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ABSTRACT

On the Origin of the Family^{*}

This paper presents an overlapping generations model to explain why humans live in families rather than in other pair groupings. Since most non-human species are not familial, something special must be behind the family. It is shown that the two necessary features that explain the origin of the family are given by uncertain paternity and overlapping cohorts of dependent children. With such two features built into our model, and under the assumption that individuals care only for the propagation of their own genes, our analysis indicates that fidelity families dominate promiscuous pair bonding, in the sense that they can achieve greater survivorship and enhanced genetic fitness. The explanation lies in the free riding behavior that characterizes the interactions between competing fathers in the same promiscuous pair grouping. Kin ties could also be related to the emergence of the family. When we consider a kinship system in which an adult male transfers resources not just to his offspring but also to his younger siblings, we find that kin ties never emerge as an equilibrium outcome in a promiscuous environment. In a fidelity family environment, instead, kinship can occur in equilibrium and, when it does, it is efficiency enhancing in terms of greater survivorship and fitness. The model can also be used to shed light on the issue as to why virtually all major world religions are centered around the importance of the family.

JEL Classification: C72, D01, D10, J12, Z13

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Why do humans live in families?¹ The fact that only 3 percent of avian and mammal species are known to be familial (Emlen 1995) suggests that the emergence of the family cannot be taken for granted, even among humans. Something special must be behind it. This paper addresses such a question within a simple framework, in which males and females only care for their genetic fitness, that is, the survivorship and propagation of their own genes (Hamilton 1964). To anticipate the salient features of our model, we identify the overlap of different cohorts of offspring and fatherhood uncertainty as the two special and indispensable forces behind the origin of the human family.

When paternity is uncertain, males must resort to guard their opposite-sex mate if they wish to increase confidence in their biological association with the children they feed.² Fatherhood uncertainty however is not unique to humans, as it is shared, for example, by all males of mammal species in which female ovulation is concealed, as in the case of rhesus monkeys (Vessey 1984) and bottlenose dolphins (Krützen et al. 2004).³ But most of such species do not form families. On its own, therefore, fatherhood uncertainty will not give rise to the family. The second special ingredient is given by the presence of overlapping cohorts of dependent children (Emlen 1994). This underlines the salience of parental investments (Trivers 1972), which in turn translate into enhanced survivorship and greater reproductive prospects.

In Section 2, we formulate a model in which these two ingredients *together* (fatherhood uncertainty and overlapping cohorts of children) provide the necessary and sufficient conditions under which the family arises. To fix ideas, our work proceeds along the following stylized comparison. Imagine two ancestral villages in which men and women plan to have more than one child and must choose the partner with whom they breed. In both villages, there is full intrahousehold labor specialization, with food being supplied by males and child rearing by females. The two villages, however, are different in the sense that in one village an individual has all his or her children with the same partner in a stable family

¹In this study, the term ‘family’ or, interchangeably, ‘fidelity family’ refers to any environment or situation in which all children share — and are raised by — the same parents.

²Even in contemporary general populations, nonpaternity rates seem to be nonnegligible. In human societies, they are often cited to be 10 percent or greater (Alfred 2002), although little empirical support is generally provided for this assertion. Baker and Bellis (1995) report a worldwide median nonpaternity rate of 9 percent from a sample of ten studies. In a meta-analysis of 67 studies, Anderson (2006) shows that nonpaternity rates vary widely with paternity confidence, from about 2 percent for men who have a high confidence to be the fathers of their putative children to about 30 percent for men with low paternity confidence.

³Several bird species also share this same feature. See Chuang-Dobbs, Webster, and Holmes (2001) and references therein.

grouping, while in the other village an individual begets each child with a different partner in a ‘promiscuous’ relationship.⁴ In which of the two villages do men and women achieve greater fitness? Notice that, regardless of where they live, males will have to guard as well as to provide food twice. That is, we impose neither economies of scale in food production nor a more efficient technology of guarding in association with a specific family configuration.

Our analysis indicates that the fidelity-based family dominates the promiscuous pair bonding, that is, the former can attain a higher probability of survival than the latter. This result is driven by the fact that, in the promiscuous village, a male shares the responsibility of supporting his own children with another male, and thus ends up *free riding* on this other male’s food provision. He, instead, devotes more of his time to guarding, increasing his paternity confidence. But since every promiscuous male follows the same strategy and guarding is socially unproductive, children in promiscuous families receive less food and are less likely to survive than children in fidelity families, and therefore the (population) growth in the promiscuous village is bound to be lower.

Section 3 illustrates this basic result in the context of the overlapping generation model described in Section 2. In Section 4, we extend the notion of the family to a more general context, in which kinship ties are accounted for. In particular, food transfers from older to younger siblings are shown to enhance individual and societal fitness, because older males shift time from the unproductive activity of guarding towards greater food provision that is meant to support their younger siblings. Interestingly, such a fitness gain can only materialize in the context of the family and *not* in the context of the promiscuous pair bonding. It should be emphasized that, in an environment in which paternity is uncertain, two individuals who are highly confident they share the same mother are likely to be genetically closer to each other than to their own offspring.

Essential to our theory is the notion that mate guarding by males is unavoidable when fatherhood is uncertain, even though from society’s viewpoint it is a complete waste. Therefore, any social ‘institution’ that can, in equilibrium, reduce guarding will lead to a fitness gain at the individual level as well as at the group (or society) level. One of such institutions is religious beliefs and norms that put the fidelity family at center stage. This

⁴This alternative to the fidelity family shares some of the features of the contemporary divorced family. It also reminds of the practice of *sequential monogamy*, which is quite common in many non-human (especially bird) species, whereby an individual has a different, but exclusive, breeding partner each mating season (e.g., Poirier, Whittingham, and Dunn 2004).

reasoning will allow us to underpin why virtually all major world religions stress the role of the fidelity family (and, more specifically, marriage) as avoidance of casual sex (Browning, Green, and Witte 2006). Our analysis in Section 5 illustrates the extent to which family-centered religious beliefs can become a successful adaptation (Wilson 2002) and deliver a more efficient equilibrium. This might have salient ramifications for our understanding of the contemporary family in environments where religious norms have different degrees of cogency. Section 6 concludes.

Before focusing on the model, the next section sets the background against which our contribution should be seen. We can only briefly overview a selection of studies from several and diverse scientific literatures which are pertinent to our research. For expositional convenience, all the formal proofs are omitted from the main text and presented in the Appendix.

1. Related Literatures

A. Economics

Since Becker's pioneering works (1973, 1974, 1981/1991), the family has become a prominent area of investigation among economists.⁵ Becker (1973, pp. 818–820) emphasizes the importance of own children as the explanation of why men and women live together in an environment in which there is complementarity of male and female time inputs in production. Because own children are important, the notion of fatherhood uncertainty is implicitly called upon in order to justify why unions of several men to one or several women are uncommon. In Becker's analysis, however, males are not allowed to respond to paternity uncertainty (for example with the introduction of implicit contracts or with guarding), and all non-monogamous unions are essentially assumed to be less efficient than monogamous partnerships.

The focus of Becker's research as well as of other subsequent studies instead has been on the gains from trade that a man and a woman can realize by marrying compared to remaining single. The gains to marriage arise from gender specialization in home and market activities, provided that individuals have no direct preferences for spending time in some tasks and not in others, and that the time inputs of household members in the household

⁵See Bergstrom (1996, 1997), Weiss (1997), and Lundberg and Pollak (2007) for insightful and wide-ranging surveys.

production of public goods are perfect substitutes.⁶ In this environment, marriage, which is broadly defined to include both formal unions and cohabitations, corresponds roughly to our notion of the fidelity family. The alternative to marriage, however, is not another form of partnership (such as the promiscuous pair bonding in the present study) but singlehood. But the comparison to singlehood is not compelling in an environment in which individuals care for the survivorship of their genetic endowment.

A recent strand of economic research explicitly incorporates biological considerations into individual or household behavior.⁷ For instance, Gould, Moav, and Simhon (2008) extend previous work by Grossbard (1976) to explain not only why polygyny exists but also why monogamy dominates the marriage market of advanced economies. Another example is the study by Siow (1998), which investigates how differential fecundity interacts with market structure to affect gender roles in monogamous societies.⁸ Alger and Weibull (2009) examine the strategic interactions between mutually altruistic siblings to assess the extent to which family ties may vary in relation to environmental factors, such as output variability and marginal returns to effort.⁹

Somewhat closer to our approach is another set of economic papers that emphasize the importance of fatherhood uncertainty. These include Edlund and Korn (2002), Edlund (2006), Saint-Paul (2008), and Bethmann and Kvasnicka (2008). But, unlike ours, such papers rule out mate guarding while, instead, underline the explicit or implicit transfers that take place between a man and a woman engaged in sexual reproduction (e.g., as in the case of legal marriages, which are seen as a contractual form of establishing paternity presumption and custodial rights to the man), and examine their consequences in terms of, for example, the matching patterns in marriage markets, the dynamics of human capital accumulation and parental investments in children, and in response to environmental

⁶Besides intrinsic productivity differences, another factor that contributes to intrahousehold specialization is the presence of increasing returns to sector-specific investments in human capital (Becker 1991). Lundberg and Pollak (2007) offer an up-to-date critical review of Becker's theory.

⁷Early work by Becker (1976) also considered the relationship between sociobiology and economics. It argues that economic models can explain biological selection of altruistic behavior toward children and other kin by the advantages of altruism when there are physical and social interactions. Cox (2007) offers a stimulating overview of economic analyses of family behavior based on biological fundamentals. Further discussion is in Bergstrom (2007).

⁸Recent work by Robson (2001), Kaplan and Robson (2002), and Robson and Kaplan (2003, 2006) show how biological thinking can be innovatively applied to time preference, rationality, risk aversion, longevity and intelligence.

⁹Interestingly, Alger and Weibull (2009) relate the same environmental factors, including the harshness of the physical environment, to the development of specific religions. Our paper also looks at the evolution of religion, but from a radically different perspective. See Section 1.B and 5.

changes that might have altered the demand for marriage (e.g., the introduction of oral contraceptives). We instead concentrate on mate guarding as males' strategic adaptation to uncertain paternity.

B. Other Social Sciences

Differently from economic research, the origin-of-the-family question was at the forefront of early anthropological and sociological studies.¹⁰ Knight (2008) offers an intriguing historical account of the rise and fall of Morgan's (1871) notion of matrilineal clan and group motherhood, from its popularization by Engels (1884) to its demise through the works of Westermarck (1903) and Malinowski (1930). But the objective of such studies is not to understand *why* humans form families, as it is in ours. Rather, it is mainly ideological. For instance, in the alleged transition from primitive (promiscuous) forms of family to the monogamous family, Engels identifies the mechanism that disempowered women and triggered male dominance and private property. Conversely, by denying that group marriage was a widespread practice among hominins, Westermarck and Malinowski asserted that monogamy must have been primeval.

