

On the Origin of the Family*

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Abstract

This paper presents an evolutionary overlapping generations model to explain the emergence of the fidelity family, in which all children share the same parents, and some of its main consequences. Two features are necessary and sufficient to induce the evolution of the fidelity family among humans, uncertain paternity and overlapping cohorts of children in need of parental investment. Our analysis establishes three new results. First, the fidelity family dominates promiscuous pair bonding, in the sense that it achieves greater survivorship and enhanced genetic fitness. The reason lies in the free riding behavior of competing fathers in the same promiscuous union. Second, the family — but not promiscuous pair bonding — fosters altruistic ties between siblings. Third, the model allows us to explain why all major world religions emphasize the importance of the fidelity family.

Keywords: Overlapping generations; Fatherhood uncertainty; Free riding; Kinship systems; Religion.

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1. Introduction

Why do humans live in families?¹ The fact that essentially all vertebrates are known to be non-familial (Lott 1991) suggests that the emergence of the family cannot be taken for granted.² This paper addresses such a question within a noncooperative evolutionary framework, in which males and females care only for their genetic fitness, that is, the survivorship and propagation of their own genes into future generations (Hamilton 1964). Following Becker's (1981/1991, 1989 and 1993) seminal work on the family, our analysis relies on an individual-optimizing approach and places a *minimal* set of assumptions to identify how the family came about.³ Specifically, the necessary and sufficient conditions in our model are two, the overlap of different cohorts of offspring and fatherhood uncertainty.

When paternity is uncertain, males must resort to guard their opposite-sex mate if they wish to enhance confidence in their biological association with the children they feed (Hawkes, Rogers, and Charnov 1995).⁴ 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 (e.g., Krützen et al. 2004). Most of such species in fact do not form families. The second special ingredient is the presence of overlapping cohorts of dependent children, which underlines the salience of parental investment (Trivers 1972). But, again, parental investment is not a sufficient condition to induce the formation of families as evidenced, for instance, by the complex (non-familial) colonies of eusocial insects (Wilson 1975).

The paper establishes three new substantive results. First, we show that when fatherhood uncertainty and overlapping cohorts of children operate *together*, the fidelity family is the dominant form of sexual organization among humans (Section 2). Second, extended kin ties are uniquely associated with the family in the sense that they provide fitness and survivorship gains only in the context of the fidelity family and not in the context of promiscuous pair bonding (Section 3). Third, in a world where men and women care for their reproductive success, casual sex and male guarding are unavoidable and yet socially wasteful activities. Their presence may induce the development of socially accepted norms that, in equilibrium, can reduce their impact and lead to fitness and survivorship gains at both individual and

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 or, equivalently, to the situation in which each man (woman) has all his (her) children with the *same* woman (man).

²Using a looser notion of family than ours (with the animal family being generically restricted to those species in which offspring continue to interact, into adulthood, with their parents), Emlen (1995) argues that less than 3 percent of avian and mammal species are known to be familial.

³Biologists and animal scientists, instead, usually identify *several* pathways that might have triggered the evolution of the family among humans and nonhuman animals alike (e.g., Emlen 1994; Reichardt and Boesch 2003; Chapais 2008).

⁴Even in contemporary general populations, nonpaternity rates seem to be non-negligible. 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 from 2 to about 30 percent.

group level. Therefore, while history has witnessed a wide range of sexual organizations, our model allows us to underpin the remarkable fact that virtually all major religions promote domestic fidelity and proscribe (or punish) sexual promiscuity, even though the punishment may directly reduce individual fitness (Section 4).

To provide an intuition of these results, we present some of the key aspects of the model. Imagine two ancestral villages in which people live for four periods, two as children and two as adults. As a child, an individual depends on the investments of the parents. As adults, men and women form their unions, women have one child in each of their adult periods, men guard their partners to increase confidence of their paternity, and all engage in casual sex. In both villages, there is full intrahousehold labor specialization (Becker 1981/1991): food can only be provided for by men (i.e., men are the sole investors in this setup), while women allocate food between their children. But the villages are different in one important respect. In one village an individual has both children with the same partner in a stable family grouping (what we call ‘fidelity’ family), while in the other village an individual begets each child with a different partner in a different period within a ‘promiscuous’ relationship.⁵

Our first main result, that the family allows its members to attain a higher probability of survival than the promiscuous pair bonding, 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 casual sex, in the attempt of spreading his genes into the future, and to guarding, in the attempt of increasing the likelihood of providing food to his own children. But since every promiscuous male follows the same strategy and casual sex and guarding are 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 of the promiscuous village is bound to be lower. We also show that the strategy underpinning the fidelity family convention is evolutionarily stable, while the promiscuous strategy is not. These results line up well with the huge body of contemporary empirical evidence according to which children who live (part of) their childhood in a blended family have lower educational attainment and experience worse outcomes later in life (e.g., McLanahan and Sandefur 1994; Duncan and Brooks-Gunn 1997; Ginther and Pollak 2004).

Private underprovision of public goods is a standard result (Samuelson 1955; Becker 1981/1991; Bergstrom, Blume, and Varian 1986). In the family context, Weiss and Willis (1985) present a model of divorce in which child expenditures are a collective good and,

⁵Note that the promiscuous pair bonding is the only alternative to the fidelity family that requires individual paternal investment. This alternative union shares some of the features of the contemporary blended (divorced) family (Ginther and Pollak 2004). It also reminds of the practice of *sequential monogamy*, which is quite common in many nonhuman (especially bird) species, whereby an individual has a different, but exclusive, breeding partner each mating season (e.g., Poirier, Whittingham, and Dunn 2004).

because upon divorce the noncustodial parent cannot control the allocative decisions of the custodial parent, the former free-rides on the amount spent on the maintenance of children. Like in their model, free-riding leads to an inefficient allocation of resources in the promiscuous family, but the mechanism in our model is different. In Weiss and Willis (as well as in most other later family applications), free-riding is between former spouses, who cannot verify each others' allocative decisions. In our setup, instead, it arises from the interaction between unrelated males who have to support their respective (blended) families and cannot write down binding verifiable contracts.

The second result, that altruistic ties between siblings cannot occur in a promiscuous environment where there is no family, emerges because each man, who is uncertain about his paternity and yet care only about reproductive success and makes crucial child investments, values his siblings because they provide him with the assurance that some of his genes will survive into future generations. This mechanism echoes those elaborated by Diamond and Locay (1989) and by earlier biological and anthropological research (Alexander 1974; Kurland 1979), although they suggest that if a male is uncertain about paternity, he may wish to invest in his *sister's* children with whom he is sure to share some genes. Our overlapping-generation model is an advance over such earlier studies in that it emphasizes the more fundamental link between older and younger siblings, with lower levels of genetic relatedness (e.g., with nephews and nieces) being expected to be only of lower importance (Hamilton 1964). By stressing the fitness gain through kinship ties, this result identifies the fidelity family as a key source of exchange among its members and thus a primary engine of primeval economic growth (Ofek 2001; Chapais 2008; Galor and Michalopoulos 2011).

Our kinship analysis uncovers two other new important findings, which deserve to be mentioned here. First, we find a primogeniture effect, according to which firstborn receive more food from their fathers compared to the case in which food transfers between siblings do not exist, while second born children receive less, even after taking account of the positive amount supplied by their older siblings. This effect emerges because, in an environment in which child survival is stochastic, fathers want to make sure that their firstborn can support their own younger offspring. Second, conditional on survival, it is second born who see their progeny enjoying a greater probability of survival than their older siblings' progeny. From the viewpoint of the second born, this 'regression-toward-the-mean' effect emerges because they expect their offspring to take advantage of the exchange in equilibrium and, without having to make kin transfers themselves, they can count on relatively greater endowments than their firstborn siblings'. Interestingly, evidence of the primogeniture effect is widely documented in the context of the contemporary family (e.g., Black, Devereux, and Salvanes 2005), while evidence in support of our regression-toward-the-mean effect has been found by Wahl (1985) for nineteenth century American families.

Finally, the third main result, that family centered religions may lead to fitness and survivorship gains, is directly explained by casual sex and guarding, two of the key ingredients of our model. Albeit socially wasteful, such activities are necessary for men who seek to maximize their reproductive success. Their presence in turn can induce the development of norms or institutions (which we call ‘religion’) that may attenuate their negative effects and yield fitness gains at the individual and group levels. The punishment imposed by religion, which essentially implies burning resources for men who engage in casual sex, may be too costly for religious norms to be ever introduced. We show, however, that an equilibrium with religion exists and that, in such a case, the direct effect of the punishment is to reduce casual sex. When casual sex goes down, the optimal response is to decrease mate guarding. But if the time spent in casual sex and guarding declines, then more time becomes available to be allocated toward the productive activity of food provision, which in turn enhances child survival.

This result therefore allows us to underpin the remarkable fact that virtually all major world religions center around the avoidance of casual sex and the importance of fidelity in the family (Browning, Green and Witte 2006). It allows us also to contribute to the understanding of the broader association between religion and economic outcomes (Acemoglu, Johnson and Robinson 2005; Guiso, Sapienza and Zingales 2006) and, more specifically, to the important debate about whether economic growth is affected by religious beliefs (Iannaccone 1998; McCleary and Barro 2006).

Related Literature — Since Becker’s pioneering works (1973, 1974, and 1981/1991), the family has become a prominent area of investigation among economists.⁶ 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 uncertain paternity 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 fatherhood 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 production

⁶See Bergstrom (1996), Weiss (1997), Lundberg and Pollak (2007), Browning, Chiappori and Weiss (2011) for insightful surveys and discussions.

of public goods are perfect substitutes (Lundberg and Pollak 2007). 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 (Robson 2001; Cox 2007; Bergstrom 2007) as well as economic development and growth (Galor and Michalopoulos 2011; Ashraf and Galor 2011).⁷ For instance, Siow (1998) investigates how differential fecundity interacts with market structure to affect gender roles in monogamous societies. Alger and Weibull (2010) 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.⁸

Somewhat closer to our approach is another set of studies that emphasize the importance of fatherhood uncertainty. These include Edlund and Korn (2002), Edlund (2006), and Saint-Paul (2008). But, unlike ours, such papers rule out casual sex and mate guarding. Rather, they underline the explicit or implicit transfers that take place between a man and a woman engaged in sexual reproduction (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 changes that might have altered the demand for marriage (e.g., the introduction of oral contraceptives). By looking at the question of why humans started to form families, we exclude the possibility of binding commitments and enforceable contracts and, rather, concentrate on mate guarding as men's strategic adaptation to casual sex and uncertain paternity.

Diamond and Locay (1989) also stress the role played by uncertain paternity in explaining kin ties. They note that males invest in sisters' children even at high paternity probabilities and that, in many societies, men invest in the children of both their official partner and their sisters. Like in our model, Diamond and Locay's explanation is that a male values his sister's children in part because they provide him with the assurance that some of his genes

⁷Earlier work by Becker (1976), which also considered the relationship between sociobiology and economics, argued 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.

