# INVESTMENT IN SISTER'S CHILDREN AS BEHAVIOR TOWARDS RISK

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*A risk-averse man will invest in his sister's children if he cares about his genetic relatedness to future generations and if he is unsure about being the father of his wife's children. The model in this paper is an advance over the earlier expected-relatedness models in that it permits mixed investment in both sister's and wife's children and also permits investment in sister's children at higher levels of paternity probability. Estimates from ordered logits suggest that paternity probability is an important determinant of investment in sister's children and that some investment in sister's children occurs even at high levels of paternity probability.*

## I. INTRODUCTION

A man in some societies invests much in the children of his sister. An explanation has been suggested by biologist Richard Alexander and examined by anthropologist Jeffrey Kurland and others.[1] They suggest that if a man has serious doubts about being the biological father of his wife's children, he may wish to invest instead in his sister's children with whom he is sure to share some genes. Since the Alexander-Kurland model forms the foundation for our work, it will be useful to present it in greater detail.

Define the "relatedness" of two persons (say, Dick and Jane) as the fraction of genes they have in common. Dick and Jane have a relatedness of ½ if they are full siblings or a relatedness of ¼ if they are half siblings.[2]

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1. We will call the model the "Alexander-Kurland model" or, when referring to the particulars of Kurland's presentation, the "Kurland model." A fairer, but prohibitively awkward, label might be the "Alexander-Irons-Flinn-Kurland-Greene model." Alexander's suggestions occur in [1974, 373; 1977, 310 and 319-324]. For full references on the rest, see the bibliography. The basic idea of the Kurland model has been independently suggested in *The Selfish Gene* [1976, 115], a controversial bestseller by Richard Dawkins. Werren and Pulliam [1981] defend a somewhat related model that emphasizes cultural similarity rather than genetic similarity.

2. Assigning these fixed values of relatedness for sibs is not entirely accurate, so some explanation is in order. Each parent has two (often identical) alleles of each gene, only one of which is passed on to a child. Thus, with very low probability, two children of the same parents can have all of their alleles in common or none of their alleles in common. But as the number of genes increases, the law of large numbers implies that the vast majority of sibs will be extremely close to the relatedness values assigned here.



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The relatedness of Dick to one of Jane's children is 1/4 if he and Jane shared the same father. If Dick and Jane did not share the same father then the relatedness of Dick to one of Jane's children would be 1/8. The relatedness of Dick to one of his wife's children is 1/2 if he in fact is the father. It is zero if he is not.

Suppose that everyone in a society has the same probability that he was fathered by his mother's husband. Call this probability the paternity probability and denote it by *p*. The lowest paternity probability among well-documented societies is probably that of the matrilineal Nayar group of castes in the Central Kerala region of India (see Gough [1961, 298–384]). Nayar women in Central Kerala may have had as many as twelve "visiting husbands" at any one time; each husband stayed with his wife on nights informally agreed upon by the woman's regular husbands. A man had more than one "wife" but lived in the household of his mother and sisters. Men ordinarily invested nothing beyond ceremonial gifts in their wives' children and instead devoted their full resources to the support of the children of their sisters. The residence and investment patterns of Nayar men may be related to their traditional occupation as soldiers. The potential connection between the military profession of the male Nayars (entailing long absences from the home) and their paternity probability was suggested early in the literature. (For references see De Moubray [1931, 46–47]).

Although the Nayar may be an extreme case, the best available evidence suggests that they are not unique in having a *p* much below what we would expect to observe in developed nations today. For example, in some matrilineal societies such as the Dobu, the Truk and the Trobriand Islanders, adultery was known to have been common (Fortune [1963, 7], Malinowski [1932, 98], Schneider [1961, 213]). In others, such as the Ashanti, the separate residences of husbands and wives increased the cost of monitoring the wife's behavior and hence increased the likelihood of adultery. Among the Truk of Micronesia sisters were free to have sexual intercourse with each other's husbands (even though the husbands were not blood relatives) (see Schneider [1961, 230]).

In societies with high divorce rates, such as the Navaho and Truk, a woman may have had children living in her household who were fathered by different men, even if she had never committed adultery (Aberle [1961, 129], Schneider [1961, 213]). If a man could invest solely in those children in his wife's household whom he had fathered, then the high divorce rates would not matter. But some forms of investment, such as maintenance of his wife's dwelling, were "household goods" that benefitted all members of the household. So to the extent that the investment by a man in his wife's household was not easily divisible between the various children, a man would face a low "effective paternity probability." Note that this would occur even if he knew with complete certainty which of his wife's children was his (Kurland [1979, 161].