Leaving this controversy aside, much of the recent contributions in social and evolutionary anthropology give evidence of a wide range of potential early kinship ties, with individuals using a fluid variety of kin and other links (Diamond and Locay 1989; Dunbar, Clark and Hurst 1995; Allen 2008; Aureli et al. 2008). A significant example is provided by the work of Beckerman and Valentine (2002), which documents the practice, among a substantial number of Lowland South American societies, of 'partible paternity', whereby the paternity of a woman's child gets partitioned among multiple males. This practice offers a cooperative solution to the issue of fatherhood uncertainty within a promiscuous family structure, and supports the notion of matrilineal kinship. Genetic data on Sub-Saharan African hunter-gatherers also indicate a matrilineal residential bias.¹¹

In our analysis, we will not attempt to model the wide variety of kinship ties just described. In fact, we first develop a basic noncooperative model of survivorship abstracting from any type of kinship. After comparing two diverse family organizations (one based

¹⁰More recent sociological research instead is less concerned with the origin issue. See Allan (1999) and Bengtson (2001).

¹¹Studies of mitochondrial versus Y-chromosomal dispersal patterns show that hunter-gatherer women have tended to reside closer to their mothers following marriage, migration rates for women being lower than for men (Destro-Bisol, et al. 2004). Similarly, on the basis of a careful cross-cultural study, Marlowe (2004) concludes that hunter-gatherer societies are more likely to be characterized by matrilocality.

on pair fidelity and the other based on promiscuous pair bonding), we then consider a new setup with a simple kinship system, which, notwithstanding its simplicity, relies on the notions of genetic relatedness and kin detection (Hamilton 1964; Lieberman, Tooby, and Cosmides 2007). In it, elderly brothers will have an incentive to transfer food to their younger siblings as long as kin recognition is perfect (or high enough).¹²

Related to our work is also another recent strand of sociological and anthropological research that focuses on religion. Relevant examples are the studies by Lansing (1991) and Stark (1996), which emphasize the secular utility of religion and provide impressive documentations of the immediate material role of otherworldly religious beliefs in the water temple system in Bali and the early Christian church, respectively. Our analysis will draw from such contributions. But closest to ours is the work by Wilson (2002), which uses an evolutionary biology perspective to interpret any religious group as an organism and religion as a successful adaptation that allows the organism to become better suited to its environment. This last perspective leads us quite naturally to the next strand of literatures which are related to our work.

C. Biology and Animal Sciences

Mating systems (including family grouping) have been discussed in evolutionary terms since Darwin (1871). Major developments in genetic theory, zoology, archeology, and paleoanthropology have allowed a better understanding of sex ratios, sexual dimorphism, and differential patterns of parental care.¹³

Important milestones toward a better understanding of the emergence of humans have also been reached. For example, among the five special traits that separate man from other hominoids, Loverjoy (1981) emphasizes the unique sexual and reproductive behavior of humans.¹⁴ This emphasis, which underlines the copulatory vigilance triggered by concealed ovulation among humans, is also echoed in our theory, but, differently from our model, it does not unfold toward the trade-off between mate guarding by the male in order to

¹²This type of reciprocity is not entirely consistent with the idea of matrilineal kinship emphasized earlier, but it is the easiest to model within our framework. The extension to other more complex kinship systems is left for future research.

¹³A comprehensive survey of all such contributions is beyond the scope of the present paper. We thus limit our focus only to selected studies that have a more direct link to our work.

¹⁴The other four characteristics identified in his theory are material culture (tools), reduced anterior dentition with molar dominance, a large neocortex, and bipedality. Influential predecessors of the centrality of the evolution of mating systems include Orians (1969), Emlen and Oring (1977), and Alexander et al. (1979).

minimize the risk of nonpaternity and other male activities. Instead, it stresses human anatomy, and, in particular, humans' greater elaboration of epigamic characters.¹⁵ Along the same vein of Lovejoy's, Kaplan and Robson (2002) stress the importance of a larger brain size and a longer life span as products of coevolutionary selection and as the two distinctive features that help explain the emergence of humans.

Related to such studies, and perhaps more closely associated with ours, are the works by Emlen (1994, 1995), which explicitly address the issue of the evolution of the family. Both contributions emphasize that families emerge when grown offspring delay dispersal and breeding and continue to reside with one or both parents (something similar, although not identical, to our notion of overlapping of different cohorts of children). Delayed breeding occurs when the production of maturing offspring exceeds the availability of acceptable opportunities for their independent reproduction (e.g., when there is shortage of high-quality breeding vacancies or of breeding partners). Under such circumstances, some offspring must wait until favorable reproductive vacancies arise and then compete to fill them. In fact, having poor options for independent breeding is part and parcel of what makes a good situation at home. Families therefore form when such waiting is best done at home: that is, they arise when remaining on the natal territory or associating with one's family increases the offspring's fitness.

Emlen's model leads to family groupings that are inherently unstable, depending on the external availability or shortage of acceptable breeding opportunities for grown offspring. But among humans, the overlap of different cohorts of dependent children (as stated in our model) typically extends over several years of the parents' lives. This in itself will exact family groupings that are fundamentally more stable than those observed among other mammals or birds. Moreover, the lower dispersal rate of human offspring may be fundamentally uncorrelated to shortages of breeding vacancies or to the low probability of reproductive success of unaided breeders. Rather, it might be driven more directly by a larger brain size at birth and a more prolonged dependency on parental care (Lovejoy 1981; Ruff, Trinkaus, and Holliday 1997). This underlines the salience of parental in-

¹⁵Interestingly, the trade-off between male competition for additional mating opportunities (but, admittedly, not mate guarding) and other activities (especially male caring for infants) is central to the analysis by Hawkes, Rogers, and Charnov (1995). However, their attention, unlike ours, is mainly directed to the characterization of the conditions under which more male-male competition and less care provision is individually more desirable. A key condition is found to be the opportunity to compete for mating among males (i.e., the intensity with which other males seek additional mating), but no attention is given to females' fitness and strategies.

vestments, which translate into potential fitness benefits, including enhanced survivorship while waiting for outside reproductive prospects to arise, improved ability to compete, and the possibility of inheriting the natal breeding position.

The role of parental investment is another dimension that evolutionary biologists and animal behavior researchers have extensively analyzed, and is highly pertinent to our theory. The conceptual pillar here is Trivers's theory (1972). This predicts that the sex that invests biologically more in creating new offspring (that is, women in the case of humans) will be more selective about whom they accept as a mate, whereas males (the sex that invests relatively less in offspring) will compete among themselves for access to females. In our model, male and female parental investments are assumed to be essentially comparable: males provide food to their offspring, while females allocate this food between children. Thus, in line with Triver's prediction, this investment equivalence means that female choice is no more discriminating than male choice. By assuming investments in children that are comparable between the sexes, we rule out strategic investment considerations that stem from the local public good nature of children (Maynard Smith 1977; Becker 1981/1991). That is, with both parental investments being indispensable, there can be no free riding of one parent on the other parent's parental investment.

2. Benchmark Model

In this section, we set up an overlapping generations model which allows us to understand how the family originated among humans. Individuals are in an environment in which the sex ratio equals about unity and live for four periods.¹⁶ During the first two periods (labeled *i* and *ii*), they are young, unproductive and live off their parents' material resources. In the last two periods (labeled 1 and 2), they become adult and fertile.

In every period 1 and 2, an adult female is matched with an adult male of the same cohort, begets one child in each period, and devotes all her time to child rearing. The

¹⁶Differential mortality between the sexes is assumed away. This allows us to avoid to deal both with unusual circumstances in the mating environment (Hamilton 1967) and with the formation and reconstruction of family units due to the imbalance that differential mortality can generate. This assumption however may have important implications in the context of our model. With greater male mortality, for example, women in promiscuous relationships could have a fitness advantage over women in fidelity families. Promiscuous females, in fact, may expect to secure more resources for their offspring through access to a larger set of male partners (Hill and Hurtado 1996; Beckerman, et al. 1998). There is, however, strong evidence of differential female mortality due to pregnancy and childbirth in our evolutionary past (Kruger and Nesse 2004). This issue is important and is left for future research.

adult male, instead, is in charge of supplying food to his offspring.¹⁷ In each period 1 and 2, he will divide his time into two activities: (a) food provision, which directly increases the chance of survival of children; and (b) mate guarding, which is a socially unproductive activity but increases the probability that the child he supports carries his genes.¹⁸ In this benchmark setup, we assume that a male provides food *only* to the female(s) he is (and was) matched to, i.e., to the “official” mother(s) of his offspring. This assumption will be relaxed in Section 4.

The reason why men guard their opposite-sex mate is because fatherhood is uncertain, and, since in this environment individuals care exclusively for the survivorship and propagation of their genes, the cost of cuckoldry is extremely high. Guarding is necessary because each man knows that, in the attempt to maximize fitness, all males seek to make pregnant not only their official mate but also the other adult females from their own cohort. We call this activity ‘casual sex’. If successful, casual sex gives a male the advantage of an enhanced chance of propagation of his own genes. Thus, unlike a female who can have only one child in a given period, any male may have more than one child in the same given period. But he may have none if he does not guard his mate effectively.

We assume that casual sex is costless to a male, whereby he sacrifices neither guarding nor providing food to the woman he guards. For simplicity, we also assume that a man can only guard (live with) one female in a given period, so that polygyny is ruled out. As mentioned, women cannot attain greater fitness from casual sex through increased reproductive advantages; and because all men are identical, females are indifferent to the identity of the father of their children.

We consider two alternative and mutually exclusive social configurations: (i) the family based on fidelity, denoted by Γ_F , where a female is matched with the same male in periods 1 and 2, and (ii) a pair-bonding promiscuous relation, denoted by Γ_P , where each female is matched with one male in period 1 and another male in period 2. All individuals of a given village cannot choose between such configurations, but instead are assumed to abide

¹⁷This full gender specialization in home and market tasks echoes Becker (1981/1991). In the ancestral context of our model, it reflects the well documented scientific evidence reported in Robson and Kaplan (2006), according to which, after taking own consumption into account, women supply 3 percent of the calories to offspring while men provide the remaining 97 percent in hunter-gatherer societies. Moreover, we should stress that all the results presented in the next sections will be qualitatively the same even without this assumption, but as long as women have greater childcare responsibilities and men play a greater role in supplying food.

¹⁸All adults (males and females alike) are self-sufficient, that is, they have an endowment of material resources which is enough for their survival. Without loss of generality, we normalize such an endowment to zero.

to either Γ_F or Γ_P .

A. Technologies and Actions

Let g_t denote the fraction of resources males spend guarding their mates in period t , $t = 1, 2$. The probability that guarding is successful is independent of the dominant social configuration in the village and across periods, and it is assumed to be a concave function of g_t with the following parametric form:

$$q(g_t) = g_t^\alpha, \tag{1}$$

where $0 < \alpha < 1/3$ to ensure concavity of the optimization program.

