From Cronk, L., Chagnon, N. and W. Irons (editors). 2000.
Adaptation and Human Behavior. An Anthropological Perspective. Aldine De Gruyter, Hawthorne, NY

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To Marry Again or Not
A Dynamic Model for Demographic Transition

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This chapter reports the results of an empirical investigation of a question concerning motivation—do men maximize children, or the amount of wealth they can give their children? Although the method described here can be used to determine what is being maximized in any behavioral domain, we pursue this particular issue because of its implications for understanding demographic transition.

Behavioral ecologists are challenged by the fact that people voluntarily reproduce at lower levels than would apparently maximize their lifetime reproduction. The "demographic transition" refers to the precipitous decline in fertility that started in many European countries in the nineteenth century (e.g., Coale and Watkins 1986) and now characterizes much of the developing world (e.g., Robinson 1992). This fertility shift often occurs in conjunction with improvements in child survival, but its magnitude is greater than would be expected if fertility levels were merely compensating for increased child survival. Furthermore fertility reductions usually occur despite general increases in availability of resources. Sociologists use the marked drop in fertility that accompanies modernization, together with the evidence of negative or indeterminate relationships between income and fertility in industrial societies (Mueller and Short 1983), to question the legitimacy of evolutionary approaches to the study of humans (e.g., Vining 1986). In response, evolutionary social scientists propose hypotheses that might explain why parents with access to plentiful resources would choose low fertility rates. There are three principal hypotheses.

1. In highly competitive environments parents optimize fitness by producing a few children with high levels of investment rather than many with less investment per capita. This hypothesis draws on the quantity/quality trade-offs organisms face in their allocation of reproductive effort, as recognized in all evolutionary (Kaplan 1996) and some economic (Becker and Lewis 1973) models. According to this hypothesis, low fertility would be favored

in environments in which high levels of parental investment are both critical to the success of the offspring (e.g., Kaplan et al. 1995) and costly to the parent (Turke 1989). This notion was first introduced by Lack (1947) for the study of clutch size in birds. It concurs in some respects with original accounts of how the European demographic transition was a response to socioeconomic changes affecting child costs (e.g., Notestein 1953). Demographers have evaluated this hypothesis by examining the timing of transitions in relation to relevant socioeconomic indicators, which has produced mixed results (Lesthaeghe and Wilson 1986). Behavioral ecologists have developed more direct tests, particularly multigenerational empirical studies and modeling.

2. Lowered fertility rates are a consequence of Darwinian but nongenetic mechanisms of inheritance, by means of which traits associated with certain influential individuals are preferentially imitated by others in the population. Boyd and Richerson (1985) propose that small family sizes might be transmitted through such a process. In an attempt to copy successful individuals in a population, imitators adopt all the traits of the model, irrespective of whether or not these contribute to the model's success. This process, which Boyd and Richerson call "indirect bias," opens up the possibility for the spread of potentially maladaptive traits, by means of Darwinian but nongenetic mechanisms.
3. Lowered fertility is a maladaptive outcome of novel social, technological, and environmental changes that have been so rapid that adaptive responses are not (yet) elicited. An obvious example in this context is birth control technology. Pérusse (1993) shows that the wealthier section of his Canadian sample of men achieve higher copulation rates than do their less wealthy counterparts, but do not achieve higher fertility because of the intervention of birth control. According to this hypothesis, then, low fertility is simply maladaptive.

We turn now to the status of and evidence for each of these hypotheses. Applying optimality models to the function of intermediate-sized families (hypothesis 1) has proved less fruitful than originally hoped. Two empirical studies (Kaplan et al. 1995; Mueller n.d.) looked at whether numbers of grandchildren were greatest among parents who produced intermediate numbers of offspring. Both failed to support the hypothesis. Others have used models to explore how specific assumptions about the relationship between parental effort and offspring success can generate situations in which small family sizes reflect an optimal tradeoff between offspring quantity and quality (e.g., Anderies 1996; Beauchamp 1994; Rogers 1990). As yet, they have failed to identify environments in which the classic features of the demographic transition arise at equilibrium. For example, in the most realistic version of his model, Rogers (1995) is unable to find either an environment in which fertility decreases with wealth (but see "Discussion"), or one in which wealth maximization ensures a higher fitness payoff than simply maximizing number of first generation descendants. Beauchamp (1994; Figure 4) finds that smaller family sizes are favored in competitive but not in noncompetitive environments; in both environments, however, high income groups still out-reproduce low income groups (consistent with Rogers 1995).

The cultural inheritance hypothesis is intriguing. It may well account for the rapid spread of fertility-limiting behavior through populations, and it is intricately linked to the notion now popular among demographers and social scientists that changes in *ideas* (rather than changes in the economy) cause fertility transitions (Bongaart and Watkins 1996). But it raises some questions too. First, why do the influential, trendsetting individuals choose lower fertility in the first place? Granted there will be tradeoffs between seeking socioeconomic status and reproducing early and often. But quite why reproduction is sacrificed to such extremes still needs to be explained, or at least raises questions about how such status-seeking becomes equilibrated in a population where there may be countervailing selection for high fertility, sending us back to hypothesis 1. Second, cultural inheritance theorists build their models on a very different set of assumptions concerning the mechanisms of evolutionary processes than do behavioral ecologists. Such abandoning of the basic organic evolutionary model may still be premature, although the potential importance of such mechanisms is pointed to in newer work, outlined below.

The maladaptationist approach (hypothesis 3), when specifically linked to the existence of birth control technology, fails to provide a satisfactory explanation for demographic transition. The European transition started before the availability of modern birth control technology (Livi-Bacci 1986); furthermore in many parts of contemporary Africa the transition does not occur despite availability of free contraceptives (Jones, et al. 1997). More generally, however, maladaptationist accounts cannot substitute for explanatory theories unless they specify precisely what has changed in the environment, why these changes lead to lowered fertility, and what kinds of evolved mechanisms might underlie this response (see Kaplan et al. 1995).

The present paper adopts a different approach from any of the above. It sets to one side the question (central to hypothesis 1) of whether individuals select fertility levels that maximize the production of grandoffspring. Rather, it turns to an empirical investigation of the simpler but perhaps more fundamental question of whether individuals (men in this case) maximize the numbers of their children or the amount of wealth they can give their children. We work from the premise that understanding reproductive behavioral processes (and the motivational factors that underlie them) is central to explaining the changing relationships between wealth and fertility.

To expose motivations behind reproductive decisions we employ in a novel way a modeling procedure central to behavioral ecology. Dynamic state variable models (Mangel and Clark 1988; Mangel and Ludwig 1992) are used to connect physiological or ecological states, measures of fitness, and behavior of individuals. Conventionally, the fitness currency is specified on the basis of the organism's natural history. On the assumption that natural selection has shaped a decision-making process to maximize this fitness currency, the model is used to explore how variations in an organism's social and material environment shape optimal decisions. We take an alternative approach. We use real world observations of Kipsigis men to determine what fitness currency best accounts for their behavior. We construct alternative models using fitness functions variously weighted toward material versus reproductive motivations, and then test which fitness function best matches the pattern of marriages observed in the real data.

