Summary

If the federal government is not going to be the major market for the application of federally funded R & D results, then the responsibility for bringing about technology utilization cannot be borne alone by the federal agency funding the R & D. That this problem is now being recognized is shown by the number of bills that were introduced in Congress in 1974, culminating in the Solar Heating and Cooling Act of 1974 (*7*).

An examination of the incentives for technology utilization in the conceptual framework of TDS (as shown in Fig. 4) reveals the following:

1) Incentives must be applied to each component of the TDS.

2) Different components in the TDS require different incentives.

3) Although information exists concerning a wide variety of incentives that are currently being used by various federal agencies to stimulate technology utilization, most of this information is in the form of raw data compiled by the respective agencies and a substantial effort will be required to collect, compile, and evaluate them.

4) All the components of a TDS must be activated if technology utilization is to occur on a self-sustaining basis. This makes experimental verification of a particular incentive on a particular component difficult.

5) A federal agency concerned with technology utilization can and should assume the responsibility for identifying all the components of the required TDS, devising incentives for each component and testing them to ensure their effectiveness. Where a TDS does not exist, the federal agency may have to assume the responsibility of creating one. The scope of this effort in many cases may transcend the present authority of the agency, and congressional action may be required to remedy this shortcoming.

References and Notes

1. J. G. Welles and R. H. Waterman, Jr., *Harv. Bus. Rev.* **42** (4), 106 (1964).
2. There are a number of excellent papers giving accounts of NASA's experiences in fostering civilian applications of NASA-generated technology. For example, see J. P. Kottonstette and J. J. Rusnik, *Res. Manage.* **16**, 24 (July 1973); J. G. Welles, "Contributions to technology and their transfer: a NASA experience," paper presented at the NATO Advanced Study Institute on Technology Transfer, Paris-Evry, France, 24 June to 6 July 1973; M. D. Robbins, *Mission Oriented R & D and the Advancement of Technology: The Impact of NASA Contributions; Final Report* (Univ. of Denver Research Institute, Denver, Colo., May 1972), vols. 1 and 2.
3. Technology transfer is sometimes used to describe information dissemination, but this is only a part of the technology transfer process.
4. These problems have been discussed extensively at two recent meetings: National Symposium on Technology Transfer, sponsored by the Division of Industrial and Engineering Chemistry of the American Chemical Society, held at the Carnegie Institution, Washington, D.C., 13 to 15 June 1972; NATO Advanced Study Institute on Technology Transfer, Paris-Evry, France, 24 June to 6 July 1973.
5. E. Wenk, Jr., chairman, "Priorities for research applicable to national needs" (Committee on Public Engineering Policy, National Academy of Engineering, Washington, D.C., 1973), p. 2.
6. The Smith-Lever Law, The Agricultural Extended Work Act, 8 May 1914 (Chapter 79, 38 Stat. 372 Title 7, USC, Sections 341–348) authorized universities to use field agents to disseminate the results of agricultural research.
7. The Solar Heating and Cooling Demonstration Act of 1974, PL 93–409.
8. "*Agriculture—Environmental and Consumer Protection Appropriations,*" *Hearings Before a Subcommittee of the Committee on Appropriations*, House of Representatives, 93rd Congress, 2nd Session (Government Printing Office, Washington, D.C., 1974), p. 231.
9. Harbridge House Inc., "Government Patent Policy Study," Final Report for the Federal Council for Science and Technology, Committee of Government Patent Policy (Harbridge House, Inc., Boston, Mass., 1964), vol. 1, pp. 1–21.
10. K. J. Arrow, in *Rate and Direction of Inventive Activity* (Princeton Univ. Press, Princeton, N.J., 1962), p. 623.
11. The Housing and Community Development Act of 1974, PL 93–383.
12. The Geothermal Energy Research, Development, and Demonstration Act of 1974—PL 93–410. It provides a budget of $50 million for guaranteeing loans for the development of geothermal energy sources.
13. Many innovations have been introduced, disseminated, and applied over the past 100 years without any aid from federal agencies, although the Federal Housing Administration's home loans helped to create a larger potential market in the past few decades for these innovations, and the National Bureau of Standards' activities in testing new building industry products provided an additional incentive to the use of new products.

The Limitation of Human Population: A Natural History

The demographic transition of modern times is a return to a pattern familiar to our hunting ancestors.

Don E. Dumond

In demographic circles it has been commonly asserted that the long-term evolution of man was possible only because his high natural fertility permitted him to overcome the effects of an exceptionally heavy premodern mortality—mortality amounting to a loss before the age of reproduction of as much as 50 percent of all individuals born (*1–3*).

A corollary of this same viewpoint is the conclusion that the direction and degree of change in human population size has been governed in preindustrial eras solely by mortality. It is this preconception that has been largely responsible for "transition theory," which holds that the so-called demographic transition of modern times is the result of a new response toward reduction of growth induced by the rising standards of living and health that have followed upon the industrial and medical revolutions (*4*).

