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Encephalization and Division of Labor by Early Humans

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Abstract

We draw on Ricardian comparative advantage between distinct persons to map out the division of labor among proto-humans in a village some 1.7 million years ago. A person specialized in maintaining a cooking fire in the village is of particular interest (Ofek [2001]). We are also interested in modelling hunting by village males in teams. The large issue is whether and how specialization (division of labor) and interpersonal trade might have driven brain-expansion in early humans. (file: sexdiv_nov07)

- Keywords: early humans, division of labor, brain expansion
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1 Introduction

Ofek [2001] argues that "mercantile" exchange as between non-kin, an extension of "nepotistic" exchange, was a strong force for selection of individuals with larger brains in the evolution of modern humans[1] from early proto-humans and in the subsequent evolution of modern humans from hunter-gatherers to urban dwelling people. He singles out fire-maintenance by an individual in a village of proto-humans as a key matter in the origin of trade between persons in a village. Early humans had no way to light a fire and thus it was necessary for a person to keep a fire going in the village and to provide "lights" to fellow villagers. This would be done only on a *quid pro quo* basis since fire-maintenance would be a fairly demanding task in its own right. Trade between the fire-maintainer and her fellow villagers thus emerged naturally in this setting and trade and

[1] Encephalization refers to the tendency for a species toward larger brains through evolutionary time. Anthropological studies indicate that bipedalism preceded encephalization in the human evolutionary lineage after divergence from the chimpanzee lineage.

specialization would be in Ofek's opinion a force for selection for larger brain size in early humans. It seems plausible that early humans with larger brains would be in a better position to pursue the *quid pro quo* of primitive exchange; that is, to adopt the conventions of mutually beneficial trade without the assistance of money or some analogous means of keeping account of exchanges over multiple periods. Mutually beneficial exchange would involve some notion of fairness. Exchange will not be sustained as an institution if participants feel cheated.

One must keep in mind that proto-humans had to live in an environment that selected for larger brain size in addition to an environment that provided the requisite nutrition that allowed larger brains to function effectively. The human brain is about 3% of the body by weight but consumes some 20% of the energy flowing through a human being. (Wade [2006, p. 19])[2]. Anthropologists are unanimous in their view that meat-eating was necessary for proto-humans to be able to "feed" an enlarged brain.[3] *Homo habilis* was the second early human species and had a brain size between 600 and 800 ccs. It was preceded by the australopithecines with brain size in the 400 to 500 cc range. Chimps have a brain size of about 400 ccs and modern humans clock in at an average of 1400 ccs. (Wade, p. 18). Wade sees "increasing social complexity" as the "likeliest reason for *habilis's* greater brain size" (p. 19).[4] Ofek would elevate interpersonal trade arising from division of labor in a village as a key part of the "social complexity" that proto-humans had to deal with. And it is the plausible division of labor in a village and interpersonal trade which we focus on here.

The dating of fire-use by early humans is controversial. *Homo erectus* emerged about 1.6 to 1.9 million years back and his or her brain was 50 percent larger than *homo habilis*. *H. erectus* also experienced the biggest drop in tooth size in

[2] Wade is a science-writer for the New York Times and his book is a survey or overview of research on human-kind's so-called "deep history".

[3] "Meat-eating allowed for a smaller gut and furnished the extra nutrition that made possible a larger brain." (Wade, p. 18). The "expensive issue hypothesis" (Aiello and Wheeler [1995]) posits that a shrinking gut in early humans freed up regular energy consumption that could go to an expanding brain.

[4] The case for more "social intelligence" and larger brain size has tended to be based on studies of primates such as baboons. "Well-connected female baboons, for example, dominate their bands. They have more babies than lower ranking females, and their babies enjoy better health and faster growth." (Zimmer [2008, p. D4]. Dr. Kay E. Holekamp argues for spotted hyenas as having social lives as complex as primates and these carnivores have relatively large brains also. "We're talking about 60 to 80 individuals who all know each other individually" remarks Ms. Holekamp (cited by Zimmer).

human evolution.[5] Wrangham (see Gorman [2008]) argues that these changes could only have been driven by a diet of cooked meat and yet many researchers date cooking from only 500,000 years ago.[6] Wrangham argues that the cooking of meat allows for a more efficient release of important nutrients to the eater. Some anthropologists argue that early humans could have obtained the nutrients required for life with a large brain from uncooked, energy-dense "meat" such as bone marrow and brain matter. Wade (p. 19) dates very primitive tools (the Olduwan Industrial Complex) to 2.5 million years back. These bits of worked stone have "a random appearance" and could have been used for "cutting through hide and ripping the flesh off of bones".

The division of labor that we and Ofek have in mind is much more of a social phenomonon than is say the familiar division of labor that we observe that insects and animals engage in. The division of labor of lower order creatures is really hard-wired into the brains of these insects and animals. Honeybee colonies have members who specialize in foraging, members who specialize in guarding the entrance to the "hive", members who clean out the "hive", and so on. Male and female pairs of birds and other animals often have the male do guard work at the nest or lair while the female forages. These sorts of division of labor imply high productivity for the family but are presumably hard-wired into the brains or nervous systems of the animals in question. Ofek is reflecting on a division of labor that has a mostly social basis as with a person specialized in fire maintenance. His argument is that a social environment with fairly complicated specializations and division of labor selects for members of the group with above average brain size. In our appendix we explore the topic of social groups and brain size increase in more detail.

Ofek [2001; pp. 32-33] argues that Darwin and Wallace were perplexed about (a) the seeming rapid brain size increase in humans without a seeming "demand" for the corresponding brain power and (b) the curiously large variation in skills and abilities of members of the same human species. Division of labor and trade

[5] "In Africa, it was not until 500,000 years ago, more than a million years after argaster's first appearance on the scene, that brain size relative to body size increased significantly, and not until 200,000 years ago that it reached the contemporary standard." (Wade, p. 27).

