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Son to Father Reciprocity and Encephalization in Early Humans

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Abstract

Humans exhibit much more sharing of food harvested by prime-age hunter-gatherers with dependents relative to such sharing by lower-order primates. We investigate this behavior in a model in which a father provides generously to his dependent child-son in period t in the hope that this gesture will inspire his son to reciprocate in the next period when the father is in "retirement". In our formulation fathers provide better when (a) they are smarter hunters (b) they have a higher probability of living to experience a "retirement" and (c) when they are more confident that their child-sons will indeed provide generously for them in their "retirement". Better food provision by prime-age fathers is associated with brain-size expansion in our model.

- key words: reciprocity, encephalization, intertemporal division of labor
- journal classification: J100, I120, J220

1   Introduction

Kaplan et. al. [2000] point out that contemporary male hunter-gatherers, as mature, young adults, produce much excess food (energy) relative to their personal needs compared with lesser primates such as apes and chimpanzees. These prime-age human males thus support many dependents with their hunting and gathering activity. This striking schedule of excess energy production inspires us to develop a theory of rational

decision-making by an adult prime-age hunter which yields this excess energy production. Our premise is that the support by a father of his dependents, including his young sons, represents a signal to the sons to provide generously to their dependents, those of the sons, when the latter have matured to become prime-age male hunters. One of a son's dependents will be his now elderly, "retired" father, assuming the latter has survived into old age. A father then rationally tats in a forward-planning way in the current period in the hope of receiving a tit (a generous food alotment) from his son in a later period. Food provision by the father constitutes a teaching and commitment mechanism that the father hopes will lead to the son, when grown up, to provide generously to his dependents, including this "aged" father. We then exploit this theory to make inferences about routes to brain-size expansion experienced by early humans some two million years ago.[1] Our approach contrasts with the view that human fathers have evolved to provide for the energy needs of dependents via a hard-wired, genetically determined mechanism as with some birds and other lower order creatures. We have no special evidence for the superiority of our approach but we pursue it as an exercise. We feel that the evidence for the innate, hard-wired approach is not clear either. The large and important question remains: how much parental support of dependents by humans is genetically based rather than learned or reasoned out.

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[1]Robson and Kaplan [2003] confront the data on excess energy production by prime-age male humans and solve for a life expectancy function that results in zero net energy surplus over all cohorts (producers and dependents) at each instant of time. They treat the providing-for by prime-age males as genetically based rather than behaviorally based. "That is, in exchange for a subsidy while young, the individual makes repayments while older. What compels older individuals to repay the loan they are given while young? The answer is that individuals have a biological motive to foster their own offspring. Indeed, natural selection would act on genes influencing resource transfers between generations. Genes maximizing their representation in future generations would be those generating such parental concern. The social food-sharing arrangements of hunter-gatherer societies smooth out this intergenerational transfer and are presumably Pareto improving, but they do not change its basically selfish nature." (pp. 156-57, Robson and Kaplan).

The "generosity" of food sharing with dependents by humans suggests strongly that this behavior is linked to the evolved largeness of the brains of modern humans relative to lower primates. Largeness here is associated with a high degree of sociality (a relatively large neocortex) rather than narrowly defined intelligence that could be associated with say superior hunting ability. Robson and Kaplan [2003] link the large volume of sharing by evolved humans relative to lower primates to an evolved high cognitive capacity in humans for hunting and gathering, relative to apes and chimpanzees, and to an evolved genetic endowment that makes humans especially caring parents. We depart from Robson and Kaplan by placing the food providing-for by a father-hunter into a choice-theoretic framework. Our prime-age male hunters provide meat for dependents in order to attempt to induce son-dependents to provide for the fathers when the latter is in "retirement" and is unable to provide for himself. The extent of providing-for by a father depends on the hunting ability of a father in our model, on the uncertainty the father faces of having a son who provides poorly when the father is in "retirement", and on the uncertainty that the father faces of simply not living to experience a "retirement". The perturbing of a parameter linked to each of these three dimensions results in more generous provision of meat for dependents by the father and in our view to brain-size increase by the children who are better provided for.[2] Our model is then compatible with at least three fairly distinct theories of brain-size expansion take-off in the history of primates.