The Nayar, the Dobu, the Trobriand Islanders, the Ashanti and the Navaho are among the societies where one would expect to find a low paternity probability. What is less clear is whether the high divorce rate, separate residences and other practices connected with a low paternity probability are the results of a society's mode of subsistence or are the results of cultural values and institutions. The paternity probability is assumed to be exogenous in the Alexander-Kurland model, as well as in ours; this assumption would be plausible if environmentally constrained modes of subsistence affect the costs of monitoring the wife's behavior. In some societies, for example, the mode of subsistence separates the husband from the wife (e.g., soldiering for the Nayar or overseas trade for the Comoro Islanders) with the result that the costs of monitoring wives is high and hence, ceteris paribus, the paternity probability is low (Gough [1961c, 312], Ottenheimer and Ottenheimer [1979, 328–35]).

The exogeneity of the paternity probability would also be more plausible to the extent that income differences lead to differences in paternity probability. One example comes from the Nayar: when aristocrats were able to marry wives who could give them credible assurance of paternity, the men often invested heavily in their wives' children by providing them with military or political positions (Gough [1961, 364 and 379]).

Apart from the exogeneity of the paternity probability, the major assumption of the Alexander-Kurland model is that a man maximizes his expected relatedness to future generations. The assumption represents one way to formalize the view of Becker [1981, 29] and others that people receive utility from the well-being of their *own* children.

The expected relatedness of a man to any one of his wife's children is given by $p/2$. Let $\pi$ be the probability that a brother and sister (say Dick and Jane) shared the same father. Then the expected relatedness of Dick to any of Jane's children ($r$) is equal to the expression $(1+\pi)/8$. Several assumptions about the relationship between $\pi$ and $p$ are possible. One is that if Dick and Jane share the same father then their common father must be their mother's husband; i.e., Dick and Jane could not have been fathered by the same extramarital lover.[3] Kurland makes this assumption when he sets $\pi = p^2$. An alternative assumption is that a woman has only one sexual partner other than her husband. In this case $\pi = 1 - 2p + 2p^2$. Alexander [1977, 321] assumes that $p = \pi$. He does not defend his assumption except to say that the relationship between $p$ and $\pi$ must be direct (so if the paternity probability

3. We recognize that the phrase "extramarital lover" has ethnocentric connotations that are not necessarily accurate. For example, with the Nayar the relatedness to a sister would depend more on how many "husbands" the man's mother had been simultaneously married to than on the number of her extramarital lovers. Applying the labels "husband" and "marriage" to the relationships in such a society is also misleading because in the West those terms are usually associated with a commitment to sexual exclusivity that was absent from the Nayar institutions.

goes down, then the probability that siblings (sibs) have the same father must also go down).

Yet another possible assumption is that Dick and Jane know whether or not they have the same father. Here $\pi = 1$ or $\pi = 0$ depending on the case. At the time that an investment decision must be made, Dick may be more likely to know his relatedness to Jane than to his wife's children, since he has had his whole childhood to observe Jane's physical appearance and his mother's behavior. For his wife's children he must often make investment decisions before he has had much time to judge their physical appearance or his wife's behavior. We also would expect that certainty about relatedness to sisters is more likely in societies where the physical appearance of males is heterogeneous.

If a man is maximizing his expected relatedness to future generations, then a critical value of $p$ exists above which he will invest solely in wife's children and below which he will invest solely in sister's children. The decision rule can thus be stated as follows.

(A) Invest in wife's children if $p >$ the critical value.
(B) Invest in sister's children if $p <$ the critical value.

To obtain the critical value, set the expected relatedness of a sister's child equal to the expected relatedness of a wife's child and then solve for $p$. The critical value turns out to be .268 under Kurland's [1979] assumption and .333 under Alexander's [1977] assumption. The other assumptions yield similar results.

One problem for the Alexander-Kurland model is immediately apparent: a critical paternity probability in the range of .27–.33 appears to be far below the credible level for any significant number of societies, even the handful of polyandrous ones. Another problem for this model, and all others where men maximize expected relatedness, is that they imply that men specialize completely in either sister's children or wife's children, contrary to what is actually the case.

Although the model we will present avoids these difficulties, it shares with the expected relatedness models an emphasis on the importance of genetic relatedness in explaining human behavior. We acknowledge, however, the potential restrictiveness of a biological framework that suggests that relatedness to future generations is the main commodity produced by investment in children. Some observed behavior, such as the adoption of unrelated children, may be hard to explain within such a framework (but see Silk [1980]). But the restrictiveness of the framework is outweighed by its simplicity and by its power in explaining the stylized facts and in yielding new implications that are, at least in principle, testable (see Becker [1976, 282–94], Hirshleifer [1977], Frech [1978]).

