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GENERATION LENGTH VARIABILITY AMONG HUMAN POPULATIONS

Since formulation of stable population theory by A. J. Lotka and R. A. Fisher's definition of the Malthusian parameter, average generation length became an important variable in demographic and biological studies. The reason is that duration time of one generation determines length of a period of population turnover influencing the rate of its natural increase and hence amount of growth per unit time. The basic relationship in the stable population is:

(1) $$\sum_{x=0}^{\omega} l_x b_x = e^{rT} = R_0$$

where: ω — the oldest attainable age, l_x — probability of surviving from birth up to the age x (survivorship), b_x — age-sex specific fertility rate, r — intrinsic rate of natural increase or the Malthusian parameter, R_0 — the net reproductive rate, T — generation length, i.e. average time the population takes to multiply by the rate R_0.

Another fundamental for the theory relationship is given by the Lotka's [1956] equation:

(2) $$1 = \sum_{x=0}^{\omega} e^{-rx} l_x b_x$$

It may be shown by approximative solution of equation (2) that T is very close to the average age at reproduction (average age of parents at childbirth). Accordingly, empirical estimates of T are commonly obtained in a form of mothers' average age at childbirth for such data are most easily obtainable in the majority of populations. Uncertainity as to who is a father of a given child prevents precise ascertainment of the male generation length, but since husbands are on the average a few years older than their wives it may be concluded that the true generation length of humans is higher than that estimated on grounds of female ages only.

Comparisons and projections of population growth as well as conclusions concerning their average fitness or relative fitnesses of subpopulations are based on estimates of intrinsic rates of increase. Taking natural logarithms of both sides of equation (1) and solving for r gives:

$$r = (\ln R_0)/T \quad (3)$$

making clear that varying generation length affects intrinsic rate of increase even without changes in net reproductive performance. Thus two populations with same mortality and natality but with different generation lengths will have different rates of increase and then unequal fitnesses. Example of influence of changing within limits encountered in human populations T values on the estimate of r at constant net reproductive rates is shown in table 1 together with magnitude of relative fitness ($W_{i,m}$). It is measured as the ratio of the rate of growth per average generation length ($\bar{T}$) of a set of individuals with a given generation length (T_i) to the growth rate of the fastest growing set — with the minimum generation length (T_m):

$$W_{i,m} = \frac{e^{r_i \bar{T}}}{e^{r_m \bar{T}}}, \quad r_i = (\ln R_0)/T_i, \quad r_m = (\ln R_0)/T_m . \quad (4)$$

Values $W_{28,24}$ in table 1 are computed for $T_i = 28$ years, $T_m = 24$ years and $\bar{T} = 26$ years. Even as they are not extreme values it is clear that differences in fitness introduced by changing generation length are quite substantial especially at higher rates of reproduction.

That the rate of population growth depends not only on numbers of born and of dying but also on ages at childbearing is a simple and long-recognized truth. However it has usually been assumed by both demographers [eg. Pollard et al. 1974: 94] and geneticists [eg. Cavalli-Sforza & Bodmer 1971: 297] that the human generation length is stable and thus T value became a constant equal 25 - 29 years. That some variability exists in generation length has been noticed but since its sources remained unexplored no practical attempt was made to take it into account. Seeming lack of regularity in generation length changes resulted in perception of its variability as a random variation.

The present paper documents interdependences between average age at childbearing and other demographic variables (life expectancy and fertility characteristics) in present-day populations. The variables are treated as indicators of degree of technological and organizational development of populations, and revealed regularities interpreted accordingly.

As a data source served information on 200 countries of the World contained in the "*World Population*" [U.S. Bureau of Census 1978] referring to the third quarter of the 20th century (1950 - 77). Since there are gaps in particular data items for some countries, numbers of them included into various calculations differ accordingly. The source publication supplies data of our interest in a form of median age of

Table 1. Values of intrinsic rate of natural increase $r \times 10^{-4}$ for various generation lengths T and net reproductive rates R_0. In the last row are given relative fitnesses W – see text for further explanation

T (years)	net reproductive rates R_0 1.01	1.10	1.50	2.00	2.50
22	5	43	184	315	416
23	4	41	176	301	398
24	4	40	169	289	382
25	4	38	162	277	367
26	4	37	156	267	352
27	4	35	150	257	339
28	4	34	145	248	327
29	3	33	140	239	316
30	3	32	135	231	305
$W_{28,24}$	0.999	0.985	0.940	0.901	0.871

mother at childbearing (we use it here as an estimate of T), e_o parameter of the life table (newborn life expectancy), median birth order and crude birth rate. Both median values are current year-of-observation estimates and not cohort values, hence they may be accepted as approximate assesment only and should be interpreted with due care. Relationship between T and other parameters was established by means of standard procedures of one-way analysis of variance.