Child survival is stochastic. The probability that a child survives into adulthood, p , is a concave function of the amounts of food received during the first two periods of life, which are denoted by y and z , respectively. That is,

$$p(y, z) = (yz)^\alpha, \tag{2}$$

where, just for simplicity, the parameter α is assumed to be the same as in (1) and $0 < \alpha < 1/3$. This parameter therefore is a measure of efficiency of both the guarding technology and the food provision technology. For analytical convenience, we assume that the actual death of a child, an event which occurs with probability $(1 - p(y, z))$, can occur only after the two periods of childhood at the beginning of the adulthood stage. This means that *all* adult males will have to supply food to one child in their first period of adulthood and to two children in the second period, and store for their youngest child after their death.¹⁹

An adult male supplies the amounts of food f_1 and f_2 to the mother of his first child in periods 1 and 2, respectively. Similarly, he gives s_2 and s_3 to the mother of his second child. Since the second-born child needs s_3 only *after* period 2 (i.e., after the father's death), we assume that food storage is perfect. That is, food can be reliably stored from one period to the next, and it can be used even after parents' death when the youngest child still needs to be fed.²⁰

¹⁹Thus, p can be more properly interpreted as the probability of reaching adulthood as a fertile individual; children always reach the adulthood stage but, without adequate parental investments y and z , they will be unfit to mate and reproduce.

²⁰Although this might seem unrealistic and confuted by much anthropological and archeological evidence (e.g., Kaplan and Hill 1985; Aureli et al. 2008), it simplifies our analysis and allows us to establish powerful results fairly comfortably. Relaxing this assumption is an extension left for future research.

As already mentioned, an adult female gives birth to one child in each period 1 and 2, and it takes a new-born child two periods to become independent. The mother has to decide how to allocate the food she receives in a given period between her offspring. This allocation decision is straightforward in period 1, when she gives all the food she receives, f_1 , to the first (and only) child. She also cannot affect the amount of food stored by the male, s_3 , on behalf of their second child for the child's second period of childhood. The mother's allocation decision instead is more complex in the second period, when she has two children to nurture. In this case, keeping her partner's decisions as given, she chooses the food allocation, m , that maximizes her fitness, which — contrary to the male's — does not include guarding, because motherhood is certain. The amounts of food she allocates to her first- and second-born children are thus given respectively by $m(f_2 + s_2)$ and $(1 - m)(f_2 + s_2)$, where $f_2 + s_2$ is the total amount of food she receives from her partner(s) in period 2.

We next consider the optimization problems of adult men and women conditional on a given family institution. In what follows, the 'hat'-notation is used to indicate variables that are not a choice under the chooser's control.

B. Preferences and Optimization Problems

Adult Male in the Fidelity Family Configuration — It is important to emphasize again that all individuals care only for the survivorship of their genes. Specifically, they are assumed to maximize inclusive fitness, which encompasses the reproductive value of one's progeny and relatives (appropriately weighted by the extent to which individuals and relatives share genes) in addition to one's own (Hamilton 1964). In this context, the male chooses $g_1, f_1, g_2, f_2, s_2, s_3$, to maximize his expected inclusive fitness which is given by

$$\underbrace{\frac{g_1^\alpha}{2} f_1^\alpha [\widehat{m}(f_2 + s_2)]^\alpha}_{\text{"first child"}} + \underbrace{\frac{g_2^\alpha}{2} [(1 - \widehat{m})(f_2 + s_2)]^\alpha s_3^\alpha}_{\text{"second child"}} \quad (3)$$

subject to the lifetime resource constraint

$$2 = g_1 + f_1 + g_2 + f_2 + s_2 + s_3. \quad (4)$$

The first term in (3) indicates that the first child is genetically related to the adult male with probability g_1^α (following (1)), and this survives the first and second periods of childhood with probability $f_1^\alpha [\widehat{m}(f_2 + s_2)]^\alpha$ (according to (2)). Note that the term $g_1^\alpha/2$

will boil down to the standard parameter of genetic relatedness (with own child) in the absence of any uncertainty about paternity ($g_1 = 1$).

The second term captures the fitness gained by a father through his second born. As in the case of the first born, fitness is attained, provided that the child is genetically related to the father (which occurs with probability g_2^α), through direct resource provision in period 2, s_2 , and the food stored by the father when he is alive, s_3 . Such investments are successful with probability $[(1 - \widehat{m})(f_2 + s_2)]^\alpha s_3^\alpha$.

Finally, the resource constraint (4) is defined over the entire adulthood. Each adult male is endowed with two units of time (one unit per period). In each period, a male can allocate his unit of time endowment either to seek paternity by guarding his opposite-sex mate or to care for the young by providing food to them. The exact timing of when the father decides to store food is irrelevant.

Adult Male in the Promiscuous Pair Bonding Configuration — As before, adult males care only for their own fitness, even though the female they guard already has (or will eventually have) a child with a different male. Thus, male's objective (3) must be modified as follows:

$$\underbrace{\frac{g_1^\alpha}{2} f_1^\alpha [\widehat{m}(f_2 + \widehat{s}_2)]^\alpha}_{\text{"first child"}} + \underbrace{\frac{g_2^\alpha}{2} [(1 - \widehat{m})(\widehat{f}_2 + s_2)]^\alpha s_3^\alpha}_{\text{"second child"}} \quad (5)$$

This formulation acknowledges that, from the viewpoint of a given male in period 2, the woman he guarded in the first period (whom he expects to be the mother of his first child) receives f_2 from him and \widehat{s}_2 from the (different) male who guards her in period 2 and with whom she begets her second child. The opposite occurs for the mother of his second child.

Adult Female — Regardless of the family configuration, a female decides on how to allocate the food transferred to her by the male over her children. Since she cannot affect the amount of food given to the first child in her first adult period, \widehat{f}_1 , and that received by the second child after her death, \widehat{s}_3 , her problem is to choose the food allocation, m , in the second period to maximize her own fitness, $\widehat{f}_1^\alpha [m(\widehat{f}_2 + \widehat{s}_2)]^\alpha + [(1 - m)(\widehat{f}_2 + \widehat{s}_2)]^\alpha \widehat{s}_3^\alpha$, taking the males' choices as given (denoted with the usual hat-notation).

The solution to this problem is given by

$$m = \left[1 + \left(\widehat{s}_3 / \widehat{f}_1 \right)^{\frac{\alpha}{1-\alpha}} \right]^{-1}. \quad (6)$$

This shows that, regardless of the value of α , females always split the resources received from the males equally between their children (from (6), $m = 1/2$), provided that the amount of food given to the first-born child in the first period, \widehat{f}_1 , equals the amount of food received by the second-born child after her death, \widehat{s}_3 . In the next section, we will show that $m = 1/2$ is indeed an equilibrium choice because, given this, the male's optimal response is to equate f_1 and s_3 .

The conditional choices that characterize male's and female's behaviors in this environment lead us quite naturally to the definition of our equilibrium concept.

C. Equilibrium

We adopt the Nash equilibrium notion, in which we restrict attention to a given family configuration, i.e., individuals do not choose the type of family structure (either fidelity family or promiscuity) in which they live. Rather, this is an institution of the village.

Definition. *An equilibrium (Γ_j, x_j) , $j = F, P$, is a family configuration Γ_j and a feasible vector of allocation of resources x_j , with $x_j = (g_1, f_1, g_2, f_2, s_2, s_3, b; m)_j$, such that x_j is a pure Nash equilibrium. That is, given Γ_j , the equilibrium allocation is a fixed point in actions, whereby each individual maximizes own fitness given the partner's actions.*

3. Analysis

A. Fidelity Family

Consider a village in which only fidelity family groupings are possible. Then, the optimization of (3) subject to (4) and taking (6) into account leads to the following result:

Proposition 1. *In the fidelity family configuration, there exists a unique equilibrium (Γ_F, x_F) with the equilibrium allocation x_F given by $f_1 = g_1 = g_2 = s_3 = 1/3$, $f_2 + s_2 = 2/3$, and $m = 1/2$.*

In the fidelity family equilibrium, therefore, an adult male will devote an equal fraction of his time endowment in periods 1 and 2 to guarantee paternity of both his children. Similarly, each of his children will receive equal amounts of food in each period, regardless of birth order.

B. Promiscuous Pair Bonding Relationship

The alternative family configuration is one in which there is no lasting pair bonding. In this case, optimization of (5) under (4) and (6) implies

Proposition 2. *In the promiscuous pair bonding configuration, there exists a unique equilibrium (Γ_P, x_P) with the equilibrium allocation x_P given by $f_1 = g_1 = g_2 = s_3 = 2/5$, $f_2 + s_2 = 2/5$, and $m = 1/2$.*

As in the fidelity family case, also in the promiscuous configuration, children receive an equal amount of resources over their entire childhood (periods i and ii). However, there are differences in the timing of the transfers by birth order: first-born children receive more food in their first period of life (period i), while second-born receive more food in their second stage of childhood. Males are also equally vigilant on their two mates in both fertile periods.

C. Comparing the Two Configurations

Compared to the fidelity case, males in promiscuous relations spend more time unproductively, guarding their partners. More mate guarding translates into a lower probability of nonpaternity. From (1), the probability of successful guarding in the promiscuous village is given by $(2/5)^\alpha$, and this is always greater than the probability of successful guarding in the fidelity village, where it is equal to $(1/3)^\alpha$. Greater guarding however comes at the cost of lower food transfers to children, and this in turn affects the probability that each child has to reach the adulthood stage. From (2), the probability of child survival in the promiscuous village is $(2/5)^\alpha(1/5)^\alpha$, which, for any given $\alpha \in (0, 1/3)$, is always lower than the corresponding probability in the alternative configuration, where instead is equal to $(1/3)^\alpha(1/3)^\alpha$.

From the point of view of each investing adult male, after combining both the probability of successful guarding and the probability of child survival, the contribution to fitness given by each child is $(1/27)^\alpha$ in the fidelity village and $(4/125)^\alpha$ in the promiscuous village. In this latter case, therefore, it is lower irrespective of the efficiency of the food provision technology, α . Thus, the fitness gain in the promiscuous village that is obtained through greater guarding is outweighed by lower food provision. These considerations lead us naturally to the following:

Proposition 3. *Survivorship of each child and overall fitness in the fidelity village are always greater than survivorship and fitness in the promiscuous village.*

Promiscuous males underprovide food to their mates (and, hence, to their children) and overguard them as opposed to what males do in the fidelity-based family configuration. Since guaranteeing paternity is decisive from the individual male’s perspective, each male in a promiscuous environment is willing to guard more his two female partners and seeks to *free ride* on the food supplied by the other male. Free riding on food provision is therefore the key mechanism underpinning the lower overall fitness achieved in the promiscuous village. An obvious corollary of this proposition is that, *ceteris paribus*, villages populated by individuals who form fidelity-based families outgrow promiscuous villages.

4. Extending the Benchmark Model to a Simple Kinship System

So far we assumed that adult males provide food only to their own children. But besides own children, they may care for the fitness of other genetic close relatives. As emphasized in Section 1, a vast social sciences literature has documented the wide array of kinship ties that have emerged among humans. In what follows, we allow for food reciprocity with kin, whereby an adult male cares both for his presumed children and for his *younger* sibling.²¹ The idea is that, in a model which emphasizes the importance of genetic links and uncertain paternity, patrilineal kin ties can only arise when adult males have relatives who are genetically as close to them as their “official” offspring. The best candidate is given by own younger siblings, who still need resources before becoming adults.

Notice that, in an environment in which fatherhood is uncertain, kin recognition, and thus food reciprocity with kin, is not straightforward. Males need to be able to assess the degree of kinship they may or may not share with other individuals who live close to them. The two most important mechanisms that are believed to track genetic relatedness in ancestral human groups are the close perinatal association between mother and neonatal, which begins with birth and is enforced by the exigence of early maternal care, and the duration of sibling coresidence (Lieberman, Tooby, and Cosmides 2007). Both such mechanisms are likely to emerge in the presence of overlapping cohorts of children.