Recent years have seen attempts to modify these opinions, however, on the part of historical demographers [for example (*5–7*)], anthropologists [for example (*8–12*)], and others (*13*), who base their views upon various data from their respective disciplines. Unfortunately, discussion of the question is hampered on the one hand by the difficulty of constructing adequate demographic arguments from evidence of populations long dead (*14, 15*), and on the other by the fact that acceptable studies of hunter-gatherers or nonindustrial agricultural peoples are limited by the scarcity of such peoples still available for study whose lives have

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not already been drastically changed by the modern world. Nevertheless, my aim in this article is to recapitulate some of this evidence, and to argue from it not only that the recent reduction in population growth in industrial countries is not a new response but that it is the modern equivalent of a pattern of behavior that has characterized most of mankind over the past million years.

Natality and Natural Selection

Biological evolution of any population may be viewed as proceeding by means of an overproduction of young, a portion of which are then forced to die by factors essentially external to the population—predation, parasitism, and the like—or are forced either to emigrate or to die by competition with other population members for scarce resources. The survivors reproduce, and population-wide frequencies of advantageous and disadvantageous characteristics are changed. The most grossly density-dependent factor, overcrowding in relation to resources, leads not only to the outright death of some of the younger individuals who are eliminated in competition, but commonly leads also to a general decline in fertility, apparently as the direct result of a slightly lowered level of nutrition that is otherwise not sufficient to seriously inhibit normal biological functions or behavior. Thus the total size of the population is limited both through reduction in natality and in deaths heaviest in the relatively young, while adult members of the population tend to remain in at least moderate health (*7*, p. 40; *16*).

Both the overproduction of young and the damping of fertility by slightly lowered nutrition provide the potential for a sharp population increase in the event of an increase in resources. It is this that permits rapid expansion of a species to fill a newly opened niche to which it is suited, and it is this that is absolutely necessary to any successful organism, in order to provide for recovery from the occasional nonroutine demographic catastrophies to which all natural populations are potentially subject.

What if a set of expectations based upon the foregoing is translated to the human societies that must be the closest modern equivalents of those of early men? It is true enough that a substantial number of the children in these societies die before the age of reproduction—at least a third of those born, in most cases (*17*, p. 49)—largely as a result of disease, that is, parasitism. But while natural predation may be present in some situations, it is not a significant check to any known population; and although men fight one another with relative regularity, so that even unorganized and desultory combat might be argued to provide some selective pressure, it seems clear that such fighting has never consistently provided as much pressure as have childhood diseases. One of these elements, then, is uniformly significant, the other only indifferently so; together they may be considered the routine external selective factors.

But a serious reservation must be entered in respect to the density-dependent factor of the lethal intrapopulation competition for resources. In the first place, no examples are at hand of any hunting-gathering people whose population has routinely suffered year-by-year inroads by starvation; rather, their population sizes seem to have been consistently and significantly less than those that could be supported in normal years within the areas in which they reside and by the technologies which they apply. In the second place, the food-sharing propensities of humans and their tendency to imbue close relationships with affective content combine so that when starvation does threaten, it is the entire population, not simply younger and weaker individuals, who experience deterioration. For hunting humans, then, any consistent production of young substantially beyond that necessary to maintain a stationary population must serve in the long run not as a selective advantage, but rather as a serious hazard.

Nevertheless, it can be shown that human populations commonly are fecund enough to permit rapid growth in circumstances of especially favorable resources. Examples are legion: recovery from the effects of epidemics that have resulted in underpopulation, the rapid filling of newly colonized areas, and so on; and it has been suggested that the natural fecundity of human populations is sufficient to permit them to more than double in size in a single generation despite normal mortality (*18*, *19*).

The model that must be adopted for early humanity, therefore, is one in which natality is in approximate balance with mortality from natural and routine external causes, in which the stable population is of a size well within the normal carrying capacity of the region, and yet in which a margin of fecundity—unrealized fertility—somehow exists as a necessary safety mechanism.

Some Vital Processes among Nomadic Hunters

Indications are that the general state of health among modern hunting-gathering peoples not under close contact with the urban world is relatively good (*13*, *20*). Unfortunately, only in few cases is it possible to obtain adequate data regarding mortality, particularly that in infancy and childhood. One survey of available literature suggests that survival of more than half the population to age 15 is generally to be expected among untouched peoples (*17*, table 7).

Especially telling is the carefully collected demographic information from a population of !Kung Bushmen of the Dobe area in Botswana. Studies of 165 women, in which their probable ages, their childbirth histories, and the probable ages at death of their parents were determined, led to the conclusion that the expectancy of life at birth was on the order of 32.5 years, with 60 percent of all born surviving to age 15 (*21*).

Although low by modern health standards, these rates are high enough that had they been accompanied by natality at the level common in many developing nations, there would have been a Dobe !Kung population explosion of remarkable proportions, and for which there is no evidence. Rather, the average completed fertility—that is, the mean number of children born to women who survived to the end of the childbearing period at age 45 to 50 years, was no more than about five even before the increased outside contact of the past few years, a figure just sufficient to produce a stationary or very slowly growing population.

Evidence of similar population balance is available from other recent hunting-gathering societies (*8*, *22*), and additional sources bear witness to a customary low natality among seasonally nomadic hunters (*23*, *24*). Furthermore, there seems to be every indication that the population levels are well below the maximum limit imposed by resources routinely available. Indeed, food is plentiful enough that among peoples such as these it has been suggested that social factors are more important in the control of population size and distribution than are resources (*22, 25*).