We focus on the marital decisions of men in a rural Kenyan Kipsigis population. There are several reasons why the study of Kipsigis men is particularly rewarding with respect to elucidating reproductive motivation. First, rural Kenya began its fertility transition only in the late 1980s (Robinson 1992). By focusing on men who married between 1941 and 1983, we therefore use data from a pre-fertility transition population (for consistency of reproductive behavior over time, see Borgerhoff Mulder 1987a). Second, many Kipsigis men marry more than one wife, such that there is high variance in men's reproductive success. Though polygynous marriage has little effect on population growth rates, it has a major impact on an individual man's reproductive success. Analyzing the decision whether or not to marry polygynously therefore offers considerable scope for the study of factors motivating men's reproduction. Third, thoroughly verified and cross-checked demographic and marital data (both retrospective and prospective) are available (e.g., Borgerhoff Mulder 1987a, 1987b, 1995).

KIPSIGIS ETHNOGRAPHY

Economy

Kipsigis are Kalenjin Nilotic Kenyans, who have lived for several centuries in what is now southwestern Kenya. Traditionally they were herders, but they have always cultivated millet and semi-domesticated cultivars to supplement a milk-and-meat-based diet. The Abosi population (Borgerhoff Mulder 1990) adopted the practice of individual ownership of land in the 1930s, and thereafter began growing maize for both subsistence and cash purposes. Livestock (cattle, sheep, and goats) remain central to the economy, as sources of milk, meat, and capital.

Since the 1930s, the basic livelihood has been quite stable. Men are the foremost decision-makers for the farm, and the sole owners of land and livestock. Women obtain use rights to land only through their husbands, although they spend much more time in agricultural work than do men (Borgerhoff Mulder et al., 1997). A few acres of land (usually a substantial proportion of the family plot) are put into maize production each year, and the rest is left fallow for livestock grazing. Men usually cultivate a small plot (a half acre or so), whereas women cultivate more, depending on the numbers of their children, their energy, and the size of the plot. A single maize harvest is raised each year, and any surplus over the estimated annual needs of the household is usually sold, in recent years, to a national marketing board. If a man's wife's (or wives') stores become depleted, he must find maize (the staple diet of every family) elsewhere, usually through purchases from local traders or at markets. Women supplement maize production with small gardens of beans and vegetables. Other food items (oil, salt, tea, and occasionally sugar) are bought from local trading posts.

Livestock are grazed primarily on the farm, although unproductive areas (such as steep hillsides) are available as commons. Herds of cattle are heavily skewed toward females (through the sale or slaughter of steers) to enhance milk production, which is used both for domestic consumption and for cash sales to a national marketing board and private customers. Small stock are kept in low numbers, primarily for meat consumption. Livestock are used for bride-wealth payments, as well as for meeting various expenses including supplementary food items, utensils, hoes, pesticides, clothing, medical treatment, and education.

Both maize and livestock production are risky for Kipsigis. Rainfall is adequate for both activities (1,265 mm per year), but is annually variable. Since Abosi lies in the driest part of the Kipsigis range, it frequently suffers years of poor maize yields and minimal milk production. Other factors contributing to an unpredictable food supply are labor shortages, agricultural pests, cattle diseases, and raids. If a man is sick in December, the fields do not get prepared and planted. If women are unhealthy anytime between January and June, their fields turn to weed. Similarly, children who are ill can keep their mothers at home, or busy traveling to distant dispensaries and traditional curers. While community labor pools ameliorate domestic problems, cooperation needs to be reciprocated or it ceases. Indeed, food deficits in households observed in 1982, 1983, and 1991 were commonly caused by labor shortages at critical times. In addition, pest infestations, both in the fields (in years of heavy rain) or in the grain stores, can decimate a crop. Livestock disease further threatens every herd, and is prevalent in the area because of the great expense of veterinary medicines, and cattle raiding still occasionally occurs.

Marriage

Women almost invariably marry soon after puberty, but men's age at marriage is much more variable, with the median ranging from 21 to 25 years between the 1950s and the 1980s. At marriage a man receives a share of his father's livestock and land, and there he settles with his new wife, in a state of semi-independence from his father. Legally these capital resources are not viewed as his until his father's death (or incapacity), yet in practice this share of land and livestock constitutes the final inheritance that a son receives from his father. For the purposes of this paper, a man's reproductive and economic career starts at his marriage. All marriages require a substantial bride-wealth payment to the bride's parents, the amount of which has been quite stable over the period between 1952 and 1991 (Borgerhoff Mulder 1995). A man's first bride-wealth payment is made by his father. Subsequent marriage payments for additional wives are his own responsibility. Men marry multiple wives for many reasons, primarily to obtain women's labor and reproductive services: a man with many wives is admired for numbers of children and for the economic power that derives from a large household. Divorce is not permitted, although some women temporarily withdraw sexual and economic services by running away.

Previous analyses show that the Kipsigis marriage system resembles resource defense polygyny in many respects (Borgerhoff Mulder 1990). Wealthy men can afford multiple bride-wealth payments, thereby gaining multiple wives. Reproductive costs associated with polygynous marriage for women are not high, suggesting that poor men are generally unable to either coerce or attract additional wives.

Raising Children to Independence

Children are produced at a fast rate in Kipsigis society, where cows' milk and solid foods are introduced at 3–4 months, breast-feeding rarely extends beyond 2.5 years, and lactating women frequently conceive. Mortality in the first five years of life is high; the average postmenopausal woman produced 9 live births, with between 5 and 8 of those children (depending on the cohort) surviving to 5 years of age. Children are viewed as an economic and social asset, and national family planning initiatives have had little impact in this and many other rural communities. No woman in the original 1982–1983 demographic study ($N = 1,257$) reported using western contraceptive methods, and only 1 ($N = 120$) in the 1991 survey.

Staple foods for children (maize, milk, vegetables, and occasionally meat) are produced on the farm and supplemented by shop-bought items as noted above. Very rudimentary primary health care is available (for cash) at several nearby dispensaries. Two hospitals, both mission-run and expensive, lie within 50 miles of Abosi; credit is permitted in some cases. All of these services are used by the majority of families, often in conjunction with visits to traditional healers, whose services are also not free. Child mortality, and indeed maternal health, bears a close relationship to family wealth (Borgerhoff Mulder 1987b).

Primary school is officially free, although there are various forms of mandatory fundraising. Secondary schooling can be expensive. Only a small number of children, usually sons, progress to secondary school (Borgerhoff Mulder 1998a).

At independence, sons' bride-wealth payments and marriage ceremony costs must be covered. Conversely, daughters bring in a bride-wealth, and their marriage expenses are paid by the groom's family. Daughters inherit no significant property whatsoever. Once married, sons inherit a share of their father's land and livestock, although this property is not considered legally theirs till the father's death, and can be used by the father should he so wish. Sons who do not marry almost inevitably leave home.

EMPIRICAL METHODS AND RESULTS

Field Methods

Detailed reproductive, marital, and economic histories were compiled for 98 men in 1982–1983 and were checked and updated for 88 of these individuals in 1991. Thus 88 men with combined prospective and retrospective data are the subject of the present paper. We have coded for each man the acreage of his plot, the size of his herd, and the number of his wives and children at the end of each seven-year period after his marriage; livestock and land are combined to measure each man's "capital" or wealth. The present paper combines data from three cohorts (Chuma, Sawe, and Korongoro); future analyses will explore variations between these cohorts in the dynamics of polygyny, capital, and investment.