Fathers in our model must reason out that they should signal to their child-sons by their behavior in order to try to get the sons to "co-operate" at a later stage. Fathers must plan and also must see the possibility of

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[2] We link more food provision for a child-dependent over a series of generations to brain-size expansion alone. An alternate formulation would have expanded food provision from a father lead to expanded fertility by females and/or to greater life expectancy by those getting the larger food alotments.

titting taking place later in return for a tat. Dunbar [1992] has argued that the large ratio of the human neocortex to overall brain size[3] indicates an extra capacity of humans for non-violent social interaction. In this view the distinguishing feature of humans is the extra capacity, above that of other primates, for social interactions, a capacity make possible by the relatively large neocortex. The complexity of mating behavior is one important aspect of social behavior (e.g. Schillaci [2008]). Dunbar suggested that one could actually quantify this capacity for extra sociality in humans by measuring the relative sizes of social groups that different primates have evolved to live within. Dunbar argued for 150 individuals for humans with their large neocortex and many fewer for lower-order primates. Grooming a fellow primate is central to peaceful gesturing, to non-kin based sociality, in the wild. Keeping track of whom to groom—and why—demands considerable mental accounting. The groomer needs to remember who is allied with whom, hostile to whom, or lusts after whom, and conduct grooming accordingly. Dunbar has argued that while lower primates use grooming of one's fellows as a bonding activity, humans evolved language to conduct their particular exercises in social bonding. Language capacity is of course seated in the neocortex of humans. The links between social interaction and brain area activation in humans has been closely studied in recent years. Imaging of the brain with fMRI has become fairly common. Recently, researchers have been able to study areas of brain activation in humans for such phenomena as punishment activity in the face of unfair actions of a fellow (reviewed by Fehr [2009]). Specific areas of the neocortex (bilateral dorsolateral prefrontal cortex (DLPFC) and bilateral anterior insula (AI)) were observed to become active in these experiments.

A fairly standard theory of brain-size expansion take-off has forest-

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[3]With a neocortex volume of 1006.5 cc and a total brain volume of 1251.8 cc, the neocortex ratio for humans is CR=4.1. This is about 50% larger than the maximum value for any other primate species (see Dunbar 1992).

acclimatized primates finding themselves fairly suddenly living in an open savannah environment some two million years ago. The new environment appeared because of an exogenous climate shift. The forest-acclimatized primates flourished in the new savannah environmental niche in part because tubers and game were plentiful. They became largely bipedal and effective at running. Their forelimbs were freed up for pursuing new tasks and their brain-size expanded. Ultimately they became effective game hunters and developed diets with regular meat portions, diets that could support relatively large and energy-extensive brains. Robson and Kaplan (p. 152) note that 65% of energy consumption by a human infant is directed to brain maintenance and expansion. Though the human brain is about 3% of an adult's body weight, the energy requirements of brain maintenance take up about 20% of energy inflow[4] (Wade [2006; p. 19]). It seems generally accepted that for early humans to experience notable brain-size expansion, they needed a diet that included regular portions of meat. And a regular meat diet would have worked best with cooking and cooking necessitated the controlled use of fire. Remnants of the "campfires" of early humans are very scarce and the dating of the controlled use of fire by early humans remains controversial.[5] A way to capture this flourishing of early humans in the new savannah environment formally is to have a parameter, representing hunting effectiveness, shift. Humans flourished because skills

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[4]Homo habilis had brain volumes of 600 to 800 cubic centimeters, The australopithecine lived with a volume of four to five hundred cubic centimeters. Chimps have brain volumes of about 400 cubic centimeters, while modern humans register at about 1400 cubic centimeters. Researchers face the problem that neanderthals had larger brains than do modern humans and so prefer to measure prospective brain capacities with the ratio of brain volume to body volume (the encephalization quotient, EQ). Chimps have an EQ of 2, australopithecines of 2.5, homo habilis of 3.1, home ergaster of 3.3 and modern humans of 5.8. (Wade, 2006; p. 18).

[5]Richard Wrangham has been suggesting that the cooking of food by early humans was the key event in triggering brain-size expansion. See Wrangham [2009]. Frances Barton [2009] argues that the sitting around a campfire decreased the melatonin levels of early humans and this accelerated key genetic changes that allowed humans to evolve relatively rapidly.

accumulated over millenia suddenly became particularly productive. We consider such a parameter shift in our model. Such a shift was central to the analysis of "excess" food provision by adult hunters of Robson and Kaplan [2003] as well.

However, we wish to focus more on the contribution of enhanced sociality (a larger neocortex) to brain size expansion. For example, if inter-clan warfare were less in the savannah, the father could be more assured of experiencing a "retirement" and this in our model induces the prime-age father to provide more generously for his dependents. Thirdly, we contemplate a shift that increases the trust of the father of the quality of support which his son will provide to him in "retirement". Less uncertainty facing the father of future support induces the father, as prime-age hunter, to provide more generously to his dependents in our framework. The more generous support a dependent receives translates in our framework to a force for brain-size expansion in the child-dependents. We contend then that larger brains support both enhanced cognitive capacities as well as enhanced capacity for productive social interaction as in team-work in hunting activity. A key dimension of enhanced sociality in general[6] in our view is the improvement in the trust that a father has in the likelihood that his son will reciprocate with support for the father in the latter's "retirement".