[6] Anthropologist Ralph Rowlett has found evidence of early controlled fire use by humans in Kenya dating from 1.6 million years ago (Gorman [2008]).

is the natural response to these two curious tendencies. Compicated trades become possible with highly intelligent creatures and division of labor is a way for social beings to organize themselves "in the face of" demonstrably different abilities. Ofek suggests that Darwin and Wallace failed to see how the difficulties in (a) and (b) in a sense vanish when one invokes division of labor and trade as "second nature" to early humans. In the words of Wade [2006; p. 7] "... 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." Wade suggests that primitive villages comprised "quarrelsome" groups of closely related individuals "without property or leaders" (p. 72). When the size reached about 150 persons, a group would break up into smaller units. Warfare with neighbors was ever-present[7] since foraging territory had to be defended from encroachment by persons from another village. The size of a territory that could be maintained free from encroachment by "foreign" hunters and gatherers would of course limit the equilibrium size of a village. Within each village "a sense of fairness and reciprocity governed exchange and social relationships.[8] Much later, the idea of reciprocity would be extended to non-kin, allowing strangers to be treated as honorary relatives and creating the framework for societies that transcended the kin-bonded tribe." (p. 73) Wade argues that what separated early humans from their ape-like ancestors was the levelling of access of males to females. "The apes ancestral to both chimpanzees and humans probably lived as small bands

[7] Wade notes that in inter-village warfare, a man who succeeded in killing someone acquired great prestige in his own village and on average fathered many more children than his fellow villager who never killed anyone in battle. (p. 150). Field work reveals that about 30% of chimps in Gombe died from aggression, about the same fraction as has been observed among men of the Yamomamo people. "Warfare was a routine occupation of primitive societies. Some 65% were at war continuously, according to Keeley's estimate, and 87% fought more than once a year." (Keeley, Lawrence H. [1996] *War Before Civilization*, Oxford: Oxford University Press.)

[8] The roots of fairness in humans are apparently very deep. Capuchin monkeys display "inequity aversion", essentially displaying anger when given treats that are inferior to those being given to their peers (grapes preferred to cucumbers). The unhappy capuchins will simply throw away the cucumbers when they see their peers getting grapes whereas when each one gets a cucumber treat, there is no distress displayed (Brosnan and de Waal [2004]). Henrich et. al. [2001] find much behavior in a variety of "primitive" societies around the world today as considerably more fair (sort of altruistic) than textbooks in economics suggest is compatible with utility maximizing, rational agents.

of related individuals who defended a home territory, often with lethal attacks against neighbors.[9] They had separate male and female hierarchies and most infants were sired by the society's dominant male or his allies. The emerging 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." (Wade, p. 7. See also p. 158.).

We wish to be more explicit on the matter of "keeping score" in primitive societies as in the seemingly simple problem of specialization and "trade" between members first of a simple couple, one male in an alliance with one female. We will have the female specialized in gathering and her partner specialized in hunting. Each will trade with the other. Though specialization by gender is quite ubiquitous, we present this first "case" only to illustrate the operation of two individuals specializing by task and engaging in interpersonal trade. We will proceed to move beyond couples and inquire about specialization and "trade" among members of a village comprising early humans. A textbook Ricardian model with each person a trading "nation", an individual with a comparative advantage in certain activities, serves as a benchmark. We will observe division of labor (specialization in tasks) and trade between members of a village. We will move to Ofek's case of a village with a person specialized in fire-maintenance and also males of the village specialized in hunting as a team. We will be dealing then with rather special instances of specialization and trade between persons with distinct skills. We will end up creating an Ofekian village using constructs common in economics textbooks.

We stick to the case of an individual in the village specialized in fire maintenance as our benchmark case of early division of labor by early humans. We will take this as occuring some 1.7 million years ago. This is we recognize controversial since it is the earliest that archeologists have located the ashes of what appears to be a campfire in Kenya. Our narrative unfolds easily once fire is

[9] Wade emphasizes the warfare practised by primitive humans and apes against neighboring tribes. The point of such violence is to defend territory for hunting and gathering, in Wade's view. Ofek (p. 4) argues on the other hand for the view that early humans were quite peaceful since bones turned up do not exhibit the telltale marks of violence.

used for cooking by early humans. Then we can accept that they were eating cooked meat and tubers regularly and had the regular energy intake to nourish larger brains. A more complicated social milieu, one with division of labor and hunting by men in teams, could easily be the environment that selected for individuals with larger brains. We make the case for division of labor as a stressor favoring brain expansion in early humans after 1.7 million years back but in addition we will emphasize a complementary stessor, namely the need for centralized decision-making in a village over the matter of meat distribution and the assignment of tasks to members of a hunting team. Between the "arrival" of very primitive tools 2.5 million years back and the use of fire for cooking say 1.7 million years back, we will buy into the notion that brains expanded as guts contracted (the expensive tissue hypothesis) and that early humans made use of glucose-rich tubers[10] and energy-rich parts (soft marrow and brain tissues) of animal carcasses left by large animal predators. Even after 1.7 million years ago, the pace of human brain-size increase was by no means uniform. We only make the case that specialization and interpersonal trade by members of a tribe or village had brain-expansion value, not that it was a mechanism that operated consistently after 1.7 million years back with great intensity.

2 Hunter Teams up with Gatherer

Our introductory situation involves say a female hunter-gatherer with a unit of labor but more skilled in gathering: her $a^f_{lh} > a^f_{\lg}$ where a^f_{lh} is labor per unit of "hunting". The male has a unit of labor and $a^m_{lh} < a^m_{\lg}$ where a^m_{lh} is labor per unit of "hunting". g stands for gathering, the other activity. We know from Ricardo that if these two individuals form a trading relationship that will end up with more of each of the outputs from hunting and gathering to consume. There are gains from trade when each trading unit has a comparative advantage. There are two generic equilibria, depending on tastes: each "trader" specialized (the female in gathering and the male in hunting) or one or the other diversified

[10] Perry, et. al. [2007] have noted that humans have a gene that codes for a protein that allows our saliva to break down starch into glucose and that lower primates do not have this gene. They argue that proto-humans could have made tubers a major part of their diet and the glucose produced could have sustained a larger brain. Large-scale starch eating may have preceded meat-eating in the view of Perry et. al.