## II. THE MODEL

Only men are included in the model as maximizing agents. Analytic simplicity is one justification for not explicitly including women. More importantly, the focus is on men because the decision problem being studied is presumably trivial for women but not so trivial for men, viz., the choice of which children should be the objects of investment. Women have much better information on maternity than men do on paternity. Hence women who have borne children will invest in those children rather than children borne by other women. For men, the uncertainty of paternity makes the decision problem more complex.[4]

In setting up a man's maximization problem, it is assumed that he has only one wife and one sister. The utility that a man receives from $m$ sister's children and from having fathered $i$ of wife's children is given by

$$U(mr + i/2),$$

where $r$ is relatedness to sister's children (either $r = 1/4$ when brother and sister are full sibs or $r = 1/8$ when half sibs).[5] The quantity $mr + i/2$ is a man's relatedness to the next generation; this quantity is called $R$. It is assumed that $dU/dR > 0$ and that $d^2U/dR^2 < 0$, i.e., the man is risk averse. Although sociobiologists have found that risk averse behavior increases genetic fitness (Gillespie [1977], and Rubenstein [1982]), few applications of the finding have been made. In particular no one has yet noted the importance of risk aversion in explaining differences in human kinship systems.

If a man's wife has $k$ children, the probability that he is the father of $i$ of them is given by the following binomial formula:

$$P_i(k) = \binom{k}{i} p^i (1-p)^{k-i}.$$

The expected utility function is compactly expressed as

$$V(m,k,p,\pi) = (\pi)\sum_{i=0}^{k} P_i(k)U(m/4 + i/2) + (1 - \pi)\sum_{i=0}^{k} P_i(k)U(m/8 + i/2).$$

Define $n_w$ as the number of wife's children, $n_s$ as the number of sister's children and $n$ as the total number of children invested in by the agent. Likewise define $a_w$ as the number of wife's children invested in by her brother, and $a_s$ as the number of sister's children invested in by her husband. A man takes $a_w$ and $a_s$ as given. His problem then is to maximize

4. Hartung [1985] has explored the possibility of allowing a more active role for women.

5. Perhaps we should emphasize that a man receives utility, not simply from the *birth* of a genetically related child, but from the survival of a genetically related child to adulthood (where "adulthood" begins when the child is old enough to reproduce).

$$\max_{n_w, n_s} V(n_w + a_w, n_s + a_s, p, \pi) \qquad (1)$$

$$\text{subject to } n_w + n_s = n,\ n_w \geq 0,\ n_s \geq 0$$

For the reader's convenience, a list of variable definitions has been included as Table VII at the end of the paper. The solution to (1) is the number of wife's children that a man will support as a function of $n, p, \pi, a_W$, and $a_S$. Let us call this function $n_W = f(n, p, \pi, a_W, a_S)$.

Recall that two difficulties of the Alexander-Kurland model are the low paternity probability required for positive investment in sister's children, and the complete specialization of investment in either wife's or sister's children. The solution to the maximization problem as formalized in (1) avoids these difficulties. A special case useful for illustrative purposes is the utility function $U(R) = -\exp(-\alpha R)$. The function exhibits constant absolute risk aversion with a coefficient of risk aversion of $\alpha$. With this utility function it turns out that a man will invest exclusively in wife's or sister's children, according to whether $p$ is greater or less than some critical value.

In order to compare the absolute risk aversion model with the expected relatedness model, the critical paternity probabilities are calculated for both models under four different assumptions about $\pi$ (the probability that a brother and sister share the same father). In order of increasing values of $\pi$, the assumptions are that the man has certainty that the sister is a half-sister ($\pi = 0$), uncertainty about the sister where the mother never had the same extramarital lover more than once ($\pi = p^2$), uncertainty about the sister where the mother had only one extramarital lover ($\pi = 1 - 2p + 2p^2$), and certainty that the sister is a full sister ($\pi = 1$). In the Kurland [1979] version of the expected relatedness model, the second assumption is made, resulting in a critical paternity probability of .268.

In Table I critical paternity probabilities are reported for both the constant absolute risk aversion model (the top numbers in the table) and the expected relatedness model (the numbers in parentheses in the table) at selected values of $\alpha$ for each of the four assumptions about $\pi$. Note first that in the risk aversion model men will invest in sister's children at higher paternity probabilities than in the expected relatedness model. Note also that the difference between the critical values for the two models increases as risk aversion increases. The reason is that in our model men will invest in sister's children not only for expected relatedness but also for the safety sister's children provide.