We then relax the assumption that adult males provide food only to their children.

²¹The inverse relationship (from younger to older siblings) and more complex kinship systems involving individuals with lower levels of genetic relatedness (e.g., cousins, nephews and nieces) are not considered here. The development of models that analyze such ties is left for future research.

Specifically, we modify the objective functions of (elder) females and males in both family configurations, allowing for food transfers from older to younger siblings. The problems faced by younger siblings are the same as those described in Section 2 and solved for in Section 3.

We will establish three main results: (a) kinship cannot emerge without family (Proposition 4); (b) even in fidelity family environments, food transfers to younger siblings will not occur in equilibrium as long as sibling recognition is not sufficiently high (Proposition 5); and (c) in families where sib detection is (almost) perfect, kinship emerges, that is, food transfers to younger siblings will occur in equilibrium (Proposition 6).

Adult Female — Regardless of family configuration, a female in our model continues to decide on how to allocate the food transferred to her by the male over her children. Again, she takes the amount of food given to the first child in her first adult period and that received by the second child after her own death as given. But now she has to take into account that her second child may receive food also from the elder male sibling (who may or may not be her child, depending on the family configuration), and this elder male may or may not be alive. Thus, her problem is to choose the food allocation, m , in the second period to maximize her own fitness

$$\widehat{f}_1^\alpha (m(\widehat{f}_2 + \widehat{s}_2))^\alpha + \text{E} \left\{ \left[(1 - m)(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + \widehat{b})^\alpha \right\}. \quad (7)$$

The expectation operator in (7) arises because the older brother might not survive to adulthood, and this by definition means that $\widehat{b} = 0$. Clearly, women can affect this probability with their choice of m . Thus, letting $\widehat{f}_2 + \widehat{s}_2 = \widehat{z}$, the female's objective is to choose m to maximize

$$\left\{ \widehat{f}_1^\alpha m^\alpha \widehat{z}^\alpha + (1 - m)^\alpha \widehat{z}^\alpha \left[m^\alpha \widehat{f}_1^\alpha \widehat{z}^\alpha (\widehat{s}_3 + \widehat{b})^\alpha + (1 - m^\alpha \widehat{f}_1^\alpha \widehat{z}^\alpha) \widehat{s}_3^\alpha \right] \right\}. \quad (8)$$

Adult Male in the Promiscuous Pair Bonding Configuration — In the presence of kin ties, the elder adult promiscuous male who has a younger sibling sees his objective function (5) modified into:

$$\begin{aligned} & \underbrace{\frac{g_1^\alpha}{2} f_1^\alpha [\widehat{m}(f_2 + \widehat{s}_2)]^\alpha}_{\text{"first child"}} + \underbrace{\frac{g_2^\alpha}{2} \text{E} \left\{ [(1 - \widehat{m})(\widehat{f}_2 + s_2)]^\alpha (s_3 + \widehat{b})^\alpha \right\}}_{\text{"second child"}} \\ & + \underbrace{\frac{\widehat{g}_1^\alpha \widehat{g}_2^\alpha}{4} \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + b)^\alpha \rho}_{\text{"younger brother"}}. \end{aligned} \quad (9)$$

The way in which the first child contributes to the male's fitness is the same regardless of whether or not there are kin ties (see the first term in (5)). The second child, however, may receive food not only from the (presumed) father but also from the older brother. This is reflected in the new second term of (9). The third term shows the fitness contribution induced by the investment in the younger brother. Notice that in the promiscuous configuration, children with the same father do not share the same mother. With uncertain paternity, therefore, their genetic relatedness is then only $\widehat{g}_1^\alpha \widehat{g}_2^\alpha / 4$, which reaches $1/4$ if guarding is successful. Finally, the last component of this term is the parameter ρ , with $\rho \in [0, 1]$, which identifies the ability of assessing genetic relatedness between self and other. If $\rho = 1$, then kin detection is perfect.

We now establish a result according to which the unique equilibrium in the presence of kin ties is the same as in the case when food transfers among siblings were not allowed.

Proposition 4. *In the promiscuous pair bonding configuration, there exists a unique equilibrium (Γ_P, x_P) with the equilibrium allocation x_P given by $f_1 = g_1 = g_2 = s_3 = 2/5$, $f_2 + s_2 = 2/5$, $b = 0$, and $m = 1/2$.*

In promiscuous villages, therefore, it is never optimal for a male to provide food to his siblings, even if kin detection is not an issue (that is, even if kin detection is perfect). The intuition is rather simple. Because all children in the village receive an equal amount of resources over their entire childhood (periods i and ii) and because any given male is genetically closer to his own children than to any other individual, including his siblings, it is optimal to provide food only to own “official” offspring. Kin ties then cannot emerge in a promiscuous environment where there is no family.

Fidelity Family — In the fidelity configuration, the elder male's objective function changes from (3) to

$$\begin{aligned}
& \underbrace{\frac{g_1^\alpha}{2} f_1^\alpha [\widehat{m}(f_2 + s_2)]^\alpha}_{\text{“first child”}} + \underbrace{\frac{g_2^\alpha}{2} \text{E} \left\{ [(1 - \widehat{m})(f_2 + s_2)]^\alpha (s_3 + \widehat{b})^\alpha \right\}}_{\text{“second child”}} \\
& + \underbrace{\frac{(1 + \widehat{g}_1^\alpha \widehat{g}_2^\alpha)}{4} \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + b)^\alpha \rho}_{\text{“younger brother”}}. \tag{10}
\end{aligned}$$

Besides the usual notation that indicates food provision from the same male rather than different males, this expression differs from (9) in its last term, in which genetic

relatedness is now captured by $(1 + \widehat{g}_1^\alpha \widehat{g}_2^\alpha)/4$. If the two siblings were certain to share the same biological father, that is, $g_1 = g_2 = 1$, then the term is equal to $1/2$. If they do not share the same father, their genetic relatedness does not disappear but is reduced to $1/4$, because they still have the same mother.

Similarly to the case of the promiscuous pair bonding configuration, here too the equilibrium is the same as in the case of the fidelity family without kinship in which food provision is restricted only to own children (Section 3), provided that sibling detection is sufficiently low.

Proposition 5. *In the fidelity family configuration, there exists a threshold level of the kin recognition parameter $\underline{\rho}$ such that, for all $\rho \leq \underline{\rho}$, the equilibrium (Γ_F, x_F) is unique, with the equilibrium allocation x_F given by $f_1 = g_1 = g_2 = s_3 = 1/3$, $f_2 + s_2 = 2/3$, $b = 0$, and $m = 1/2$.*

The emergence of kin ties therefore is not straightforward even when individuals form families. It is important to point out that, at the critical value $\underline{\rho}$ which is determined in equilibrium, the older male is in expectation equally related to his younger sibling as he is to his own “official” offspring. Notice also that $\underline{\rho}$, which is a decreasing function of α , is typically quite high.²² For example, when $\alpha = 0.3$, the corresponding value of $\underline{\rho}$ is approximately equal to 0.948. As α declines, the critical probability of kinship detection increases: e.g., if $\alpha = 0.2$, $\underline{\rho} = 0.976$. Thus, even when kin recognition is high (but as long as it is not perfect), adult males in fidelity villages provide food only to their official offspring and not to their siblings.

The relationship between b and ρ is interesting and deserves attention. The lower the ability to identify genetic relatedness (smaller ρ), the lower the importance of the last term in (10), which is the only one containing b . The value $\underline{\rho}$ indicates the threshold of kin detection below which no food transfer should be observed in equilibrium. Therefore, when kin detection is below this threshold adult males cannot rely on their elder son to provide food to their younger child after their death, because they know that their elder son’s fitness gain is not large enough. Values of ρ above $\underline{\rho}$ instead justify positive food transfers to younger siblings because, at the equilibrium level of guarding, the expected genetic relatedness between siblings is the same as that between father and offspring. This is what emerges in our next result.

²²The expression for the threshold is given by $\underline{\rho} = 2(1/3)^\alpha(1 + (1/3)^{2\alpha})^{-1}$.

Proposition 6. *In the fidelity family configuration, if $\underline{\rho} < \rho \leq 1$, then $b > 0$ and, compared to the case without food transfers between siblings, total survivorship and fitness are greater.*

Based on the numerical solution described in the Appendix, Figure 1 shows parental investments, child survival and adult fitness, for a given value of α ($\alpha = 0.2$) and as the value of the kin detection parameter increases from $\underline{\rho}$ to 1. When $\rho > \underline{\rho}$, food transfers from the older brother to the younger sibling should then occur in equilibrium (i.e., $b > 0$).

As compared to the case in which kin detection is below $\underline{\rho}$, first born children will receive *more* food from their fathers in both their childhood periods. Second born children instead will receive less food directly from their fathers, but after taking into account the transfer from their older brother, they too end up with *more* food than what they would receive in the context without kin ties. Thus, the resulting probability of survival will be higher for both children.

As sib recognition becomes more precise, the amount of food transferred to the younger brother increases and so does the amount received by the first child (Figure 1, panel (a)), while the amount of food received by the second born declines (Figure 1, panel (b)). But, for any given value of ρ above $\underline{\rho}$, this reduction is more than compensated by the transfer made by the older brother. Thus, villages with kin ties as opposed to villages without kin ties will be characterized by greater food provision, whether to offspring or to younger siblings. This will lead to greater child survival. The greater amount of resources that males devote to survivorship is accompanied by less guarding in both periods (Figure 1, panels (a) and (b)). However, despite the greater probability of nonpaternity, positive transfers between kin allow fidelity families to achieve greater fitness (Figure 1, panel (c)). Why?

The main reason lies in fatherhood uncertainty. Because paternity is uncertain, two individuals who are highly confident they share the same mother (and thus ρ is very high) are likely to be genetically closer to each other than to their own offspring. In these circumstances, transferring food to a younger (still dependent) sibling is thus efficiency enhancing as inclusive fitness will increase. Despite the risk of cuckoldry, this transfer requires the male to shift resources either from own offspring's food provision or, more likely, from unproductive guarding, or both. Lower guarding is only possible within the family configuration and when kin detection is high or perfect.

5. The Secular Utility of Religion

A recurrent theme of this study is the idea that guarding is unavoidable when paternity is uncertain, even though from the society's viewpoint guarding is a waste. Social norms or institutions that can optimally reduce guarding, therefore, will lead to a fitness gain at both the individual and the group (or society) level. One such institution is religion or, more precisely, all religions and moral systems that are centered around the importance of the family and stress the necessary role of domestic fidelity and avoidance of casual sex. Our analysis will shed light on the issue as to why virtually all major world religions, which have survived so far, share these features.

To see how family-centered religious beliefs affect our results, consider two fidelity villages in which kin detection is perfect ($\rho = 1$), so that food transfers between siblings are observed in equilibrium. One of the villages is populated by individuals whose behavior is described in the previous section and characterized in Proposition 6. Individuals in the other village behave exactly in the same manner, but in addition they all try to abide by religious beliefs according to which casual sex is sinful (and, thus, it is prohibited and punished), while fidelity is virtuous (and, thus, it is promoted and nurtured).