(devoting some of his or her labor to both hunting and gathering) while the other "trader" is specialized.

In autarky or not-in-trade we have two maximization problems, one for each agent:

$$\begin{aligned} \max\ U^f(q_h^f, q_g^f) \text{ subject to } a_{lh}^f q_h^f + a_{\text{lg}}^f q_g^f &\leqq 1 \\ \text{and } \max\ U^m(q_h^m, q_g^m) \text{ subject to } a_{lh}^m q_h^m + a_{\text{lg}}^m q_g^m &\leqq 1 \end{aligned}$$

where $U^i(.)$ is agent $i's$ concave utility function defined over outputs q_h^i and q_g^i. In trade we can represent the equilibrium as the solution to a linear program. We indicate the female as worker 1 and the male as worker 2.

$$\begin{aligned} \max\ \sum_{i=1}^{2}[p_h q_h^i + p_g q_g^i] \text{ subject to } a_{lh}^1 q_h^1 + a_{\text{lg}}^1 q_g^1 &\leqq 1 \\ \text{and } a_{lh}^2 q_h^2 + a_{\text{lg}}^2 q_g^2 &\leqq 1 \end{aligned}$$

and the $q's$ non-negative and an appropriate selection of prices, p_h and p_g. More on prices below. This linear program possesses a dual program in prices (non-negative wage rates) w^1 and w^2

$$\begin{aligned} \min\ w^1 + w^2 \text{ subject to } a_{lh}^1 w^1 &\geqq p_h \\ a_{lh}^2 w^2 &\geqq p^h \\ a_{\text{lg}}^1 w^1 &\geqq p_g \\ \text{and } a_{\text{lg}}^2 w^2 &\geqq p_g \end{aligned}$$

There is value balance for the two programs once solved, namely $\sum_{i=1}^{3}[p_h q_h^{i*} + p_g q_g^{i*}] = w^{1*} + w^{2*}$. This is the result that the value of total expenditure in this two person economy equals the value of total income. More subtle is the "selection" of prices p_h and p_g that results in a market equilibrium with each person's income equal her expenditure and the ratios of marginal utilities for each person equal to the relevant ratio of prices.[11] That is, the correct prices[12]

[11] These prices define "the market solution" for our allocation problem. An anthropogist might argue that the male has more power in the relationship say due to physical size and would force the terms of trade in his favor, implicitly dictating the prices and assigning himself more income than he would have in "the market solution". More on this below.

[12] We can normalize prices by setting say $p_h = 1$.

above will satisfy

$$
\begin{aligned}
\frac{\partial U^1/\partial c_h^1}{\partial U^1/\partial c_g^1} &= \frac{p_h}{p_g} \text{ and } w^1 = p_h c_h^1 + p_g c_g^1 \\
\frac{\partial U^2/\partial c_h^2}{\partial U^2/\partial c_g^2} &= \frac{p_h}{p_g} \text{ and } w^2 = p_h c_h^2 + p_g c_g^2 \\
q_h^1 + q_h^2 &= c_h^1 + c_h^2 \\
\text{and } q_g^1 + q_g^2 &= c_g^1 + c_g^2
\end{aligned}
$$

for utility functions $U^1(c_h^1, c_g^1)$ and $U^2(c_h^2, c_g^2)$ and $q_h^1, q_h^2, q_g^1, q_g^2, w^1$ and w^2 solution values for our primal-dual linear programs above. For our purposes, we can assume that the "correct" prices, p_h and p_g are in effect. These prices satisfy the condition that the value of one person's "exports" equals the value of that person's "imports" The above two person trading equilibrium admits a solution with each worker specialized or possibly one specialized and one diversified. This latter solution occurs when so-called autarky prices for one agent are the same prices that prevail in the trading equilibrium (when the solution lies on a facet rather than at a point of intersection in the definition of the constraint set).

The above equilibrium is favored by economists as essentially a free market outcome. Clearly the outcome implies a distribution of gains from trade and it is reasonable to ask if the outcome is fair or equitable. Economists would argue that the contribution by each agent is being fairly rewarded (at market wages) and the equilibrium has each agent's income equal to her expeniture on the two "final" goods. Each agent's value of her "exports" equals the value of her "imports" at the market prices. Hence there is a clear link between input (say the effort of each agent) and "realized" consumer goods. One might argue however that males are often larger and can extract "more surplus" in an exchange relationship. Such would be the case when the so-called terms of trade are "manipulated" against the female as when she faces a "tariff" on her "imports" from the male. This "manipulation" can go on until the female is indifferent to being in trade or remaining in "autarky". Then the male will have captured all the gains from trade for himself. And there are cases intermediate between full capture and so-called "free trade". There is no need for us to suggest that primitive people solved even implicitly the free trade problem or that the free trade solution is a "natural" outcome that will be gravitated to by primitive but intelligent proto-humans. We simply posit that an equilibrium with some trade will have emerged.

We proceed now to employ the ideas above in a sketch of a village of hunter-gatherers. One person will specialize in fire-maintenance.