Empirical Results

As in all other published analyses on Kipsigis there is a positive correlation between wealth and polygyny, indicative of a "polygyny threshold" (Borgerhoff Mulder 1990). The relationship between initial (or inherited) capital and number of wives after 21 years of married life is shown in Figure 16.1. Furthermore, richer men take a second wife sooner than do poorer men (data not shown). These results tell us nothing new about the Kipsigis social and economic system, but they do show that this sample is comparable to others drawn from the population, and they provide patterns against which the output of the simulation models can be compared.

A DYNAMIC STATE VARIABLE MODEL FOR MARRIAGE BEHAVIOR

Model and Parameters

In this section we describe a model specifying how food, wealth, and children are produced in the environment and society of Abosi. This model is used to determine optimal marital decisions for each of a man's first 21 years of married life. Optimal marital decisions are modeled as a function of a man's current state (wives, children, and wealth).

We use a dynamic state variable model (Mangel and Clark 1988; Mangel and Ludwig 1992) to detect the motivation behind the marriage behavior of individual

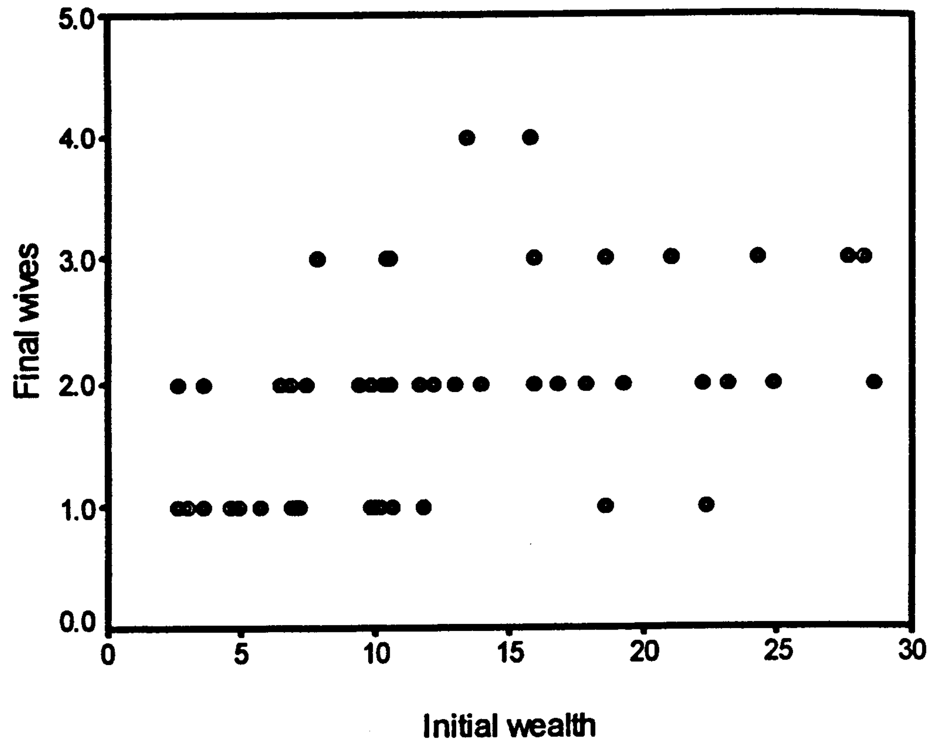

Figure 16.1. Empirical results. The number of wives at the end of the 21-year sampling interval (y) increased with initial value of livestock and land (x), yielding a regression equation of $y = 1.37 + 0.05(x)$, with $r^2 = 0.17$.

men. This type of model proposes that behavior is dependent on the states of individuals. In our model, a man's states are

- W(t) = value of livestock (in thousand Kenyan Shillings, tKS, at their 1960 monetary value) a man has at the start of year *t*
- C(t) = number of wives he has at the start of year *t*
- K(t) = number of children he has at the start of year *t*
- L = amount of land (in acres) he possesses; this value does not vary

These state variables are constrained as follows: $1 \leq C(t) \leq c_{max}$, $w_{min} \leq W(t) \leq w_{max}$, and $0 \leq K(t) \leq k_{max}$, where c_{max} is the maximum number of wives allowed in the model, w_{min} and w_{max} are the minimum and maximum number of livestock allowed, and k_{max} is the maximum number of children allowed.

The limits we placed on the variables are based on empirical data (1982–1983 values; Table 16.1). Although men have married as many as 12 wives, it is unusual for a man to have more than 4 wives, so we set $c_{max} = 4$. Similarly, 24 children is the maximum allowed in the model, although in unusual cases men may have as many as 50 children. The parameters w_{min} and w_{max} for livestock wealth are taken

Table 1. Variables and Parameters in the Model

Symbol	*Interpretation*	*Value*	*Note*
t	Year, with T (= 21) being the terminal year	Varies	
L	Amount of land owned	Fixed	[a]
W(t)	Livestock wealth at the start of year t	Varies	[b]
w_{max}	Maximum possible livestock wealth	50 tKS	[b]
w_{min}	Minimum possible livestock wealth	1 tKS	
ω_T	Total wealth, land and livestock	Varies	
ω_c	Total wealth per child	Varies	
w_{crit}	Critical wealth for raising children so that they contribute to fitness	3	[c]
C(t)	Number of wives, start of year t	Varies	
c_{max}	Maximum number of wives	4	[d]
$cost_w$	Cost of marrying a wife	4.6 tKS	[e]
L_w	Amount of land a wife can farm	1.5 acres	[f]
L_g	Amount of land not being farmed, and being used for grazing cattle		
α	Value of food produced per acre	.93 tKS/acre	[g]
F_p	Parental food requirements per year	.2 tKS	[h]
F_k	Child food requirements per year	.132 tKS	[h]
F_b	Price paid to buy food	1.5 tKS	[i]
F_s	Price received to sell food	1 tKS	[i]
K(t)	Number of children, start of year t	Varies	
k_{max}	Maximum number of children	24	[j]
k_a	Average yearly production of children, per wife	0.27	[k]
$cost_k$	Cost of maintaining children per year	.4 tKS	[l]
$cost_e$	Cost of educating children	1 tKS	[m]
$cost_s$	Cost of sick children	2 tKS	[n]

[a] For simplicity land was held fixed in the model. Productive land (suitable for grazing or cultivation) ranges between 1 and 22.5 acres (tKS value 1.1 – 24.8). Unpublished analyses show the results of this paper are unaffected by whether the model output is compared with the full empirical data set (n = 88) or only those who did not buy or sell land (n = 61).

[b] Livestock holdings range in tKS value between 0.1 and 18.2. Summing livestock and land values, capital varies from 1.8 to 40.2. The model allows w_{max} to reach 50 tKS, to compensate for the fixed land constraint.

[c] Both child mortality (Borgerhoff Mulder 1987b) and wife's temporary desertion rates are high among women married to men with little land.