These known examples do not serve to contradict the contention that before the modern era the balance between human survival and extinction has been a delicate one; for although mortality may seldom have been astronomical, natality has generally been only sufficient to provide for replacement. Contradiction is provided, however, in the factor that apparently contributes most strongly to that modest natality: the spacing of births, necessary both to accommodate activities normal to hunting-gathering peoples, and to provide for the nutrition of the very young, as will be explained.

The realization of the existence of such a need among hunters was articulated more than 50 years ago in consideration of reports dating about as much earlier (*23, 24*). In one of its most specific formulations, it is said that the simple inability of a mother to carry more than a single child together with her normal baggage, and her inability to nurse more than one child at a time, impose a minimum limit of 3 years between offspring (*8*). Other evidence suggests the birth interval among nomadic hunting peoples is more commonly around 4 years (*26*; compare *27, 28*).

One student of the problem has calculated the difference in work that would be assumed by a Dobe !Kung mother under various birth intervals, with the results summarized in Table 1. When one bears in mind that each woman travels an average of 4200 kilometers per year carrying her baggage and young children, the differences in labor expenditure are substantial (*29*, tables 14.4 and 14.5). Furthermore, the extra labor required for the provision of food for the young does not end when the child begins to walk for himself.

A probably equally compelling need for birth spacing is presented by the relative unavailability to hunting-gathering peoples of foods soft enough to permit weaning of infants at ages under about 2.5 to 3 years (*24*, p. 127; *29*). It should be stressed that this inability to care for more than a single infant at a time is not based simply upon observer's inference, but has been clearly articulated by the people themselves in case after case (for example, *21, 24, 30*).

Table 1. Effect of birth interval on amount of work performed by Dobe !Kung mothers over a 10-year period. [Constructed from Lee's data (*29*, tables 14.4 and 14.5)]

Work details	Birth interval in years			
	2	3	4	5
Number of offspring after 10-year period	5	4	3	2
Number of years spent transporting two children	8	3	0	0
Number of years spent transporting fewer than two children	2	7	10	10
Average baby weight transported per year (kilogram)	17.0	12.2	9.2	7.8
Average baby weight (kilogram) times average distance traveled (kilometer)	32,064	22,824	17,808	14,256

But given the recognized need for and presence of a relatively long interval between births, the mechanisms that actually effect it are not entirely clear. People of many societies practice postpartum sexual abstinence for a period of significant duration. In a number of cases these periods may in fact last as long as 2 years and more, although the great majority are of 1 year or less (*31*)—sufficient to result in birth spacing of no more than about 2 years. Although induced abortion has been shown to be well-nigh universal (*32*), it need not be thought to account consistently for the interval: among the Dobe !Kung, for instance, fetal wastage is reportedly too moderate to indicate a systematic practice of induced abortion (*21*). One suggestion is that among these last people the lactation of 2.5 to 3.5 years serves to suppress ovulation, although it is admitted that evidence for any clear and complete suppressive effect of ovulation in human populations is most ambiguous (*29*).

Among some hunting-gathering groups, evidence suggests that the rate of infanticide has been substantial (*10*, with references therein); in particular, data concerning aboriginal Australians have been said to indicate its practice in between 15 and 50 percent of all births (*8, 24*). Infanticide was admitted by Dobe !Kung women in cases in which births followed too closely upon one another, although specific instances noted constituted little more than 1 percent of births (*21*); it was, however, a topic treated with some secrecy, with men apparently suspecting women of practicing it more often than admitted (*33*, p. 371). Some reports from other !Kung suggest it was probably not uncommon (*30, 34*).

Whatever the means or combination of means employed by hunting-gathering peoples to effect the necessary child spacing, the evidence discussed seems to point to a situation very like the model referred to above: The total population of successful hunters is well within the bounds of available resources and remains at a near-stationary level, yet there is a margin of fecundity above the level of surviving births; this margin is held under control by conscious and personally applied mechanisms adopted to effect birth spacing.

If it can be presumed that the mobility- and baby-food–induced limitation upon the natality of relatively modern hunting-gathering peoples also applies to their Pleistocene counterparts, it will allow the projection of some fertility rates reasonable for earlier periods of human development. A series of hypothetical schedules of age-specific fertility rates is provided in Table 2, together with the actual rates for the Dobe !Kung.

Natality and Child Transport

Before I turn to early humans, I shall consider briefly some studies of monkeys and apes, although accurate demographic data collected under completely natural conditions are seldom available. In terms of their mobility, these forms are somewhat similar to human hunters, although moving according to different rhythms.

One study of baboons, based unfortunately on a very small sample, suggests that 40 percent of the offspring survive to the age of reproduction, and that young are born at the annual rate of about 550 per 1000 females of all ages—that is, at least as frequently as every second year for sexually more active females (*35*). Gestation requires about 6 months, and nursing and transport of the young by the mother occupy

Table 2. Annual age-specific natality rates (per 1000 married women). Schedule 4 is presumed to represent the highest natality feasible for relatively nomadic hunters. For simplicity, figures for births expectable to females over age 44 are here combined with those of age 40 to 44 years.