Generation length is significantly related to life expectancy at birth (fig. 1, tab. 2). The relationship is curvilinear: T is low in populations

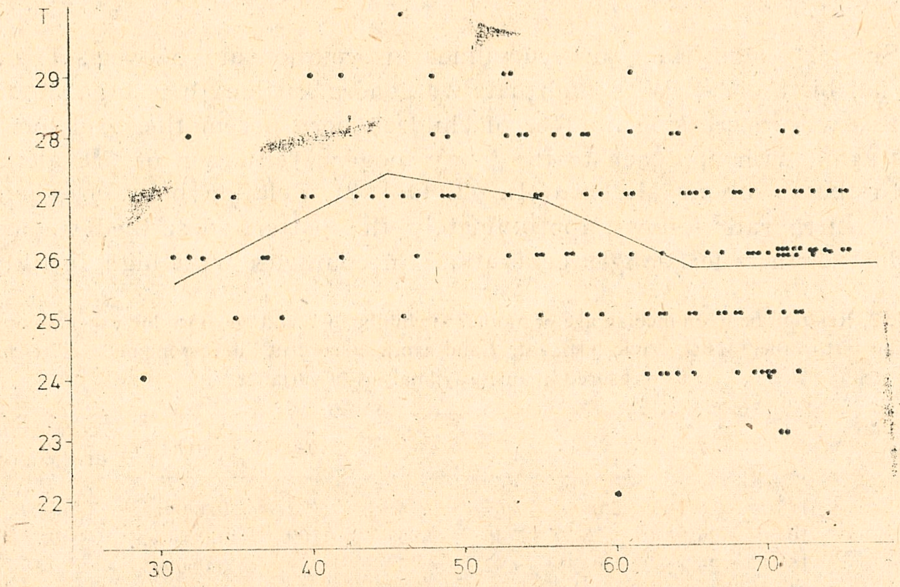

Fig. 1. Relation between median age of mother at childbirth T and newborn life expectancy e_0 for 128 countries of the World

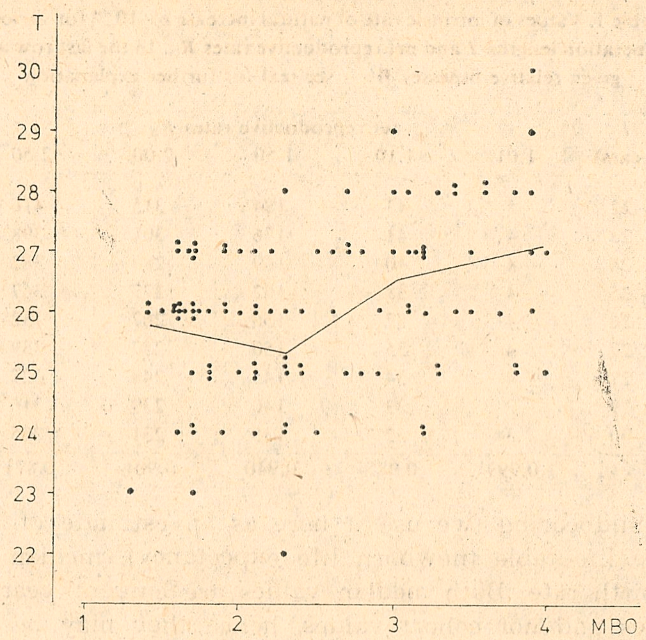

Fig. 2. Relation between median age of mother at childbirth T and median birth order MBO for 104 countries of the World

with very high mortality, it increases along with life expectancy increase up to moderate e_0 values (40 - 50 yrs) and then T drops and becomes stabilized as populations attain the "developed country" mortality level.