One way to embed this specific moral system in our model is to assume that it modifies the probability of successful guarding (1) as follows:

$$q(g_t) = \bar{g} + g_t^\alpha, \tag{11}$$

where, for $t = 1, 2$, the parameter $\bar{g} \in (0, g_{max})$ is the probability of fatherhood for a male who does not guard his mate, with g_{max} , an upper bound that depends on α , ensuring interior solutions, and $0 < \alpha < 1/3$.

Under the new guarding technology (11), and using (8) and (10), numerical analysis yields the following proposition:

Proposition 7. *Total survivorship and fitness are greater in the religious village ($\bar{g} > 0$) than in the non-religious village ($\bar{g} = 0$), while mate guarding declines and kin ties become weaker.*

Figure 2 shows child-specific food provision, kin transfers, guarding, survivorship and adult fitness as \bar{g} increases from 0 to 0.2, for a given value of α ($\alpha = 0.2$). As the default probability of paternity increases, the amount of food received by both own children in all

periods and by younger siblings goes up, and so do child survival probabilities and adult fitness, while the fraction of time spent by adult males guarding their partners declines.

If, by emphasizing the salience of the family and clamping down on casual sex, a religion can guarantee a nonzero probability of fatherhood even when males do not guard their official partners, then that religion will provide large material benefits for all its followers. The lower risk of casual sex reduces the need of unproductive guarding among males. Males then will devote more resources to food provision, which in turn enhances child survival. Interestingly, in comparison to fathers from the non-religious village, those in the religious village supply more food to own offspring and less to their younger siblings. This lower reliance on kin transfers stems from the fact that, in equilibrium, males are more confident that their “official” children are indeed genetically theirs, and thus they have a lower need of guarding. Because family-centered religious beliefs guarantee some (and, possibly, even high) success in assuring paternity, males can attain a greater propagation of their own genes by lavishing their own children with greater amounts of food.²³

Religion, therefore, is efficiency enhancing because it curbs the waste generated by guarding. In this sense, the societal material effects of religion are similar to those produced by kinship. But, differently from kinship, religion does not generate additional (individual- and group-level) benefits by inducing males to transfer resources also to genetically close relatives in addition to their own presumed offspring. In our model, religion allows all villagers to attain greater fitness and survivorship by modifying directly their guarding technology, thereby giving them enough confidence that fidelity is the norm in sexual life and casual sex is immoral and, at various degrees, is punished.

Proposition 7 suggests that a family-based religion offers tangible collective benefits, measured in the hard currency of greater survival and reproduction, for its members. All religions and belief systems that are centered around the family can thus be seen as an extremely successful group-level adaptation (Wilson 2002). It is interesting to note that virtually all major world religions have emphasized, on the one hand, the centrality of the fidelity family (and especially marriage as a public and community-recognized contract and commitment) as well as the procreation and nurture of legitimate children²⁴, and,

²³Religion not only reduces the amount of food transferred to kin but also increases the critical value of the sib recognition parameter, ρ , below which kinship cannot emerge. Moreover, stricter or more exigent belief systems that increase \bar{g} will lead to further reductions in guarding and food transfers to siblings, and to further increases in food supplied to own offspring. As a result, survivorship and fitness will also increase.

²⁴This is the case also for Christianity and Buddhism, despite the fact that they proposed or commanded

on the other hand, have proscribed a wide range of sexual sins, including adultery and fornication, and stigmatized the product of casual sex, illegitimate children (Browning, Green, and Witte 2006).

In villages (or societies) in which family-centered religious beliefs are strong (i.e., \bar{g} is high), our theory predicts the fidelity family to be the dominant form of marital life, with little room for other types of partnership. For other environments, instead, in which religion is not so strong (because, for example, religious norm enforcement is low), we expect the fidelity family to be less prevalent and to coexist with other family types.

Besides empirical examinations of this prediction, there are several other issues that could be examined in future work. For example, how can family-centered beliefs be credibly enforced? If family-centered religions and moral systems are so crucial to guarantee multilevel (group) selection, do we observe increasing long-run trends in religiosity even in times and civilizations where other institutions (such as the state and the law) could defend and promote the fidelity family? Addressing these questions would make up a rather full agenda for future research.

6. Conclusion

This paper presents an overlapping generations model with uncertain paternity and overlapping cohorts of dependent children to explain why humans live in families rather than in other pair groupings. Our analysis indicates that the fidelity family dominates the promiscuous pair bonding, in the sense that it can achieve greater survivorship and enhanced genetic fitness. The explanation is rather intuitive. In a promiscuous environment, a male has to share the responsibility of supporting his own offspring with another male, and thus ends up free riding on this other male's provisions. He, instead, will devote more of his time to guarding, increasing his paternity confidence. But since every promiscuous male follows the same strategy and since guarding is socially unproductive, children in promiscuous families will receive less food and will be less likely to survive than children in fidelity families, and thus promiscuous villages will grow less than fidelity villages.

We extend our benchmark model to a kinship system in which an adult male, who continues to care only for his own genes, may consider transferring resources not just to his offspring but also to his younger siblings. In this world, we show that kin ties never

celibacy for (at least) some of their religious leaders, and sometimes idealized the sexually abstinent marriage.

emerge as an equilibrium outcome in a promiscuous environment. In fact, even in a fidelity family environment, food transfers to younger siblings will not occur in equilibrium as long as sibling recognition is not sufficiently high. Thus, it is only when sib detection is (almost) perfect that kinship emerges, and only within fidelity families.

A substantive implication of the model is related to the idea that norms and religious beliefs that are centered around the fidelity family can be seen as a successful group-level adaptation. Societies which adopt a belief system that supports the family are likely to outgrow otherwise comparable societies that do not. Our analysis predicts that, in societies with strong family-based religious norms, the family will be the dominant form of family life, whereas in societies in which family-centered norms are weak or not enforced, the fidelity family is expected to coexist with other family types. It may not be a coincidence that virtually all the surviving world religions emphasize the centrality of the family.

The model yields other implications and opportunities for further analysis. An important implication is given by the observation that the promiscuous family in our model shares a number of features with the contemporary “blended” family described in Ginther and Pollak (2004). Like our promiscuous partnership, the blended family is characterized by stepchildren (born from an earlier marital union) living together with their half-siblings who are the joint children from an ongoing union. A vast empirical literature has documented that experience of life in a blended family is associated with unfavorable child outcomes (e.g., Duncan and Brooks-Gunn 1997). Such poorer outcomes are explained by a variety of mechanisms, including parental stress and family conflict after separation and remarriage, inferior maternal time allocation within blended families, and economic hardship following family disruption. Our model instead suggests a different explanation, based on the free riding over resources given to children by the first father-figure and the second father-figure: males in promiscuous unions undersupply resources to their children, while seeking to free ride on each others’ provisions.²⁵ Related to this issue, future research may focus on the increasing importance of mothers’ contribution to household resources.

Moreover, in a world with perfect food storage, parents can easily secure their youngest (still needy) offspring full access to resources even after their death. But if food storage were not perfect, then this security is not automatic and parents will have to resort to

²⁵This free riding explanation echoes that proposed by Weiss and Willis (1985), but with an important difference. In Weiss and Willis the free riding problem arises between former spouses (mother and father), who after divorce lose control over each others’ allocative decisions. In our model, instead, it is the result of the interaction between unrelated males who have to support their respective blended families.

other forms of intergenerational transfers. One of such forms is extended kin ties. When we allow storage to be impractical or impossible, parents have to rely on kin transfers for the survivorship of their own non-adult offspring, and the food substitution from parents to kin will be complete. The notion of kinship here should be fairly broad and, besides own children, future extensions could include other related kin, such as uncles and cousins.

In the same vein, future work may also focus on other systems of parent-child transfers, which rely on goods that either are easier to store than food or can be bequeathed, and may or may not require support from kin other than own offspring. An example is *fiat* money, i.e., any object with no intrinsic value (such as a collection of pieces of paper or certain types of seashells) that can be used only as a medium of exchange (Kiyotaki and Wright 1989). An extension concerned with fiat money will have to deal with the possibility of saving, as distinct from the (in)ability of storing resources, as well as with strategic interactions between elderly parents and adult children (Lundberg and Pollak 2007). The presence of money may allow us to address new substantive questions by examining, for instance, the extent to which money reduces the need for parents to rely on extended kinship systems to transfer resources to their offspring.

Appendix: Proofs

Derivation of the Female's Optimum When There Are No Kin Ties

Let $\widehat{f}_2 + \widehat{s}_2 = \widehat{z}$. Then the female's objective function is given by

$$\max_m \left\{ (m\widehat{f}_1\widehat{z})^\alpha + [(1-m)\widehat{z}\widehat{s}_3]^\alpha \right\},$$

which is strictly concave, and has one global maximum. The first-order condition of this problem is

$$\alpha m^{\alpha-1} [\widehat{f}_1\widehat{z}]^\alpha - \alpha(1-m)^{\alpha-1} [\widehat{z}\widehat{s}_3]^\alpha = 0. \quad (\text{A.1})$$

Algebraic manipulation of (A.1) leads to (6).

Proof of Proposition 1 (*Fidelity Family*)

Let $f_2 + s_2 = z$. The problem faced by the male is to choose g_1, g_2, f_1, z and s_3 to maximize

$$g_1^\alpha f_1^\alpha (\widehat{m}z)^\alpha / 2 + g_2^\alpha [(1-\widehat{m})z]^\alpha s_3^\alpha, \quad \text{s.t. } 2 = g_1 + f_1 + g_2 + z + s_3, \quad \text{with } g_1, f_1, z, s_3, g_1, g_2 \geq 0.$$

This objective function is strictly concave in f_1, z, g_1, g_2 , and s_3 . Assume first that there are no sign constraints. Then, the linearity of the equality constraint gives existence and uniqueness of the global maximum. Eliminate g_1 from the budget constraint, and denote

$$A = 2 - f_1 - s_3 - z - g_2. \quad (\text{A.2})$$

Note that A is not a constant. The first order conditions are as follows:

$$A^\alpha - f_1 A^{\alpha-1} = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.3a})$$

$$f_1^\alpha \widehat{m}^\alpha A^\alpha - z f_1^\alpha \widehat{m}^\alpha A^{\alpha-1} + (1-\widehat{m})^\alpha s_3^\alpha g_2^\alpha = 0 \quad (\text{w.r.t. } z) \quad (\text{A.3b})$$

$$-f_1^\alpha (\widehat{m}z)^\alpha A^{\alpha-1} + [(1-\widehat{m})z]^\alpha s_3^\alpha g_2^{\alpha-1} = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.3c})$$

$$-f_1^\alpha (\widehat{m}z)^\alpha A^{\alpha-1} + [(1-\widehat{m})z]^\alpha s_3^{\alpha-1} g_2^\alpha = 0 \quad (\text{w.r.t. } s_3). \quad (\text{A.3d})$$

Using (A.2), equations (A.3a)–(A.3d) form a system of four equations in four unknowns (f_1, s_3, z , and g_2) with no bounds, and with six exogenous parameters, $\widehat{g}_1, \widehat{g}_2, \widehat{z}, \widehat{s}_3, \widehat{m}$, and ρ .