Age (years)	Hypothetical schedules						Dobe !Kung† (actual figures)
	1*	2	3	4	5	6	
15 to 19	300	250	200	200	150	100	46.5
20 to 24	400	350	350	300	300	250	260.5
25 to 29	500	400	350	300	250	250	205
30 to 34	400	350	300	250	200	200	174
35 to 39	350	250	250	200	150	150	120
40 to 44	250	200	150	150	100	50	64
Average completed fertility among mothers over age 44	11	9	8	7	6	5	4.35

* Schedule 1 is based on data from 20th-century Hutterites, who are among the most fecund people known (*58, 67*). † Modern !Kung Bushman figures are from Howell (*21*); their completed fertility before they had contact with Europeans is thought by Howell to have been about 5, so that their precontact natality may be assumed to be roughly approximated by schedule 6.

11 to 15 months (*36*), when she comes into estrus again and breeds.

Mountain gorillas have been reported to have a birth rate of about 250 per year per 1000 females, with intervals between young varying between 3.5 and 4.5 years. The infant is carried by the mother for about 3 years. About 40 to 50 percent survive to the age of sexual receptivity at 6 or 7 years. The chimpanzee is similar, with birth intervals somewhere between 3 and more than 4.5 years (*37, 38*).

In all of these cases, which may be taken to represent higher nonhominid primates generally, the mother physically transports her infant during much of the period of nursing; at the end of the period, care of the juvenile by the mother either ends entirely or is substantially reduced. Thus she is not faced with the problem of transporting more than a single infant at a time, and she is not faced with a continuing problem of the provision and preparation of food for her young. Birth spacing is, of course, under involuntary hormonal control (*39*).

For the early hominids even less information is available. It is thought that even before the advent of the Pleistocene, forms such as *Australopithecus*, now sometimes referred to as *Homo africanus*, had shifted to an omnivorous diet (*40*), implying a pattern of subsistence and movement closer to that of known hunters and gatherers than to that of ground-dwelling monkeys and apes.

Estimates of age at death of slightly more than 300 *Australopithecus* individuals—a sample within which, unfortunately, infant specimens are almost certainly underrepresented—average 18 to 23 years (*37, 41*). In one manipulation of the data, McKinley (*37*) assumed an age of 11 for sexual maturation, and a period of about 6 years for infant dependency; a comparison of these figures with the data available on survivorship, corrected as nearly as possible to account for missing infant mortality, suggested to McKinley a birth interval of 3 to 5 years, significantly less than the probable period of total infant care (*37*), but one that would accord with a time of infant transport. The length of the fertile period is, of course, not known. The degree to which natality was under the control of an estrus cycle damped by nursing and child care is also unknown, but in view of some essentially human physical developmental progressions, such as in the teeth (*41*), it is not farfetched to think that involuntary hormonal control of breeding was giving way at this time.

With the advent of the Middle Pleistocene and the hominids once referred to the genera *Sinanthropus* and *Pithecanthropus*, now more often termed *Homo erectus*, the developmental scene is clearer. The substantially modern postcranial skeleton seems to imply a development to maturity not significantly different from that of *H. sapiens*; a similar inference has been drawn from a consideration of the complex matter of cranial suture closure (*42*, pp. 139–143). Such food refuse as is available, together with instances of the use of fire, suggests strongly that the pattern of subsistence, hence of seasonally nomadic movement and of infant transport, was essentially that of more modern hunting-gathering peoples. It therefore seems probable that the period of fertility and the reproductive system in general was substantially that of *H. sapiens*.

A Natural History of Human Vital Processes

Ideally, evidence of mortality can be derived directly from skeletal remains. Yet practically speaking, even with large samples there are problems of deciding the extent to which a valid contemporary population is represented (*15*). Misrepresentation of infant deaths is especially frequent (*43*), both because of differential survival of bones and because of different disposal measures practiced for corpses of adults or subadults and for those of small children. Valid age and sex determination can also be problems.

Despite these limitations, however, some samples are available that can be used in a tentative way. With the mortality suggested by these, and with some idea of the overall rates of world population growth before the industrial revolution (*2, 11*), it is possible to estimate the level of natality necessary to provide at least minimally for such an increase.

A recent study by Acsadi and Nemeskeri (*42*) has focused in particular upon the history and prehistory of mortality, and offers the unusual advantages that comparable and systematic methods of age determination were used in assessing most of the populations, and that relatively detailed life tables were generated from the data.

Based on the life tables, some relevant survivorship schedules are plotted as curves in Fig. 1. Curve A is based ultimately upon fragments of 22 individuals of *H. erectus*, of the subspecies formerly assigned to the genus *Sinanthropus*, which were recovered in excavations at the Chinese cave of Choukoutien, and probably date from the Middle Pleistocene (*44*).

Curve B is based on the remains of more than 200 individuals recovered from the caves of Taforalt and Afalou in the Maghreb region of Morocco and Algeria, dating from the end of the Paleolithic or the beginning of the Mesolithic, at the end of the Pleistocene (*45*). It would almost certainly be a mistake to assume this schedule to represent a typical nomadic hunting population, however, for the sample derives from the very period in which increased sedentation is demonstrated in the archeological record. Indeed, the systematic disposal of dead in a single location must of itself indicate a measure of residence stability, so that any cemetery must be suspected either of deriving from relatively sedentary folk or of providing only a haphazard mortality sample. The caution must apply also to the remains from Choukoutien, as well as to those from certain other series that are not dealt with directly here (*46*). This problem of sampling the mortality of prehistoric hunters will be returned to.