[d] Two men married 12 wives, but >4 wives is unusual.

[e] Mean for this sample.

[f] See the section on Kipsigis economy.

[g] Based on cattle market exchange rates, retrospective interviews, and group discussions.

[h] Food intake estimates based on observational data and parents' estimates.

[i] Market fluctuations reflecting supply, demand, and government policy.

[j] Some men have >50 children, but >24 children is unusual.

[k] Mean number of offspring surviving to five years for women in this sample is 6.8, over a median reproductive lifespan of 25 years.

[l] These include store-purchased food, such as tea, oil, salt, and sugar, as well as clothing, soap, primary school materials, etc., and are set at 0.32 tKS per year per child. The cost of minor illnesses is set at 0.08 tKS.

[m] Government schools cost about .7 tKS per annum, whereas mission or private schools can exceed 3 tKS. Since most children attending secondary school use government institutions, the average is set at 1 tKS.

[n] Costs vary widely (across hospitals and healers), but 2 tKS was a commonly cited payment for major illnesses of offspring.

from the empirical data; the lower limit is set by social factors extraneous to the model—specifically the customary support that poor or unlucky individuals gain through cattle loaning and grants of assistance (Peristiany 1939).

The Terminal Payoff

We envision that the men behave in a manner to maximize a long-term payoff that is obtained at time T (e.g., after 21 years of marriage to his first wife). T is used to represent terminal time period and t is used to represent earlier time periods. The payoff is a combination of the number of children and the wealth (land plus value of livestock) a man has at time T. We denote this payoff as F(w,c,k,L,T), where W(T) = w, C(T) = c, K(T) = k, and L is the (fixed) amount of land that a man owns. We evaluate the terminal payoff as follows. The total wealth (in tKS) a man has at time T is

$$\omega_T = w + 1.1L \tag{1}$$

where the term 1.1 accounts for the value in tKS of an acre of land. Wealth per child is

$$\omega_c = \omega_T / k \tag{2}$$

We assume that if a man's wealth per child is less than a critical value, w_{crit} (3 tKS), his terminal payoff is 0. We base this assumption on the fact that child mortality increases dramatically among women married to men with little land (Borgerhoff Mulder 1987b), and also on qualitative observations that a wife is much more likely to run away from her husband if he is very poor. Thus, when $\omega_c < w_{crit}$, men attain no fitness.

We use a terminal fitness function (Mangel and Clark 1988; Mangel and Ludwig 1992) that captures the conflict between a man maximizing accumulated wealth and maximizing children. To do this, we use a weighting parameter γ, which ranges between 0 and 1, and which balances these two conflicting goals. In particular, the terminal fitness function is

$$F(w,c,k,L,T) = (1-\gamma)k + 0.1\gamma k(\omega_c - w_{crit}) \tag{3}$$

when $\omega_c > w_{crit}$. In this expression, the coefficient 0.1 is chosen so that the two terms on the right hand side of equation 3 are approximately equal at intermediate values of the weighting parameter γ and wealth.

This fitness function represents the conflicting motivation to maximize children or maximize wealth per child to various degrees. For example, if $\gamma = 0$, then F(w,c,k,L,T) = k, and one would assert that the men are "maximizing children." If $\gamma = 1$, then $F(w,c,k,L,T) = 0.1k(\omega_c - w_{crit})$, and one would assert that men are "maximizing wealth per child." Values of γ between 0 and 1 produce fitness functions in which both number of children and wealth per child are important (Figure 16.2).

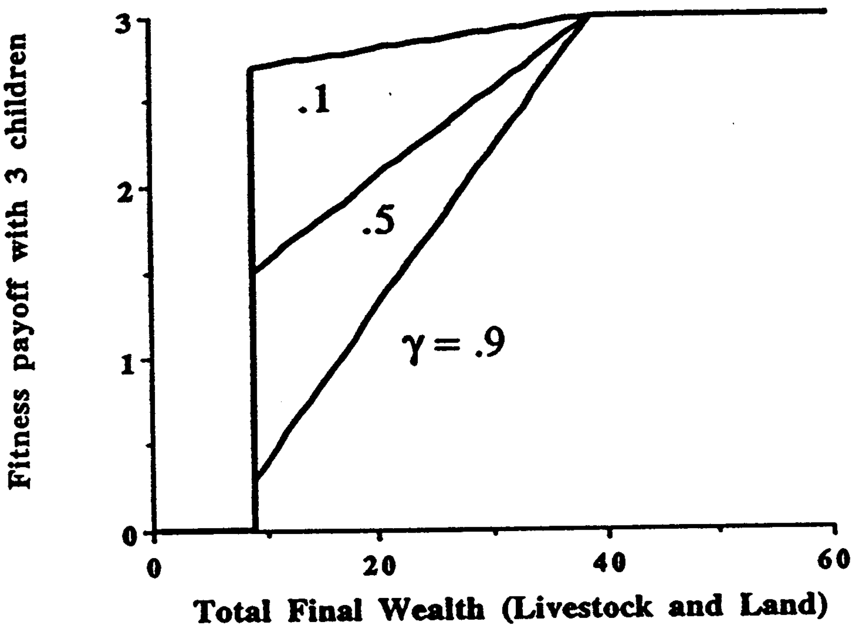

Figure 16.2. The terminal payoff to a man with three children as a function of the total value of livestock and land, for three values of the weighting parameter γ. Smaller values of the weight parameter mean that more emphasis is given to children vs. wealth; hence the slope of the terminal payoff function is shallower. When the weighting parameter is larger, wealth is more important—hence the larger slope. Beyond the level of critical wealth, maximum fitness per child is reached when wealth per child equals 13 (39 for 3 children).

Finally, we assume that if a man's wealth per child is 10 tKS or greater than the critical value, $\omega_c > 13$, his contribution to his child's success saturates. Thus, when $\omega_c > 13$, then $F(w,c,k,L,T) = k$, and the terminal payoff is his number of children.

The Dynamics of Wealth, Wives, and Children

Food, wealth, and children are produced in the following way. Each man possesses a fixed amount of land, L, of which he farms 0.5 acres and each wife can farm L_w acres. Thus the total land that the wives farm is either $L - 0.5$, when land is limited, or cL_w, when land is unlimited; we denote this is by $\min(cL_w, L - 0.5)$. Assuming that the food produced is valued at .93 tKS per acre (based on cattle market exchange rates and retrospective interviews and averaged across years), the total value of food produced by a man and his wives is

$$v_{food} = .93[.5 + \min(cL_w, L - 0.5)] \text{ tKS} \quad (4)$$

The excess land that a man may possess, which is not being farmed, is used for grazing cattle. The land available for grazing, L_g, is either 0, when all of his land is being used for farming, or $L - cL_w - 0.5$. We used an empirically derived regression linking livestock productivity to the amount of land available for grazing (a nonlinear function reflecting the fact that labor constraints limit livestock yields, and particularly milk yields) to compute the yearly value (in tKS) of land used for grazing

$$v_{grz} = \begin{cases} .5\,L_g & \text{if } L_g < 6 \\ 3 + .3(L_g - 6) & \text{if } 6 \le L_g \le 12 \\ 4.8 + .1(L_g - 12) & \text{if } L_g > 12 \end{cases} \qquad (5)$$

For simplicity, we have linked livestock productivity to the amount of land available for grazing. This is reasonable, given the strong correlations between land and livestock in all Kipsigis cohorts. The relationship in equation 5 is nonlinear because (*a*) families cannot milk more than a certain number of cows each day and (*b*) men with large farms tend to have land on rocky hillsides, which are not productive for livestock.