⁸Interestingly, Alger and Weibull (2010) 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, albeit from a different perspective. See Section 4.

will survive into future generations. But as the number of children of his official partner increases, the probability that the male 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 own official children. As noted, our framework emphasizes an even more fundamental link, that is, the link between older and younger siblings rather than that between an adult man and his sororal nephews and nieces.

A growing number of studies focuses on the relevance of religion among individuals, groups and cultures (Iannaccone 1998; Acemoglu, Johnson and Robinson 2005; Guiso, Sapienza and Zingales 2006). This paper contributes to that broad research agenda, especially to the area concerned with the economic consequences of religion and social norms (Freeman 1986; Botticini and Eckstein 2007; McCleary and Barro 2006; Becker and Woessmann 2009), but looks at religious beliefs from a different perspective. In particular, by stressing the role of the punishment of socially wasteful activities, our model points explicitly to the secular utility of religion for all the individuals of the village that adopts it. Religion then is an extremely successful adaptation against casual sex, allowing the whole group, and not just an individual, to become better suited to its environment (Wilson 2002).

2. Benchmark Model

A. Preliminaries

In this section, we set up an overlapping generations model which allows us to understand how the family originated among humans. There are two villages populated by individuals who live for four periods. In every period in both villages, there is a unity sex ratio between identical men and identical women. During the first two periods (labeled i and ii), individuals are young, infertile, unproductive, and dependent.

In the last two periods (labeled 1 and 2), they become adult, fertile, and productive. In each of these two periods, two opposite-sex individuals from the same cohort are matched and have one child. Men are hunters and provide food for their offspring. Women are carers and allocate the food they receive from their partners between their children.⁹ In each period 1 and 2, a man divides his unit of time endowment into three activities: (a) food provision, which directly increases the odds of child survival; (b) mate guarding, which is socially unproductive but increases the probability that the child he supports carries his

⁹This full gender specialization in home and market tasks echoes Becker (1981/1991). All our results will be qualitatively the same even without this assumption, as long as men play a greater role in supplying food. Interestingly, for hunter-gatherer societies, Robson and Kaplan (2006) provide evidence 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. For further discussion, see Kaplan et al. (2000).

genes; and (c) casual sex, which increases the chance that his genes are represented in the next generation’s gene pool.¹⁰ In this benchmark setup, we assume that a male provides food *only* to the female(s) he is (or was) matched to, i.e., to the “official” mother(s) of his offspring. In the next section we shall relax this assumption and consider the case in which a male might choose to provide food also to other members of his extended family in addition to his own official mate(s).

We consider two alternative and mutually exclusive social configurations (or conventions): (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. We start by assuming that individuals of a given village cannot choose between such configurations, but abide to either Γ_F or Γ_P . We then show that Γ_F is stable, in the sense that fidelity family individuals do not gain from deviating to promiscuity, while Γ_P is an evolutionarily unstable convention.

B. Technologies and Actions

Let g_t denote the amount of time males spend guarding their mates in any period t , $t=1, 2$, and k_t be the amount of time spent in casual sex. The probability that guarding is successful is assumed to take the following form:

$$\gamma(g_t, \widehat{k}_t) = \left(\frac{g_t}{g_t + \widehat{k}_t} \right)^\alpha, \quad (1)$$

where $0 < \alpha < 1/2$ and \widehat{k}_t is the total amount of time each of the other men of the village spends in casual sex in period t . This formulation captures the idea that, when every man on average devotes \widehat{k}_t to casual sex, each woman (and her male partner alike) is exposed to \widehat{k}_t exactly. From the viewpoint of each male, this technology implies that the probability of successful guarding is inversely related to the average level of casual sex in the village, and when no one engages in casual sex (i.e., $k_t = 0 = \widehat{k}_t$), a male can afford to spend virtually no time guarding his mate, since he is guaranteed to be the father (or, $\gamma = 1$). For any period t , the complement to 1 of $\gamma(\cdot)$ represents the probability that an adult man’s guarding is not successful.

Child survival is stochastic and depends only on food, the paternal investment. In particular, the probability that a child survives into adulthood, θ , is a concave function of the amounts of food received during the first two periods of life, denoted by y_t and y_{t+1} , respectively. Assuming there is a one-to-one relationship between the time a man spends hunting

¹⁰All 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.

and the amount of food he can supply, then survivorship is given by

$$\theta(y_t, y_{t+1}) = (y_t y_{t+1})^\alpha, \quad (2)$$

where, for simplicity, the parameter α is assumed to be the same as in (1) and $0 < \alpha < 1/2$. 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 $(1 - \theta(y_t, y_{t+1}))$, can occur only after the two periods of childhood at the beginning of the adulthood stage.¹¹

An adult male supplies the time equivalent 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. However, the second born child needs s_3 only *after* period 2 (i.e., after the father's death). To deal with this issue, we assume that food storage is perfect. That is, food can be reliably stored from one period to the next at any point in time, and it can be used even after parents' death when the youngest child still needs to be fed.¹² Figure 1 illustrates food exchange in the two family configurations.

As already mentioned, an adult female gives birth to one child in each period 1 and 2. It takes a newborn child two periods to become independent. Because we focus on male investment and we intend to avoid complications driven by strategic interactions between men and women, we assume that women do not provide food nor can they store it.

A mother therefore 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 her 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 allocation decision instead is more complex in the second period, when the mother 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, nor casual sex, because she can only have one child in a given period. 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.

¹¹Thus, θ can be interpreted as the probability of reaching adulthood as a *fertile* and *productive* individual. All children reach the adulthood stage but, without adequate parental investments, they will be unfit to mate and (re-)produce.

¹²Perfect storage allows us to establish powerful results fairly comfortably. Relaxing this assumption is an extension left for future research (see subsection 2.F, where we return to this point). Notice also that the model abstracts from other features which are not essential for our results to hold. For example, we impose neither economies of scale in food production nor a convention-specific technology of guarding. In addition, the specific functional forms (1) and (2) are not crucial, and have been used here because — besides their simplicity — they deliver closed form solutions in this benchmark setup.

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.

C. Preferences and Optimization Problems

Adult Male in the Fidelity Family Convention — It is important to emphasize again that 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 section, only own children matter. Thus, a male chooses $g_1, k_1, f_1, g_2, k_2, f_2, s_2$, and s_3 , to maximize his expected fitness, Φ_F , which is given by

$$\begin{aligned} \Phi_F = & \underbrace{\frac{1}{2} \left(\frac{g_1}{g_1 + \widehat{k}_1} \right)^\alpha f_1^\alpha [\widehat{m}(f_2 + s_2)]^\alpha}_{\text{“fitness from first child”}} + \underbrace{\frac{1}{2} \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^\alpha [(1 - \widehat{m})(f_2 + s_2)]^\alpha s_3^\alpha}_{\text{“fitness from second child”}} \\ & + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_1}{\widehat{g}_1 + k_1} \right)^\alpha \right] \widehat{f}_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{“fitness from first period casual sex”}} + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_2}{\widehat{g}_2 + k_2} \right)^\alpha \right] [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha \widehat{s}_3^\alpha}_{\text{“fitness from second period casual sex”}} \quad (3) \end{aligned}$$

subject to the lifetime resource constraint

$$2 = g_1 + f_1 + k_1 + g_2 + f_2 + s_2 + k_2 + s_3. \quad (4)$$

The first term in (3) indicates the contribution to inclusive fitness from the first child. This child, who is genetically related to the adult male with probability $\frac{1}{2}[g_1/(g_1 + \widehat{k}_1)]^\alpha$, survives the first and second periods of childhood with probability $[f_1 \widehat{m}(f_2 + s_2)]^\alpha$ (making use of (2) and taking the mother’s action as given). Notice that in the absence of casual sex ($\widehat{k}_1 = 0$), γ_1 will boil down to $1/2$, the standard parameter of genetic relatedness with own child.

The second term captures the fitness gained by a father through his second born. Provided that the child is genetically related to the father (which occurs with probability $\frac{1}{2}[g_2/(g_2 + \widehat{k}_2)]^\alpha$), full fitness is attained 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 $[(1 - \widehat{m})(f_2 + s_2)s_3]^\alpha$.

The last two terms in (3) refer to the fitness a male can obtain from casual sex. With probability $1 - [\widehat{g}_t/(\widehat{g}_t + k_t)]^\alpha$, for period $t = 1, 2$, he is the unofficial father of another child in the village who cannot be supported by him, because he is unaware of the child’s identity. The child instead will receive food by the cuckolded official mate of the mother and the

cheating male does not have control over such transfers. This is why he takes them as given and we denote them with a ‘hat’, i.e., $[\widehat{f}_1 \widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha$ and $[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)\widehat{s}_3]^\alpha$.

It is worth noting that Φ_F is not globally concave. We however checked numerically that, for $0 < \alpha < 1/2$, the solution to the first order conditions associated with the optimization problem is the global maximum.

Finally, the resource constraint (4) is defined over the entire adulthood period. Each adult male is endowed with two units of time (one unit per period). In each period, a male can allocate his time endowment either to seek paternity by guarding his opposite-sex mate, or to engage in casual sex, or to care for the young by providing food to them. The exact timing of when the father decides to store food is irrelevant.¹³

Adult Male in the Promiscuous Pair Bonding Convention — As before, adult males care only for their own fitness (denoted by Φ_P), taking into account that the female they guard already has (or will eventually have) a child with a different male. Thus, the male’s objective is to choose $g_1, k_1, f_1, g_2, k_2, f_2, s_2$, and s_3 , to maximize

$$\begin{aligned} \Phi_P = & \underbrace{\frac{1}{2} \left(\frac{g_1}{g_1 + \widehat{k}_1} \right)^\alpha f_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{“fitness from first child”}} + \underbrace{\frac{1}{2} \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^\alpha [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha s_3^\alpha}_{\text{“fitness from second child”}} \\ & + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_1}{\widehat{g}_1 + k_1} \right)^\alpha \right] \widehat{f}_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{“fitness from first period casual sex”}} + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_2}{\widehat{g}_2 + k_2} \right)^\alpha \right] [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha \widehat{s}_3^\alpha}_{\text{“fitness from second period casual sex”}}. \quad (5) \end{aligned}$$

The difference between (5) and (3) is in the first two terms. 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. As in the previous case, Φ_P is not globally concave. But, for $0 < \alpha < 1/2$, our numerical analysis shows that the solution to the first order conditions associated with the optimization problem is the global maximum.

Adult Female — Regardless of the family configuration, a female decides on how to allocate the food transferred to her by the male to her children. She cannot affect the amount of food given to the first child in her first adult period, \widehat{f}_1 , nor the amount of food received by the second child after her death, \widehat{s}_3 . Her problem is thus 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 males’ choices as given (denoted with a hat).

¹³Although we do not explicitly restrict $f_t + g_t + k_t$ to be not greater than 1 for each $t = 1, 2$, these additional constraints are satisfied in equilibrium.

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, irrespective 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.