Matters could of course be more complicated. Consider the case of the brain of an early human having parts specialized in two activities:

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[6]Wade argues for two large forces selecting for increased sociality. (1) Access of males to females was democratized. Dominant males no longer monopolized access to females for mating. Some 1.7 million years ago there emerged *ergaster* with a brain size of about 800 cubic centimeters. The males and females were closer in size than in previous proto-humans. "This is a hint of some important change in social structure, very possibly a switch from the separate male and female hierarchies of chimp communities to the male-female bond that characterizes human societies." (Wade, p.11) (2) "... a steady increase in brain size – probably evolved in response to the most critical aspect of the environment, the society in which an individual lived. Judging whom to trust, forming alliances, keeping score of favors given and received – all were necessities made easier by greater cognitive ability." (p. 7).

hunting skill and team-play skill. Suppose when our ape-like ancestors were "re-located" to the savannah, their existing team-player capacities became suddenly very productive in hunting activity. Better harvests then would have led to better fed children and to brain-size increase. These larger brains may well have possessed an enhanced capacity for hunting or tool-using *per se*. There could have been important complementarities in operation. Our point is that the savannah could well have triggered brain-size expansion via routes involving sociality (individuals functioning well in teams) rather than more narrowly defined cognitive capacity. The record indicates that the body sizes of early human males and females moved closer together some 1.7 million years ago.[7] (Wade [2006], p.21). Brain-size expansion could have involved a subtle see-saw path with sociality capacities leading at times and generalized tool-making capacities leading at other times. Expansion of brain areas that support say team-play could well have yielded an increased capacity for tool-making and problem-solving. Here we connect brain-size expansion to a utility-maximizing, two period model of hunting activity by a father, activity which has a large influence on his level of support

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[7]The reduction in the size of males relative to females some 1.7 million years back co-incided with females evolving with a smaller pelvis. This suggests that babies would have been less mature at birth and mothers with baby in arms would have been vulnerable to attacks. A male partner must, judging *ex post*, have had an interest in protecting the mother and infant if he were to be successful in passing along his genes. (Only the genes of the successful procreators and next generation successful procreators, etc. do in fact get passed on.) About 1.7 million years back then, pair-bonding or mating "competition" appears to have taken a new turn. Not only would fathers need to provide protection for their mates and infants but they may well have had to provide meat for mother and children as well. Wade (p. 7) puts the evolution of pair-bonding as follows. "The apes ancestral to both chimpanzees and humans probably lived as small bands of related individuals who defended a home territory, often with lethal attacks against neighbors. They had separate male and female hierarchies and most infants were sired by the society's dominant male or his allies. The emergence of the human line was also territorial but in time developed a new social structure based on pair bonding, a stable relationship between a male and one or more females. This critical shift would have given all males a chance of reproduction and hence a stronger interest in the group's welfare, making human societies larger and more cohesive." Or, family sociality, form this perspective, was a necessary pre-condition for clan sociality.

he anticipates that he will receive in his "reitirement".

Roughly speaking, we are pursuing a notion of division of labor and trade across periods rather than across space. Fathers supply food to child-sons when the father has a special capacity for food-harvesting and sons reciprocate when they have grown to possess the special food-harvesting capacity. This is a more complicated form of trade than that which occurs at a point in time (A gives B some widgets in return for some yams from B (trade across space at a point in time)). Elsewhere I noted (Hartwick [2008]) that this ordinary division of labor and interpersonal trade itself requires the development of certain capacities for "fairness" or sociality. Participants must leave a "transaction" not aggrieved by the terms of trade. Here we take up the matter of the capacity for sociality needed for a certain type of intertemporal, interpersonal trade.

2 A Model

Consider a male in a primitive villages who has three phases each of about eighteen years to his life: dependency, prime-age hunting and "retirement". As a dependent he receives a food alotment determined by his parents. He does no choosing in this dependency phase but he does become aware of generous or not-so-generous provision by his father compared with the providing-for activities of other fathers. During the second phase he supplies the energy needs of himself and a large group of dependents (his mate and children and say two surviving grandparents). During his "retirement" phase, he provides childcare and instruction for children[8] and one of his male children provides food for an extended

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[8]Hrdy's [2009] view is that there is no defined 'maternal instinct', as it depends on a number of variables, and is therefore not innate, as once thought. She also stands by her view that humans evolved as cooperative breeders, making them essentially unable to raise offspring without a helper. This is where the concept of allomothering comes in - relatives other than the mother, such as the father, grandparents, and older siblings, as well as genetically unrelated helpers, such as nannies, nurses, and child care groups, who spend time with an infant, leaving the mother with more free time

family, including our hunter, now in "retirement". Our young adult hunter's lifetime utility has two adult phases: a productive prime-age hunting phase say from age eighteen to thirty-six and a "retirement" from age thirty-seven to fifty-four. These two phases are captured in this utility function:

$$U(C^Y, T - H) + \rho\{\gamma U((\lambda_0 C^E, T - B(\lambda_0)) + (1 - \gamma)U(\lambda C^E, T - B(\lambda))\}.$$