We assume that the values in equations 4 and 5 apply in "good years." There are two kinds of "bad years." The first, which occurs 10% of the time, is a total crop failure, so that v_{food} and v_{grz} are 0. The second, which occurs 25% of the time, is a 50% crop failure, so the values in equations 4 and 5 are reduced by 50%.

The food produced by a man and his wives is used to feed the family, and any excess food is sold. We assume that the food requirement for a child, F_k, is .132 (tKS) per year and for an adult, F_p, .2 (tKS) per year; these estimates are based on both observational data and the widely held belief among Kipsigis that one acre of maize (.93 tKS) is sufficient to feed a family of six (husband, wife, and four children) for a year and that children eat about two-thirds as much as an adult. Thus, the value of food (in tKS) required to feed the family is

$$v_{req} = .2(c + 1) + .132k \qquad (6)$$

If the total value of food produced exceeds the value of food required, the excess is sold at a price, F_s, of 1 tKS. If less food is produced than is required, we assume that food must be purchased at a price, F_b, of 1.5 tKS for each 1 tKS required. Maize (or maize-flour) purchased a few months before the next harvest can cost more than twice as much as it costs at the time of harvest; hence the scarcity factor of 1.5 is a gross estimate of the additional cost of running out of food.

If a man chooses to acquire a new wife in a given year, then

$$C(t + 1) = C(t) + 1 \qquad (7)$$

subject to the constraint that C(t+1) cannot exceed c_{max}. He also pays a cost, $cost_w$, of 4.6 tKS, which was the mean bride-wealth for marriages in the sample.

We assume that the number of children born to a man is a product of his number of wives, with each wife producing a child roughly every four years, k_a being 0.27 children per year, determined from the mean number of surviving offspring in the sample (6.8 children over a median reproductive span of 25 years). If a man currently has C(t) wives and K(t) children, then the number of children next year is

$$K(t + 1) = K(t) + .27C(t) \tag{8}$$

Fractional values of children are removed but are included in the next year's calculation of number of new children.

Children involve three additional costs, other than food requirements. First, there are basic maintenance costs, $cost_k$. These include store-purchased food, such as tea, oil, salt, and sugar, as well as clothing, soap, primary school materials, etc. We set these costs at 0.32 tKS per year per child, on the basis of costs in 1982–1983. In addition, children have minor illnesses, which incur a 0.08 tKS annual cost for the treatment. Thus, the cost of maintaining children, $cost_k$, is 0.40 tKS per year per child. Second, there is the cost of secondary education, $cost_e$, which includes fees and occasional maintenance away from home. Until recently only a few sons (usually aged 12–18) attended secondary school, at an annual cost of 1 tKS. Assuming an even sex ratio and an even age distribution, a man with k children incurs a total cost of k/6 tKS for educating his children. The third cost is that of a major illness or accident, $cost_s$. We assume that children become sick independent of each other and that each child has a 10% chance of incurring a major sickness or accident, costing 2 tKS in treatment.

Choosing Whether to Marry Additional Wives

The model spans 21 years, to match the empirical data. Each year a man decides whether or not to take an additional wife. Marriage entails economic and reproductive consequences. The husband must pay a bride-wealth, reducing his wealth. His additional wife farms some land, if it is not already completely farmed, which may generate food and wealth. She produces children who incur costs. Whether the economic costs of marrying an additional wife outweigh the reproductive benefits depend on the man's current state, and whether the terminal fitness function favors the maximization of children or wealth per child. In the appendix we present details of how the costs and benefits of taking an additional wife are determined and compared.

A Forward Iteration to Predict Behavior and Compare with Observations

To compare the marital decisions produced by the model with the actual decisions of men in the empirical database, we simulated the behavior of these men using the values of land and livestock they possessed at the beginning of their adult lives and the optimal rules generated from equation 17 (see appendix). Because of the various stochastic events in the model, we constructed thirty independent replicates of each man. All simulated men started with one wife and no children.

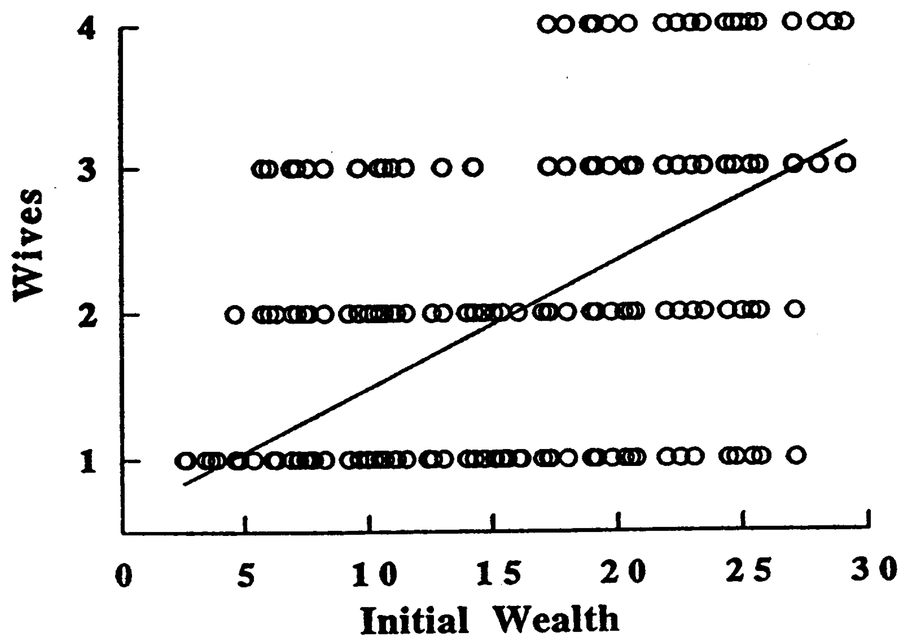

Figure 16.3. Model output. The model predicts that men with more wealth marry more wives. This is analogous to a "polygyny threshold." The regression equation for the model output is $y = 0.617 + 0.08(x)$, $r^2 = 0.5556$.

The Model Predicts Empirical Findings

Consistent with the empirical evidence the model predicts a positive relationship between a man's initial wealth and the number of his wives (Figure 16.3), when an intermediate value of γ is used, 0.7. Also consistent with empirical findings, the model predicts that men with more initial wealth marry a second wife quicker than men with less initial wealth (model output not shown). We now use the model to explore the scatter in the real data by examining the effect of γ on the accuracy of the model's predictions.