Curves C and D are derived from the highest and lowest of the age-specific mortality rates from substantial series of skeletons of European agricultural peoples (*47*). A number of other rates (*42, 43*) were eliminated from consideration here, simply because the collections on which they were based included no figures for deaths in early childhood. Indeed, even curve D may be suspect in that regard (*48*). In all curves, pooled data for both sexes is used, both for consistency, since separate information for the sexes is not available in all cases, and because it seems safer in view of the difficulty of accurately sexing immature skeletons and of the apparent tendency to wrongly identify the sex of even a proportion of older ones (*17*).

Table 3 presents estimates of the net reproductive rate (that is, the proportion of itself that one generation of females will produce) within a stable population in which the females conform to the mortality curves of Fig. 1, and to the natality rates of the separate hypothetical schedules of Table 2. For simplicity, an equal sex ratio is assumed. In succeeding sections I will trace the history of vital processes through several stages of human culture.

Table 3. Net reproductive rates calculated from natality shown in Table 2 and mortality shown in Fig. 1. It is assumed that sex ratios are equal and that all women are always married.

Mortality (Fig. 1)	Natality schedules (Table 2)						
	1	2	3	4	5	6	Dobe !Kung
A (Sinanthropus)	1.05	0.87	0.78	0.69	0.58	0.50	0.43
B (Maghreb type)	1.89	1.56	1.39	1.21	1.02	0.88	0.76
C (Agriculturalists)	2.25	1.86	1.65	1.45	1.21	1.05	0.91
D (Agriculturalists)	2.81	2.70	2.41	2.11	1.75	1.52	1.31

Early Hunters

The world population of 10,000 years ago—the end of the Pleistocene and the practical beginning of the era of more sedentary human living patterns—has been estimated at from about 3 to 5 million, the culmination of a long-term rate of increase averaging from 0.0007 to 0.0015 percent per year, and spanning 1 to 2 million years (*2, 28*). In the present discussion, a rate of increase sufficient to achieve this long-term result is taken to be represented by any net reproductive rate over 1.0.

Table 3 indicates that a population with a stable mortality of type A (Sinanthropus) and a stable natality such as that of the rates in schedule 4 (the highest probably feasible for hunting-gathering peoples if the assumptions regarding child spacing are correct) would replace only about two-thirds of its female population each generation. A population with such mortality among females could replace itself fully only with fertility approaching that of schedule 1, which is based on modern figures that are the highest ever recorded for a group of humans. It is therefore possible to conclude that the small Choukoutien skeletal collection almost certainly does not constitute a valid sample of *H. erectus* mortality (*49*).

On the other hand, a population with mortality of type B (Maghreb) could maintain itself with a fertility similar to that of schedule 5. And a population with mortality similar to that of Dobe !Kung, which falls between C and D, much closer to the latter, would experience with the same natality a significant population increase, an increase which surely could not have been accommodated for any substantial period of time under stable hunting-gathering conditions.

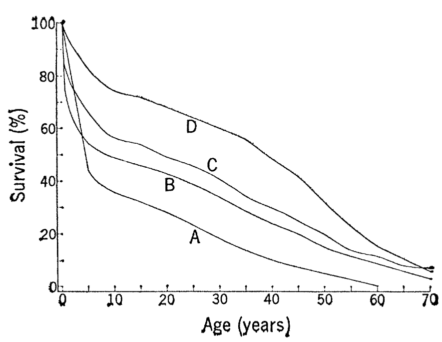

Fig. 1. Survivorship derived from skeletal evidence, both sexes, constructed from the data of Acsadi and Nemeskeri (*42*). (A) Sinanthropus (*42*, table 49); life expectancy at birth, 13 years. (B) Maghreb type derived from remains of late Paleolithic or early Mesolithic populations at Taforalt and Afalou (*42*, table 104); life expectancy at birth, 21 years. (C) Agriculturalists, composite data from 1st- to 4th-century Roman era population and 9th-century Frankish population (*42*, tables 121, 127); life expectancy at birth, 25 years. (D) Agriculturalists of the late Roman era (*42*, table 124); life expectancy at birth, 35 years.

What seems to be a weakness of the model developed here is that it presumes substantially all of the females of the population to be married at a very young age. However, it is clear from the anthropological literature that in nomadic hunting-gathering societies virtually all nubile females are married (with nubility frequently arriving before puberty), creating thereby the most important economic unit as well as the reproductive one.

Through the recognition of real kinship bonds, or through various more or less fictive kinlike ties, any such nuclear family is then presented a wide choice among other families with whom legitimately to affiliate and draw assistance in the face of fluctuating resources; despite any number of these affiliations, however, it remains a relatively autonomous unit (*24, 50*). Put another way, responsibility for the day-to-day business of maintaining life falls squarely upon the small family, parents and their children, hence the repercussions of overprocreation are felt immediately and inescapably by the procreators themselves; each couple is responsible for its own progeny.