D. Equilibrium

We first focus on one family convention at a time and define the equilibrium within each configuration. Arguably, a family configuration, unlike the other decisions considered here, cannot be under direct individual control. If everyone selects one convention, a unilateral deviation to the other configuration will always be suboptimal because it cannot be implemented without the participation of (at least some) other players. In this sense, therefore, each convention is exogenous. A related and important concern is to identify the family configuration that will be selected by evolutionary forces. Thus, after having derived the Nash equilibrium properties for each convention separately, we elaborate arguments to select between the two configurations according to an evolutionary stability notion.

Our first definition then assumes that individuals do not choose the type of family structure (either fidelity family or promiscuity) in which they live. Rather, this is an exogenous institution of the village. Within each configuration, then, we adopt a pure strategy Nash equilibrium concept:

Definition 1. *An equilibrium $(\Gamma_j, \mathbf{x}_j^*)$, $j = F, P$, is a family convention Γ_j and a feasible vector of allocation of resources \mathbf{x}_j^* , with $\mathbf{x}_j^* = (g_1^*, f_1^*, k_1^*, g_2^*, f_2^*, s_2^*, k_2^*, s_3^*; m^*)_j$, such that \mathbf{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, Φ_j , given the partner's actions as well as the actions of everyone else.*

In our context, it is also important to establish which of the family configurations Γ_F or Γ_P is evolutionarily stable (Weibull 1995). To this end, we shall check whether, in a fidelity village, a small group of individuals who try the promiscuous strategy, \mathbf{x}_P^* , grows at a slower rate than the rest of the individuals who continue to play \mathbf{x}_F^* . That is, we

see if $\theta(\bar{\mathbf{x}}_{PF}) < \theta(\mathbf{x}_F^*)$, where $\theta(\bar{\mathbf{x}}_{PF})$ denotes the survivorship of the mutants who play the promiscuous strategy while facing the casual sex norm of the fidelity village. Similarly, we check whether, in the promiscuous village, mutant individuals who use the fidelity family strategy experience a higher rate of growth than those individuals who stick to the status quo allocation \mathbf{x}_P^* , i.e., $\theta(\bar{\mathbf{x}}_{FP}) > \theta(\mathbf{x}_P^*)$. We therefore adopt the following notion:

Definition 2. *An equilibrium $(\Gamma_j, \mathbf{x}_j^*)$, $j = F, P$, is evolutionarily stable if, for $j' \neq j$, $\theta(\mathbf{x}_j^*) > \theta(\bar{\mathbf{x}}_{j'j})$.*

Put differently, a family configuration is evolutionarily stable when individuals who follow the optimal resource allocation of the alternative convention can never achieve a greater average expected survivorship. Definition 2 therefore allows mutants to make optimal decisions over all their individual actions, including casual sex, assuming the non-mutants follows the norm of the village. Our stability results hold also under a weaker definition in which mutants deviate in their individual actions and are required to follow the casual sex norm of the family configuration they deviate to.

E. Results

Fidelity Family

Consider a village in which only fidelity family groupings are possible. Then, the optimization of Φ_F in (3) subject to (4) and taking the mother's solution (6) into account leads to the following result:¹⁴

Proposition 1. *In the fidelity family configuration, there exists a unique interior Nash equilibrium $(\Gamma_F, \mathbf{x}_F^*)$ with the equilibrium allocation \mathbf{x}_F^* given by $g_1^* = k_1^* = g_2^* = k_2^* = 1/6$, $f_1^* = s_3^* = 1/3$, $f_2^* + s_2^* = 2/3$, and $m^* = 1/2$.*

This equilibrium allocation does not depend on α . As mentioned earlier, even though Φ_F is not globally concave, the solution to the first order conditions associated with the optimization of (3) subject to (4) and (6) is the global maximum as long as $\alpha \in (0, 1/2)$. The same holds true for the problem in the P -convention below.

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

¹⁴In this game, there is also another inefficient Nash equilibrium in which males and females choose $s_3 = 0$ and $m = 1$, respectively. This is an equilibrium only because players are assumed to move simultaneously and can be ruled out using a simple Stackelberg-type refinement as follows. Suppose the male makes his choice first, then he will choose $s_3 > 0$, because he knows his partner will respond with a positive $(1 - m)$.

Promiscuous Pair Bonding Relationship

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

Proposition 2. *In the promiscuous pair bonding configuration, there exists a unique interior Nash equilibrium $(\Gamma_P, \mathbf{x}_P^*)$ with the equilibrium allocation \mathbf{x}_P^* given by $g_1^* = k_1^* = g_2^* = k_2^* = 1/5$, $f_1^* = s_3^* = 2/5$, $f_2^* + s_2^* = 2/5$, and $m^* = 1/2$.*

As in the fidelity family case, also in the promiscuous convention, 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 children receive more food in their second stage of childhood. Males are also equally vigilant on their two mates and spend equal fractions of their time engaging in casual sex in both fertile periods.

Comparing the Two Family Configurations

Compared to the promiscuous convention, males in the fidelity village spend less time guarding their partners. When this is the case, one could expect to observe a greater amount of resources spent in casual sex, because this activity could be more advantageous. In equilibrium, however, this is not true. Since there is no room for free riding in the fidelity family, food provision is relatively more productive there than in the promiscuous configuration. Resources therefore are shifted towards this activity and away from casual sex and guarding. Because of this simultaneous reduction, lower guarding does not necessarily yield a greater probability of nonpaternity. In equilibrium, in fact, the probability of successful guarding (1) is identical in the two conventions, and equal to $(1/2)^\alpha$. More resources devoted to guarding and to casual sex in the promiscuous village come at the cost of lower food transfers to children, and this in turn negatively affects the probability that each child has to reach the adulthood stage. From (2), the probability of child survival in the promiscuous village is $\theta_P = (2/5)^\alpha(1/5)^\alpha$, which, irrespective of the efficiency of the food provision technology α , is always lower than the corresponding probability in the alternative configuration, where instead it is equal to $\theta_F = (1/3)^\alpha(1/3)^\alpha$, i.e., $\theta_F > \theta_P$ for all admissible values of $\alpha \in (0, 1/2)$.

Because we focus on symmetric equilibria, it is straightforward to see from (3) and (5) that in equilibrium the adult man's fitness coincides with his offspring survivorship. That is, individual utility maximization is aligned with social welfare. This and the previous considerations lead us to the following:

Corollary 1. *Survivorship of each child and overall fitness in the fidelity village are always greater than survivorship and fitness in the promiscuous village.*

Promiscuous men's productivity in food provision is lower than that of men in the fidelity village. This is because each male in the promiscuous convention seeks to *free ride* on the food given to his mate by her other male partner. Food underprovision is accompanied by overguarding. Overguarding, however, does not lead to a fitness gain in term of greater paternity confidence. The reason for this is that the lower productivity in food provision gives promiscuous men a greater incentive to engage in casual sex, and this activity in turn requires greater guarding. Free riding on food provision, therefore, is the mechanism underpinning the lower growth rate achieved in the promiscuous convention.

Stability

Corollary 1 is obtained from a comparative statics exercise. It does not guarantee that the fidelity family is a stable convention and the promiscuous configuration is not. To establish this result, we use Definition 2 and look at the dynamic stability of the fixed points found so far by allowing deviations (of a small subgroup of individuals) from one family convention to the other and viceversa.

Suppose a small population share of individuals in the fidelity village deviate and adopt promiscuous strategies. Because this deviation involves at least two adult men and two adult women, we assume mutants can coordinate over their new actions, with offspring inheriting their official parents' (or, equivalently, their mother's) strategies.

Promiscuous mutants will not allocate resources as their promiscuous counterparts who make decisions in the village where promiscuity is the convention. Their effort devoted to casual sex, which depends on the (lower) amount of guarding of fidelity males, will be lower than in the promiscuous configuration but still higher than that emerging in the fidelity village. It can be verified (see the Appendix) that, in equilibrium, the mutant strategy yields child survivorship that is lower than that associated with the incumbent strategy. We then perform a similar analysis for the opposite type of mutation. Suppose a small group of mutants play the fidelity family strategy in the promiscuous village. In this case, the survivorship gain from deviation is strictly positive. We summarize these arguments in the following result:

Corollary 2. *The fidelity family is an evolutionarily stable configuration, while the promiscuous pair bonding is not.*

Mutations to the fidelity family strategy therefore will lead to the extinction of the promiscuous village and the takeover of the fidelity convention. This is driven by the greater survivorship of children of fidelity family parents, who, despite the fact that individuals around them engage more in casual sex (and guarding) and thus threaten their fatherhood claims, are more willing to invest in their offspring. This in turn is driven by the greater

productivity in food provision among males from the fidelity village. Invasions of promiscuous mutants instead cannot undo the convention established in the fidelity village for precisely the opposite reason.

F. Discussion of the Basic Ingredients of the Model

We underline five features of our model. First, the man is the sole investor, in the sense that he is the only food provider (Kaplan et al. 2000; Robson and Kaplan (2006)). Just as in the standard Becker's framework, this implies full gender specialization in home and market tasks, and, by ruling out strategic interactions (and free riding) over food provision between men and women, it greatly simplifies the analysis and sharpens our results. Notice, however, that this is not a source of differential gains to the fidelity family as opposed to the promiscuous pair bonding (Lundberg and Pollak 2007). Both conventions, in fact, are equally defined by full specialization. Allowing for mother's food provision would lead to the same qualitative results, as long as the male contribution remains greater than the female share.

Second, there is no differential mortality between the sexes. This, coupled with the assumption of a balanced sex ratio, allows us to avoid dealing with unusual circumstances in the mating environment (Hamilton 1967). On the one hand, men could face a higher probability of dying before the end of the second adult period, to the extent that hunting (food provision) is a risky activity. On the other hand, women could have greater mortality risks associated with pregnancy or delivery, so that the two risks could effectively cancel each other out and have no effect on the sex ratio, without affecting our key findings. Relaxing this assumption, nonetheless, may have interesting implications for our model, and this is left for future research.

Third, the model does not allow for within-gender heterogeneity. All individuals on the same side of the marriage market are therefore identical. Since agents can only form their unions with opposite-sex (identical) individuals from the same cohort (age), they do not have an incentive to choose one partner or another. But if the type of agent heterogeneity (e.g., males could have different endowments, while females could differ in terms of fecundity) is the same across family conventions, our main results are not sensitive to this restriction.

Fourth, women do not solve a time allocation problem even if they distribute food to their children and engage in casual sex. This is because such two activities do not imply an economically meaningful trade-off. The idea is that food distribution does not require a time investment and, with one child being born in every period with probability one, the degree of reproductive success of females — unlike males — is largely independent of the number of mates they have in each reproductive cycle (Bateman 1948).

Fifth, the assumption that food storage is perfect and its timing irrelevant allows us to

avoid introducing other means of exchange (e.g., fiat money) and modeling their transmission from one generation to the next. Of course, food exchange between siblings (which will be analyzed in the next section) may supplement or replace the food stored by the father up to the point that the perfect storage technology become effectively inoperative.

3. Model with Kin Transfers

So far we have assumed that adult males provide food only to their own children. But besides them, males may care for the fitness of other genetically close relatives. Several studies have documented a wide array of kinship ties (Alexander 1974; Kurland 1979; Diamond and Locay 1989; Dunbar, Clark and Hurst 1995; Knight 2008), supporting the notion that the costs and benefits of altruistic acts — in our case, food transfers among kin — are weighted by the closeness of genetic relatedness (Hamilton 1964; Cox 2007). This section will establish that kin transfers can only occur within the fidelity family configuration.