From (A.3a), $f_1 = A$, while (A.3c) and (A.3d) imply $s_3 = g_2$. Then it is easy to verify that, when $m = 1/2$, this set equations is satisfied by

$$f_1 = g_1 = g_2 = s_3 = z/2 = 1/3.$$

The Nash equilibrium is obtained setting $\widehat{g}_1 = g_1$, $\widehat{g}_2 = g_2$, $\widehat{z} = z$, and $\widehat{s}_3 = s_3$. It remains to be checked that $m = 1/2$ is also the mother's optimal response given the values chosen by the male. As the optimal choice of the male is always such that $f_1 = s_3$, her optimal response indeed is $m = 1/2$. Therefore, $\widehat{m} = m$. Hence:

$$f_1 = g_1 = g_2 = s_3 = z/2 = (f_2 + s_2)/2 = 1/3 \quad \text{and} \quad m = 1/2.$$

Since all optimal values are interior to the bounds, the solution with and without sign constraints is the same.

Proof of Proposition 2 (*Promiscuous Pair Bonding*)

Let $\tilde{f}_2 = \hat{m}(f_2 + \hat{s}_2)$ and $\tilde{s}_2 = (1 - \hat{m})(\hat{f}_2 + s_2)$. Note that $f_2 = \tilde{f}_2/\hat{m} - \hat{s}_2$ and $s_2 = \tilde{s}_2/(1 - \hat{m}) - \hat{f}_2$. Assuming no sign constraints, the optimization problem becomes

$$\max \left(g_1^\alpha f_1^\alpha \tilde{f}_2^\alpha + g_2^\alpha \tilde{s}_2^\alpha s_3^\alpha \right) / 2 \quad \text{s.t.} \quad 2 = g_1 + f_1 + g_2 + \tilde{s}_2 / (1 - \hat{m}) - \hat{f}_2 + \tilde{f}_2 / \hat{m} - \hat{s}_2 + s_3$$

Since the objective function is strictly concave in $f_1, \tilde{f}_2, g_1, g_2, \tilde{s}_2$ and s_3 , and the maximization is subject to a linear equality constraint, the first order conditions are necessary and sufficient to pin down the unique and global maximum.

Under the assumption that $m = 1/2$ is the equilibrium response of the mother, let us derive the optimal strategy of the father. We shall then check that the optimal choice of the male does induce $m = 1/2$ as the woman's optimal equilibrium choice. Eliminating g_1 and letting $A = 2 - f_1 - 2\tilde{f}_2 - 2\tilde{s}_2 - s_3 - g_2 + \hat{f}_2 + \hat{s}_2$, the first order conditions are

$$\alpha f_1^{\alpha-1} \tilde{f}_2^\alpha A^\alpha - \alpha A^{(\alpha-1)} f_1^\alpha \tilde{f}_2^\alpha = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.4a})$$

$$\alpha \tilde{f}_2^{\alpha-1} f_1^\alpha A^\alpha - 2\alpha \tilde{f}_2^\alpha f_1^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } \tilde{f}_2) \quad (\text{A.4b})$$

$$\tilde{s}_2^\alpha s_3^\alpha g_2^{\alpha-1} - f_1^\alpha \tilde{f}_2^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.4c})$$

$$\alpha \tilde{s}_2^{\alpha-1} s_3^\alpha g_2^\alpha - 2\alpha f_1^\alpha \tilde{f}_2^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } \tilde{s}_2) \quad (\text{A.4d})$$

$$\alpha \tilde{s}_2^\alpha s_3^{\alpha-1} g_2^\alpha - \alpha f_1^\alpha \tilde{f}_2^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } s_3) \quad (\text{A.4e})$$

It is straightforward to verify that $f_1 = g_1 = g_2 = s_3 = 2/5$ and $\tilde{s}_2 = \tilde{f}_2 = 1/5$ is the solution to the five first-order conditions above. Now, to determine the Nash equilibrium, we note that, because $f_1 = s_3$, the optimal response of the mother must be $m = 1/2$. Given this, we can recover f_2 and s_2 from

$$f_2 = [1/(1/2)](1/5) - \hat{s}_2 \quad (\text{A.5})$$

$$s_2 = [1/(1 - 1/2)](1/5) - \hat{f}_2 \quad (\text{A.6})$$

At the Nash equilibrium, $f_2 = \hat{f}_2$ and $s_2 = \hat{s}_2$. The system (A.5)–(A.6) becomes singular, and boils down to the single expression $f_2 + s_2 = 2/5$. Therefore, the Nash equilibrium is

$$f_1 = g_1 = g_2 = s_3 = 2/5 \quad \text{and} \quad s_2 + f_2 = 2/5.$$

As in the case of Proposition 1, this solution (without sign constraints) coincides with the solution with sign constraints, since all optimal values are interior to the bounds.

Derivation of the Female's Optimum in the Presence of Kin Ties

Let $\hat{f}_2 + \hat{s}_2 = \hat{z}$. Rearranging (8), the female's problem becomes that of choosing m to maximize

$$m^\alpha (\hat{f}_1 \hat{z})^\alpha + (1 - m)^\alpha \hat{z}^\alpha \left[m^\alpha \hat{f}_1^\alpha \hat{z}^\alpha (\hat{s}_3 + \hat{b})^\alpha + (1 - m^\alpha \hat{f}_1^\alpha \hat{z}^\alpha) \hat{s}_3^\alpha \right].$$

The first-order necessary condition is

$$m^{\alpha-1} \hat{f}_1^\alpha - (1 - m)^{\alpha-1} \left\{ m^\alpha \hat{f}_1^\alpha \hat{z}^\alpha \left[(\hat{s}_3 + \hat{b})^\alpha - \hat{s}_3^\alpha \right] + \hat{s}_3^\alpha \right\} + (1 - m)^\alpha m^{\alpha-1} \hat{f}_1^\alpha \hat{z}^\alpha \left[(\hat{s}_3 + \hat{b})^\alpha - \hat{s}_3^\alpha \right] = 0,$$

and this leads to the equation that implicitly defines m , that is:

$$\left(\frac{m}{1-m}\right)^{\alpha-1} \widehat{f}_1^\alpha - \widehat{s}_3^\alpha - m^{\alpha-1}(2m-1) \left\{ \widehat{f}_1^\alpha (\widehat{f}_2 + \widehat{s}_2)^\alpha \left[(\widehat{s}_3 + \widehat{b})^\alpha - \widehat{s}_3^\alpha \right] \right\} = 0. \quad (\text{A.7})$$

Numerical analysis shows that the necessary condition is also sufficient, and that the solution to (A.7) is the global maximum.

Proof of Proposition 4 (*Promiscuous Pair Bonding with Kinship*)

Using the same notation as that used in the proof of Proposition 2, the male's problem is to choose $g_1, f_1, g_2, \widetilde{f}_2, \widetilde{s}_2, s_3$ and b to maximize

$$g_1^\alpha f_1^\alpha \widetilde{f}_2^\alpha / 2 + g_2^\alpha \left[f_1^\alpha \widetilde{f}_2^\alpha \widetilde{s}_2^\alpha (s_3 + \widehat{b})^\alpha + \left(1 - f_1^\alpha \widetilde{f}_2^\alpha\right) \widetilde{s}_2^\alpha s_3^\alpha \right] / 2 + \widehat{g}_1^\alpha \widehat{g}_2^\alpha \widehat{s}_2^\alpha (\widehat{s}_3 + b)^\alpha \rho / 4$$

$$\begin{aligned} \text{s.t. } 2 &= f_1 + s_3 + \widetilde{s}_2 / (1 - \widehat{m}) - \widehat{f}_2 + g_2 + \widetilde{f}_2 / \widehat{m} - \widehat{s}_2 + b + g_1 \\ 0 &\leq f_1, \widetilde{f}_2, g_1, g_2, \widetilde{s}_2, s_3, b. \end{aligned}$$

Proposition 2 proves that, in the absence of kinship ties ($b=0$), the Nash equilibrium is such that $f_1 = s_3$, and the global maximum for the mother is $m = 1/2$. Therefore, we now derive the male's optimal strategy under the assumption $\widehat{m} = 1/2$, and we then check that his optimal choice is indeed such $f_1 = s_3$. For the time being, we ignore the sign constraints on all the control variables, except that on b . The male's objective function then can be rewritten as

$$\frac{1}{2} \left\{ f_1^\alpha \widetilde{f}_2^\alpha \left[g_1^\alpha + \widetilde{s}_2^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] + \widetilde{s}_2^\alpha s_3^\alpha g_2^\alpha \right] + \frac{\widehat{g}_1^\alpha \widehat{g}_2^\alpha}{4} \widehat{s}_2^\alpha (\widehat{s}_3 + b)^\alpha \rho \right\}$$

$$\begin{aligned} \text{s.t. } 2 &= f_1 + s_3 + 2\widetilde{s}_2 - \widehat{f}_2 + g_2 + 2\widetilde{f}_2 - \widehat{s}_2 + b + g_1 \\ 0 &\leq b. \end{aligned}$$

Eliminating g_1 and letting $A = 2 - f_1 - 2\widetilde{f}_2 - 2\widetilde{s}_2 - s_3 - b - g_2 + \widehat{f}_2 + \widehat{s}_2$, the Kuhn-Tucker conditions are:

$$\alpha f_1^{\alpha-1} \widetilde{f}_2^\alpha \left\{ A^\alpha + \widetilde{s}_2^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] \right\} - \alpha A^{\alpha-1} f_1^\alpha \widetilde{f}_2^\alpha = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.8a})$$

$$\alpha \widetilde{f}_2^{\alpha-1} f_1^\alpha \left\{ A^\alpha + \widetilde{s}_2^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] \right\} - 2\alpha \widetilde{f}_2^{\alpha-1} f_1^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } \widetilde{f}_2) \quad (\text{A.8b})$$

$$\alpha f_1^\alpha \widetilde{f}_2^\alpha g_2^{\alpha-1} \widetilde{s}_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] - \alpha \widetilde{f}_2^\alpha f_1^\alpha A^{\alpha-1} + \alpha g_2^{\alpha-1} \widetilde{s}_2^\alpha s_3^\alpha = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.8c})$$

$$\alpha \widetilde{s}_2^{\alpha-1} f_1^\alpha \widetilde{f}_2^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] + \alpha \widetilde{s}_2^{\alpha-1} s_3^\alpha g_2^\alpha - 2\alpha f_1^\alpha \widetilde{f}_2^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } \widetilde{s}_2) \quad (\text{A.8d})$$

$$\alpha \widetilde{s}_2^\alpha f_1^\alpha \widetilde{f}_2^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^{\alpha-1} - s_3^{\alpha-1} \right] + \alpha \widetilde{s}_2^\alpha s_3^{\alpha-1} g_2^\alpha - \alpha f_1^\alpha \widetilde{f}_2^\alpha A^{\alpha-1} = 0 \quad (\text{w.r.t. } s_3) \quad (\text{A.8e})$$