$U(C^Y, T - H)$ is the utility a productive young, adult hunter gets over this "productive" phase of his life. C^Y is own consumption of energy, say meat, and $T - H$ is own consumption of leisure. H is hours hunting and T is total hours available. $\{\gamma U(\lambda_0 C^E, T - B(\lambda_0)) + (1 - \gamma)U(\lambda C^E, T - B(\lambda))\}$ is the expected utility of this same hunter, viewed from his prime-age hunting stage, in his "retirement". When he reaches "retirement" he anticipates getting either consumption bundle $[\lambda_0 C^E, T - B(\lambda_0)]$ with probability γ or $[\lambda C^E, T - B(\lambda)]$ with probability $(1 - \gamma)$. $\lambda_0 C^E$ is own consumption of meat in the "γ state" ($C^E = [\beta H - C^Y]/\zeta$) and λC^E is own consumption of meat in the "$(1 - \gamma)$ state". ζ is the number of dependents, treated as exogenous, that the father will share aggregate "donations" with when in "retirement". $T - B(\lambda_0)$ is leisure in the γ state and $T - B(\lambda)$ is leisure in the $(1 - \gamma)$ state. We will view $B(\lambda_0)$ and $B(\lambda)$ as hours of childcare and instruction provided by the male hunter, now in "retirement". More hours are provided by the father in retirement when the son provides a large alotment, $\lambda_0 C^E$ to the father, now in retirement.

We assume a form of rational expectations: we assume that the expected support in "retirement", provided now by a son, equals the support the father provided earlier to his son and other dependents. That is, we assume that $\gamma\lambda_0 + (1 - \gamma)\lambda = 1$. In addition, for concreteness, we assume that $\lambda_0 > \lambda$. This implies that $\frac{1}{\gamma} > \lambda_0 > 1$ and $1 > \lambda > 0$.

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to meet her own needs.

β is the efficiency of an hour of hunting effort. Then $[\beta H - C^Y]/\zeta$ is the per dependent provision that the father chose to provide when he was a young, adult hunter. The father faces uncertainty about the amount of support that his son will provide for him in "retirement" when he, the father, is engaged in supporting his dependents. The father commits to a level of support of his dependents while being uncertain about what level of support that his son will provide for him, the father, when he moves into "retirement". The retired father becomes is one of the ζ dependents in the father's final phase of life.

ρ is a life expectancy parameter lying between 0 and unity. It captures the probability that a young, active hunter will in fact survive to enjoy a "retirement". Since we assume for concreteness that two grandparents are supported as dependents, among five in total, it is appropriate to assume that $\rho = \frac{1}{2}$. Thus the father faces a probability of 1/2 for enjoying a "retirement" of an unvarying duration, say eighteen years. For a perfectly co-ordinated over-lapping structure, we can postulate a period of childhood dependency of eighteen years, of adult, productive hunting activity of eighteen years and of expected retirement of eighteen years. Robson and Kaplan (p. 154) indicate that contemporary hunter-gatherers face steeply rising mortality probabilities at about age sixty-five. Hence life-expectancy can be quite good for people in primitive cultures if they make it through childhood.

Central of the level of sociality in this model is the possibility of a reduction in risk incurred by the father, risk associated with the level of support that his son will provide to him in his "retirement". Of course, we are only dealing here with intra-familty sociality, but it seems reasonable to infer that this is the domain where sociality first gets rooted and is then transferred by various mechanisms to social dynamics beyond the familty. We recapitulate. In our model, fathers supply food (meat or energy) to their dependents and the per person allocation is the same in

expected value as that supplied by the sons to their dependents, including the aged fathers, now in "retirement". More sociality involves, via signalling to sons, larger allocations of meat by fathers to dependents. In addition to $\gamma \lambda_0 C^E + (1 - \gamma)\lambda C^E$ being expected consumption, when elderly, we have $\gamma B(\lambda_0) + (1-\gamma)B(1-\lambda_0)$ as the elderly father's expected time commitment to the family as for example in childcare activity and in instructing children in say hunting activity. We assume that B is increasing in λ_0 and thus that leisure in old age for a father "in retirement" is $T - B(\lambda_0)$. This seems to be an uncontroversial assumption. More sociality within the family leads to more childcare activity by the grandfather, while the latter is in "retirement". Less clear is what assumption should be made about the response of the grandfather's childcare activity in the "bad" state. We have formulated it as $B(1-\lambda_0)$ declining with λ_0 increasing. Hence an increase in sociality within the family leads to more childcare activity in the "good" state but at the same time, less childcare activity in the bad state. How leisure time is organized by the grandfather in his "retirement" is crucial in our model as to how a drift up in sociality (λ_0 increases) affects the welfare of dependents (via changes in $\beta H - C^Y$). For example, if we formulated time devoted to childcare in "retirement" as strongly increasing in λ_0, this would imply "strongly" less leisure for a grandfather in "retirement" when λ_0 drifted up. With "strong" complementarity between consumption of meat and leisure in "retirement", this could yield a smaller alotment of meat to the dependents, including the grandfather in the "retirement" phase. Such an outcome would indeed be counter-intuitive since we would be dealing with a case of increased sociality within the family and a reduced alotment of meat to each dependent. Below in our calculations we have $B(\lambda_0)$ increase "gently" with λ_0.