3 Specialization and Diversification in a Hunter-gatherer Village

We will consider a village of adult male-female couples in which hunting is done by males in groups. Above we made the case for a male-female pair forming a "trading relationship" in order to reap the gains from specialization and "trade". Here we assume *a priori* that hunting by males in groups is in a sense more productive than hunting by one male alone. Each male does some hunting, by assumption. We also assume then that females do not hunt, *a priori*, and in addition that males do not do "domestic" activity (here fire-maintenance). Formalizing our arrangement of males hunting in a group leads to a problem in which the solution has wives specialized and some husbands diversified over two activities (engaged in multi-tasking). We assume that a hunt involves some tracking activity and some killing activity. Each of these latter activities "get assigned" to individual males in accord with comparative advantage. Our central observation is that in a village with males specialized in hunting one observes some husbands diversified across two possible tasks and all wives specialized. One woman will be specialized in fire-maintenance. When we add more couples to our small village we continue to observe females specialized and two males diversified over the two tasks associated with hunting. As one expands the size of the village, the same pattern obtains: all women specialized and all but one man specialized. Hence the larger the village the more specialization of individuals to tasks is observed. Roughly speaking we interpret this to mean that a larger agglomeration of adult couples looks more like a "textbook" village of hunter-gatherers with husbands specialized in some part of hunting activity and wives specialized in either "domestic" activity or gathering.[13]

We assume that a wife possibly divides her 1 unit of labor between domestic activity, indicated with a d and gathering activity, indicated with a g. A representative wife i would then have her labor constraint in $a^i_{\text{lg}}q^i_g + a^i_{ld}q^i_d \leqq 1$. Her husband, Mr. j is assumed to engage in hunting and possibly also gathering. A successful hunt comprises some tracking activity at some level q_r and some killing activity at level q_k. Successful harvesting from hunting is indicated by level q_h. We wish to capture the notion that hunting is a team activity and a successful kill comprises a certain amount of tracking and killing activity. Every male is assumed to be part of each hunt. A male's "extra" labor can be applied to gathering, *a priori*. However we will end up with no male doing any gathering, below. The labor constraint of male j is then $a^j_{\text{lg}}q^j_g + a^j_{lr}q^j_r + a^j_{lk}q^j_k \leqq 1$, where a^j_{lg} is labor per unit of gathering for man j. Man j has one unit of labor to supply. We indicate wives with an odd superscript and husbands with an even superscript and consider villages comprising only couples and possibly some children, though the latter do no labor. In addition hunting activity is assumed to comprise equal amounts of tracking activity and killing activity. That is, for our example with two males, we have $-q^2_r - q^4_r + q_h \leqq 0$ and $-q^2_k - q^4_k + q_h \leqq 0$. Recall that a male in indicated by an even numbered superscript.

We represent our 2 couple economy by a linear program:

$$\text{maximize } p_g q^1_g + p_d q^1_d + p_g q^2_g + p_g q^3_g + p_d q^3_d + p_g q^4_g + p_h q_h$$

$$\begin{aligned} \text{subject to } a^1_{\text{lg}}q^1_g + a^1_{ld}q^1_d &\leqq 1 \\ a^2_{\text{lg}}q^2_g + a^2_{lr}q^2_r + a^2_{lk}q^2_k &\leqq 1 \\ a^3_{\text{lg}}q^3_g + a^3_{ld}q^3_d &\leqq 1 \\ a^4_{\text{lg}}q^4_g + a^4_{lr}q^4_r + a^4_{lk}q^4_k &\leqq 1 \\ -q^2_r - q^4_r + q_h &\leqq 0 \\ -q^2_k - q^4_k + q_h &\leqq 0 \end{aligned}$$

[13] A different argument for couples agglomerating to form a village would be that couple i could specialize in activity k and trade with couple j specialized in another activity. There would be gains from specialization by couple and trade between couples. We believe this to be an important dimension of the agglomeration of families to form villages but we leave this matter aside here.

and the $q's$ non-negative. We assume that each woman can do either gathering or domestic activity (fire maintenance). Each male is assumed to be a hunter and provides his labor to either tracking, q_r^i or killing, q_k^i or both and possibly gathering in the event that a male diversifies his activity beyond hunting activity. The first four constraints reflect the amount of labor available from each person, namely 1 unit. The last two constraints indicate that hunting involves two activities, namely tracking prey and killing prey. The output from hunting is q_h and the "technology" indicates that a successful hunt requires equal amount of tracking and killing activity.

Our problem has 11 activities and 6 constraints. A typical solution will have 6 activities positive for our 4 people. If each male is doing only some sort of hunting activity, 4 activities will be "used up" including q_h. We are being somewhat arbitrary here by imposing a solution with no male in any activity but hunting. Our justification for this approach is that the labor input can be thought of as time and it is difficult to conceive of a male only spending a fraction of his time on hunting when hunting is assumed to be a team activity. A male is not going to join his fellows for a fraction of a hunt. With this in mind we will have 3 $q's$ for our two men. Hence one will be diversified in tracking and killing activity and the other will be presumably specialized in killing. (We are leaving butchering activity aside.) It is reasonable to think of harvest q_h as a collection of distinct kills, say one every three days. Then tracking must be "re-done" for each kill. We rule out doing tracking once and observing a large quantity of killing ensuing. In such a case there would be scale economies to tracking and we wish to rule such a scale economy out in our formulation. The two remaining activities (other two positive $q's$) will generally involve each woman specialized, presumably one in domestic activity (doing fire maintenance) and the other in gathering. This would be a two couple economy in which a woman doing fire maintenance activity is trading for meat from her husband and some of the output from gathering from her fellow female. There will thus be trade between two members of a couple and trade between our two couples. Economists define a "market equilibrium" which characterizes how the trade flows get determined and how much welfare each person in the economy ends up with. We will discuss this below. Our main point here is that we are looking at a complicated problem in allocating flows "in trade" in our two couple economy and that larger brains could be selected for in the process of solving such problems in such a way that harmony in the community is maintained. We suggest below that division of labor occurs more easily in a setting with prices, money and clear property rights. Thus early humans had to develop specialization and interpersonal trade "the hard way". We do not imply that proto-humans arrived at the market solution to the problem of specialization and interpersonal trade. There can presumably be partial solutions of some sort but we suggest as we think Ofek does, that some form of specialization and interpersonal trade will emerge in the villages of proto-humans, after say 1.7 million years back. Ofek argues that the need for a permanently lit village fire forced division of labor to develop. Two assumptions that we have drawn upon to build in some division of labor *a priori* are (1) division of tasks by gender (men do not to fire maintenance and women do not do hunting) and (2) hunting done by men must be done in teams.