As noted earlier, it has been suggested with some empirical support that humans have commonly been fecund enough that, when presented with unoccupied, favorable territory, they have been capable of doubling their population in a single generation—that is, of achieving a net reproductive rate of 2.0. From Table 3 it is evident that populations with mortality no heavier than that of type C, normally balanced by fertility equivalent to that of type 6, could without shortening birth intervals below about 3 years succeed in achieving a population growth at the rate of 50 percent per generation, if their natality were allowed to increase to that of schedule 4. As mentioned, this level is probably the highest ordinarily feasible for nomadic hunters (*51*). Furthermore, if either mortality or the need for mobility were temporarily lessened for such people by an entry into new, rich surroundings, even more rapid growth (whether at the rate of 2.0 is not so certain) would be possible.

In short, an early hunting population with mortality no more stringent than that of type C might be expected to maintain itself and to possess at least a modest margin of unrealized fecundity, even if the need for child spacing is taken into account. In view of the data on the !Kung Bushmen, survivorship among most early hunters may have been substantially better than that of type C, providing an even greater margin of fecundity to be held in check by simple, consciously applied controls.

It is unfortunate and somewhat embarrassing that we have no convincingly complete sample of the mortality of any fossil population of hunter-gatherers. It would be foolish to argue that mortality as low as that of the single example of the Dobe !Kung was consistent either among modern hunters or their Pleistocene forebears. On the other hand, if the requirement for mobility and the resultant reduction in natality have been consistent and real, the relationships between natality and mortality that are summarized in Table 3 seem to hint that mortality was effectively no higher under conditions of hunting than under those of a more sedentary life, including agriculture. Indeed, a probable increase in the level of parasitism in sedentary agricultural societies (to be mentioned shortly) may mean that the mortality rates of hunters were more often significantly lower.

Preindustrial Agriculturalists

It has been estimated that between about 8000 B.C. and A.D. 1750 the population of the world increased some 160 times, to around 800 million. To do this it doubled itself less often than once each 1000 years, achieving an average yearly growth rate of less than 0.1 percent (*2*). Approximately this rate has been estimated for the Near East during the Neolithic (*52*); it is less than the rate of growth that is indicated in major countries after the beginning of the Christian era, which may over the long run have amounted to between 0.15 and 0.4 percent per year (*12, 19*). Although these overall rates of growth are small when compared with some of those to be encountered in the modern world, they are drastically above that of the Pleistocene.

Several arguments have recently been made to the effect that sedentism itself is sufficient to promote population growth, simply by relaxing the need for movement and child transport (*27, 29, 53*). Certainly it is with the Mesolithic era that the growth of settled villages can be generally observed. Then and later, efficient strategies of collecting seeds or coastal products are known to have been successfully employed by people with relatively high population densities. In some places what have been claimed to be true urban population agglomerations may even have been supported in this way (*54*); yet in most favorable locations agriculture apparently followed shortly after the development of intensive collecting economies such as those that characterized the Mesolithic.

Whether one adopts a populationist notion of the causes of agricultural development (*33, 55*), or a more traditional or "neo-Malthusian" approach in which innovation in agriculture is conceived as bringing on population increase (*28, 56*), or one that is somewhere between the two (*19, 53*), there seems to be no argument against the proposition that overall population growth and agriculture as a way of life have gone hand in hand. And with them have come increasingly ramified and exclusive family systems, possessed of increasingly complicated property arrangements and inheritance practices. These larger kin groups take over control from the nuclear family as the basic economic unit of society. Marriage becomes a union of these greater families, implying new adjustments of property rights. The management of power becomes a problem, specialists in its management appear. Classes emerge. An elaboration of religion, at times involving ancestral cults that extend kinship concepts outside the realm of the living, may provide a sacred rationale for a plentiful issue.

Certain prominent results of this changed way of life would seem to militate against population increase. In most agricultural societies there are a significant number of individuals of both sexes who never marry. The degree to which this is the case varies greatly from society to society, and no attempt at exhaustive review need be made. But, as an extreme example, the common Medieval European practice of impartible inheritance of land tended to accompany the development of the so-called "stem" family, in which only the heir to the property achieved sanction to marry and reproduce, while younger siblings remained unattached and unpropagating; in some cases fully half the nubile females were reportedly so removed from reproduction. Where lands have been divided among siblings, on the other hand, marriage has been less restricted, with fewer than one-fifth, and sometimes almost none, of the females remaining unmarried (*7, 18, 24, 57*). When marriages and attendant property settlements are negotiated by families there also frequently has resulted delay in marriage for those who do achieve it—this being a condition that will lower overall natality, of course, inasmuch as the total number of children produced is in approximately linear relationship to the age of females at marriage, when that age is between 20 and 35 (*58*).

Nevertheless, it is almost a truism that agricultural endeavor has commonly tended to encourage high natality, because additional offspring are thought to be economic benefits (*24, 59*). Some students suggest that this tendency may be further increased where there are certain kinds of taxes levied by central governments—colonial or otherwise—making the perceived economic advantage of another offspring sufficiently attractive that it outweighs even a noticeable resultant depression of family living (*59, 60*). Furthermore, the existence of the more complex and economically dominant extended family, often reflected in an expanded, supranuclear family residence unit, tends to remove parents from direct responsibility for both the economic and the affective support of their own progeny, hence from direct and immediate experience of consequences of any excess in procreation. Whatever the factors most at work in specific cases, among married women the rate of natality increases, so that the average interval between births in preindustrial agricultural societies often approaches, if it seldom quite achieves, the low figure of 2 years (*7, 58, 61*).