3 Solving the Model

For $\zeta = 5$, our representative adult hunter's life-time (two period) welfare is $W = U(C^Y, T-H) + \rho\{\gamma U(\lambda_0[\frac{\beta H - C^Y}{5}], T - B(\lambda_0)) + (1-\gamma)U(\lambda[\frac{\beta H - C^Y}{5}], T - B(1 - \lambda_0))\}$. The young, adult hunter selects C^Y and H to maximize this life-time utility. The first order conditions are

$$U_{C^Y} - \rho\{\gamma U_{C^E}\frac{\lambda_0}{5} + (1-\gamma)U_{C^E}\frac{\lambda}{5}\} = 0 \tag{1}$$

$$\text{and } -U_{T-H} + \rho\beta\{\gamma U_{C^E}\frac{\lambda_0}{5} + (1-\gamma)U_{C^E}\frac{\lambda}{5}\} = 0.$$

In the first equation, U_{C^Y} is the marginal gain from an increment in C^Y in the current period and $\rho\{\gamma U_{C^E}\frac{\lambda_0}{5} + (1-\gamma)U_{C^E}\frac{\lambda}{5}\}$ is the "discounted" cost of this increment. In the second equation, $-U_{T-H}$ is the marginal cost from an increment in H in the current period (less leisure, a lower increment in current utility) and $\rho\beta\{\gamma U_{C^E}\frac{\lambda_0}{5} + (1-\gamma)U_{C^E}\frac{\lambda}{5}\}$ is the "discounted" incremental gain (creating more $\beta H - C^Y$ in the second period). In providing $\beta H - C^Y$ for his dependents in the current period, the young, adult hunter is hoping to be reciprocated with $\frac{\beta H - C^Y}{\zeta}$ in the second period. The more likely he feels that he will in fact be reciprocated with $\frac{\beta H - C^Y}{\zeta}$ (the lower is risk) in the second period, the larger he will set $\beta H - C^Y$ in the first period. $\beta H - C^Y$ can be looked upon as (a) support provided for dependents currently and (b) a signal to the hunter's son, a child, to support the hunter in "retirement". These two equations (first order conditions) yield the key condition

$$\frac{U_{C^Y}}{U_{T-H}} = \frac{1}{\beta}. \tag{2}$$

β is acting as the price of leisure in the first period. Since $U(.)$ is assumed to be concave and increasing in both arguments, it follows that an increase in β must decrease the ratio of the marginal utility of meat to the marginal utility of leisure. β is the efficiency of hunting effort. Hence a rise in β is for the moment assumed to increase first period utility. In addition the "budget constraint" will "rotate" as the price of

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leisure rises. There will be a tendency for $T - H$ to decline and for C^Y to rise. However the final effect on (C^Y, H) will depend on the "income" shift for the "budget constraint".

We will work with the CES utility function

$$U(C^Y, T - H) \equiv \{[aC^Y]^{-\delta} + (1 - a)[T - H]^{-\delta}\}^{-1/\delta}$$
$$\text{for } \delta = \frac{1}{\sigma} - 1, \text{ for } -1 < \delta < \infty.$$

For the CES utility function[9], (2) takes the form

$$\frac{C^Y}{(T - H)} = \left(\frac{\beta a}{(1 - a)}\right)^{\sigma}. \tag{3}$$

Observe that is σ is close to zero (low elasticity of substitution between C^Y and $T - H$ in the utility function, then the ratio of C^Y and $T - H$ will not change with a change in β, the efficiency of hunting effort. Our calculations indeed confirm this and in addition for this case of low substitutability a small change in β leaves the levels of C^Y and $T - H$ unchanged. The important support allocation to dependents, namely $\beta H - C^Y$ rises. This support allocation rises for the case of σ greater than unity as well. Hence the central result: an exogenous drift up in β the efficiency of hunting effort contributes to brain-size expansion, via the route of more meat per child in the current period, as well as in the subsequent period.