An allocation problem involves an assignment of the labor of men to different activities in hunting. We consider this "assignment" to be very difficult to effect in a decentralized manner. We return to this below.

We can expand our economy to three couples and our "typical" equilibrium will have the three males doing hunting activity, two specialized in either tracking or killing and one diversified over tracking and killing. There will be 8 constraints and we must consider the appearance of 8 activities "in operation" in equilibrium. 5 activities will be "used up" in the hunting sector. Each of the three women will be specialized, presumably one doing fire maintenance and the other two doing gathering activity.

Recall that Wade suggests that some seventy-five couples is the maximum that a primitive village could sustain before a group would split off to form a new village. The so-called market outcome, which we are focusing on here, has much specialization in tasks (extensive division of labor) and hence much trade between members of a village. Keeping the allocation of food and fire-trade free of acrimony would presumably have good survival value for a village.

The dual linear program for our two couple economy is:

minimize $\sum_{i=1}^{4} w^i$ subject to

$$
\begin{aligned}
a^2_{lk}w^2 - \lambda_k &\geqq 0 \\
a^4_{lk}w^4 - \lambda_k &\geqq 0 \\
a^2_{lr}w^2 - \lambda_r &\geqq 0 \\
a^4_{lr}w^4 - \lambda_r &\geqq 0 \\
\lambda_k + \lambda_r &\geqq p_h \\
a^2_{\mathrm{lg}}w^2 &\geqq p_g \\
a^4_{\mathrm{lg}}w^4 &\geqq p_g \\
a^1_{\mathrm{lg}}w^1 &\geqq p_g \\
a^1_{ld}w^1 &\geqq p_d \\
a^3_{\mathrm{lg}}w^3 &\geqq p_g \\
a^3_{ld}w^3 &\geqq p_d
\end{aligned}
$$

and the wages and $\lambda' s$ non-negative. The last four inequalities pertain to use of labor by the two women: the cost of their acitivity measured at the relevant wage rate cannot be less than the value of product produced. This holds for each of four possible activities for the two women. Our hypothesized solution will have two of these inequalities solving as equalities. One woman will be doing some domestic activity and the other will be doing gathering activity.[14] The next two inequalities up pertain to the cost of each man doing gathering. We hypothesize that these will solve as inequalities. It will be too expensive for either man to be engaged in gathering activity.

The first four inequalities pertain to the cost of each man doing either tracking activity or killing. The cost at the prevailing wage cannot be less than the relevant value; here the relevant numerical realizations for the $\lambda' s$. λ_r is the shadow price of a unit of tracking activity and λ_k is the shadow price of a unit of killing activity. Our hypothesized solution for our economy will have $a^i_{lk}w^i - \lambda_k = 0$ for man i and $a^j_{lr}w^j - \lambda_r = 0$ for man j. In addition, either man i or j will diversify into the complementary activity required for hunting. For

[14] We are assuming that some positive amounts of gathering output, fire-maintenance, and hunting output must be produced in our village. An assumption below on the form of the utility functions will guarantee this.

concreteness, we will have $a^i_{lr}w^i - \lambda_r = 0$. The fifth inequality pertains to the cost of a unit of hunting activity. A successful "unit of hunting" yields value p_h and when it is being done should equal the cost of the activity, here $\lambda_k + \lambda_r$.

As we noted above, the solution will generally solve with four of the the first five inequalities binding. Then for each woman either the d or g inequality will be binding. If a woman specializes in gathering then she and her husband will trade output from gathering for some "output" from the domestic activity. Alternatively if a woman is specialized in domestic activity, she and her husband will trade for some output from the woman doing the gathering activity. Each woman will be specialized in one activity and one man will be specialized in one line of hunting activity. The other man will be doing hunting also, but dividing his time over both tracking and killing. With many couples, one male will continue to be diversified over tracking and killing game and all women will be specialized.

There remains the matter of the allocation of output to the people for their consumption in our economy. We know from linear programming that the value of aggregate product equals the value of aggregate labor input. This follows from the objective function of one of the solved linear programs being equal in value to the objective function of the dual solved program, a generic property of linear programs. A straightforward way to close the model is to assume that our vector of output prices above also satisfies each individual's ratio of marginal utilities in

$$\begin{aligned}\frac{\partial U^i/\partial c^i_d}{\partial U^i/\partial c^i_g} &= \frac{p_d}{p_g} \text{ and } \frac{\partial U^i/\partial c^i_h}{\partial U^i/\partial c^i_g} = \frac{p_h}{p_g} \\ \text{and } w^i &= p_d c^i_d + p_g c^i_g + p_h c^i_h \text{ for } i = 1, ..., 4,\end{aligned}$$

and

$$\begin{aligned}q^1_d + q^3_d &= \sum_{i=1}^{4} c^i_d \\ \sum_{i=1}^{4} q^i_g &= \sum_{i=1}^{4} c^i_g \\ \text{and } q_h &= \sum_{i=1}^{4} c^i_h,\end{aligned}$$

for $U^i(c_d^i, c_g^i, c_h^i)$ the ith person's utility function. c_d^i is person i's consumption of fire-maintenance services. c_g^i and c_h^i are defined analogously. In addition, at the "correct" market prices, the value of each person's "exports" must equal the value of that person's "imports". We might refer to this as closing the model with "market" prices. Again we emphasize that we are not suggesting that an invisible hand guided villagers some 1.7 million years ago to solve the market allocation for their village. The market allocation is a benchmark illustrating specialization and interpersonal trade in a village. Ofek argues that specialization and interpersonal trade of some form would have developed in the villages of proto-humans[15] (in particular specialization by one person or family in fire maintenance) and that this mode of social interaction would have had survival value for members of such villages. Smarter individuals would have "done better" in such social environments and left more offspring compared to individuals who were less intelligent. This is one line of argument that encephalization was favored by primitive division of labor and interpersonal trade.