The Value of γ Affects Marriage Behavior

The effect of the weighting parameter can be seen in the marriage behavior of model men. As γ is varied, the frequency distribution of wives changes (Figure 16.4). As γ increases, the average number of wives decreases and fewer men are polygynous. Thus there is a "polygyny threshold" in the weighting parameter γ as well as in the initial capital. This prediction parallels that of Beauchamp (1994; see also Mace, this volume). Beauchamp's use of concave and convex functions to determine how parental expenditure affects offspring quality is somewhat similar to our use of the gamma weighting parameter. He found that, for a given wealth category, parents have fewer children in competitive environments (where most of

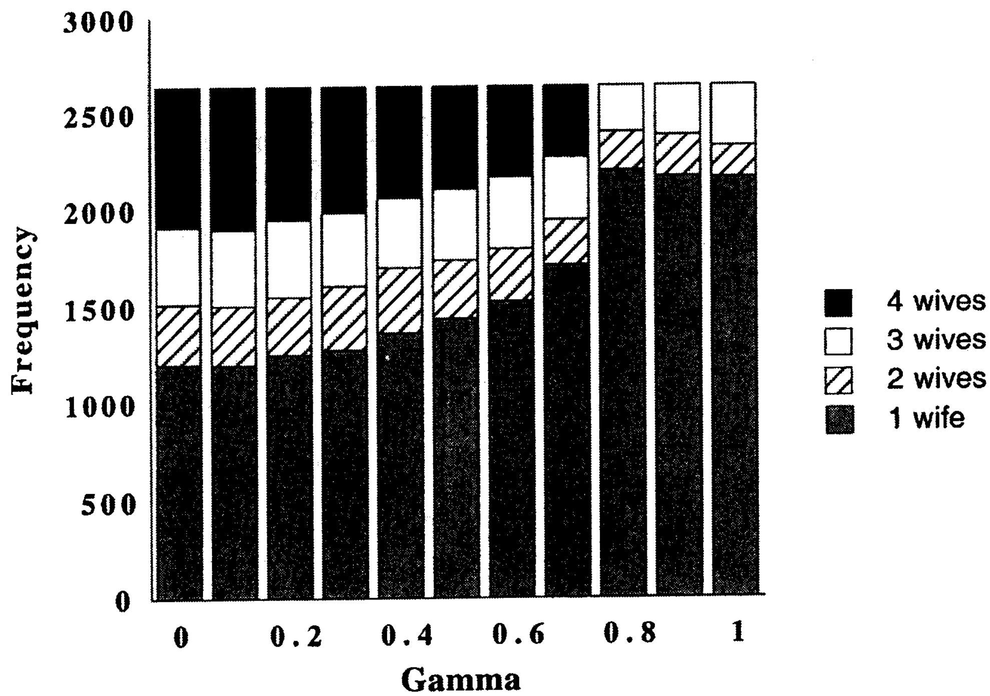

Figure 16.4. The marriage behavior of simulated men varies with the weighting parameter. The frequency distribution shows that when γ is large more men have only one wife and no men have four wives.

the impact of parental effort on offspring success occurs in the higher range of allocation) than in benign environments (where most of the impact on offspring success resulting from parental effort occurs in the lower range of allocation). Similarly our model shows that where men want to preserve resources over their reproductive career (i.e., where gamma is weighted toward 1), they less often marry a second wife.

Observed Marriage Behavior Allows Inference about γ

We compare the behavior of men using fitness functions with different γ weightings with their actual behavior to infer which value of γ best matches the actual "motivations" of Kipsigis men. For each man in the data set the number of wives at period 7, 14, and 21, which we denote by $C_{j,7}$, $C_{j,14}$, and $C_{j,21}$, is recorded. Some of these data are missing due to sample truncation. Similarly, the number of wives of the kth simulated man, $C_{jk}(7|\gamma)$, $C_{jk}(14|\gamma)$, and $C_{jk}(21|\gamma)$, who had the same initial conditions as the jth man in the data set, depends on the value of the weighting parameter used in the fitness function. A simple way to compare the empirical data and the simulation data is the sum of squared deviations of number of wives at years 7, 14, and 21, which depends on the weighting parameter:

$$SSQ(\gamma) = \Sigma_{jk}\{ [C_{j,7} - C_{jk}(7|\gamma)]^2 + [C_{j,14} - C_{jk}(14|\gamma)]^2 + [C_{j,21} - C_{jk}(21|\gamma)]^2\} \quad (9)$$

This is a measure of the variance between the predictions of the model and the empirical data.

We computed SSQ(γ) for values of γ between and including 0 and 1 (Figure 16.5). A number of points emerge from this computation. First, men with high values of γ (0.7 to 0.9) in their fitness functions behave more similarily to the actual behavior of Kipsigis men than men with lower γ. Thus, it appears that Kipsigis men are maximizing wealth per child rather than number of children. Second, the values of γ that provide the minimum value of SSQ(γ) allow us to infer how men are weighting wealth and children in their marriage decisions. Third, although not shown in Figure 16.5, SSQ(γ) is completely flat over the range of γ shown in year 7. It is only in years 14 and 21 that differences emerge, indicating the importance of long-term and/or retrospective studies.

Sensitivity analyses (not presented here) on a subsample of men show that the error of the predicted relative to the observed results (sum of squares) is always lower at high γ than low γ. The shape of the distribution in Figure 16.5 is largely unchanged when parameters for the following variables were modified: amount of land wife can farm, value of food produced per acre, probability of a total food production failure, costs of maintaining children, costs and probability of a major illness, and level at which inherited wealth maximizes a child's fitness.

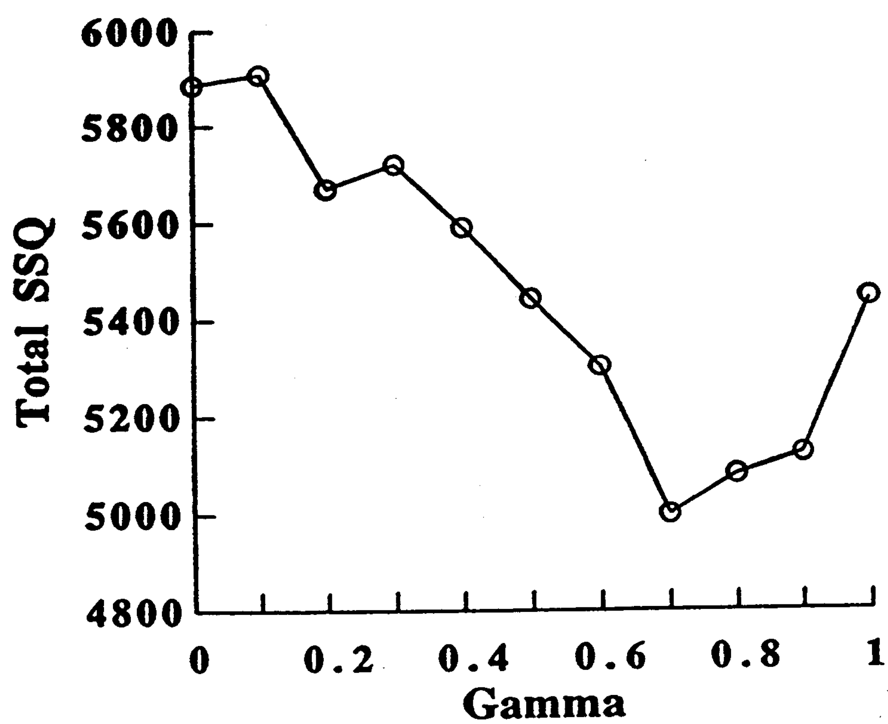

Figure 16.5. The total sum of squares SSQ(γ) computed by comparing the predicted and observed marriage behavior of men. Higher levels of γ produce reproductive decisions that more closely match the actual behavior of the men. The actual values of γ used are shown by circles and the line is interpolated for ease of viewing.

