefore, the honest signaling and responding strategy H can invade a non-signaling and responding population when the skills gained from paying prestige to highly skilled signalers multiplied by the degree of relatedness is larger than the cost to the responder of paying the cost of prestige deference.

Appendix 2

To examine how rates of change between unskilled (L) and highly skilled (H) states might influence p (the frequency of highly skilled individuals in the population) over time, we modify the model slightly to incorporate these rates into our calculations. When individuals are chosen at random from the population to form interacting pairs, it follows that the likelihood of choosing two of the same type or one of each are as given below:

p^2	probability of 2 highly skilled individuals being drawn from the population
$2p(1-p)$	probability that a skilled and an unskilled individual will be drawn
$(1-p)^2$	probability that 2 unskilled individuals will be drawn

Following the interaction of individuals within their pairing, let the probability of changing from unskilled to highly skilled $Pr(L \rightarrow H)=\alpha$, where $0<\alpha<1$, the probability of changing from high to low skilled $Pr(H \rightarrow L)=0$, and the probability of remaining highly skilled if already highly skilled $Pr(H \rightarrow H)=1$. Thus the

proportion of highly skilled individuals following the first round of interaction, p', can be given by the following expression:

$$\begin{aligned} p' = & \underbrace{p[P(H \to H)]}_{\text{Pr self}=H*\text{Pr remaining}H} + \underbrace{p(1-p)[P(L \to H)]}_{\text{Pr partner}=H*\text{Pr becoming}H} \\ & = p(1) + p(1-p)\alpha \\ & = p + p(1-p)\alpha \end{aligned}$$

At this point individuals are returned to the total population. Before they are re-sampled into pairs for the next round of interaction, we assume a certain amount of "mutation" in the population from a highly skilled to unskilled state, which we will term μ. Following this change, the proportion of highly skilled individuals in the total population, p'', is determined in the following calculation:

$$\begin{aligned} p'' &= p'(1-\mu) \\ &= [p + p(1-p)\alpha][1-\mu] \\ &\textit{or} \\ &= p(1-\mu) + [p(1-p)\alpha(1-\mu)] \\ &= p - \mu p + p(1-p)\alpha(1-\mu) \\ &= \underbrace{(1-p)\alpha(1-\mu)}_{freqH} - \mu \end{aligned}$$

Now we can examine the question of whether it is possible for the frequency of highly skilled individuals to reach an equilibrium, such that the population does not over time reach a point where all members are highly skilled, thus reducing the utility of learning and therefore of signaling the possession of a high degree of skill. Let $\widehat{p}$=the frequency of highly skilled individuals in the population at equilibrium, when there is no change in the proportion of highly skilled individuals at p'' and p. Solving for $\widehat{p}$ gives the following equation:

$$\begin{aligned} p'' &= p \\ [p + p(1-p)\alpha][1-\mu] &= p \\ p + p(1-p)\alpha - \mu p - \mu p(1-p)\alpha &= p \\ p(1-p)\alpha - \mu p - \mu p(1-p)\alpha &= 0^* \\ (1-p)\alpha - \mu - \mu(1-p)\alpha &= 0 \\ (1-p)(\alpha - \alpha\mu) - \mu &= 0 \\ (1-p)(\alpha - \alpha\mu) &= \mu \\ (1-p) &= \frac{\mu}{(\alpha - \alpha\mu)} \\ \left(1-\hat{p}\right) &= \frac{\mu}{\alpha(1-\mu)} \end{aligned}$$

* Assuming that $p \neq 0$

It is thus demonstrated that such an equilibrium can exist, when the proportion of unskilled individuals is equal to the rate at which highly skilled individuals "mutate"

to unskilled individuals divided by the rate at which unskilled individuals become skilled multiplied by one minus the mutation rate.

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Aimée Plourde received her Ph.D. in anthropology at UCLA and currently is a U.S. National Science Foundation International Research Fellow (Award No. 0402116), conducting research at the AHRC Centre for the Evolution of Cultural Diversity, Institute of Archaeology, University College London. Her main interests are in cultural transmission mechanisms and evolution, particularly the evolution of social institutions supporting hierarchical political structures. She has recently studied the role of prestige goods in the development of early ranked societies, using archaeological data on cultural development in the northern Lake Titicaca Basin, Peru, as a case study.