In what follows, we then allow for food reciprocity with kin, whereby an adult male transfers food to both his presumed children and his presumed *younger* sibling. In a model that emphasizes the importance of genetic links with uncertain paternity and father's investment, patrilineal ties are more likely to arise when men are confident to have relatives who are genetically close to them. The best candidate is given by own younger siblings, who still need resources before becoming adults. The opposite transfers (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 expected to be of second order importance in our framework and are thus not considered here.

To allocate food to his presumed siblings, a male must be able to identify them among all the individuals who live close to him. Sibling recognition then will be a new ingredient of the male's objective function in both conventions.¹⁵

We shall establish three main results: (a) kinship cannot emerge without family (Proposition 3); (b) even in the fidelity family convention, food transfers to younger siblings will not occur in equilibrium as long as sibling recognition is not sufficiently high (Proposition 4); and (c) in families where sib detection is (almost) perfect, kin ties emerge, that is, food transfers to younger siblings will occur in equilibrium yielding fitness and survivorship gains as compared to the case without kinship (Proposition 5).

Before characterizing the male and female programs, it is useful to extend Figure 1 to the world in which there are transfers from older to younger siblings. Figure 2 shows this

¹⁵The two most important mechanisms that are believed to track genetic relatedness in ancestral human groups are a close association between mother and infant, 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.

case.

Adult Female — A female has to take into account that her second child may receive food, \widehat{b} , from the older brother (who may or may not be her child, depending on the family configuration), and that this older brother may or may not be alive. The female’s new problem then is to choose the food allocation, m , in the second period to maximize her own fitness

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

The expectation operator $\mathbb{E}[\cdot]$ in(7) arises because the older brother might not survive to adulthood, and this by definition means $\widehat{b} = 0$. Clearly, mothers 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

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

The possibility of food transfers from older to younger siblings opens two new modeling issues that distinguish this framework from that developed in the previous section. First, the sex of a child matters. Since food can be supplied only by males, a father without boys cannot rely on his adult older son to provide food to his younger offspring. In order to keep a balanced sex ratio and avoid useless complications, we thus assume that each birth in a given period is twinned. Second, siblings’ birth order matters, so that the optimization problem faced by older males will differ from that faced by their younger brothers.

Elder Male in the Promiscuous Convention — In the presence of kin ties, the elder promiscuous male modifies his objective function (5) into:

$$\begin{aligned} \Phi_P = & \underbrace{\frac{1}{2} \left(\frac{g_1}{g_1 + \widehat{k}_1} \right)^\alpha f_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{“fitness from first child”}} + \underbrace{\frac{1}{2} \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^\alpha \mathbb{E} \left\{ [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha (s_3 + \widehat{b})^\alpha \right\}}_{\text{“fitness from second child”}} \\ & + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_1}{\widehat{g}_1 + \widehat{k}_1} \right)^\alpha \right] \widehat{f}_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{“fitness from first period casual sex”}} + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_2}{\widehat{g}_2 + \widehat{k}_2} \right)^\alpha \right] \mathbb{E} \left\{ [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha (\widehat{s}_3 + \widehat{b})^\alpha \right\}}_{\text{“fitness from casual sex in the second period”}} \\ & + \underbrace{\frac{1}{4} \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + b_M)^\alpha \rho}_{\text{“fitness from younger half-brother from maternal side”}} + \underbrace{\left(\frac{\widehat{\gamma}_1 \widehat{\gamma}_2}{4} \right) [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha (\widehat{s}_3 + b_F)^\alpha \rho}_{\text{“fitness from younger half-brother from paternal side”}}, \quad (9) \end{aligned}$$

where $\widehat{\gamma}_j = [\widehat{g}_j / (\widehat{g}_j + \widehat{k}_j)]^\alpha$, for $j = 1, 2$, and $\widehat{b} = \widehat{b}_M + \widehat{b}_F$, reflecting that in a promiscuous family a second-born child may receive transfers from the older half-brother on the maternal side, \widehat{b}_M , as well as from the older half-brother on the paternal side, \widehat{b}_F .

Comparing the first and third terms in (9) to the corresponding first and third terms in (5) reveals that first child and first period casual sex contribute to an older male’s fitness always in the same manner, irrespective of whether or not there are kin ties. The second child, however, may receive food not only from the (presumed) father but also from older brothers. This is reflected in the new second term in (9). The fourth term, which defines the contribution to Φ_P of second period casual sex, emphasizes the fact that survival of the child born in that period is linked to the uncertain transfer from the older brother.

The last two terms show the fitness contribution induced by investments in younger siblings. In the P -convention, children with the same father do not share the same mother. With uncertain paternity, therefore, their genetic relatedness is $\widehat{\gamma}_1\widehat{\gamma}_2/4$, which equals the standard $1/4$ if there is no casual sex (last term). Children who, instead, share the same mother but not the same father have a certain genetic relatedness of $1/4$ (next to the last term). Finally, the parameter ρ , with $\rho \in [0, 1]$, identifies the ability of assessing genetic relatedness between self and other. If $\rho=1$, kin detection is perfect.

A *younger* male faces a slightly different problem, because he does not have younger siblings to transfer resources to. This implies that the last two terms in (9) do not depend on actions that are under control of the male; that is, b_M and b_F are not in his choice set.

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

Proposition 3. *In the promiscuous pair bonding convention, there exists a unique interior Nash equilibrium $(\Gamma_P, \mathbf{x}_P^*)$ with the equilibrium allocation \mathbf{x}_P^* given by $g_1^* = k_1^* = g_2^* = k_2^* = 1/5$, $f_1^* = s_3^* = 2/5$, $f_2^* + s_2^* = 2/5$, $b_M^* = b_F^* = 0$, and $m^* = 1/2$. The equilibrium is the same for elder as for younger pairs.*

In promiscuous villages, therefore, it is never optimal for a male, irrespective of whether he is a firstborn or not, to transfer food to his half-siblings, on either his father’s or his mother’s side, even if kin detection is not an issue, that is, even if kin detection is perfect. The intuition is simple. Because all children in the village receive an equal amount of resources over their entire childhood and because any given male is genetically closer to his own children than to any other individual in the village, including his own siblings, it is optimal to provide food only to own official offspring. Altruistic ties between siblings then cannot emerge in a promiscuous environment where there is no family.

Elder Male in the Fidelity Family — In the fidelity configuration, the elder male’s objective function changes from (3) to

$$\Phi_F = \underbrace{\frac{1}{2} \left(\frac{g_1}{\widehat{k}_1 + g_1} \right)^\alpha f_1^\alpha [\widehat{m}(f_2 + s_2)]^\alpha}_{\text{“fitness from first child”}} + \underbrace{\frac{1}{2} \left(\frac{g_2}{\widehat{k}_2 + g_2} \right)^\alpha \mathbb{E} \left\{ [(1 - \widehat{m})(f_2 + s_2)]^\alpha (s_3 + \widehat{b})^\alpha \right\}}_{\text{“fitness from second child”}}$$

$$\begin{aligned}
& + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_1}{k_1 + \widehat{g}_1} \right)^\alpha \right] \widehat{f}_1^\alpha [\widehat{m}(\widehat{f}_2 + \widehat{s}_2)]^\alpha}_{\text{"fitness from casual sex in the first period"}} + \underbrace{\frac{1}{2} \left[1 - \left(\frac{\widehat{g}_2}{k_2 + \widehat{g}_2} \right)^\alpha \right] \mathbb{E} \left\{ [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha (\widehat{s}_3 + \widehat{b})^\alpha \right\}}_{\text{"fitness from casual sex in the second period"}} \\
& + \underbrace{\left(\frac{1 + \widehat{\gamma}_1 \widehat{\gamma}_2}{4} \right) [(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2)]^\alpha (\widehat{s}_3 + b)^\alpha \rho}_{\text{"fitness from younger brother"}} \tag{10}
\end{aligned}$$

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 $(1 + \widehat{\gamma}_1 \widehat{\gamma}_2)/4$. In the extreme case of no casual sex (i.e., $\widehat{\gamma}_1 = \widehat{\gamma}_2 = 1$), the two siblings are certain to share the same biological father and this term is equal to $1/2$, the standard coefficient of relationship between siblings. In all other cases, however, their genetic relatedness is lower than $1/2$. As in the promiscuous case, the *younger* male cannot transfer resources to other (younger) siblings, i.e., he does not make decisions on b , so that the last term in (10) does not enter into his optimization problem.

Differently from the case of the promiscuous pair bonding configuration, here only if the sibling detection parameter, ρ , is below some threshold $\underline{\rho} < 1$, the equilibrium is the same as in the case of the fidelity family without kinship:

Proposition 4. *In the fidelity family convention, there exists a threshold level of the kin recognition parameter $\underline{\rho} < 1$ such that, for all $\rho \leq \underline{\rho}$, the interior equilibrium $(\Gamma_F, \mathbf{x}_F^*)$ is unique, with the equilibrium allocation \mathbf{x}_F^* given by $g_1^* = k_1^* = g_2^* = k_2^* = 1/6$, $f_1^* = s_3^* = 1/3$, $f_2^* + s_2^* = 2/3$, $b^* = 0$, and $m^* = 1/2$. The equilibrium is the same for elder as for younger pairs.*

The emergence of kin ties therefore is not straightforward even when individuals form durable 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. The threshold $\underline{\rho}$, which is a decreasing function of α , is very high.¹⁶ For example, when $\alpha = 0.45$, the corresponding value of $\underline{\rho}$ is approximately equal to 0.9533. As α declines, the critical probability level for kinship detection increases: e.g., if $\alpha = 0.10$, $\underline{\rho} = 0.9976$. Thus, even when sib detection is relatively accurate, 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 kin tie is 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

¹⁶The expression for the threshold is given by $\underline{\rho} = (1/2)^{\alpha-1} (1 + (1/2)^{2\alpha})^{-1}$.

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 transfers to younger siblings because, at the equilibrium levels of guarding and casual sex, the expected genetic relatedness between siblings is equivalent to that between father and offspring. This is what emerges in our next result.

Proposition 5. *In the fidelity family convention, if $\underline{\rho} < \rho \leq 1$, then: (i) $b^* > 0$; (ii) kin transfers increase as kin recognition increases; and (iii) compared to the case without kin ties, total survivorship is greater.*

Based on the numerical solution that underpins Proposition 5, which is described in the Appendix, Figure 2 allows us to illustrate four important, related points.¹⁷ First, when $\rho > \underline{\rho}$, positive kin transfers occur in equilibrium. Second, as a result of the positive transfers, older pairs have a smaller amount of resources (less time) to allocate to their offspring. The equilibrium allocation of resources, however, does not differ between older and younger couples.