DISCUSSION

For two reasons our results should be taken more as an illustration of the inferences that can be drawn from the method, rather than a conclusion about the precise value of the weighting parameter that the men are using. First, we have not conducted a full sensitivity analysis of the model; second, data from different cohorts have been combined. Regarding this latter point, we stress that our results are not a consequence of using partially censored data since at year 7 the behavior of real men is explained equally well (or poorly) by models predicated on different gamma values; in other words, SSQ(γ) is completely flat (see above). The results, preliminary as they are, nevertheless raise several issues for discussion.

Kipsigis Men's Concern with Wealth

In one sense the finding that Kipsigis men are concerned with the accumulation of wealth over their lifespan is easy to explain. Kipsigis practice patrilineal inheritance of the family estate—primarily of livestock and land. A father's land and livestock are divided among his sons only at his death (until then they have only rights of use). For this reason we did not incorporate a "cost of fledging" in the dynamic state model. In addition, a father needs to preserve resources for the bride-wealth payments of his sons (should they outnumber his daughters). As such Kipsigis men's strategies are likely to be motivated by materialistic concerns. The principal finding of this paper is therefore not surprising. Further, it is in line with conventional qualitative arguments, that pastoralists try to keep their fertility "in balance" with resources (Stenning 1959), and that agriculturalists adopt family-building strategies aimed at providing heirs with adequate estates (Goody 1976; Skinner 1997). Note that while this finding is loosely consistent with the quantity/quality tradeoff hypothesis it offers no information on long-term fitness consequences. The present study is new insofar as it provides quantitative support for material motivations that reduce men's fertility (in this context it says nothing about women's motivations, whose fertility preferences often diverge significantly from those of men).

Before turning to the broader theoretical implications of this study for demographic transition, we need some further discussion of the gamma function (γ). Having γ in the fitness function allows us to vary the effect of a man's wealth on the success of his offspring. More specifically, as γ increases, a man's wealth has a greater impact on the success of his offspring, and the slope of that impact increases (Figure 16.2). The base model used for these analyses specifies that the effects of inherited wealth on sons saturate at 13 tKS (10tKS above the 3 tKS threshold, below which reproduction is unsuccessful), which, assuming a 50:50 sex ratio, is equivalent to capital goods of 26 tKS. Two considerations give us confidence in the appropriateness of this function. First, the empirical data show very few cases where men inherit capital goods of greater value than 26 tKS—in fact the range of inheritances closely matches those of men in the empirical data base;

thus our parameter is empirically valid. Second, sensitivity analyses show that varying the saturating level between 5 tKS and 15 tKS above the threshold has no substantial effect on the pattern shown in Figure 16.5. This gamma function therefore allows us to differentiate strategies aimed at the maximization of reasonable amounts of wealth per child (for the Kipsigis cohorts studied) from strategies geared to the maximization of fertility per se. To test hypotheses about how the costs of children affect fertility (discussed below), we need to vary the costs of children (c_m, c_e, g1) incurred prior to their father's death, as well as the value at which inherited wealth saturates. To test whether individuals select fertility levels that maximize the production of grandoffspring (no studies to date have shown that intermediate fertility levels are optimal; see above), empirical analyses of second-generation effects are required.

In short, the results of this initial paper speak more directly to the issue of reproductive motivation than fitness optimization. We suggest that the method can usefully be applied across a range of different types of human societies (see below).

Implications for Explanations of Demographic Transition

Two key features of the demographic transition were identified above: across societies there is an overall decline in completed fertility despite favorable material conditions (wealth), and within societies there is an erosion of positive correlations between wealth and fertility. What light do the present findings shed on these puzzling phenomena?

With regard to the first, Rogers (1990,1995) tried to determine the precise conditions (social, environmental, or institutional) under which material motivations might be selected over pure reproductive motivations. He used simulation models to see whether in an environment in which wealth is heritable there are circumstances in which long-term fitness is better predicted by an individual's wealth than by the number of his/her children. If such environments exist (and were common in our history) there would be some evolutionary explanation for the apparent predominance of material over reproductive motivations in post–demographic transition societies. Unfortunately, in the most recent and appropriate simulation work, reproductive and material motivations are indistinguishable (Rogers 1995: fig. 5.7).

In this context the present empirically based study becomes interesting. Among Kipsigis men there is a positive correlation between wealth and number of children (here shown only as number of wives, but see Borgerhoff Mulder 1987a). In fact, the Kipsigis case (an example of a highly pronatal community) is commonly cited as evidence that men are concerned with maximizing their fitness. Yet we can now see from the present work that materialist motivations may indeed be implicated, even where wealth-fertility correlations are strong, especially in competitive environments. More generally, as Symons (1987) cautioned, inferring evolved psychological mechanisms from correlational findings is fraught with complexity (see also Irons 1979).

To the extent that materialist motivation is common in other pre-transition populations, it becomes less difficult to explain the demographic transition. Parents in post-transition societies are merely at one end of a continuum with respect to their need for investing material resources (and/or time) into the competitive chances of offspring. Thus studies of pre–demographic transition societies can shed light on the underlying processes entailed in demographic change, a position demographers increasingly appreciate (e.g., Wilson and Airey 1999). Indeed Kaplan and colleagues argue for a general (pre– and post–demographic transition) human psychology designed to maximize the sum of incomes of all descendants produced (Kaplan et al. 1995:131) and Kaplan (1996) points to how investment in human capital in competitive market economies might underlie fertility reductions.

The present study provides empirical evidence for this position by showing that materialist motivations have been around for a long time (certainly since humans began accumulating resources to be transmitted to their offspring), even where tight correlations between wealth and reproductive success have made us think otherwise. How these motivations played out in historical societies, for example, how they differ between societies with different kinds of heritable capital (such as land and livestock based economies), nevertheless remains a major puzzle. We might hypothesize that the proximate cues that hunter-gatherer parents use to determine optimal levels of investment can account for fertility variations (e.g., Kaplan 1996), but we still need to understand how these proximal cues get translated into wealth conservation in land-limited, pastoral, and other kinds of societies. Only then can we grasp how such proximate mechanisms might generate the deviations from fertility-maximizing behavior that we see in post-transition societies. Anthropology is well placed to offer a window onto this diversity (e.g., Low 1994), in combination with theory developed in economics and evolutionary biology.