The function with constant absolute risk aversion that was used for illustration is an atypical solution to the maximization problem summarized in (1) since, like the Alexander-Kurland account, the function implies that a man will necessarily specialize in either wife's or sister's children. For more

**TABLE I**
Comparison of Critical Paternity Probabilities*
With and Without Risk Aversion+

| $\alpha$ (Coefficient of risk aversion) | (1) $\pi = 0$ (Certain that sister is half sister) | (2) $\pi = p^2$ (Uncertain about sister where mother had multiple lovers) | (3) $\pi = 1-2p+2p^2$ (Uncertain about sister where mother had only one lover) | (4) $\pi = 1$ (Certain that sister is full sister) |
|---|---|---|---|---|
| 1 | .300<br>(.250) | .335<br>(.268) | .432<br>(.382) | .562<br>(.500) |
| 2 | .350<br>(.250) | .392<br>(.268) | .446<br>(.382) | .622<br>(.500) |
| 3 | .403<br>(.250) | .460<br>(.268) | .542<br>(.382) | .679<br>(.500) |
| 4 | .455<br>(.250) | .534<br>(.268) | .598<br>(.382) | .731<br>(.500) |
| 5 | .506<br>(.250) | .606<br>(.268) | .655<br>(.382) | .777<br>(.500) |
| 10 | .718<br>(.250) | .861<br>(.268) | .881<br>(.382) | .924<br>(.500) |

*When the paternity probability is above the critical level, the husband invests in his wife's children. When the paternity probability is below the critical level, the husband invests in his sister's children.

+The top numbers are critical paternity probabilities for the constant absolute risk aversion model under various assumptions about the coefficient of risk aversion and the probability that a sister is a full sister. The utility function is assumed to be $U = -\exp(-\alpha R)$. The bottom numbers (in parentheses) are critical paternity probabilities for the model in which the husband maximizes expected relatedness (so the coefficient of risk aversion does not affect his decision).

typical solutions to (1) there is usually a range of paternity probabilities over which positive investment in both sister's and wife's children takes place if $n \geq 2$. This is illustrated in Table II. In the table the desired level of investment in wife's and sister's children is shown for each of the previously discussed assumptions about the man's relatedness to his sister ($\pi$) and for various values of the paternity probability ($p$). The man's utility is assumed to be given by the function $U(R) = -R^{-3}$ (a constant level of relative risk aversion of four). In all calculations we have arbitrarily set $a_W = 1$, $a_S = 1$ and $n = 3$. Positive investment in both wife's and sister's children occurs when the paternity probability falls in the range from .65 through .8 for the first three assumptions about $\pi$, and from .7 through .8 for the fourth assumption about $\pi$. Table II also illustrates that as the paternity prob-

**TABLE II**
Investment in Wife's and Sister's Children under Constant Relative Risk Aversion

| $p$ (Paternity probability) | (1) $\pi = 0$ (Certain that sister is half sister) | (2) $\pi = p^2$ (Uncertain about sister where mother had multiple lovers) | (3) $\pi = 1-2p+2p^2$ (Uncertain about sister where mother had only one lover) | (4) $\pi = 1$ (Certain that sister is full sister) |
|---|---|---|---|---|
| | $n_w, n_s$ | $n_w, n_s$ | $n_w, n_s$ | $n_w, n_s$ |
| ↑ | ↑ | ↑ | ↑ | ↑ |
| 0.6 | 0,3 | 0,3 | 0,3 | 0,3 |
| 0.625 | 1,2 | 1,2 | 1,2 | " |
| 0.65 | " | " | " | " |
| 0.675 | " | " | " | " |
| 0.7 | 2,1 | 2,1 | " | 1,2 |
| 0.725 | " | " | 2,1 | " |
| 0.75 | " | " | " | 2,1 |
| 0.775 | " | " | " | " |
| 0.8 | " | " | " | " |
| 0.825 | 3,0 | 3,0 | 3,0 | 3,0 |
| ↓ | ↓ | ↓ | ↓ | ↓ |

*Constant relative risk aversion implies decreasing absolute risk aversion. The first number of each pair is the number of wife's children the husband invests in. The second number is the number of sister's children the husband invests in. It is assumed here that the sister's husband invests in one of his wife's children (i.e., $a_s = 1$) and that the wife's brother invests in one of his sister's children (i.e., $a_w = 1$). The utility function is assumed to take the form $U = -R^{-3}$ (which implies a constant level of relative risk aversion of 4).

ability increases, the number of wife's children invested in increases. The ratio of investment in wife's children to total investment in children therefore also increases since the higher the paternity probability, the more attractive an investment wife's children become relative to sister's children.