Third, in comparison to the case in which kin detection is below $\underline{\rho}$ (or, equivalently, the world of Propositions 1 and 4 with no kinship), firstborn receive strictly *more* food from their fathers in both periods of childhood, regardless of whether their parents are older or younger. Second born children instead receive less food from their fathers, and even after taking into account the positive transfer from their older brothers, their total resources are *lower* than what they would have received in a context without kin ties. This *primogeniture* effect, which arises endogenously in the model, emerges because in equilibrium fathers, irrespective of whether they made or received food transfers, have an incentive to provide more resources to their firstborn in an environment in which older siblings support younger ones.¹⁸

Fourth, survivorship of the offspring of both older and younger pairs is greater than in the case without kin ties. Interestingly, it is the younger brother — who received a lower amount of resources than his older brother from their official father during childhood — who sees his progeny enjoying a greater probability of survival than his elder brother's progeny. From the viewpoint of the younger brother, this 'regression-toward-the-mean' result emerges because in equilibrium he expects a positive b^* to be received by his second born child from his firstborn when adult, and because, without having to make kin transfers himself, he can

¹⁷The figure shows parental investments, child survival and adult fitness as the value of the kin detection parameter increases from $\underline{\rho}$ to 1, for a given value of α ($\alpha = 0.45$). Similar results hold for other values of α .

¹⁸Recent empirical studies based on contemporary data find evidence that is consistent with our primogeniture effect, with sizeable negative impacts of higher birth order on education, earnings, employment, and teenage fertility (e.g., Black, Devereux, and Salvanes 2005).

count on a relatively greater endowment than his elder brother's.¹⁹

Figures 3 and 4 allow us also to document how such relationships change with ρ . When 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, while the amount of food received by the second born declines. But, for any given value of ρ above $\underline{\rho}$, this reduction is partly (albeit not totally) compensated by the positive and increasing transfer made by the older brother. In fact, fidelity villages in which families are linked through food exchange as opposed to fidelity villages without kin ties will be characterized by greater total food provision. This, in turn, will lead to enhanced child survivorship and overall fitness.

This result is made possible by the shift away from the socially wasteful activities of casual sex and guarding.²⁰ Because paternity is uncertain, two males who know they share the same mother could be genetically close to each other as much as they are to their own offspring. In these circumstances, transferring food to a younger (still dependent) sibling is efficiency enhancing as inclusive fitness and survivorship increase. Facing the same risk of cuckoldry as in the case without kinship, a male can then afford to reduce guarding, with casual sex having receded too. Lower casual sex and lower guarding are possible only within the fidelity family convention and when kin detection is extremely high or perfect. The family therefore allows its members not only to achieve greater fitness and survivorship but also to foster altruistic behavior among siblings. Moreover, by stressing the fitness gain through kinship ties, this result identifies the fidelity family as a key source of exchange among its members and thus a primary engine of economic growth (Ofek 2001; Chapais 2008; Galor and Michalopoulos 2011).

The notion of investing in siblings and more distant kin is relatively underinvestigated in economic research. Diamond and Locay (1989) offer the first and, to our knowledge, the only model that can explain why a risk-averse man invests in his sister's children when he cares about his own fitness and is uncertain about his paternity. They note that some investments take place even at high paternity probabilities and that men, in many societies, invest in both wife's and sister's children. Their explanation is that a male values his 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 children of his official partner increases, the probability that the male is the father of at least one of them also increases. Thus the value of the assurance provided by the sister's children decreases with either an increase in the paternity probability or an increase in the number of the official partner's children.

¹⁹This result echoes the Galton-type negative partial relation between the resources of grandparents and grandchildren found by Becker and Tomes (1986) and empirically documented by Wahl (1985) for nineteenth century American families.

²⁰It is worth stressing however that, despite the lower levels of casual sex and guarding, the probability of successful guarding in a world with kin food exchange is identical to that found in the case without kin ties.

The overlapping-generation model developed in this paper allows us to focus on the more basic kinship links between older and younger siblings rather than those between a man and his sister’s children. This framework then provides us with the natural architecture for extending the analysis to lower levels of genetic relatedness, as in the case of Diamond and Locay, as well as other forms of kin ties, such as matrilineal kinship (Morgan 1871; Allen et al. 2008).

4. The Secular Utility of Religion

Central to our theory is the observation that, in a world where individuals seek to maximize their reproductive success, casual sex and mate guarding are unavoidable, even though from society’s viewpoint these are wasteful activities. The presence of such activities may therefore induce the development of social norms or institutions that, in equilibrium, can attenuate their negative effects and possibly lead to fitness and survivorship gains at both the individual and the group (or society) level. This reasoning allows us to underpin the remarkable fact that virtually all major world religions center around the avoidance of casual sex and the importance of fidelity in the intimate relationship between a man and a woman (Browning, Green and Witte 2006). While history has witnessed all kinds of different sexual organizations (Knight 2008), yet those that survived and flourished are those that promote domestic fidelity and proscribe sexual promiscuity.

We elaborate on this reasoning by introducing a universally accepted, self-enforcing institution, which we label ‘religion’. Religion punishes individuals when caught engaging in casual sex. The punishment can be inflicted only on males, the sole investors in our framework, and materializes in terms of direct individual fitness reduction, such as burning part of their (time) endowment or introducing a tax on their use of some resources. The immediate effect of religion is therefore a downward pressure on the rate of growth of the village that adopts it. As a result, religion may never be introduced unless its indirect effect on fitness at the group level outweighs the negative effect at the individual level.

Consider two villages with an identical fidelity convention, in which kin detection is perfect ($\rho = 1$), so that food transfers between siblings exist in equilibrium.²¹ One of the villages is populated by individuals whose behavior is described in the previous section and characterized in Proposition 5. The other fidelity village instead adopts a religious institution. Individuals here behave in the same manner as before, except that, casual sex is ‘punished’ by means of a tax, τ , which represents the additional cost all males bear for engaging in casual sex in any given period.

²¹The nature of the results that follow remains the same for other values of $\rho > \underline{\rho}$. Clearly, the same results, apart those on kinship, hold also in the case without kin transfers ($\rho \leq \underline{\rho}$).

Spending time in casual sex, therefore, not only competes with the direct investment in own children (reducing the amount of time devoted to food provision) but also may lead to a loss of resources for that period. More precisely, the cost of casual sex is not one as before, but rather $1+\tau$, and the higher is τ the harsher is the expected punishment. For simplicity, we take the value of τ as given.²² The budget constraint (4) now becomes

$$2 = g_1 + f_1 + (1 + \tau)k_1 + g_2 + f_2 + s_2 + (1 + \tau)k_2 + s_3 + b. \quad (11)$$

Under this new lifetime constraint, numerical analysis yields the following proposition:

Proposition 6. *Total survivorship and fitness are greater in the religious village ($0 < \tau \leq 1$) than in the non-religious village ($\tau = 0$). As the punishment becomes harsher, survivorship increases, casual sex and guarding decline, and kin ties become weaker.*

Figure 5 displays child-specific food provision, guarding, casual sex, and kin transfers while Figure 6 shows child survivorship as τ increases from 0 to 1, for a given value of α ($\alpha = 0.45$). As the harshness of the punishment increases, the amount of food received by all children (both the two children of an elder male and the two children of his younger brother) goes up in all periods, and so do child-specific survival probabilities. This improvement occurs even if part of the male's resources are effectively lost. The figure gives an eloquent account of why this happens by showing the direct and indirect effects of the punishment τ . The direct effect is a straightforward reduction of casual sex. When casual sex goes down, the optimal response is to decrease mate guarding. If the time spent in casual sex and guarding declines, more time becomes available to be allocated toward the productive activity of food provision, which enhances child survival.

An interesting result is that, 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, clamping down on casual sex does reduce casual sex more than guarding. Males are then *more* confident that their official children are indeed genetically theirs, and thus they have a relatively greater incentive to support them and a lower incentive to support their siblings. A related implication of the lower kin transfers is that religion increases the critical value of the sib recognition parameter, $\underline{\rho}$, below which kinship cannot emerge.

²²This tax is a reduced form characterization of an environment in which casual sex is not perfectly observable and the tax represents the expected punishment when the probability of detection is taken into account. More generally, the level of τ may be determined by the probability of detection times the expected individual fitness loss due to child death, and this cannot be lower than the individual fitness gain due to casual sex. In what follows, we restrict our attention to values of τ less than 1, although in principle τ could be infinitely large.

Proposition 6 suggests that a family-based religion offers material collective benefits, measured in the hard currency of greater survival and reproduction success, for all 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 useful 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 children²³, and, 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).

Recent empirical research has documented that, in the last fifty years and across a large cross-section of countries, economic growth has responded positively to religious beliefs (Barro and McCleary 2003) and that greater religious beliefs instill stronger work ethic (McCleary and Barro 2006). Some studies, however, find no evidence of an effect of religion on growth (e.g., Acemoglu, Johnson and Robinson 2001), while others stress the importance of an indirect effect of religion on economic growth through greater human capital accumulation (Botticini and Eckstein 2007; Becker and Woessmann 2009). With its emphasis on moral beliefs about the fidelity family and on the harshness of the punishment for deviations from the religious norms, our model is likely to bring a new perspective to this important debate.

5. Conclusion

This paper presents an overlapping generations noncooperative evolutionary model with uncertain paternity and parental investments in overlapping cohorts of children to explain why humans live in families rather than in other pair groupings. We make three new major contributions. First, the fidelity family delivers greater survivorship and enhanced genetic fitness than the promiscuous pair bonding, and it is underpinned by evolutionarily stable strategies while the promiscuous convention is not. The explanation lies on the fact that promiscuous men's productivity in food provision is lower than that of fidelity men. This is because each male in the promiscuous convention seeks to *free ride* on the food given to his mate by her other male partner. Food underprovision is accompanied by overguarding. Overguarding, however, does not lead to a fitness gain in term of greater paternity confidence. The reason for this is that the lower productivity in food provision gives promiscuous men a greater incentive to engage in casual sex, and this activity in turn requires greater guarding.

²³This is the case also for Christianity and Buddhism, despite the fact that they proposed or commanded celibacy for (at least) some of their religious leaders, and sometimes idealized the sexually abstinent marriage.

Free riding on food provision, therefore, is the mechanism underpinning the lower growth rate achieved in the promiscuous convention.

Second, altruism between siblings can never emerge in an environment where there is no fidelity family. In fact, even in a fidelity family convention, food transfers to younger siblings will not occur in equilibrium when sibling recognition is not very high. Thus, it is only when sib detection is almost perfect that kinship emerges, and only within fidelity families. This result emerges because each man, who is uncertain about his paternity and yet cares only about reproductive success and makes crucial investments in children, values his siblings in part because they provide him with the assurance that some of his genes will survive into future generations.

This kinship model delivers also two other interesting results, a primogeniture effect and a regression-toward-the-mean effect. Through the former, first born children receive more resources during childhood than their younger siblings do. This is because, in a world where child survival is stochastic, a father wants to make sure his firstborn can support his younger progeny when he is no longer alive. The latter effect means that later born children, provided they reach adulthood, see their offspring enjoying a greater probability of survival than their older siblings' children, despite the lower amount of resources they actually received during childhood. This emerges because younger siblings, without having to make kin transfers, can count on relatively greater endowments than their elder brothers'.