It is interesting to try to conjure up what an Ofek village "looked like". There was no money, no prices, and no intricate language. Prices and money (a medium of exchange) are creations of modern humans to (a) guide production and trade decisions of individuals and (b) to value personal property, ultimately in order to trade property at socially agreed-upon terms. 1.7 million years ago we would see a village of say 20 couples with children, one woman in charge of a village back-up fire. Presumably other women who specialized in gathering nuts and berries and possibly tubers would return each day and leave a small "gift" with the fire-woman. This would entitle the gifting women to get a free light from the fire-maintainer's fire when a light was needed. The size of the "gift" might vary, depending on how often the gifting woman showed up for a light for her fire – more trips, larger "gifts". Getting the *quid pro quo* "right" or fair is presumably what people refer to when they talk about primitive humans learning who to trust and reciprocate with and who to "keep distance from". Ofek seems correct to single out fire-maintenance and the exchange associated with this activity as one that made substantial demands on the abilities of poto-

[15] A different model from the individualistic one above would have each husband and wife pool their incomes and consume in accord with a utility function defined over joint consumption of each commodity. Final utility levels would be determined by bargaining in the home.

humans to calculate, learn fairness, and prosper, as when exchange functioned smoothly. An alternative was rancorous "exchange" for a light by a woman about to cook some meat for a meal. Rancorous exchanges could involve regular altercations, possibly violent, and less "productivity" from division of labor.

The other central social-economic nexus associated with our village would be the dividing up of meat by men from say a successful scavenge. Scavenging from carcasses is presumed to be a mode of meat-gathering that pre-dated hunting. Presumably a few large pieces of a carcuss would get dragged to the butchering spot and portions would be allocated to each head of a household. The apportioning would be fraught with potential conflict and some agreed-upon allocation mechanism would be required. The plausible method of course is allocation by a sanctioned leader. In our view these primitive villages could not function without some form of "centralized" leadership and we argue for this institution as being key to relatively rapid brain-size development in proto-humans. A clear dimension of conflict is over effort versus need. Individuals who were lucky or more successful at finding valuable carcusses would presumably demand a larger portion of meat and others with say more children would be left begging for special consideration. After the carcuss-scavenging phase would have been the team-hunting phase and team-hunting involves both division of labor and fair-division of the meat. Certainly good hunters would be expecting a somewhat larger portion of meat and again this could create conflict when men with more children begged for a better deal. The need for an allocation mechanism that minimized conflict and recrimination would be paramount. And meat is most valuable to proto-humans when cooked. Hence the need for rational fire-management in the village. We return to these lines of thinking in the Appendix.

4 Encephalization and Division of Labor

Let us try to be more precise about links between brain-size increase, division of labor and trade between members of a village, say some 1.7 million years back.

(1) Efficiency: Economists would emphasize that specialization and trade (S&T) is productive. The same amount of labor can generate considerably

more output when distinct workers specialize in lines of activity in which they have a comparative advantage. One might argue then that among hundreds of competing, similar villages, those that could "solve" the S&T problem most satisfactorily could have villagers living on average with more food. Hence residents of such "superior" villages might have a reproductive advantage. If we assume in addition that the "solution" of the S&T problem makes demands on the intelligence of villagers, we would have smarter villagers propagating more successfully. This virtuous circle would presumably involve evolution toward proto-humans with larger brains.

(2) Defense of a Village: Members of a village who had a good "solution" to the S&T problem may have learned a range of skills for task assignment. These skills could be very valuable in village defense. It seems clear that an organized defense (with specialization in certain lines of activity) rather than a mob approach would make for more effective protection for a village. The best defended villages would have members with on average better life expectancy and this could translate into more prolific propagation. Again we would need to link a larger average brain size to villagers who were successful in S&T.

(3) Intra-village Amity: It seems clear that an important desideratum in village development would be the avoidance of interpersonal conflict and strife. Villagers had to learn to interact with their fellow villagers in ways that were free of animosity. First violence among members of a village would shorten average life-spans and this would in general lead to lesser numbers of such villagers passing on their genes. This negative selection effect could have been very significant. "Violent villages" would die out in a Darwinian contest of fitness with less violent villages. Villages with much internal strife would presumably have been less effective in defense against attack from neighboring villages. Can we link "more amity" in a village to more S&T? If Ofek's fire maintenance person were properly rewarded for her work, properly compensated by other families for providing a light for their family fire, this would payoff in both efficiency and amity dimensions. Compare this to the rough and tumble of bilateral bargaining time and time agains for a light from the maintainer's fire. A harmonious process of exchange would surely have survival value for participants in the exchange. Ideally the exchange happens quickly and neither party

departs aggrieved. An accumulation of resentments, in contrast, could lead to later violence between villagers. We suggest then that the type of S&T that developed should have been one that conserved on good will between parties in exchange. Our "market" solution would appear to be relatively free of cumlative resentments among participants. But this is topic worthy of much reflection. When are market outcomes deemed fair by participants and when do they lead to later recrimination?

(4) Allocation of "Public Goods": In the Appendix we argue that certain key decisions (for example dividing up the meat from a find or successful kill) cannot be solved by market-like forces – decentralized to-ing and fro-ing. An acknowledged leader must step forth to sort out such allocation problems or somehow a concensus among many individuals on an allocation must emerge regularly. Unfair allocations could of course result in feuds and possible violence. In our view this unavoidable problem in group decision-making is distinct from the matter of specialization and interpersonal trade. One might consider a leader to be a person specialized in producing mediation services, and she exchanges such services for other commodities. But though this is an interesting way of thinking about leadership, it is clearly inadequate. Well-functioning villages will exhibit some form of specialization and interpersonal trade as well as some mechanism to solve, on a regular basis, serious allocation problems that must be made by concensus or by an acknowledged leader. Decision-making by a sanctioned "wise" leader is simpler than decision-making by working to a concensus. We suggest in the appendix that a leader is needed in order for fair allocations of meat to be made regularly. Meat is in some sense required for brain size increase since the human brain is so energy-consuming of a given stream of food inflow. Better brains would appear to be a necessary accoutrement of proto-humans in order for some rudimentary form of specialization and interpersonal trade to develop.