It can be easily verified that the system (A.8a)–(A.8e) when evaluated at $b = 0$ has the same solution as when there is no kin tie (Proposition 2), that is $f_1 = g_1 = g_2 = s_3 = 2/5$ and $\widetilde{s}_2 = \widetilde{f}_2 = 1/5$. The Kuhn-Tucker condition on b is given by

$$\alpha(1 - \widehat{m})^\alpha (\widehat{s}_2 + \widehat{f}_2)^\alpha (\widehat{s}_3 + b)^{\alpha-1} \rho / 4 - \alpha A^{\alpha-1} (1 - \widehat{m})^\alpha (s_2 + \widehat{f}_2)^\alpha s_3^\alpha / 2 + \mu = 0, \quad (\text{A.9})$$

where μ is the multiplier associated to the constraint $b \geq 0$. The Kuhn-Tucker theorem implies $-b \leq 0$, $\mu \geq 0$, and $\mu b = 0$. At the Nash equilibrium we must have $f_2 = \hat{f}_2$, $s_2 = \hat{s}_2$, and $s_3 = \hat{s}_3$. We have already shown that, when $b = 0$, the system (A.8a)–(A.8e) delivers the same solution as that given in Proposition 2 where kin ties are ruled out. With $b = 0$, equation (A.9) becomes

$$\left[\frac{\rho}{2} - \left(\frac{2}{5} \right)^\alpha \right] \left[\frac{\alpha}{2} \left(1 - \frac{1}{2} \right)^\alpha \left(\frac{2}{5} \right)^\alpha \left(\frac{2}{5} \right)^{\alpha-1} \right] + \mu = 0$$

The value of ρ that sets μ to zero is $2(2/5)^\alpha$. At such a value, Proposition 2 holds. When $\rho < 2(2/5)^\alpha$, then $\mu > 0$, and again Proposition 2 holds with $b=0$. If instead $\rho > 2(2/5)^\alpha$, then $b = 0$ cannot be not a solution. Note however that the upper bound on admissible values of $2(2/5)^\alpha$ is obtained when $\alpha = 1/3$. At this value of α , $\rho > 1$, which is a contradiction. Therefore, in equilibrium, as long as ρ is below $2(2/5)^\alpha$, b must be zero.

As mentioned, this solution satisfies the necessary first-order conditions with no sign constraints, except $b \geq 0$. But this solution is interior, and thus it satisfies the necessary first-order conditions of the original optimization problem with sign constraints on all variables. Showing that such conditions are also sufficient requires computing the determinants of several cumbersome matrices. With the numerical algorithm described in the proof of Proposition 6, we will show that the solution to the first-order conditions is indeed the global maximum of this case.

Proof of Proposition 5 (*Fidelity Family with Kinship and Low Kin Recognition*)

Let $f_2 + s_2 = z$. The problem faced by the male is to choose g_1, f_1, g_2, z, s_3 and b to maximize

$$f_1^\alpha (\hat{m}z)^\alpha g_1^\alpha + E \left\{ [(1 - \hat{m})z]^\alpha (s_3 + \hat{b})^\alpha g_2^\alpha \right\} + \left(\frac{1 + \hat{g}_1^\alpha \hat{g}_2^\alpha}{2} \right) [(1 - \hat{m})\hat{z}]^\alpha (\hat{s}_3 + b)^\alpha \rho$$

$$\text{s.t. } 2 = f_1 + z + s_3 + g_2 + b + g_1 \quad \text{with } g_1, f_1, z, s_3, g_2, b \geq 0.$$

The objective function is equivalent to

$$f_1^\alpha (\hat{m}z)^\alpha g_1^\alpha + f_1^\alpha (\hat{m}z)^\alpha [(1 - \hat{m})z]^\alpha (s_3 + \hat{b})^\alpha g_2^\alpha \\ + [1 - f_1^\alpha (\hat{m}z)^\alpha] [(1 - \hat{m})z]^\alpha s_3^\alpha g_2^\alpha + \left(\frac{1 + \hat{g}_1^\alpha \hat{g}_2^\alpha}{2} \right) [(1 - \hat{m})\hat{z}]^\alpha (\hat{s}_3 + b)^\alpha \rho$$

We ignore sign constraints on all variables except on b . Eliminating g_1 , denoting $A = 2 - f_1 - s_3 - z - g_2 - b$, and noting that A is not a constant, the necessary Kuhn-Tucker conditions are given by:

$$A^\alpha - f_1 A^{\alpha-1} + z^\alpha (1 - \hat{m})^\alpha g_2^\alpha \left[(s_3 + \hat{b})^\alpha - s_3^\alpha \right] = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.10a})$$

$$f_1^\alpha \hat{m}^\alpha A^\alpha - z f_1^\alpha \hat{m}^\alpha A^{\alpha-1} + (1 - \hat{m})^\alpha s_3^\alpha g_2^\alpha \\ + 2z^\alpha f_1^\alpha \hat{m}^\alpha (1 - \hat{m})^\alpha g_2^\alpha \left[(s_3 + \hat{b})^\alpha - s_3^\alpha \right] = 0 \quad (\text{w.r.t. } z) \quad (\text{A.10b})$$

$$-f_1^\alpha (\hat{m}z)^\alpha A^{\alpha-1} + f_1^\alpha (\hat{m}z)^\alpha g_2^{\alpha-1} ((1 - \hat{m})z)^\alpha (s_3 + \hat{b})^\alpha \\ + (1 - f_1^\alpha (\hat{m}z)^\alpha) g_2^{\alpha-1} ((1 - \hat{m})z)^\alpha s_3^\alpha = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.10c})$$

$$-f_1^\alpha (\hat{m}z)^\alpha A^{\alpha-1} + f_1^\alpha (\hat{m}z)^\alpha g_2^\alpha ((1 - \hat{m})z)^\alpha (s_3 + \hat{b})^{\alpha-1} \\ + (1 - f_1^\alpha (\hat{m}z)^\alpha) g_2^\alpha ((1 - \hat{m})z)^\alpha s_3^{\alpha-1} = 0 \quad (\text{w.r.t. } s_3) \quad (\text{A.10d})$$

$$-f_1^\alpha (\widehat{m}z)^\alpha A^{\alpha-1} + \frac{\rho}{2}(1 + \widehat{g}_1^\alpha \widehat{g}_2^\alpha)((1 - \widehat{m})\widehat{z})^\alpha (\widehat{s}_3 + b)^{\alpha-1} + \mu = 0 \quad (\text{w.r.t. } b), \quad (\text{A.10e})$$

where μ is the multiplier associated to $b \geq 0$. Given that $A = 2 - f_1 - s_3 - z - g_2 - b = g_1$, (A.10a)–(A.10e) form a system of six equations in six unknowns (f_1, s_3, z, g_2, b and g_1) and no bounds on the variables. The seven exogenous parameters are $\{\widehat{g}_1, \widehat{g}_2, \widehat{z}, \widehat{s}_3, \widehat{m}, \widehat{b}, \rho\}$. It can be verified that the system (A.10a)–(A.10d) evaluated at $b = 0$ delivers the same solution as the corresponding system of equations of Proposition 1 where kinship was ruled out. That is, $f_1 = g_1 = g_2 = s_3 = z/2 = (f_2 + s_2)/2 = 1/3$ and $m = 1/2$. The question is to check whether (A.10e) turns to zero when it is evaluated at such values. Using these proposed equilibrium values, the left-hand side of (A.10e) becomes

$$\left(\frac{1}{3}\right)^{2\alpha-1} \left\{ -\left(\frac{1}{3}\right)^\alpha + \frac{\rho}{2} \left[1 + \left(\frac{1}{3}\right)^\alpha \left(\frac{1}{3}\right)^\alpha \right] \right\} + \mu. \quad (\text{A.11})$$

Note that, from the expression in brackets, the first term in (A.11) is nonpositive when

$$\rho \leq \underline{\rho} = 2 \left(\frac{1}{3}\right)^\alpha \left(1 + \left(\frac{1}{3}\right)^{2\alpha} \right)^{-1}.$$

Recall that the Kuhn-Tucker theorem implies $-b \leq 0$, $\mu \geq 0$, and $\mu b = 0$. Now, if $\rho \leq \underline{\rho}$, in equilibrium we must have $f_1 = g_1 = g_2 = s_3 = z/2 = (f_2 + s_2)/2 = 1/3$ and $b = 0$, as stated in Proposition 1 where kin ties are ruled out. Therefore, when $b = 0$, the system (A.10a)–(A.10d) is satisfied by our guessed solution, which is same as that found in Proposition 1, as long as ρ does not exceed $\underline{\rho}$. In particular, if $\rho = \underline{\rho}$, the proposed solution verifies (A.10e) (or, equivalently, (A.11)) and $\mu = 0$, while if $\rho < \underline{\rho}$, the multiplier associated to b , μ , is positive at the guessed solution. On the other hand, when kin recognition is high enough, i.e., $\rho > \underline{\rho}$, the value of μ at the proposed solution is strictly negative, which fails to meet the requirements of the Kuhn-Tucker theorem, and $b = 0$ cannot be a solution.

As mentioned, this solution satisfies the necessary first-order conditions with no sign constraints, except $b \geq 0$. But this solution is interior, and thus it satisfies the necessary first-order conditions of the original optimization problem with sign constraints on all variables. Showing that such conditions are also sufficient requires computing the determinants of several cumbersome matrices. With the numerical algorithm described in the proof of Proposition 6, we will show that the solution to the first-order conditions is indeed the global maximum of this case.

We finally have to check that the assumed $m = 1/2$ is the mother's optimal response given the proposed equilibrium values of the variables under the male's control. If $b = \widehat{b} = 0$ and $\widehat{m} = 1/2$, the male will choose in a way such that $f_1 = s_3$ in equilibrium. At such values, the female's optimal response is indeed $m = 1/2$.

Proof of Proposition 6 (*Fidelity Family with Kinship and High Kin Recognition*)

This proof relies on numerical simulations performed with a two-step optimization procedure. Codes of the algorithms are in C++ and are available at <http://privatewww.essex.ac.uk/~cghig/#material>. The first step consists of a constrained optimization algorithm associated with the maximization problem faced by each agent. The second step is an evolutionary algorithm which iteratively finds the fixed point in actions of the problem by minimizing the difference between the proposed solution to the problem and the other agents' actions.