To solve the model for the case of the CES utility function, we sub-

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[9]For the Cobb-Douglas utility function, we have $U(C^Y, T-H) \equiv [C^Y]^{\alpha}[T-H]^{1-\alpha}$ and (2) becomes $\frac{C^Y}{(T-H)} = \frac{\beta\alpha}{(1-\alpha)}$.

stitute (3) into (1) to get the following equation in H :

$$a * [C^Y]\hat{\ }(-\delta) + (1-a) * (T-H)\hat{\ }(-\delta))\hat{\ }ex1 * a * C^Y\hat{\ }ex2$$

$$+\rho * \gamma * ((a * ((\lambda_0/5) * (\beta * H - C^Y))\hat{\ }(-\delta)$$

$$+(1-a) * (T - \lambda_0\hat{\ }1.2)\hat{\ }(-\delta))\hat{\ }ex1 * a * (-\lambda_0/5) * ((\lambda_0/5) * (\beta * H - C^Y))\hat{\ }ex2)$$

$$+(1-\gamma) * ((a * ((\lambda/5) * (\beta * H - C^Y))\hat{\ }(-\delta)$$

$$+(1-a) * (T - (1-\lambda_0)\hat{\ }1.2)\hat{\ }(-\delta))\hat{\ }ex1$$

$$*a * (-\lambda/5) * ((\lambda/5) * (\beta * H - C^Y))\hat{\ }ex2 = 0,$$

for $C^Y = \left(\frac{\beta a}{(1-a)}\right)^{\sigma} (T-H)$, $ex1 = (-1-\delta)/\delta$, $ex2 = (-1-\delta)$, and $\lambda_0 \times \gamma + \lambda(1-\gamma) = 1$.

Consider some illustrative examples.

4   Improved Hunting Effectiveness

First, when $\sigma > 1$ (elastic substitutability). For this elastic case ($T = 6, a = 0.5, \rho = 0.9, \gamma = 0.5, \delta = -0.39$ and $\beta = 0.2$, and $\lambda_0 = 1.5$ and $\lambda = 0.5$), we start with $H = 1.8135$, $C^Y = 0.2992255$ and $(\beta H - C^Y) = 0.063474$. We increase β to 0.21 and observe that $H = 1.8519$, $C^Y = 0.32117$ and $(\beta H - C^Y) = 0.067730$. In other "runs" with $\sigma > 1$, we observed the same qualitative results: more efficiency in hunting activity (β increased) yielded more hunting, more meat consumption by the hunter and more "surplus" meat for the dependents. We interpret these results to mean that "improvements" in hunting effectiveness yields the indirect effect of providing more meat per dependent (is pro brain-size expansion).

The case of $\sigma < 1$ is slightly counter-intuitive. For the inelastic case ($\delta = 9.9$, $\beta = 5.8$, $\lambda_0 = 3/2$ and $\lambda = 1/2$) we start with $H = 2.962$, $C^Y = 3.569661$ and $(\beta H - C^Y) = 13.6099$.

With β increased to 5.9, H declines to 2.928, and C^Y and $(\beta H - C^Y)$ increase respectively to 3.615277 and 13.65992. For H to decline was quite standard for this case of $\sigma < 1$. With σ "very" inelastic, H and

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C^Y remained almost unchanged with β somewhat larger. We illustrate.

With $\delta = 25.9$ and $\beta = 19.9$, we obtained $H = 1.1263$, $C^Y = 5.446823$ and $(\beta H - C^Y) = 16.9665$. With β increased to 19.91, $H = 1.1263$, $C^Y = 5.446925$ and $(\beta H - C^Y) = 16.97771$. The increase in "surplus", $(\beta H - C^Y)$, is accounted for largely by the direct impact of the β increase directly. In summary, in all cases, improved effectiveness in hunting yielded larger alotments of meat to dependents. Put colloquially, smarter hunters provided for children better and the latter became smarter hunters because they grew up better fed (with larger brains), and perhaps under the tutorship of better hunters.

Becoming more effective (more intelligent?) hunters is the standard interpretation of what occurred when early humans were "re-located" to the savannah some two million years ago. A different interpretation of the impact of the climate change and switch to the open, savannah-type living is that "warfare" between groups of proto-humans diminished in the new environment and the life-expectancy of a representative hunter was increased. This in our model would have induced an increase in commitment on the part of a young, adult hunter to his own personal future and at the same time to his current dependents. Recall our mechanism of more commitment to one's personal future inducing the supplying of more surplus from hunting to the current dependents. The dependents would have become better nourished and would have experienced a brain-size increase. A brain-size increase would contribute to (a) an increase in β or hunting effectiveness and (b) to an increase in sociality or trust (a reduction in the risk that the son will not reciprocate to the father, in the second stage of the father's life). The effect of a "sudden" increase in life-expectancy could of course have been co-incident with an increase in β, but life-expectancy increase could also have preceded the crucial increase in hunting effectiveness.

5 Life Expectancy Increase

We change $\rho = 0.9$ for our examples above to $\rho = 0.95$. We start with our benchmark case with $\sigma > 1$. For this elastic case ($T = 6$, $a = 0.5$, $\rho = 0.9$, $\gamma = 0.5$, $\delta = -0.39$ and $\beta = 0.2$, and $\lambda_0 = 1.5$ and $\lambda = 0.5$), we start with $H = 1.8135$, $C^Y = 0.2992255$ and $(\beta H - C^Y) = 0.063474.//$ We increase ρ to 0.95 and observe that $H = 1.823$, $C^Y = 0.298547$ and $(\beta H - C^Y) = 0.066053$. We obtain the expected result: better life expectancy leads to more surplus for current dependents ($\beta H - C^Y$ rises from 0.063474 to 0.066053).