Finally, we take a brief look at why wealth and fertility become disassociated, the second enigma posed by demographic transition. Why would the wealthy ever produce fewer children than the poor? Here several studies are closing in on an explanation (Borgerhoff Mulder 1998b). Kaplan (1996) argues that what drives wealthy parents to have fewer children than poorer parents is the fact that the time, resources, or skills wealthy parents transmit to their offspring are intrinsically more valuable than those transmitted by parents of lesser means, in part because of the cumulative nature of learning. Under such circumstances the opportunity costs of producing an additional child among the rich are greater than they are among the poor, driving negative or curvilinear relationships between parental wealth and fertility. Mace (this volume) models a similar nonlinear process, whereby different strata in society optimize fitness with different fertility—specifically, the wealthy do so with a lower fertility than the poor. Similarly Rogers, who was until recently unable to simulate an environment in which optimal fertility decreases with wealth (Rogers 1995), now reports that in environments in which inheritance greatly boosts an individual's ability to earn income (each dollar inherited generates on average 2 dollars of earned wealth) wealthy parents at equilibrium produce fewer children than poorer parents (Alan Rogers, University of Utah, unpublished results). New Kipsigis evidence (unpublished data), showing that in recent cohorts men who inherit more capital (land and livestock) become wealthy at a faster rate than those who inherit less capital (because of increased market access in recent years), suggests that such potentially nonlinear responses to investing wealth in children are emerging among Kipsigis, and may precipitate fertility transition. Once low fertility arises among the richest families, it can spread to other social classes even if the appropriate conditions do not exist, by the processes of indirect bias posited in cultural evolution models (Boyd and Richerson 1985). In short, a hybrid theory of demographic transition built on evolutionary psychology, behavioral ecology, and cultural inheritance theory may be materializing (Borgerhoff Mulder 1998b).

SUMMARY

1. The evolutionary rationale for the demographic transition remains elusive, since to date empirical analyses have failed to identify fitness benefits contingent on fertility reduction.
2. We use dynamic state variable models to predict reproductive behavior, specifically a man's decision to take another wife.
3. We build a model of the conditions for production and reproduction in a typical pre–demographic transition agropastoral society. While the parameters are based on a specific group (Kenyan Kipsigis), the model is general enough to apply to many agricultural/pastoral communities.
4. We assume that an individual's lifetime fitness is a combination of accumulated wealth and total reproduction. Weighting these in different ways, we use simulations to determine the optimal marital decisions contingent on what combination of children or wealth per child is being maximized.
5. A comparison of the simulation output with empirical data shows that a decision rule weighted toward "wealth maximization" (a combined function of maximizing children and wealth per child) best predicts the marital careers of men.
6. The concern for wealth accumulation among Kipsigis men is not surprising given their capital-based economy, but the finding is notable for other reasons. First, it provides quantitative support for strong material motivations in a society where wealth-fertility correlations are high. Second, it demonstrates material motivations in a case commonly cited as providing evidence for reproductive motivation.

7. We propose this as a useful method in the study of worldwide fertility variation and decline, insofar as it can identify motivational structures underlying reproductive decision-making and can be used to test these structures against clearly stated alternatives.

ACKNOWLEDGMENT

Kipsigis research was funded by the National Geographic Society and the University of California at Davis (MBM). The work of BTL and MM was partially supported by NSF grants (to MM) and by the Center for Population Biology, University of California at Davis. We thank Sarah Hrdy, Debra Judge, Hilly Kaplan, Eric Smith, Mary Towner, and Bruce Winterhalder for comments and discussion.

APPENDIX

CALCULATION OF COSTS AND BENEFITS OF ADDITIONAL MARRIAGES

For years prior to the terminal payoff, we define F(w,c,k,L,t) as the maximum expected terminal payoff, given that W(t) = w, C(t) = c, K(t) = k, and land is L. The expectation is calculated over the deterministic and stochastic changes in wealth that occur between t and T. The maximum expected value is determined by choosing the marriage profile to maximize the expected terminal payoff.

We can describe the expected fitness and thereby predict the conditions under which a man will acquire a new wife. Imagine a man whose livestock currently has value w, who has c wives and k children.

In a good year, which occurs with a probability 0.65, if the total value of food produced by the man and his wives exceeds their needs, and s of his children become sick with a major illness, livestock value next year will be

$$w'(w,c,k,L,s) = w + (v_{food} - v_{req}) + v_{grz} - k\ cost_k - (k/6)\ cost_e - s\ cost_s \tag{10}$$

On the other hand, if the value of food produced is less than the food requirements, the livestock value next year will be

$$w'(w,c,k,L,s) = w + 1.5(v_{food} - v_{req}) + v_{grz} - k\ cost_k - (k/6)\ cost_e - s\ cost_s \tag{11}$$

In years in which there is a 50% crop failure, reasoning similar to that shown in equations 10 and 11 apply, except that the value of food produced and the value of grazing are reduced by 50%. Thus, the analogues of these equations are

$$w''(w,c,k,L,s) = w + (.5v_{food} - v_{req}) + .5v_{grz} - k\ cost_k - (k/6)\ cost_e - s\ cost_s \tag{12}$$

or

$$w''(w,c,k,L,s) = w + 1.5(.5v_{food} - v_{req}) + .5v_{grz} - k\ cost_k - (k/6)\ cost_e - s\ cost_s \quad (13)$$

Finally, in years in which there is a complete crop failure, the value of livestock next year will be

$$w'''(w,c,k,L,s) = w - 1.5v_{req} - k\ cost_k - k/6\ cost_e - s\ cost_s \quad (14)$$

Equations 10–14 are conditioned on the number of sick children.

We can now compute the fitness value ($V_{no\ marry}$) of a man who chooses to not acquire a wife this year by averaging over the number of sick children and the chance of crop failure:

$$V_{no\ marry}(w,c,k,L,t) = E_s\{.65F[w'(w,c,k,L,s), c, k + .27c, L, t + 1] + .25F[w''(w,c,k,L,s), c, k + .27c, L, t + 1] + .1F[w.'''(w,c,k,L,s), c, k + .27c, L, t + 1]\} \quad (15)$$

In this equation, E_s denotes the expectation over the number of sick children (binomial with parameters k and 0.1).

Alternatively, a man who chooses to acquire a wife pays a cost (4.6 tKS, the mean bride-wealth for marriages in the sample), which is subtracted from his wealth. We assume that this occurs before crop failure is known and before it is known how many children will be sick in this year. Thus, the cost of the wife is subtracted from each term in equation 15, and the fitness value of marrying a wife is

$$V_{marry}(w,c,k,L,t) = E_s\{.65F[w'(w,c,k,L,s) - 4.6, c, k + .27c, L, t + 1] + .25F[w''(w,c,k,L,s) - 4.6, c, k + .27c, L, t + 1] + .1F[w'''(w,c,k,L,s) - 4.6, c, k + .27c, L, t + 1]\} \quad (16)$$

The optimal pattern of marriage is that which maximizes the expected payoff, hence

$$F(w,c,k,L,t) = \max[V_{no\ marry}(w,c,k,L,t), V_{marry}(w,c,k,L,t)] \quad (17)$$

Equation 17 is solved backward, starting at $t = T - 1$, and generates the expected payoff for every combination of time and states. It also generates the optimal behavior (to take a wife or not) for every time and state (Figure 16.5). When solving it, we used linear interpolation on wealth and number of children to deal with non-integer values of the state variables (Mangel and Clark 1988).

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