Third, norms or institutions that punish casual sex, such as family centered religious beliefs, can yield substantial fitness and survivorship gains. We show that, as the punishment becomes harsher, casual sex declines. When casual sex goes down, the optimal individual response is to decrease guarding, and if time spent in casual sex and guarding goes down, more time becomes available to be allocated toward food provision. Men in an environment with family centered religious norms supply more food to own offspring but less to their younger siblings. This is because casual sex declines more than guarding, and thus males are more confident that their official children are indeed genetically theirs. Therefore, societies that punish casual sex are likely to outgrow otherwise comparable societies that do not.

Some caution, however, should be taken before being tempted to use such three sets of implications to interpret the contemporary family. With the aid of reliable DNA paternity testing, the issue of fatherhood uncertainty might have become less pressing than what it used to be among our ancestral predecessors.²⁴ Similarly, parental investment in children, albeit remaining crucial (e.g., Cunha and Heckman 2010), has been supplemented or replaced by the state (Becker 1991; Lundberg and Pollak, 2007). Another dimension of caution refers to the increased labor force participation of mothers (Goldin 2006), which is in contrast with the full gender specialization assumed in our model. The market and the state, together with

²⁴Anderson (2006) and the works cited therein, however, seem to suggest the opposite.

the greater economic independence of women, might have influenced the nature of exchange within the extended family in ways that our model cannot capture (Laitner, 1997).

With those caveats in mind, there are a few stylized facts about contemporary families that square extremely well with the results of our paper. For instance, a vast empirical literature has documented that experience of life in a blended family is associated with unfavorable child outcomes (e.g., McLanahan and Sandefur 1994; Duncan and Brooks-Gunn 1997; Ginther and Pollak 2004). Poorer outcomes are typically explained by a variety of mechanisms, including parental stress and family conflict after separation and remarriage, inferior maternal time allocation, and economic hardship following family disruption. While not ruling out any of such explanations, our model suggests an additional pathway 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.

Another example is given by the well documented evidence of large negative impacts of later births on education, earnings, employment, and teenage fertility (e.g., Black, Devereux, and Salvanes 2005), which is in line with our primogeniture effect. Finally, our model lends itself quite naturally to interpret the positive effects of religion and family centered social norms on economic growth (e.g., Barro and McCleary 2003; Botticini and Eckstein 2007).

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 is given by

$$\max_{m \in (0,1)} \left\{ (m\widehat{f}_1\widehat{z})^\alpha + [(1-m)\widehat{z}\widehat{s}_3]^\alpha \right\},$$

which is a strictly concave function of m and has a 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) whenever $\widehat{z} > 0$ and $\widehat{f}_1 > 0$. As mentioned in the text, there is another inefficient non-interior solution of this game, in which men choose $s_3 = 0$ and women choose $m = 1$. This is an equilibrium only because players are assumed to move simultaneously. It can be ruled out, however, using a simple Stackelberg-type refinement as follows. Suppose the male is the first mover, then he will choose $s_3 > 0$, because he knows his partner will respond with a positive $(1-m)$.

Proof of Proposition 1 (*Fidelity Family*)

Let $f_2 + s_2 = z$ and $G_\alpha(x, y) = \left(\frac{x}{x+y}\right)^\alpha$. The problem faced by the male is to choose $k_1, k_2, g_1, g_2, f_1, z$ and s_3 to maximize

$$G_\alpha(g_1, \widehat{k}_1)(f_1\widehat{m}z)^\alpha + G_\alpha(g_2, \widehat{k}_2)[(1-\widehat{m})zs_3]^\alpha + [1 - G_\alpha(\widehat{g}_1, k_1)](\widehat{f}_1\widehat{m}\widehat{z})^\alpha + [1 - G_\alpha(\widehat{g}_2, k_2)][(1-\widehat{m})\widehat{z}\widehat{s}_3]^\alpha$$

s.t. $2 = k_1 + g_1 + f_1 + k_2 + g_2 + z + s_3$, with $k_1, g_1, f_1, k_2, g_2, z, s_3 \geq 0$.

Assume first that there are no sign constraints. From the budget constraint, then, denote

$$A = 2 - k_1 - f_1 - g_2 - k_2 - z - s_3. \quad (\text{A.2})$$

Note that A is not a constant. Setting the first order partial derivatives associated to the above optimization to zero gives us the following set of equations:

$$A(A + \widehat{k}_1) - \widehat{k}_1 f_1 = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.3a})$$

$$(f_1\widehat{m})^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^\alpha - z(f_1\widehat{m})^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} \frac{\widehat{k}_1}{(\widehat{k}_1 + A)^2} + (1 - \widehat{m})^\alpha s_3^\alpha \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^\alpha = 0 \quad (\text{w.r.t. } z) \quad (\text{A.3b})$$

$$- \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} (f_1\widehat{m})^\alpha + \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^{\alpha-1} \frac{\widehat{k}_2}{(g_2 + \widehat{k}_2)^2} [(1 - \widehat{m})s_3]^\alpha = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.3c})$$

$$-(f_1\widehat{m})^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} \frac{\widehat{k}_1}{(A + \widehat{k}_1)^2} + (1 - \widehat{m})^\alpha s_3^{\alpha-1} \left(\frac{g_2}{g_2 + \widehat{k}_2} \right)^\alpha = 0 \quad (\text{w.r.t. } s_3) \quad (\text{A.3d})$$

$$-\left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(A+\widehat{k}_1)^2} + \left(\frac{\widehat{g}_1}{\widehat{g}_1+k_1}\right)^{\alpha-1} \frac{\widehat{g}_1}{(\widehat{g}_1+k_1)^2} = 0 \quad (\text{w.r.t. } k_1) \quad (\text{A.3e})$$

$$-(f_1\widehat{m})^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(A+\widehat{k}_1)^2} + [(1-\widehat{m})\widehat{s}_3]^\alpha \left(\frac{\widehat{g}_2}{\widehat{g}_2+k_2}\right)^{\alpha-1} \frac{\widehat{g}_2}{(\widehat{g}_2+k_2)^2} = 0 \quad (\text{w.r.t. } k_2). \quad (\text{A.3f})$$

Equations (A.3a)–(A.3f) and (A.2) form a system of seven equations in seven unknowns (A, k_1, f_1, g_2, k_2, z , and s_3) with no bounds, and with eight exogenous parameters, $\widehat{g}_1, \widehat{g}_2, \widehat{f}_1, \widehat{k}_1, \widehat{k}_2, \widehat{z}, \widehat{s}_3$, and \widehat{m} .

If $\widehat{m} = 1/2$ and setting $\widehat{g}_1 = g_1$, $\widehat{f}_1 = f_1$, $\widehat{k}_1 = k_1$, $\widehat{g}_2 = g_2$, $\widehat{k}_2 = k_2$, $\widehat{z} = z$, and $\widehat{s}_3 = s_3$, algebraic manipulation of (A.3a)–(A.3f) implies

$$k_1 = g_1 = k_2 = g_2 = 1/6, \quad f_1 = s_3 = 1/3, \quad \text{and} \quad z = (f_2 + s_2) = 2/3.$$

It remains to be checked that $\widehat{m} = 1/2$ is also the mother's optimal response given the values chosen by the male. As the optimal response of the male is such that $f_1 = s_3$, her optimal response indeed is $m = 1/2$. Therefore, $\widehat{m} = m$. Finally, as mentioned in the text, since Φ_F is not globally concave, we checked numerically that the solution to the first order conditions indeed is a global maximum of the problem with sign constraints. With our restriction on α ($0 < \alpha < 1/2$), this is the case. Hence, the unique Nash equilibrium is as stated.

Proof of Proposition 2 (*Promiscuous Pair Bonding*)

Let $\widetilde{f}_2 = \widehat{m}(f_2 + \widehat{s}_2)$ and $\widetilde{s}_2 = (1 - \widehat{m})(\widehat{f}_2 + s_2)$. Note that $f_2 = \widetilde{f}_2/\widehat{m} - \widehat{s}_2$ and $s_2 = \widetilde{s}_2/(1 - \widehat{m}) - \widehat{f}_2$. Assuming no sign constraints, the optimization problem is to maximize

$$G_\alpha(g_1, \widehat{k}_1)(f_1\widetilde{f}_2)^\alpha + G_\alpha(g_2, \widehat{k}_2)[\widetilde{s}_2s_3]^\alpha + [1 - G_\alpha(\widehat{g}_1, k_1)](\widehat{f}_1\widehat{f}_2)^\alpha + [1 - G_\alpha(\widehat{g}_2, k_2)][\widehat{s}_2\widehat{s}_3]^\alpha$$

$$\text{s.t. } 2 = g_1 + k_1 + f_1 + g_2 + k_2 + \widetilde{f}_2/\widehat{m} - \widehat{s}_2 + \widetilde{s}_2/(1 - \widehat{m}) - \widehat{f}_2 + s_3$$

As before, we first derive the optimal strategy of the man under the assumption that $m = 1/2$ is the equilibrium choice of the mother. We then check that the optimal choice of the male does induce $m = 1/2$ as the woman's equilibrium choice.

Eliminating g_1 and letting $A = 2 - k_1 - k_2 - f_1 - 2\widetilde{f}_2 - 2\widetilde{s}_2 - s_3 - g_2 + \widehat{f}_2 + \widehat{s}_2$, and equating to zero the first order derivatives associated to the above optimization, we obtain the following set of equations:

$$\alpha \frac{1}{2} f_1^{\alpha-1} \widetilde{f}_2^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^\alpha - \alpha \frac{1}{2} f_1^\alpha \widetilde{f}_2^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(A+\widehat{k}_1)^2} = 0 \quad (\text{w.r.t. } f_1) \quad (\text{A.4a})$$

$$\alpha \frac{1}{2} f_1^\alpha \widetilde{f}_2^{\alpha-1} \left(\frac{A}{A+\widehat{k}_1}\right)^\alpha - \alpha \frac{1}{2} f_1^\alpha \widetilde{f}_2^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(A+\widehat{k}_1)^2} = 0 \quad (\text{w.r.t. } \widetilde{f}_2) \quad (\text{A.4b})$$

$$-\alpha \frac{1}{2} f_1^\alpha \widetilde{f}_2^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(\widehat{k}_1+A)^2} + \alpha \frac{1}{2} \widetilde{s}_2^\alpha s_3^\alpha \left(\frac{g_2}{g_2+\widehat{k}_2}\right)^{\alpha-1} \frac{\widehat{k}_2}{(g_2+\widehat{k}_2)^2} = 0 \quad (\text{w.r.t. } g_2) \quad (\text{A.4c})$$

$$-\alpha \frac{1}{2} f_1^\alpha \widetilde{f}_2^\alpha \left(\frac{A}{A+\widehat{k}_1}\right)^{\alpha-1} \frac{\widehat{k}_1}{(A+\widehat{k}_1)^2} + \alpha \frac{1}{2} s_3^\alpha \widetilde{s}_2^{\alpha-1} \left(\frac{g_2}{g_2+\widehat{k}_2}\right)^\alpha = 0 \quad (\text{w.r.t. } \widetilde{s}_2) \quad (\text{A.4d})$$