For the inelastic case ($\delta = 9.9$, $\beta = 5.8$, $\lambda_0 = 3/2$ and $\lambda = 1/2$) we start with $H = 2.962$, $C^Y = 3.569661$ and $(\beta H - C^Y) = 13.6099$. With ρ increased to 0.95, we have $H = 2.973$, $C^Y = 3.55674$ and $(\beta H - C^Y) = 13.68666$. Again surplus to dependents increases with improved life expectancy and own consumption by the adult hunter in the first period declines.

6 Risk Decline (More Trust of son by father)

We reduce the variance in second period allocation to the father, now a dependent. We change $\lambda_0 = 1.5$ and $\lambda = 0.5$ to $\lambda_0 = 9/8$ and $\lambda = 7/8$.

For the elastic case ($T = 6$, $a = 0.5$, $\rho = 0.9$, $\gamma = 0.5$, $\delta = -0.39$ and $\beta = 0.2$, and $\lambda_0 = 1.5$ and $\lambda = 0.5$), we start with $H = 1.8135$, $C^Y = 0.2992255$ and $(\beta H - C^Y) = 0.063474$. With $\lambda_0 = 9/8$ and $\lambda = 7/8$ we have $H = 1.83$, $C^Y = 0.2980462$ and $(\beta H - C^Y) = 0.0679538$. Hunting effort increases slightly with risk reduction and own consumption by the hunter declines slightly. The surplus going to dependents rises.

For the inelastic case ($\delta = 9.9$, $\beta = 5.8$, $\lambda_0 = 3/2$ and $\lambda = 1/2$) we start with $H = 2.962$, $C^Y = 3.569661$ and $(\beta H - C^Y) = 13.6099$. With $\lambda_0 = 9/8$ and $\lambda = 7/8$ we have $H = 3.993$, $C^Y = 2.35823$ and $(\beta H - C^Y) = 20.801167$. Own consumption by the hunter has declined significantly while time devoted to hunting and the surplus for depen-

dents have each increased significantly.

Each of our experiments yields anticipated results. Better hunting effectiveness, increased own longevity and more trust each lead to a mature, hunter providing more meat (energy) to his current dependents.

7 A Two Type Steady State Population

We now consider that adult hunters comprise N^H high producers and N^L low producers. These "population" values satisfy

$$\begin{bmatrix} P^{HH} & P^{LH} \\ P^{HL} & P^{LL} \end{bmatrix} \begin{bmatrix} N^H \\ N^L \end{bmatrix} = \begin{bmatrix} N^H \\ N^L \end{bmatrix}$$

and

$$N^H + N^L \leqq K(S)$$

$$\text{or } [N^H \beta H^H + N^L \beta H^L] \leqq S.$$

where S is the carrying capacity of the environment that members of this clan are living in. The P^{HH}, P^{LH}, etc. are probabilities with $P^{HH} = (1 - P^{HL})$ and $P^{HH} > P^{HL}$; and $P^{LL} = (1 - P^{LH})$ and $P^{LL} > P^{LH}$.

We now utilize these probabilities, P^{HH}, P^{LH}, etc. in the utility maximization problem carried out by each type of adult, prime-age hunter. (P^{HH} replaces γ above and P^{HL} replaces $(1 - \gamma)$.We do not have an analogue of a "low" producing hunter above.) The utility maximization problem for each type as a productive, adult hunter:

$$W^H = U(C^{YH}, T - H^H) + \rho\{P^{HH} U(\lambda_0^H [\frac{\beta H^H - C^{YH}}{5}], T - B(P^{HH}))$$

$$+ (1 - P^{HH}) U(\lambda^H [\frac{\beta H^H - C^{YH}}{5}], T - B(1 - P^{HH}))\}$$

and

$$W^L = U(C^{YL}, T - H^L) + \rho\{P^{LH} U(\lambda_0^L [\frac{\beta H^L - C^{YL}}{5}], T - B(P^{LH}))$$

$$+ (1 - P^{LH}) U(\lambda^L [\frac{\beta H^L - C^{YL}}{5}], T - B(1 - P^{LH}))\}$$