Mortality is often suggested to have declined somewhat with the beginnings of agriculture, with the decline responsible for much of the estimated increase in the rate of overall population growth (*2, 3, 42*); such a suggestion has nevertheless been questioned by others (*12*). And although the survival curves of Fig. 1 may seem to support it, the evidence for a decline in mortality is in fact sketchy, simply because valid evidence of mortality among hunting-gathering peoples is so difficult to come by. The level of disease must have increased with sedentary living and the accompanying crowding of population, and disease-caused mortality, at least, must have risen significantly. In preindustrial cities it was apparently especially high (*62*). For present purposes it seems more acceptable to conclude that mortality remained at least as heavy as it had been during earlier less sedentary millennia.

Meanwhile, any increase in natality, perhaps up to as high as schedule 3 in the long run, could provide for substantial population growth even though the age at marriage was raised, and even though a significant portion of females might be withdrawn from reproduction through failure to wed.

Despite the probability that agriculture as a way of life tends to promote the production of children as economic assets, it cannot be really surprising to find it shown by historical demographers that many populations of this sort purposefully limited their production of children before they ever felt the effects of the revolution in medical technology (*6, 7*). They must have done so, for in spite of the inhibiting social factors mentioned earlier, population increase throughout the era of preindustrial agriculture would otherwise certainly have exceeded the relatively modest overall rate it in fact achieved.

After the Revolutions

The situation occasioned by the industrial and medical revolutions is familiar to all of us, and will be touched upon only lightly. In those countries participating directly in the industrial revolution, a sudden burgeoning of population was responded to by a drastic drop in natality, in what has been called the "demographic transition." The original view, that the population increase had been brought on by a sharp decline in mortality, seems to be modified now by knowledge that the actual population rise was triggered by an increase in fertility shortly before or contemporaneously with the advent of the industrial revolution, and significantly before any real decline of mortality through medical advances (*4, 7*; compare *63*). Even as mortality was being drastically reduced by the medical extensions of the new technology, a marked downturn in natality occurred, the result of individual choices exercised regarding marriage and childbirth, the latter assisted by technological applications. Sociological explanations of the fertility decline include the point that the major functions of the old extended family were shifted to other specialized institutions, and that the decrease in mortality called for the production of fewer total offspring in order to provide a desired level of issue (*4*).

While this may be true, I prefer to place emphasis on the return to primary importance of the nuclear family, with a renewal of its former status as the basic economic, affective, and residence unit (*64*). Except for the absence of any immediate need for the modern human mother to transport her offspring several thousand kilometers per year on her back or her hip, the position of the nuclear family within industrial society is remarkably similar to its position in societies of nomadic hunters and gatherers: as an autonomous unit it assumes direct responsibility for its own progeny.

Given the success with which human hunting populations regulated themselves for so long and in such nice balance with available resources, it should not be at all surprising on the one hand that the relatively high fertility of agricultural society was capable of being reduced substantially and rapidly to cope with the new needs of industrialization, and on the other that Western prosperity in the mid-20th century was often accompanied by a marked rise in natality.

The recent general rise in population in the industrially undeveloped countries is a rise that *has* clearly been brought about by extensions of the revolution in medical technology and has not been accompanied by a redefinition of economy and social life around the independent nuclear family. The presumed advantages of offspring to agricultural peoples have continued within the general perception, and total numbers have swelled sharply with the new and improved level of survivorship. Increased communication and cooperation between modern and increasingly compassionate nation states have even, by leading to massive programs of international assistance and relief, decreased the punitive effect on individual procreators of their own steadily declining resources. Even should old, tried measures of abortion, infanticide, and the like be resorted to, the limits of their efficacy have been overshot. Where these measures may have been adequate for a population faced with a normal mortality of a third of all offspring in the first 15 years of life, they are not adequate at all for populations faced with child mortality a fifth of that. Furthermore, the imposition of official value systems of Western industrial nations have often caused the use of some of these older and once-practical measures of population limitation to be held criminal or at least thoroughly unacceptable.

This is the dilemma that is so often decried in articles like this one, where a resolution is both groped for and argued.

Summary and Conclusions

In this article I have suggested that overproduction of offspring by early human populations would have tended to work to the selective disadvantage of the entire society, but that, nevertheless, a permanently successful society requires some margin of unrealized fecundity with which to respond to any catastrophic decreases in size. If this is true, without involuntary hormonal control of breeding and in the absence of a clearly effective damping of ovulation by lengthy lactation, it must also be true that people of successful societies have always limited their natality below the level of their reasonably achievable fecundity.

Among early hunters, the strongest motive for keeping this margin of possible births unrealized apparently lay in the need experienced within each nuclear family to space births in order to permit the mother to perform the tasks expected of her. This motive probably existed throughout the Pleistocene, and would have resulted in relatively consistent efforts by individuals to space their offspring.

With the advent of sedentary life, this motive for child spacing was considerably weakened. Residence in extended families tended to remove parents from direct economic and affective responsibility for their own issue. Among agriculturalists, in particular, children have generally been considered an economic advantage, and this has encouraged some increase in fertility rates, although natality has at the same time been inhibited by a rise in age and a reduction of the proportion of the women who married. Under conditions of centralized rule, social stratification, and colonialism, demands of rulers for taxes and rents may often have served to promote a further labor intensification and population increase. But seldom, if ever, has natality approached the maximum possible.