$$-\alpha \frac{1}{2} f_1^\alpha \tilde{f}_2^\alpha \left(\frac{A}{A + \hat{k}_1} \right)^{\alpha-1} \frac{\hat{k}_1}{(A + \hat{k}_1)^2} + \alpha \frac{1}{2} s_3^{\alpha-1} \tilde{s}_2^\alpha \left(\frac{g_2}{g_2 + \hat{k}_2} \right)^\alpha = 0 \quad (\text{w.r.t. } s_3) \quad (\text{A.4e})$$

$$-\alpha \frac{1}{2} f_1^\alpha \tilde{f}_2^\alpha \left(\frac{A}{A + \hat{k}_1} \right)^{\alpha-1} \frac{\hat{k}_1}{(A + \hat{k}_1)^2} + \alpha \frac{1}{2} \hat{f}_1^\alpha \hat{f}_2^\alpha \left(\frac{\hat{g}_1}{\hat{g}_1 + k_1} \right)^{\alpha-1} \frac{\hat{g}_1}{(\hat{g}_1 + k_1)^2} = 0 \quad (\text{w.r.t. } k_1) \quad (\text{A.4f})$$

$$-\alpha \frac{1}{2} f_1^\alpha \tilde{f}_2^\alpha \left(\frac{A}{A + \hat{k}_1} \right)^{\alpha-1} \frac{\hat{k}_1}{(A + \hat{k}_1)^2} + \alpha \frac{1}{2} \hat{s}_3^{\alpha-1} \hat{s}_2^\alpha \left(\frac{\hat{g}_2}{\hat{g}_2 + k_2} \right)^{\alpha-1} \frac{\hat{g}_2}{(\hat{g}_2 + k_2)^2} = 0 \quad (\text{w.r.t. } k_2). \quad (\text{A.4g})$$

If $\hat{m} = 1/2$ and $\hat{g}_1 = g_1, \hat{k}_1 = k_1, \hat{f}_1 = f_1, \hat{g}_2 = g_2, \hat{k}_2 = k_2, \hat{f}_2 = f_2, \hat{s}_2 = s_2$, and $\hat{s}_3 = s_3$, it is straightforward to verify that $g_1 = g_2 = k_1 = k_2 = 1/5$ and $\tilde{s}_2 = \tilde{f}_2 = 1/5$ is the solution to the eight equations given above.

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

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

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

At the Nash equilibrium, $f_2 = \hat{f}_2$ and $s_2 = \hat{s}_2$. The system (A.5)–(A.6) becomes singular, and reduces to the single expression $f_2 + s_2 = 2/5$. Finally, as in the fidelity case, we checked numerically that the proposed solution is indeed a global maximum of the problem with sign constraints. With the restriction that $\alpha \in (0, 1/2)$, this is the case. Therefore, the unique interior Nash equilibrium is

$$g_1 = g_2 = k_1 = k_2 = 1/5, \quad f_1 = s_3 = 2/5, \quad \text{and} \quad s_2 + f_2 = 2/5.$$

Proof of Corollary 2 (*Evolutionary Stability*)

The promiscuous convention is evolutionarily unstable — Let $\bar{\mathbf{x}}_P = \{\bar{f}_1, \bar{f}_2, \bar{g}_1, \bar{g}_2, \bar{k}_1, \bar{k}_2, \bar{s}_2, \bar{s}_3; \bar{m}\}$ be the promiscuous equilibrium allocation. Consider an individual deviation to the fidelity strategy and let $\mathbf{x}_{PF}^*(\bar{\mathbf{x}}_P) = \{f_1^*(\bar{\mathbf{x}}_P), f_2^*(\bar{\mathbf{x}}_P), s_2^*(\bar{\mathbf{x}}_P), s_3^*(\bar{\mathbf{x}}_P), k_1^*(\bar{\mathbf{x}}_P), k_2^*(\bar{\mathbf{x}}_P), g_1^*(\bar{\mathbf{x}}_P), g_2^*(\bar{\mathbf{x}}_P); \bar{m}\}$ be the vector that maximizes

$$\begin{aligned} & \frac{1}{2} \left(\frac{g_1}{g_1 + k_1} \right)^\alpha f_1^\alpha [\bar{m}(f_2 + s_2)]^\alpha + \frac{1}{2} \left(\frac{g_2}{g_2 + k_2} \right)^\alpha [(1 - \bar{m})(f_2 + s_2)]^\alpha s_3^\alpha \\ & + \frac{1}{2} \left[1 - \left(\frac{\bar{g}_1}{\bar{g}_1 + \bar{k}_1} \right)^\alpha \right] [\bar{f}_1 \bar{m} (\bar{f}_2 + \bar{s}_2)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{\bar{g}_2}{\bar{g}_2 + \bar{k}_2} \right)^\alpha \right] [(1 - \bar{m})(\bar{f}_2 + \bar{s}_2) \bar{s}_3]^\alpha, \end{aligned}$$

subject to $2 = g_1 + f_1 + g_2 + f_2 + s_2 + s_3 + k_1 + k_2$. Notice that the notation above emphasizes that each component of the vector $\mathbf{x}_{PF}^*(\bar{\mathbf{x}}_P)$ depends on the incumbents' strategy $\bar{\mathbf{x}}_P$. The terms with a bar on top are chosen by the promiscuous incumbents and are thus taken as given by the fidelity mutant. In addition, female partners of mutant males are assumed to continue choose their food allocation according to the promiscuous strategy. Below we relax this assumption. Then:

$$\begin{aligned} & \frac{1}{2} \left(\frac{\bar{g}_1}{\bar{g}_1 + \bar{k}_1} \right)^\alpha [\bar{f}_1 \bar{m} (\bar{f}_2 + \bar{s}_2)]^\alpha + \frac{1}{2} \left(\frac{\bar{g}_2}{\bar{g}_2 + \bar{k}_2} \right)^\alpha [(1 - \bar{m})(\bar{f}_2 + \bar{s}_2) \bar{s}_3]^\alpha \\ & + \frac{1}{2} \left[1 - \left(\frac{\bar{g}_1}{\bar{g}_1 + \bar{k}_1} \right)^\alpha \right] [\bar{f}_1 \bar{m} (\bar{f}_2 + \bar{s}_2)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{\bar{g}_2}{\bar{g}_2 + \bar{k}_2} \right)^\alpha \right] [(1 - \bar{m})(\bar{f}_2 + \bar{s}_2) \bar{s}_3]^\alpha \\ & < \frac{1}{2} \left(\frac{g_1^*}{g_1^* + k_1^*} \right)^\alpha [f_1^* \bar{m} (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left(\frac{g_2^*}{g_2^* + k_2^*} \right)^\alpha [(1 - \bar{m})(f_2^* + s_2^* s_3^*)]^\alpha \\ & + \frac{1}{2} \left[1 - \left(\frac{g_1^*}{g_1^* + k_1^*} \right)^\alpha \right] [f_1^* \bar{m} (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{g_2^*}{g_2^* + k_2^*} \right)^\alpha \right] [(1 - \bar{m})(f_2^* + s_2^* s_3^*)]^\alpha, \end{aligned}$$

which means that

$$\Phi_P(\bar{\mathbf{x}}_P) < \Phi_F(\mathbf{x}_{FP}^*).$$

This is because $\Phi_F(\bar{\mathbf{x}}_{FP})$ is attained without imposing the additional constraints on f_2 and s_2 that, in the promiscuous configuration, are chosen by a different male.

We already mentioned that women play their best response using the food allocation strategy of the promiscuous convention. We now allow them to take into account their partner's deviation to the fidelity strategy. The female allocation decision when her partner plays the mutant fidelity strategy, $m^* \equiv m(f_1^*, f_2^*, s_2^*, s_3^*)$, is such that her fitness (which coincides with child survival) is greater than the fitness (and child survival) she obtains if she plays $\bar{m} \equiv m(\bar{f}_1, \bar{f}_2, \bar{s}_2, \bar{s}_3)$, i.e., her best response to the man's promiscuous strategy. This is because males provides more food when they deviate to the fidelity strategy than under the incumbent Γ_P convention. This then implies that

$$\begin{aligned} \theta_P(\bar{\mathbf{x}}_P) &\equiv [\bar{f}_1 \bar{m} (\bar{f}_2 + \bar{s}_2)]^\alpha + [(1 - \bar{m}) (\bar{f}_2 + \bar{s}_2) \bar{s}_3]^\alpha \\ &< \theta(\mathbf{x}_{FP}^*) &\equiv [f_1^* m^* (f_2^* + s_2^*)]^\alpha + [(1 - m^*) (f_2^* + s_2^*) s_3^*]^\alpha \end{aligned}$$

The mutation to the fidelity strategy yields greater survivorship and the promiscuous convention is thus unstable.

The fidelity convention is evolutionarily stable — Let $\mathbf{x}_F^* = \{f_1^*, f_2^*, g_1^*, g_2^*, k_1^*, k_2^*, s_2^*, s_3^*; m^*\}$ be the fidelity equilibrium allocation. Consider an individual deviation to the promiscuous strategy and let $\bar{\mathbf{x}}_{FP}(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*) = \{\bar{f}_1(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{f}_2(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{s}_2(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{s}_3(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{k}_1(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{k}_2(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{g}_1(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*), \bar{g}_2(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*); m^*\}$ be the vector that maximizes

$$\begin{aligned} &\frac{1}{2} \left(\frac{g_1}{g_1 + k_1} \right)^\alpha f_1^\alpha [m^* (f_2 + \tilde{s}_2)]^\alpha + \frac{1}{2} \left(\frac{g_2}{g_2 + k_2} \right)^\alpha [(1 - m^*) (\tilde{f}_2 + s_2)]^\alpha s_3^\alpha \\ &+ \frac{1}{2} \left[1 - \left(\frac{g_1^*}{g_1^* + k_1} \right)^\alpha \right] [f_1^* m^* (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{g_2^*}{g_2^* + k_2} \right)^\alpha \right] [(1 - m^*) (f_2^* + s_2^*) s_3^*]^\alpha, \end{aligned}$$

subject to $2 = g_1 + f_1 + g_2 + f_2 + s_2 + s_3 + k_1 + k_2$ and for given \tilde{f}_2 and \tilde{s}_2 . Notice that the notation above emphasizes that each component of the vector $\bar{\mathbf{x}}_{FP}(\tilde{f}_2, \tilde{s}_2; \mathbf{x}_F^*)$ depends on the incumbents' strategy \mathbf{x}_F^* as well as on the endogenously chosen variables \tilde{f}_2 and \tilde{s}_2 . The terms marked with an asterisk are chosen by the fidelity incumbents and are thus taken as given by the promiscuous mutant. In addition, female partners of mutant males are assumed to continue play according to the fidelity strategy. Below we relax this assumption. Then:

$$\begin{aligned} &\frac{1}{2} \left(\frac{\bar{g}_1}{\bar{g}_1 + \bar{k}_1} \right)^\alpha [\bar{f}_1 m^* (\bar{f}_2 + \bar{s}_2)]^\alpha + \frac{1}{2} \left(\frac{\bar{g}_2}{\bar{g}_2 + \bar{k}_2} \right)^\alpha [(1 - m^*) (\bar{f}_2 + \bar{s}_2 \bar{s}_3)]^\alpha \\ &+ \frac{1}{2} \left[1 - \left(\frac{g_1^*}{g_1^* + \bar{k}_1} \right)^\alpha \right] [f_1^* m^* (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{g_2^*}{g_2^* + \bar{k}_2} \right)^\alpha \right] [(1 - m^*) (f_2^* + s_2^*) s_3^*]^\alpha \\ &< \frac{1}{2} \left(\frac{g_1^*}{g_1^* + k_1} \right)^\alpha [f_1^* m^* (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left(\frac{g_2^*}{g_2^* + k_2} \right)^\alpha [(1 - m^*) (f_2^* + s_2^* s_3^*)]^\alpha \\ &+ \frac{1}{2} \left[1 - \left(\frac{g_1^*}{g_1^* + k_1} \right)^\alpha \right] [f_1^* m^* (f_2^* + s_2^*)]^\alpha + \frac{1}{2} \left[1 - \left(\frac{g_2^*}{g_2^* + k_2} \right)^\alpha \right] [(1 - m^*) (f_2^* + s_2^*) s_3^*]^\alpha, \end{aligned}$$

which means that

$$\Phi_P(\bar{\mathbf{x}}_{PF}) < \Phi_F(\mathbf{x}_F^*).$$

This is because $\Phi_P(\bar{\mathbf{x}}_{PF})$ is attained through the two additional constraints on \tilde{f}_2 and \tilde{s}_2 .