This paper argues that the motive for investing in sister's children, even when the expected relatedness of such children is less than the expected relatedness of wife's children, is the beneficial risk reduction that such investments provide. Sister's children guarantee a certain (albeit low) level of genetic relatedness. An alternative way to achieve risk reduction is to invest in a large number of wife's children. This is because the relatedness of the wife's $i^{th}$ child to her husband is independent of the husband's relatedness to any other child. It would be an unlucky man indeed who invests in a large number of his wife's children, and none turn out to be his. Consequently the larger the number of children invested in ($n$), the relatively more attractive investing in wife's children should be. What the effect of $n$ is, however, on the desired number of wife's children and on the ratio of investment in wife's children to total investment in children, depends on attitudes toward risk.

We believe that under the reasonable assumption of decreasing absolute risk aversion, the ratio of investment in wife's children to total investment in children ($\theta$) is a nondecreasing function of $n$. This important implication is not obvious and is in principle testable. The implication has been proven (in an appendix available from the authors) for the case where the man is either certain that his sister is a full sister or else certain that his sister is a half sister. As illustrated with a particular functional form in Table III, the claim is also expected to be true for the cases considered here in which a man is uncertain about his relatedness to his sister. In Table III we illustrate the implication using the same constant relative risk aversion utility function that was assumed for the illustration in Table II. As an aid in reading the table, note (for example) that with a $p$ of .825, as the total investment in children increases from 1 to 3, the ratio of investment in wife's children to total investment in children ($\theta$) increases from 0 to 1.

In addition to $p$ and $n$, a man's investment in his wife's children depends on the investment the man's wife's brother makes in the children of the man's wife ($a_W$) and on the investment the man's sister's husband makes in the children of the man's sister ($a_S$). Under the assumption that the ratio of investment in wife's children to total investment in children is a nondecreasing function on $n$, if a man is investing a positive amount in his wife's children, then an increase in $n$ of one must result in an increase in investment in wife's children of at least one. This implies that the total number of wife's children ($n_W + a_W$) must also increase by at least one. Since investment in children is fungible, so long as a man is investing in at least one of his wife's children and in at least one of his sister's children (i.e., he is not at a corner), then an investment in one more child by his wife's brother or by his sister's husband will have the same effect on the total number of wife's children ($n_W + a_W$) and on the total number of sister's children ($n_S + a_S$) as would an increase in $n$ of one. If the wife's brother, therefore, increases his investment in her children by one, the increased investment will not be offset by her husband. He may even be encouraged by the risk reduction resulting from more wife's children to transfer more investment from his sister to his wife. If the sister's husband, however, increases his investment in her children, her brother will have to offset it, otherwise the ratio of sister's children to wife's children will rise. He may, of course, more than offset it.

**TABLE III**
Investment in Wife's and Sister's Children under Constant Relative Risk Aversion as Total Investment in Children Increases*

| $p$ | $n$ | (1) $\pi = 0$ (Certain that sister is half sister) $n_w,n_s$ ($\theta$) | (2) $\pi = p^2$ (Uncertain about sister where mother had multiple lovers) $n_w,n_s$ ($\theta$) | (3) $\pi = 1-2p+2p^2$ (Uncertain about sister where mother had only one lover) $n_w,n_s$ ($\theta$) | (4) $\pi = 1$ (Certain that sister is full sister) $n_w,n_s$ ($\theta$) |
|---|---|---|---|---|---|
| .675 | 1 | 0,1 (0) | 0,1 (0) | 0,1 (0) | 0,1 (0) |
| | 2 | 0,2 (0) | 0,2 (0) | 0,2 (0) | 0,2 (0) |
| | 3 | 1,2 (.33) | 1,2 (.33) | 1,2 (.33) | 0,3 (0) |
| | 4 | 3,1 (.75) | 3,1 (.75) | 2,2 (.5) | 0,4 (0) |
| .8 | 1 | 0,1 (0) | 0,1 (0) | 0,1 (0) | 0,1 (0) |
| | 2 | 1,1 (.5) | 1,1 (.5) | 1,1 (.5) | 1,1 (.5) |
| | 3 | 2,1 (.66) | 2,1 (.66) | 2,1 (.66) | 2,1 (.66) |
| | 4 | 4,0 (1) | 4,0 (1) | 4,0 (1) | 4,0 (1) |
| .825 | 1 | 0,1 (0) | 0,1 (0) | 0,1 (0) | 0,1 (0) |
| | 2 | 1,1 (.5) | 1,1 (.5) | 1,1 (.5) | 1,1 (.5) |
| | 3 | 3,0 (1) | 3,0 (1) | 3,0 (1) | 3,0 (1) |
| | 4 | 4,0 (1) | 4,0 (1) | 4,0 (1) | 4,0 (1) |