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Four first order conditions give us four equations in H^H, H^L, C^{YH}, and C^{YL}. A high alotment provider has $\lambda_0^H > \lambda^H$ and $P^{HH} > 1 - P^{HH}$ and a low alotment provider has $\lambda_0^L > \lambda^L$ and $P^{LL} > 1 - P^{LL}$. In addition we require that (a) our rational expectations conditions are satisfied, namely

$$P^{HH}\lambda_0^H + (1 - P^{HH})\lambda^H = 1$$
$$\text{and } P^{LL}\lambda^L + (1 - P^{LL})\lambda_0^L = 1$$

and (b) the level of a high alotment from a "high" maximizer is the same as the level of the high alotment from "low" maximizer (and analogously for the low alotments); that is we require

$$\lambda_0^H[\beta H^H - C^{YH}]/\zeta = \lambda_0^L[\beta H^L - C^{YL}]/\zeta$$
$$\text{and } \lambda^H[\beta H^H - C^{YH}]/\zeta = \lambda^L[\beta H^L - C^{YL}]/\zeta.$$

These latter conditions imply that the recipient of an alotment is indifferent as to the source of his or her alotment (whether the supplier was a "high" supplier or a "low" supplier) but is not indifferent to the size of his or her alotment.

Our system is now 8 equations in $H^H, H^L, C^{YH}, C^{YL}, \lambda_0^H, \lambda_0^L, \lambda^H$, and λ^L. These solution values emerge at the beginning of each period and are the same values period after period in a version of our model which admits a non-stochastic steady state. (ρ would be now interpreted as a non-stochastic discount factor.) Key variables here are net supplies of meat, $\beta H^H - C^{YH}$ and $\beta H^L - C^{YL}$ for the current period. There are N^H "high"maximizers and N^L "low" maximizers each producing βH^H and βH^L respectively.

Dependents (demanders of meat) at the beginning of each period comprise, in expected values, $[P^{HH}N^H + P^{LH}N^L]\zeta$ expecting a high alotment, $\lambda_0^H[\beta H^H - C^{YH}]/\zeta$ (equal to $\lambda_0^L[\beta H^L - C^{YL}]/\zeta$) and $[P^{HL}N^H + P^{LL}N^L]\zeta$ expecting a low alotment, $\lambda^H[\beta H^H - C^{YH}]/\zeta$ (equal to $\lambda^L[\beta H^L -$

$C^{YL}]/\zeta$). Our rational expectations formulation guarantees in expectation, that the "surplus" supplies of meat in the aggregate at the beginning of each period, namely, $[\beta H^H - C^{YH}]N^H + [\beta H^L - C^{YL}]N^L$ equal demands, also in the aggregate, namely, $[P^{HH}N^H + P^{LH}N^L]\zeta \times \lambda_0^H[\beta H^H - C^{YH}]/\zeta + [P^{HL}N^H + P^{LL}N^L]\zeta \times \lambda^H[\beta H^H - C^{YH}]/\zeta$. Hence we have an economy-wide equilibrium, in the limited sense of matching quantities supplied and demanded *in expectations*.[10] Also our "population" size for our community is a function of the carrying capacity of the environment.

If we take the randomness in "second period outcomes" at face value at each date, we will have a complicated situation in which our N^H and N^L move stochastically and at each date quantities supplied must be adjusted to match quantities demanded. In addition we will have to determine the nature of the limiting distributions of our N^H and N^L, as random variables. We leave the investigation of the fully stochastic version of our model for another occasion.

Here the nutrition status (carrying capacity of the local environment) implicitly affects the number of dynasties N^H and N^L rather than affecting current family size. At each stage we have a hunter providing for a fixed number of dependents with some hunters providing "high" alotments and some "low" alotments.

8 Concluding Remark

We have presented a theory of food-sharing by male, adult hunters based entirely on non-altruistic behavior. Hunters provide meat to their dependents, including their child-sons, in order to (a) have the sons grow up to be good hunters and providers and (b) to encourage the sons to provide

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[10]The Robson-Kaplan model is also solved in expectations. Central to their model is the life expectancy function. Outcomes of their model should have each individual with a distinct realized life duration. This would of course make their model a very complicated stochastic process. They detour around this problem by taking each person's life expectancy as an expected value.

meat to their dependents, including their now-retired father. Fathers, as good adult hunters, look forward to their years of "retirement" and make provision for their future welfare by encouraging their child-sons to provide for them, as retired adults. The "encouragement" takes the form of the fathers setting an example to the sons, while the sons are young. Given this theory, we indicate how brain-size expansion could have taken place. We perturb key parameters and indicate how fathers, as mature hunters, respond by providing more generously to their dependents. Some novel scenarios for brain-size expansion emerge here. When dependents are better provided for, we infer that they can experience "pressure" for brain-size expansion. Our approach places emphasis on hominid fathers as calculating planners. They are not hard-wired to provide for their dependents instinctively as in responding to genetic triggers. Rather they reason that provision for dependents is a strategy for lengthening their own lives because the providing for of dependents constitutes a signal to child-sons to provide for their dependents, including their aged parents, when they the children have become good, adult hunters. We have included some *quid pro quo* by aged fathers. Though the fathers in "retirement" do not hunt, they do provide child care and instruction to children and thus in part "earn their keep".

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