Letting $f_2 + s_2 = z$, the problem faced by an adult male is to choose g_1, f_1, g_2, z, s_3 and b to maximize

$$z^\alpha f_1^\alpha \widehat{m}^\alpha g_1^\alpha + z^\alpha (1 - \widehat{m})^\alpha s_3^\alpha g_2^\alpha + z^{2\alpha} f_1^\alpha \widehat{m}^\alpha (1 - \widehat{m})^\alpha g_2^\alpha \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right]$$

$$+(1 + \widehat{g}_1^\alpha \widehat{g}_2^\alpha) [(1 - \widehat{m}) \widehat{z}]^\alpha (\widehat{s}_3 + b)^\alpha \rho / 2, \quad \text{s.t. } 2 = f_1 + g_1 + g_2 + z + s_3 + b,$$

taking $\widehat{g}_1, \widehat{g}_2, \widehat{z}, \widehat{s}_3, \widehat{m}, \widehat{b}$ and ρ as given, and with $g_1, f_1, z, s_3, g_2, b \geq 0$. The solution to this problem is a vector $\{g_1^*, f_1^*, g_2^*, z^*, s_3^*, b^*\}$ in which each component is a function of $\widehat{g}_1, \widehat{g}_2, \widehat{z}, \widehat{s}_3, \widehat{m}, \widehat{b}$ and ρ . This solution is obtained from the first algorithm of our two-step procedure. The optimal m, m^* , instead is obtained, using the secant algorithm, as a root of the implicit equation

$$\left(\frac{m}{1-m}\right)^{\alpha-1} \widehat{f}_1^\alpha - \widehat{s}_3^\alpha - m^{\alpha-1} (2m-1) \left\{ \widehat{f}_1^\alpha \widehat{z}^\alpha [(\widehat{s}_3 + \widehat{b})^\alpha - \widehat{s}_3^\alpha] \right\} = 0.$$

The equilibrium is a fixed point, which occurs when $\widehat{g}_1 = g_1^*, \widehat{f}_1 = f_1^*, \widehat{g}_2 = g_2^*, \widehat{z} = z^*, \widehat{s}_3 = s_3^*, \widehat{b} = b^*$, and $\widehat{m} = m^*$, with the equilibrium allocations depending on the parameters ρ and α . Once the optimization is performed, the second step consists of minimizing the Euclidean distance between $\{\widehat{g}_1, \widehat{f}_1, \widehat{g}_2, \widehat{z}, \widehat{s}_3, \widehat{b}, \widehat{m}\}$ and $\{g_1^*, f_1^*, g_2^*, z^*, s_3^*, b^*, m^*\}$, by choosing the ‘hat’ variables. The fixed point is reached by iteration. The numerical results as ρ increases from $\underline{\rho}$ to 1 for a given value of α ($\alpha = 0.2$) are shown in Figure 1.

Proof of Proposition 7

Using the guarding technology given in (11), and letting $f_2 + s_2 = z$, the problem faced by an adult male is to choose g_1, f_1, g_2, z, s_3 and b to maximize

$$z^\alpha f_1^\alpha \widehat{m}^\alpha (\bar{g} + g_1^\alpha) + z^\alpha (1 - \widehat{m})^\alpha s_3^\alpha (\bar{g} + g_2^\alpha) + z^{2\alpha} f_1^\alpha \widehat{m}^\alpha (1 - \widehat{m})^\alpha (\bar{g} + g_2^\alpha) \left[(s_3 + \widehat{b})^\alpha - s_3^\alpha \right] \\ + \frac{1}{2} [1 + (\bar{g} + g_1^\alpha)(\bar{g} + g_2^\alpha)] [(1 - \widehat{m}) \widehat{z}]^\alpha (\widehat{s}_3 + b)^\alpha \rho, \quad \text{s.t. } 2 = f_1 + g_1 + g_2 + z + s_3 + b,$$

with $g_1, f_1, z, s_3, g_2, b \geq 0$.

We solve this program numerically, following the same two-stage procedure as that used for Proposition 6. Codes of the algorithms are in C++ and are available at <http://privatewww.essex.ac.uk/~cghig/#material>. Numerical results as \bar{g} increases from 0 to 0.2 for a given value of α ($\alpha = 0.2$) are reported in Figure 2.

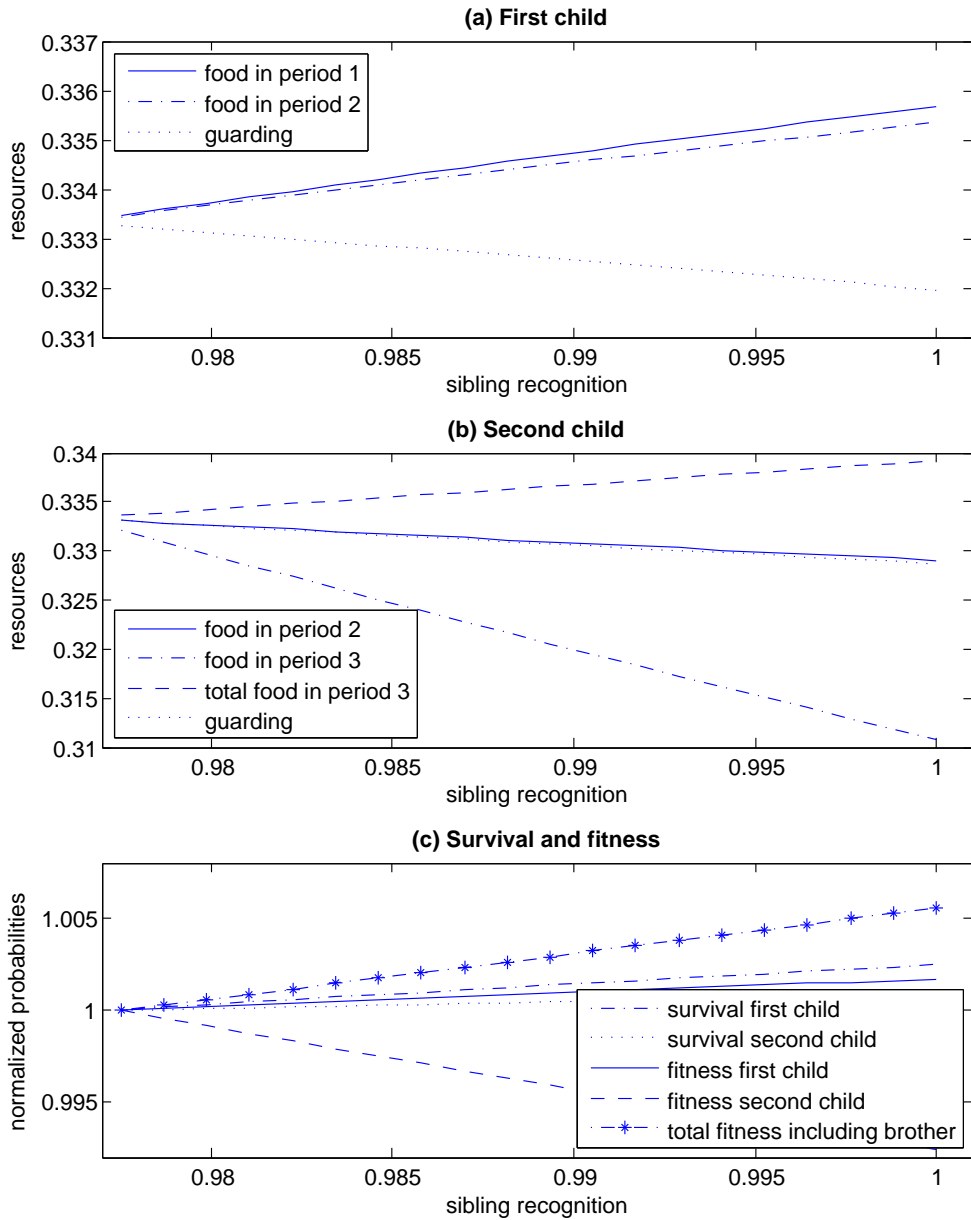


Figure 1: FOOD PROVISION, GUARDING, SURVIVORSHIP, AND FITNESS IN THE FIDELITY FAMILY WITH KINSHIP AS THE SIB RECOGNITION PARAMETER INCREASES FROM $\underline{\rho}$ TO 1

Note: Each figure in panel (c) is normalized to the corresponding probability at $\rho = \underline{\rho}$.

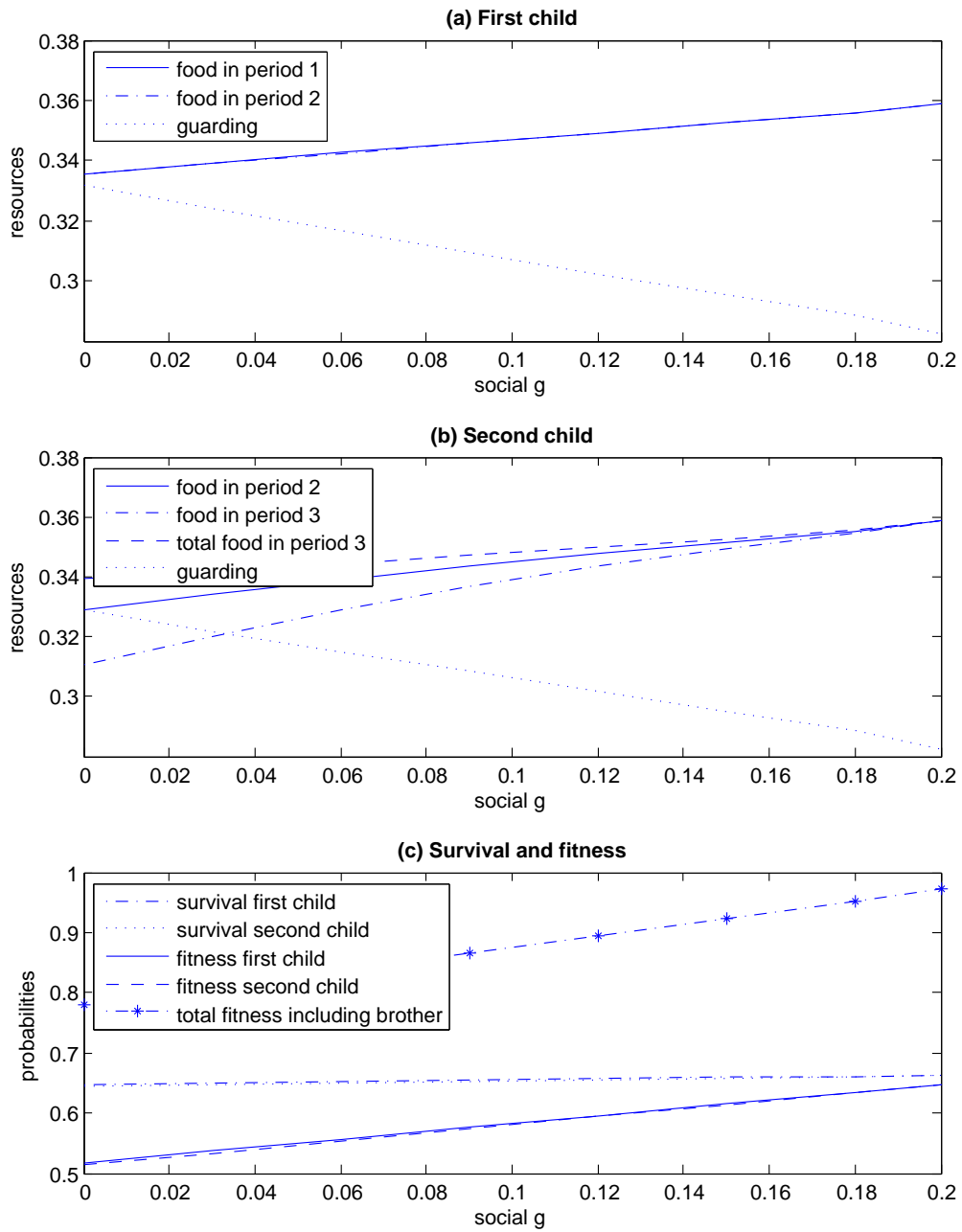


Figure 2: FOOD PROVISION, GUARDING, SURVIVORSHIP, AND FITNESS IN THE FIDELITY FAMILY WITH KINSHIP AS \bar{g} INCREASES FROM 0 TO 0.2

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