Similarly significant and curvilinear is relationship between T and median birth order. With high natality generation length is high, it decreases with decreasing number of children born per mother and increases again with approach to the "very modern" situation of prevalence of firstborns among all born (fig. 2, tabl. 2). Relation between T and crude birth rate follows approximately the pattern described for the median birth order: longer generations in countries with high fertility,

Table 2. Relation between median age of mother at childbirth T and newborn life expectancy e_0, median birth order MBO, crude birth rate f and average score of "development level" (*score*) as measured by one-way analysis of variance

Relation of T to:	N	$\bar{\bar{T}}$	S^2	F	df_1	df_2	$Q(F)$	correlation quotient (η)*
e_0	128	26.2	2.04	7.67	4	123	0.000015	0.20
MBO	104	26.1	1.78	7.45	3	100	0.00015	0.18
f	155	26.4	1.93	9.92	3	151	0.000005	0.16
score	125	26.2	2.06	4.67	8	116	0.000057	0.24

* – fraction of total variance of T explained by variance in the other variable.

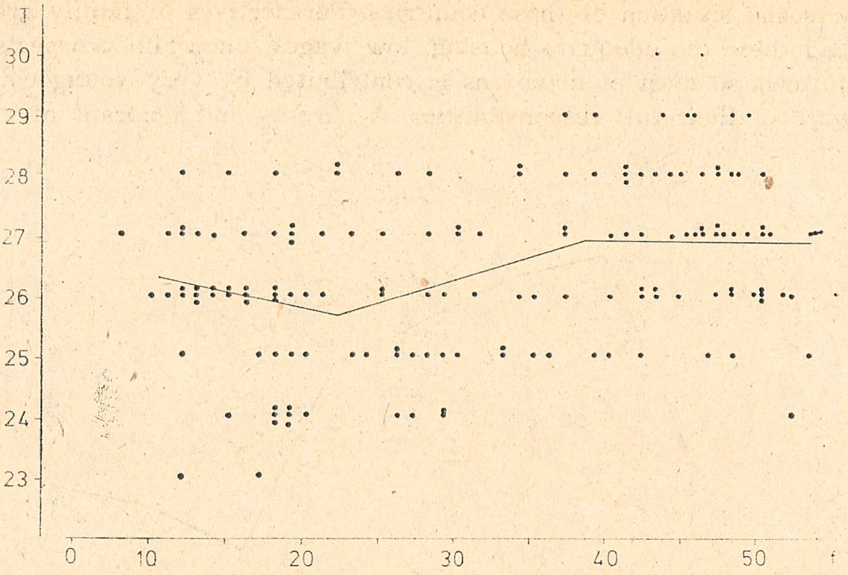

Fig. 3. Relation between median age of mother at childbirth T and crude birth rate f for 155 countries of the World

shorter in countries with moderate fertility and again longer in countries of the lowest "developed type" fertility (fig. 3, tab. 2).

Increase of T with decreasing mortality and increasing fertility is understandable within framework of purely "demographic" interrelations between survivorship, age-specific fertility and frequency of mothers giving birth at various ages. However reversal of the trend towards shorter generations with increasing survivorship and towards longer generations with decrease in fertility at approach to "developed country" values requires another explanation. In this explanation average age at childbirth is not a simple function of survivorship and fertility but an expression of attitude towards timing of family build-up under conditions of negligible infant and child mortality and effective birth control. Observed on the average increase of mothers' age with "modernization" is probably a result of longer time used for preparation to found a family (long period of education, preoccupation with initial stages of professional career etc.). People simply want first to get well established in life and only afterwards feel prepared to have children. Children appear when prospects for family development and prosperity are good.

European Socialist countries (Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland and Romania) form an exception to the rule just described. Their life expectancies are very high (above 65 yrs), median birth order and fertility rates very low but T is also very low (range 23 - 25, $\bar{x}=23.8$ yrs). This most probably reflects peculiar social situation of those countries. Perspectives of family growth are bad there (no adequate housing, low wages, uncertain prospects for the future), so most of newborns is contributed by very young couples unaware of their full responsibilities as parents and ignorant of effec-