*$p$ is the paternity probability. $n$ is the total number of children that the husband invests in (equal to $n_w + n_s$). The first number in each pair is the number of wife's children invested in by the man ($n_w$). The second number in each pair is the number of sister's children invested in by the man ($n_s$). The number in parentheses is the ratio of wife's children invested in to total number of children invested in (i.e., $n_w / n = \theta$). It is assumed here that the sister's husband invests in one of his wife's children (i.e., $a_s = 1$) and that the wife's brother invests in one of his sister's children (i.e., $a_w = 1$). The utility function is assumed to take the form $U = -R^{-3}$ (which implies a constant level of relative risk aversion of 4).

## III. ANALYSIS OF THE EVIDENCE

The discussion so far has focused on the individual's decision problem. The available data on investment in sister's children, however, is cross-cultural rather than individual. In order to best exploit the data, the implications about social aggregates ought to be derived from the analysis of individual behavior. To do so in a full and systematic way, however, would be beyond the scope of this paper. Some less formal remarks are nonetheless in order.

For a given society the average ratio of a man's investment in wife's children to his total investment in children, as a function of $p$, will be denoted $\bar{\theta}(p)$. $\bar{\theta}$ will be a function of $p$ and of the distribution of $n, \pi, a_W$ and $a_S$. Changes in $p$ will have a direct effect on the individual $\theta$'s as discussed previously. The effect of changes in $p$ on $\bar{\theta}$ will include not only this direct effect, but also the induced effects of changes in individuals' values of $n, \pi, a_W$ and $a_S$ resulting from the changes in $p$. These induced effects are expected to reinforce the direct effect of changes in $p$ on individual $\theta$'s. Consider an increase in $p$. Since men will tend to redistribute investment from sister's to wife's children, all men will experience a decline in the investment their wives receive from their brothers, while at the same time experiencing an increase in the investment their sisters receive from their husbands. As a result the induced decreases in $a_W$'s and increases in $a_S$'s should lead to a larger average increase in investment in wife's children than would have resulted from the same increase in $p$ holding $a_W$ and $a_S$ constant. Changes in $p$ may also induce changes in the distribution of $n$, but we suspect that these will either reinforce the direct effects on $\bar{\theta}$ or else be unimportant. It is assumed in the empirical work that $\bar{\theta}$ depends only on $p$. All other differences across societies are subsumed in the error term.

Unlike the solution of the individual's maximization problem, the determination of $\bar{\theta}(p)$ involves the strategic behavior of a husband and his wife's brothers toward one another. Since the number of men who are directly or indirectly affected by any given investment decision is potentially large, it is likely that men would find the costs of cooperative behavior prohibitively high. The free-rider problem that results will lead to less than optimal investment in children. We expect that societies have developed institutionally enforced rules to alleviate the problem. Further research on the existence and characteristics of such rules appears promising. For a fuller discussion see Diamond and Locay [1983].

The data analyzed was compiled by anthropologist Mark Flinn based on his systematic examination of the Human Relations Area Files and additional ethnographic sources (on the files, see Murdock [1975]). The observations analyzed in the present study consist of 150 societies selected randomly from the 565 in Murdock's "World Ethnographic Sample" [1957] and 150 societies that were intended to be a complete listing of all those that were matrilineal

**TABLE IV**
Frequencies of Alternative Sources of Investment in Children

| Source of investment in children | Number of societies |
|---|---|
| Father's kin as primary source | 50 |
| Mixed with father's kin as major source | 146 |
| Mixed with both important sources | 58 |
| Mixed with mother's kin as major source | 31 |
| Mother's kin as primary source | 4 |

by any measured criterion.[6] For the sample of roughly 300 societies, Flinn constructed quantal measures of paternity probability, frequency of divorce, source of investment in children and other relevant variables.

Since the paternity probability has been systematically estimated for only a handful of societies, Flinn examined materials under the headings "extra-marital sex" and "sex and marital offenses" in order to determine the paternity probability for a society. His measure of paternity probability would thus not take account of what we have called the low "effective paternity probability" experienced by a man whose wife had children from a previous marriage. The frequency of divorce variable is thus of interest as a means of controlling for differences in effective paternity probability. When the divorce variable is included in the estimation, however, caution should be exercised in interpreting the results since divorce may be endogenous even when the paternity probability is exogenous.