5 Concluding Remarks

The central point is that somehow early humans solved the task assignment problem (specialization associated with division of labor) and divied up the gains from trade in a way that prevented persistent unhappiness and a consequent diminution in "co-operation" among members of a village. Clearly the maintenance of "prosperity" and harmony among members of a village would have survival value for the village and each member of the village. Hence "fair" assignment of tasks and of the gains from specialization and interpersonal trade had to be worked out in a way that fostered solidarity in the members of the group comprising a village. It seems reasonable to argue that the solution of the allocation problem involved superior intelligence by those in the village. "Village development" followed from a satisficing solution to the task assignment problem and harmony within a village would have had survival value for the members of "the tribe". Larger brains should be fostered by the solution to the allocation problems posed by life in groups. This seems to be one of Ofek's central points and we have attempted to fill in some details of his line of thinking. We have taken the tools of textbook economics and provided a benchmark model of a village comprising proto-humans, some 1.7 million years back. We have attempted to construct a model village in which specialization in task by individuals and interpersonal trade are central features. In the appendix we argue that division of labor and interpersonal trade was supportive of brain-expansion by early humans but that brain-expansion may have been primarily driven by the emergence of leaders (decision-makers acting for the collectivity) in early proto-human agglomerations. Leadership was required in arriving at fair allocations of meat either scavenged or yielded by a successful hunt.

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Appendix: Brain Size Increase

Let us accept that in mating one or both parents must have a larger than average brain size in order for there to be a chance of offspring having larger than average brain sizes. Wade is clear in his report that a man in a primitive tribe who succeeds in killing a person, presumably male, in another tribe is more attractive to women and sires on average more children than does a man who does not kill a person in another tribe. If one associates success in mortal combat or in a stealth attack with "more intelligence" then we might have a simple theory of brain size increase. Killers have cunning ("more intelligence" on average) and killers procreate in the villages of early humans more on average.

A somewhat different line of thought is that survival to the age of mating is the crucial "variable" and that "more intelligence" correlates with greater survivability. This could hold for both men and women. Less intelligent persons survive for shorter spells and leave fewer offspring. Avoiding conflict and/or other dangerous situations would correlate with greater survivability and such a trait could easily be linked to superior intelligence. Ofek reminds us that humans would serve as convenient food for carnivores such as lions and tigers and part of survival way back would be avoiding been eaten by such dangerous predators.

Consider some special cases. It could be that all men possessed similar brain size and intelligence, but some women were born smarter (with larger brains) on average. These women could use their superior intelligence in turn to make their mates happier or healthier and the pair could end up with more offspring on average. The population might then have average brain size increasing over time. Alternatively it could be that all women possessed similar brain size and intelligence but some men were born smarter on average. These men could strategize better in seducing fertile women or winning such women in "contests" with other men and leave on average more offspring. Again there would be more offspring with larger brains, on average. The bottom line is that on average the brain size of adult members of generation $t+1$ must be somewhat larger some how than is the brain size of adult members of generation t, if human brain size is to increase. Individuals with larger brains had to keep themselves better fed and mated than those with smaller brains if brains size was to drift upward over the millenia. Superior "social" skill is a plausible explanation for an individual to end up better fed and mated and of course one tends to correlate superior "social" skill with "more intelligence" or larger brain size. This is the tack favored by Ofek [2001] and Wade [2006] and each links "social" skill to a capacity to engage in beneficial exchanges on a regular basis with one's fellow villagers. Ofek emphasizes specialization and trade as the key "social" skill leading to brain-size expansion. A successful person has to learn to not get cheated in various sorts of exchange. Exchange or trade is in a sense the flip-side of specialization in tasks or division of labor. Regardless of brain size, division of labor and interpersonal trade is very productive way to organize people with somewhat different skills, but these require a "supportive" attitude of individuals involved. One cannot simply impose specialization and interpersonal trade on a group of people. Rather the specialization and trade must emerge as a byproduct of the "more casual" social interaction of individuals in the group. Wade (p. 163) reports on research on the biological basis of trusting behavior.[16] It seems easy to argue that "more intelligent" individuals can carry out specialization and interpersonal trade better (deeper and more creatively) than can "less intelligent" individuals.

Observers of evolution emphasize that "the environment" selects for traits that have allowed individuals in the current generation, generation t to "succeed" and to procreate. Traits with survival and procreation value get passed down in the offspring (generation $t+1$) of who have adapted well to the current environment in period t. What was the nature of the environment that selected for early humans with larger brains? "It is easier to explain how *habilis* sustained its larger brain than why it got it." (Wade, p. 19) *Habilis* appeared about the same time as did early tools (2.5 million years ago). Cooked meat became central to the diet of humans sometime later than 1.7 million years back. Meat-eating is more efficient for brain nourishment than is plant-eating. "Still, that does not explain what specific environmental forces made a large

[16] Hamlin et. al. [2007] have found that preverbal infants are "drawn toward" an individual who assists a third party and "avoided" an individual who hindered a third party. Hence a case for a hard-wiring in humans for co-operation with co-operators vis-a-vis "defectors".

brain advantageous in the first place. Higher social primates like apes and people probably encounter no problems more challenging than those of dealing with other members of their community. If so, the likeliest reason for *habilis's* greater brain size sould have been increasing social complexity." (Wade, p. 19). Ofek would argue that specialization and interpersonal trade was the key aspect of "social complexity" that filtered the winners from the losers. Individuals who were good at specialization and trade would be more successful "in their lives" and would end up procreating more on average than those who were not so clever in specialization and interpersonal trade.