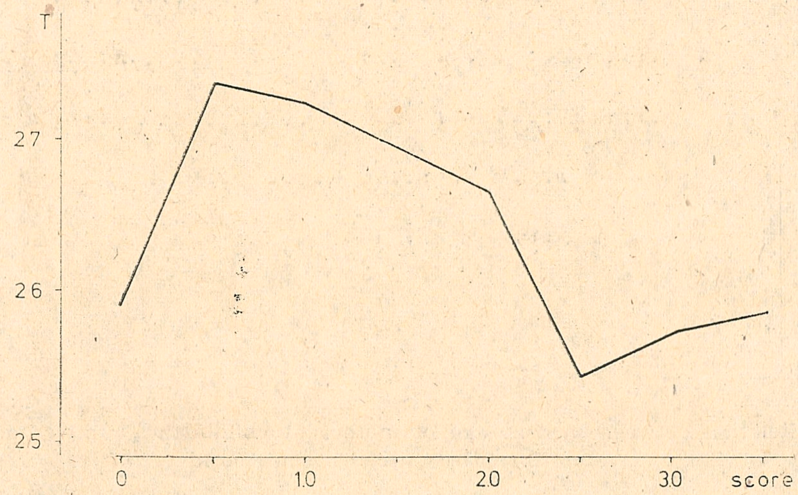

Fig. 4. Relation between median age of mother at childbirth T and „development level" of populations measured by average score based on demographic data (see text)

tive birth control. The state of these populations is "conscious refusal to breed" with the majority of births being "accidental" exceptions.

It should be stressed that the above description of reasons for generation lengths observed in developed countries overemphasizes main causes. There are still in those populations large groups of people with traditional views toward family planning and substantial numbers of individuals not conforming to the general pattern. Nevertheless with further "modernization" still more and more people will find themselves under circumstances described here in "idealized" form.

Analyzed in this paper relations between generation length and demographic parameters may be interpreted jointly as a response of T to changing life conditions. In order to illustrate this point a general score measuring „developmental level" has been constructed in a following way. The range of life expectancies was divided into 5 categories numbered 0 - 4 in order of increasing e_0 values, the range of crude birth rates into 4 categories numbered 0 - 3 in order of decreasing fertility. Each population, according to its e_0 and birth rate values was classified and characterized by an average of the two scores. Average score „0" means high mortality and fertility, increase in score value reflects approach towards „developed country" level. Relationship between such measured level of development and generation length (fig. 4, tab. 2) is highly significant and curvilinear.

Assuming that median age of mother at childbirth is a sufficient approximation to the true generation length and that the scores properly reflect degree of cultural adaptation of populations we may state that in underdeveloped traditional populations with high mortality and fertility generation time is short, then with initial stages of improvement in living conditions increases sharply while its slow decrease accompanies further development and finaly in highly developed populations it becomes stabilized, after very slight increase, at a level similar to that observed in underdeveloped countries.

We used here only contemporary cross-sectional data, but use of uniformitarian principle seems quite well founded in this case and if so then the described regularity of changes in T with degree of cultural adaptation may be thought of as reflecting the sequence of events occuring through time during human demographic and cultural evolution.

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ZMIENNOŚĆ CZASU TRWANIA POKOLENIA W POPULACJACH LUDZKICH

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Czas trwania pokolenia jest istotnym regulatorem tempa przyrostu populacji ludzkich, a co za tym idzie także możliwości działania w nich doboru naturalnego. W tab. 1 zilustrowano zmiany współczynnika przyrostu naturalnego populacji ustabilizowanej r w zależności od czasu trwania pokolenia T przy różnych współczynnikach reprodukcji netto R_0 oraz pokazano, jak wpływa zmiana wartości T na ocenę sprawności względnej (relative fitness) obliczanej według równania (4). Posługując się danymi z lat 1950 - 1977 dla 200 krajów świata [U. S. Bureau of Census] stwierdzono istnienie zależności pomiędzy empirycznym oszacowaniem T a oczekiwanym trwaniem życia noworodka e_0, medianą kolejności urodzenia dzieci rodzonych w ciągu roku (*MBO*) reprezentującą przeciętną dzietność, surowym współczynnikiem urodzeń b oraz punktową miarą zaawansowania roz-

woju kulturowego populacji (*score*), opartą na danych o wymieralności i płodności (rys. 1 - 4, tab. 2). Zależność ma we wszystkich przypadkach charakter krzywoliniowy, odzwierciedlając ogólną prawidłowość polegającą na tym, że czas trwania pokolenia, niski w populacjach krajów rozwijających się o wysokiej wymieralności i płodności, rośnie wraz z początkowymi stadiami poprawy warunków życia; dalszej poprawie towarzyszy powolny spadek wartości T, a w warunkach krajów wysoko rozwiniętych czas trwania pokolenia ulega stabilizacji po nieznacznym wzroście jego wartości (rys. 4). Autor uważa, że ta stwierdzona na danych przekrojowych prawidłowość da się odnieść do zmian czasu trwania pokolenia w czasie kulturowej i demograficznej ewolucji populacji ludzkich.