In order to test whether a society's average paternity probability influences the extent of investment in sister's children in the society, an ordinal logit (see Walker and Duncan [1967]) was estimated using the Flinn data. The categorical dependent variable in the analysis consists of the ordered source of investment in children (which ranges from the extreme where father and father's kin is the nearly exclusive source to the extreme where mother and mother's kin is the nearly exclusive source). Table IV reports the number of societies that fall under each category of source of investment.

The observations analyzed in the present study are not a random sample of the population since societies with substantial investment in sister's children are overrepresented. Such a sample has been called a "choice-based

6. Flinn has noted in correspondence that his paper incorrectly identifies the source of the sample as Murdock's [1967] *Ethnographic Atlas*.

sample" where the choice here is the society's "choice" of investment category. Although maximum likelihood estimates obtained from a choice-based sample are generally inconsistent for both intercepts and slope coefficients, Manski and Lerman [1977] have shown that an appropriate weighting of the log likelihood function will result in consistent estimates.

The estimates from the ordinal logits are reported in Table V. The logits in columns 1 and 3 are unweighted, while those in columns 2 and 4 are weighted to correct for the inconsistency of estimates that results from using a choice-based sample. Dummy variables are included for the frequency of

**TABLE V**
Ordinal Logits*

| Variable | Regression # (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Moderate paternity probability** | −0.443<br>(−.848) | −1.255<br>(−1.882) | −0.903<br>(−1.821) | −1.75<br>(−2.747) |
| High paternity probability | −2.975<br>(−5.250) | −3.544<br>(−5.049) | −3.709<br>(−7.084) | −4.26<br>(−6.430) |
| Very high paternity probability | −3.771<br>(−5.548) | −4.477<br>(−5.760) | −5.193<br>(−8.430) | −5.737<br>(−7.906) |
| Moderate divorce probability*** | 1.707<br>(4.838) | 1.472<br>(4.477) | — | — |
| High divorce probability | 2.555<br>(5.438) | 2.212<br>(4.351) | — | — |
| Constant1 | 3.526<br>(5.762) | 3.985<br>(5.461) | 5.174<br>(9.537) | 5.474<br>(8.198) |
| Constant2 | −0.031<br>(−0.501) | −0.276<br>(−0.385) | 1.837<br>(3.926) | 1.62<br>(2.723) |
| Constant3 | −2.286<br>(−3.716) | −1.997<br>(−2.816) | 0.002<br>(0.005) | −0.018<br>(−0.031) |
| Constant4 | −4.922<br>(−6.431) | −3.742<br>(−4.609) | −2.532<br>(−3.975) | −1.696<br>(−2.457) |
| Number of observations | 282 | 282 | 289 | 289 |
| −2 log likelihood | 529.16 | 463.77 | 580.89 | 504.31 |
| Likelihood ratio | 204.61 | 154.11 | 152.88 | 113.57 |

*Asymptotic t-statistics are reported in parentheses. The t-statistics as computed by the GQOPT program for the weighted logits may not be consistent. (See Hsieh, Manski and McFadden [1984]). The dependent variable is source of investment in sister's children where 1= "father's kin are the primary source of investment" and categories 2, 3, 4 and 5 indicate increasing proportions of investment from mother's kin.

**The omitted categories are "very low paternity probability" and "low paternity probability."

***The omitted category is "low divorce probability."

divorce in the first logit on the previously mentioned grounds that the presence in the household of wife's children from an earlier marriage would reduce the "effective paternity probability." The coefficients reported on the divorce dummy variables in columns 1 and 2 are consistent with our interpretation that divorce lowers the effective paternity probability and hence increases investment in sister's children. The coefficients on the paternity probability variables in all four logits are as expected: the higher the paternity probability, the less likely will be investment in sister's children. The evidence from the logits thus indicates a strong relationship between paternity probability and source of investment in sister's children.

The coefficients from the weighted logits are similar in magnitude and significance to those of the unweighted logits. The goodness of fit of the weighted and the unweighted logits was tested using the frequencies from the random sample. The statistic used in the test is the sum of the squared differences between actual and predicted frequencies divided by the predicted frequencies. The limiting distribution of the statistic is bounded by a chi-square distribution with degrees of freedom equal to the number of categories of the dependent variable minus one. The values for the two unweighted logits (1 and 3) are 8.39 and 13.92. The values for the two weighted logits (2 and 4) are 0.82 and 0.89. The chi-square statistics are much greater for the unweighted than the weighted logits implying that the weighted logits fit the random data much better than the unweighted logits. In fact the chi squares from the unweighted logits are significantly different from zero at the 5 percent level for logit 1 and at the .5 percent level for logit 3.