It is worth emphasizing that specialization and interpersonal trade in modern societies is hugely facilitated by a system of prices and a medium of exchange (currency). One does not have to bargain or barter in order to acquire something in our society. Our system of prices and money economizes hugely on bargaining costs. Not only is bargaining costly in time but the deals struck can leave one side feeling poorly treated. Proto-humans had to carry out exchanges, albeit over a narrow range of "goods", without the crutch of money and prices and it is easy to speculate that good bargainers could have prospered relative to poor bargainers in such a rough and tumble environment. A harmonious group of villagers 1.7 million years back would develop rules of thumb for carrying out fair exchanges in order to economize on time and goodwill. The large challenge to a modern person is not in being a good exchanger for goods but in finding a supportive niche in society, a marketable skill that yields a good income stream. "More intelligence" measured over a range of dimensions, perhaps a wide range, should correlate with "good positions" in modern complex societies. No doubt, the getting of a "good position" in modern society is more demanding of a person's "intelligence" (strategic thinking?) than the retaining of a "good position".

Both Ofek and Wade overlook a plausible explanation for rapid brain evolution in early humans, some 1.7 million years back. About this time primitive tools for butchering meat were evident and and the structures of teeth suggest that meat became a more standard food. As we noted above large brains require much nutrition and meat serves well in this. Bramble and Lieberman [2004] argue that proto-humans learned first to get meat from large animals killed by other predatory animals. They argue that early humans would have developed great facility is running in order to gain access to "felled" prey. Meat scavenging fostered bipedalism and bipedalism pre-dated brain-size increase. The meat scavenged would still have had to be brought back to the village to supply women and children. There would have been a basic allocation problem at the carcass: who gets which piece and how much? Distribution of meat would have been central to (a) maintaining the health of members of the village and (b) to harmony among individuals in the village. There is no way that communal life could flourish without the development of a means of divying up the meat from a fresh carcass or a successful hunt in a procedure, free of rancor. The solution of this allocation problem cries out for a leader with a large brain, a person who is considered wise and fair. We are of course talking about a period in which observers agree that language did not exist. One has to keep in mind that there could be lean periods with all of the villagers going hungary for weeks. The allocation of meat could be a life or death decision in such times. Harmony had to be maintained even in times of great meat scarcity. A Solomon, an accepted decision-maker, would be required or some way for the villagers to reach a concensus[17] for dividing up the fresh meat among the families of a village. Either way, this allocation decision would be a routine which involved selection for individuals with larger brains.

Of course hunting large animals by proto-humans in teams is itself a highly specialized social activity. Team activity requires leadership, including the delegation of tasks to team members. Team leaders would be individuals with a record of successful hunts. And there remains the complicated social activity associated the allocation of the meat to individuals and/families after each successful outing.

One might invert this line of thought and argue that regular meat-eating by proto-humans had to await (a) reliable fire-maintenance or an "institution" that resulted in a cooking fire being maintained in a village and (b) the emergence of the "institution" of "solomon" who could effect a fair allocation of meat among the families comprising a village. A "solomon" or leader could be expected to be

[17] Honeybees make group decisions about moving their "hive" to a new location. The process has bee analyzed in Seeley and Buhrman [1999]. Honeybees also have an extensive division of labor which in contrast with humans is hard-wired into the biology of the bees.

somewhat better fed on average as well as better endowed with mates. Larger brained offspring would then become somewhat more prevalent in a village, on average. Village life and a meat-eating diet meant that certain group decisions had to get made and a dominant decision-maker would be the natural way for such decisions to get made. Dominant decision-makers would tend to be somewhat "more intelligent" on average and they would most certainly leave more offspring as well.

It is not too difficult to weave a rapid expansion in brain size into our web of phenonena, dating from about 1.7 million years back: the emergence of primitive butchering tools, the emergence of reliable fire-maintenance in a village, the emergence of "annointed" individuals who would make decisions for the group, particularly decisions involving the allocation of meat from a kill, the transition to meat-eating among all the villagers, and the above average procreative success of the "annointed" decision-makers as well as of the superior hunters. There are two avenues to brain size increase here – more meat per capita could sustain a larger brain in a person with such a diet and secondly leaders of various kinds could get themselves better fed and better mated than could the non-leaders. The most plausible force for brain size increase is the superior success in procreation of the leaders in the village.

Ofek rightly in our view emphasizes the importance of solving the fire-maintenance problem as central to deepening the division of labor in a village. There is no doubt that specialization by task is a highly productive innovation and in the absense of money and prices could be challenging to make routine. A smart person would be a better fire-maintenance person than a not-so-smart person. However in our view the paramount importance in getting meat-eating an entrenched behavior turned on the solution of key group decision-making problems. The solution of public goods allocation problems (allocation decisions made at a center in the interests of the social group or collectivity) remains to this day a vexing issue in advanced economies. The holding of an election or referendum is often resorted to in modern societies in order to "solve" decisions involving the community as a whole as in: "how big should the budget for national defense be?"

Wade espouses the view that organized religion emerged with the capacity for language and that collective religious rituals served to strengthen social bonds in the village. In particular he believes that religion became a mechanism for punishing what he calls freeloaders in a community (Wade, pp. 163-168). We suggest that our charismatic "Solomons" above would have come to invoke supernatural explanations for their special decision-making abilities or to cast themselves as proto-priests. It is a small step for such individuals to take on the role of leader in group dances and vocalizations. Villages would then have a priest and "religious" rituals for the collectivity linked to the priest. It is easy to agree with Wade that religious rituals promote group sociality and that "religion" can be used to punish villagers who violate the norms of acceptable behavior in the village. We suggest however that dancing and singing collectively would get linked to a charismatic decision-maker, a proto-priest, and that religion would emerge via the need for a group to have an individual who makes certain decisions for the group.