In these preindustrial cases, the rate of natural mortality was sufficiently high to have made the margin between tolerable and intolerable births relatively small, so that the number of births to be aborted or offspring to be disposed of by any single female were relatively few, whatever her motivation. Although it may be technically correct to say that mortality served as the chief controlling factor of population dynamics—simply because natural deaths before or during the period of reproduction took away a far greater proportion of the population than was prevented or removed by conscious population limitation measures—it seems more meaningful to argue that the significant margin of control lay in voluntary measures.

Furthermore, and despite some arguments to the contrary, the evidence provides no clear support for any general decline in human mortality before the industrial and medical revolutions. I suggest rather that there was no consistent decline until around A.D. 1900; that earlier population fluctuations were the result of fluctuations in natality at least as often as they were of short-run variations in mortality; and that a regular component in the natality rates was voluntary intent. Thus it is unreasonable to argue as has been done that human beings, alone among living organisms, have failed to develop any density-dependent mechanisms of population control (*65*). Rather, their primary density-dependent mechanism is the most flexible there is, the only device flexible enough to suit the needs of the enormous variety of societies of humans, and a device that is consequently subject to considerable short-run aberration—that is, self-consciousness and volition.

Decisions regarding population limitation have been highly personal ones made by individuals not so much upon the basis of broader long-range subsistence questions or of community policy as upon considerations regarding the amount of short-run effort they are able and willing to invest in each child. It is no doubt fair to say that there have always been families larger than average, willingly produced by parents who accept the added burden. In the modern industrial world, despite the evident current fad for zero population growth as an abstract ideal, the most cogent consideration will undoubtedly continue to be whether the production of another offspring is worth the investment of time and money for the care and education that is now demanded for full social membership. Thus the position of the potential parent is directly analogous to that of the adult in a hunting-gathering society, in which the question is whether the child is worth the extra labor in transport and the preparation of food, or the risk of depriving a sibling of milk. In both, the cost of children to parents is high. And in either case the decision is a personal one that may be expected to vary somewhat between individuals, regardless of the similarity of their particular histories or of their cultural surroundings.

Although a similar choice is made in modern agricultural societies and in developing countries, the limits of the decisions are different simply because the cost of children to their immediate parents is still low: portability is not a factor, neither is education, and the general decline in living is spread among everyone. The choice may be expected to change significantly only as the direct cost to each parent of each child—in effort, in money, or in anguish—rises.

This is an argument that a change in values and social organization is the key to a change in the present upward population trend, but it is by no means an argument that improved birth control technology is not similarly important (*66*). For modern mortality-reducing measures have vastly increased the numbers of family limitation decisions that must be made; to assist in this, improved technology is indispensable.

There has been a tendency for demographers to assume that all preindustrial peoples have possessed values similar to those of modern, predominantly agricultural, underdeveloped nations, with high fertility and high mortality. I have tried here to argue briefly that this has not been the case, that, indeed, the outlook of humans for most of their career as a species has been rather different, and that their behavior in industrial nations has been more like a return to that of our earlier evolutionary history, than a uniquely new development.

In most cases where growth of population has occurred, it has been both recognized and tolerated. The modern growth of population will be slowed permanently only to the extent that in the judgment of each individual, whatever his background, extra children are worth less than they will cost in time, in effort, in money, in emotion—or in the threat that is posed by their very existence.

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Graduate Admission Variables and Future Success

We cannot tell whether the standard selection measures used by graduate schools are valid.

Robyn M. Dawes

The standard variables considered in selecting students for graduate school do not correlate well with later measures of the success or attainments of the selected students (*1*, *2*). The low correlations have led at least one investigator (*3*) to propose abandoning one of these standard variables, the Graduate Record Examination (GRE). The purpose of the present report is to demonstrate that variables that are the basis for admitting students to graduate school *must* have low correlations with future measures of the success of these students.

The usual reason given for such low correlations is that the admitted students tend to have scores within a restricted (high) range on each of these variables and that empirical investigations are necessarily limited to these students, the rejected ones being typically unavailable to the researcher. *Potential* correlations based on the whole applicant group might be much higher, but there is no way of evaluating such correlations empirically, and "prophecy" formulas for estimating them are of dubious value because the restriction is so severe and because the covariance structure of the variables for the selected group is different from that of the applicant group. With the ratio of applicants to selected students increasing every year (it was 14 to 1 for the class entering the psychology department of the University of Oregon in the fall of 1974), the problem of restricted range likewise becomes worse. But, as will be demonstrated later in this article, that is not the main problem.

The main problem concerns the covariance structure of the admissions variables in the selected group. That structure consists largely of negative correlations because "whatever vague methods are used by admissions committees for combining criteria, these methods tend to be compensatory" (*1*). Even if a multiple elimination procedure is used to screen out unacceptable applicants at an initial selection phase, choice from among those passing the screening tends to be compensatory. Thus, if selected applicants are low on any particular variable, they will be high on others. It follows that for any two variables important in selection there will be people who are high-high, high-low, and low-high, but few

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