The estimated probabilities of various combinations of paternity probability and category of investment in sister's children can be calculated by substituting into expression (4) the coefficients estimated in one of the logits. The results for logits 3 and 4 are reported in Table VI. In each cell of the table, the top number is the predicted probability derived from logit 3, the number in brackets is the predicted probability derived from logit 4 and the number in parentheses is the actual proportion of societies (from the sample used to estimate the logits) that, given a level of paternity probability, fall under each of the five categories of investment. For concreteness, consider the triad of numbers in the fifth row and the first column. The top number indicates that the unweighted ordinal logit predicts that, of societies in the lowest paternity probability group, 7 percent will have mother's kin as the nearly exclusive source of investment in children. The number in brackets indicates that the weighted logit predicts 16 percent, while the number in parentheses indicates that the actual percent of societies (from the sample used to estimate the logits) is 22 percent. When the top probability of each triad is added together for a given column, the sum should equal one. The same is true for the probabilities in brackets and the proportions in parentheses.

**TABLE VI**
Estimated and Actual Probabilities that Societies with Various Paternity Probabilities Will Fall into a Given Category of Source of Investment*

| Source of investment | Paternity probability: Very low | Moderate and low | High | Very high |
|---|---|---|---|---|
| Father's kin as primary source | 0.01<br>[0.00]<br>(0.00) | 0.01<br>[0.02]<br>(0.03) | 0.19<br>[0.23]<br>(0.18) | 0.50<br>[0.50]<br>(0.51) |
| Mixed with father's kin as major source | 0.13<br>[0.16]<br>(0.11) | 0.27<br>[0.51]<br>(0.28) | 0.68<br>[0.70]<br>(0.69) | 0.46<br>[0.49]<br>(0.44) |
| Mixed with both as important sources | 0.36<br>[0.34]<br>(0.50) | 0.43<br>[0.32]<br>(0.38) | 0.11<br>[0.05]<br>(0.11) | 0.03<br>[0.01]<br>(0.05) |
| Mixed with mother's kin as major source | 0.43<br>[0.34]<br>(0.17) | 0.26<br>[0.11]<br>(0.33) | 0.02<br>[0.01]<br>(0.01) | 0.01<br>[0.00]<br>(0.00) |
| Mother's kin as primary source | 0.07<br>[0.16]<br>(0.22) | 0.03<br>[0.03]<br>(0.00) | 0.00<br>[0.00]<br>(0.00) | 0.00<br>[0.00]<br>(0.00) |

*The top probabilities in this table are calculated using the coefficients in the unweighted ordinal logit reported in column (3) of Table V. The probabilities in brackets in this table are calculated using the coefficients in the weighted ordinal logit reported in column (4) of Table V. In parentheses we have reported the observed proportion of societies (from the sample used to estimate the logits) that, for a given paternity probability, fall under each category of source of investment.

**TABLE VII**
Definition of Variables

| | |
|---|---|
| $p$ | the paternity probability (the probability that a child was fathered by his mother's husband) |
| $r$ | genetic relatedness of a brother to his sister's children |
| $R$ | a man's total genetic relatedness to the next generation |
| $n_s$ | the number of sister's children invested in by a man |
| $n_w$ | the number of wife's children invested in by a man |
| $a_w$ | the number of wife's children invested in by her brother |
| $a_s$ | the number of sister's children invested in by her husband |
| $\pi$ | probability that brother and sister shared the same father |
| $n$ | total number of children a man will invest in ($= n_w + n_s$) |
| $U(R)$ | utility of genetic relatedness |
| $P_i(k)$ | $= \{k!/[i!(k-i)!]\}p^i(1-p)^{k-i}$ |
| $\theta$ | $= n_w / n$ |

## IV. SUMMARY

The aim has been to learn why in many societies men invest resources in their sisters' children. By assuming that men are risk averse, the model explains two facts about investment in sister's children that are inconsistent with expected relatedness models. The one fact is that some investment in sister's children takes place at high paternity probabilities. The other fact is that men in many societies invest in both wife's and sister's children. In our account, a man values sister's children in part because they provide him with the assurance that some of his genes will survive into future generations. As the number of wife's children increases, the probability that the husband is the father of at least one of them also increases. Thus the value of the assurance provided by sister's children decreases with either an increase in the paternity probability or an increase in the number of wife's children.

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