We already mentioned that women play their best response using the food allocation strategy of the fidelity convention. We now allow them to take into account their partner's deviation to the promiscuous strategy. The female allocation decision when her partner plays the mutant promiscuous strategy, $\bar{m} \equiv m(\bar{f}_1, \bar{f}_2, \bar{s}_2, \bar{s}_3)$, is such that her fitness (which coincides with child survival) is lower than the fitness (and child survival) she obtains if she plays $m^* \equiv m(f_1^*, f_2^*, s_2^*, s_3^*)$, i.e., her best response to the man's fidelity strategy. This is because males provides less food when they deviate to the promiscuous strategy than under the incumbent Γ_F convention. This then implies that

$$\begin{aligned} \theta_P(\bar{\mathbf{x}}_{PF}) &\equiv [\bar{f}_1 \bar{m} (\bar{f}_2 + \bar{s}_2)]^\alpha + [(1 - \bar{m})(\bar{f}_2 + \bar{s}_2) \bar{s}_3]^\alpha \\ &< \theta(\mathbf{x}_F^*) &\equiv [f_1^* m^* (f_2^* + s_2^*)]^\alpha + [(1 - m^*)(f_2^* + s_2^*) s_3^*]^\alpha \end{aligned}$$

The mutation to the promiscuous strategy cannot yield greater survivorship and the fidelity convention is thus stable.

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

Fidelity Family — Let $\hat{f}_2 + \hat{s}_2 = \hat{z}$. Rearranging (8), the female's problem becomes that of choosing $m \in (0, 1)$ to maximize

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

or

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

The mother's choice of m affects the survival of her first child and therefore the transfer that the second child will receive from the first. The first-order necessary condition for an interior solution is

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

which leads to the following equation that implicitly defines m

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

The implicit equation (A.7) gives all equilibrium candidates to interior maxima. As in the case without kin ties, however, there is another inefficient non-interior solution, in which males and females choose $s_3 = 0$ and $m = 1$, respectively. This equilibrium can be ruled out using the Stackelberg-type refinement we have already proposed.

Finally, we numerically checked that for the values of the exogenous variables (i.e., not under the mother's control) at the fixed point, that is, the candidate Nash equilibrium, the solution to the implicit equation (A.7) delivers the global maximum for the mother. This is indeed the case.

Promiscuous Pair Bonding — Rearranging (8), the female's problem becomes that of choosing $m \in (0, 1)$ to maximize

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

A mother can only affect the probability of survival of her own children, and not that of her nieces and nephews: m , therefore, is a choice variable that only affects the probability of her second child receiving a transfer from her first child. To stress the maternal link, we denote this transfer between half-siblings with b_M . Her behavior, however, cannot not affect the transfer between half-siblings who are (possibly) linked through the father. We denote this transfer with b_F . The objective of the mother is then to maximize

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

The solution to this optimization exists and is a function of the parameters exogenous to the mother's decision. Note that, when kin transfers are zero, (A.8) boils down to (A.1).

Proof of Proposition 3 (*Promiscuous Pair Bonding with Kinship*)

As discussed in the text, we have one program faced by older men and another different program faced by younger men. Younger men cannot make transfers (because, by definition, they do not have younger siblings to transfer resources to), so the interesting case is the problem faced by the older man. With the same notation used in the proof of Proposition 2, the older male's program is to choose $g_1, f_1, k_1, g_2, f_2, s_2, k_2, s_3, b_M$ and b_F to maximize

$$\frac{1}{2} G_\alpha(g_1, \widehat{k}_1) f_1^\alpha (\widehat{m}(f_2 + \widehat{s}_2))^\alpha + \frac{1}{2} G_\alpha(g_2, \widehat{k}_2) \left[(1 - \widehat{m})(\widehat{f}_2 + s_2) \right]^\alpha \widehat{f}_1^\alpha \widehat{m}^\alpha (\widehat{f}_2 + s_2)^\alpha (s_3 + \widehat{b}_M + \widehat{b}_F)^\alpha \\ + \frac{1}{2} G_\alpha(g_2, \widehat{k}_2) \left[(1 - \widehat{m})(\widehat{f}_2 + s_2) \right]^\alpha \left[1 - \widehat{f}_1^\alpha \widehat{m}^\alpha (\widehat{f}_2 + s_2)^\alpha \right] s_3^\alpha + \frac{1}{2} [1 - G_\alpha(\widehat{g}_1, k_1)] \widehat{f}_1^\alpha \left[\widehat{m}(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha \\ + \frac{1}{2} [1 - G_\alpha(\widehat{g}_2, k_2)] \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha f_1^\alpha \left[\widehat{m}(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + \widehat{b}_M + \widehat{b}_F)^\alpha \\ + \frac{1}{2} [1 - G_\alpha(\widehat{g}_2, k_2)] \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha \left[1 - \widehat{f}_1^\alpha \widehat{m}^\alpha (\widehat{f}_2 + \widehat{s}_2)^\alpha \right] \widehat{s}_3^\alpha \\ + \frac{1}{4} \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + b_M + \widehat{b}_F)^\alpha \rho \\ + \frac{1}{4} G_\alpha(\widehat{g}_1, \widehat{k}_1) G_\alpha(\widehat{g}_2, \widehat{k}_2) \left[(1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right]^\alpha (\widehat{s}_3 + \widehat{b}_M + b_F)^\alpha \rho$$

subject to $2 = g_1 + f_1 + g_2 + f_2 + s_2 + s_3 + k_1 + k_2 + b_M + b_F$ and $0 \leq f_1, f_2, g_1, g_2, k_1, k_2, s_2, s_3, b_M, b_F$. The transfers b_M and b_F only appear in the constraint and in the last two terms of the objective function. Because they cannot be negative, we are concerned with the value of ρ , denoted $\underline{\rho}$, such that in the unconstrained optimization problem one of the transfers is strictly negative and the other is exactly zero. In such a case, therefore, the corresponding fixed point when players face the constrained optimization problem (including the sign constraints on the transfers) must yield $b_M = b_F = 0$ in equilibrium.

For $\rho = \underline{\rho}$, the first order conditions evaluated at the equilibrium are identical to those found for the case without kin ties, except those relative to b_M and or b_F . We then need to consider the first order conditions relative to the transfers and, as mentioned, we ignore the sign constraints on all the control variables, apart from b_M and b_F . Eliminating g_1 and letting $A = 2 - (f_1 + g_2 + f_2 + s_2 + s_3 + k_1 + k_2 + b_M + b_F)$, the first order conditions with respect to the transfers are

$$-\alpha f_1^\alpha (\widehat{m}(f_2 + \widehat{s}_2))^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} \frac{\widehat{k}_1}{(A + \widehat{k}_1)^2} \\ + \frac{1}{2} \alpha \left((1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right)^\alpha (\widehat{s}_3 + b_M + \widehat{b}_F)^{\alpha-1} \rho = 0 \quad (\text{w.r.t. } b_M) \quad (\text{A.9a})$$

$$\begin{aligned}
& -\alpha f_1^\alpha (\widehat{m}(f_2 + \widehat{s}_2))^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} \frac{\widehat{k}_1}{(A + \widehat{k}_1)^2} \\
& + \frac{1}{2} \alpha G_\alpha(\widehat{g}_1, \widehat{k}_1) G_\alpha(\widehat{g}_2, \widehat{k}_2) \left((1 - \widehat{m})(\widehat{f}_2 + \widehat{s}_2) \right)^\alpha (\widehat{s}_3 + \widehat{b}_M + b_F)^{\alpha-1} \rho = 0 \quad (\text{w.r.t. } b_F) \quad (\text{A.9b})
\end{aligned}$$

To find the critical values of ρ , consider (A.9a) and (A.9b) and evaluate them at the equilibrium without kin transfers. Since the promiscuous equilibrium without kinship (see Proposition 2) is characterized by $g_1 = g_2 = k_1 = k_2 = 1/5$, $f_1 = s_3 = 2/5$, $s_2 + f_2 = 2/5$ and $m = 1/2$, we obtain

$$\left(\frac{2}{5} \right)^\alpha \left(\frac{1/5}{1/5 + 1/5} \right)^{\alpha-1} \frac{1/5}{(1/5 + 1/5)^2} = \frac{1}{2} \left(\frac{2}{5} \right)^{\alpha-1} \underline{\rho}(b_M),$$

and

$$\left(\frac{2}{5} \right)^\alpha \left(\frac{1/5}{1/5 + 1/5} \right)^{\alpha-1} \frac{1/5}{(1/5 + 1/5)^2} = \frac{1}{2} \left(\frac{1/5}{1/5 + 1/5} \right)^{2\alpha} \left(\frac{2}{5} \right)^{\alpha-1} \underline{\rho}(b_F),$$

where $\underline{\rho}(b_M)$ and $\underline{\rho}(b_F)$ are the critical values of ρ for the b_M and b_F transfers respectively. It is easy to verify that $\underline{\rho}(b_M) = 2^{1-\alpha} > 1$ and $\underline{\rho}(b_F) = 2^{\alpha+1} > 1$. Both critical values are larger than one, which is a contradiction since ρ cannot be greater than unity. In the promiscuous configuration, therefore, kin transfers are never operative (positive). Finally, we checked numerically that the solution to the first order conditions when $b_M = b_F = 0$ is a global maximum of the problem with sign constraints. This is confirmed to be the case. Hence, the unique interior Nash equilibrium is as stated.

Proof of Proposition 4 (*Fidelity Family with Kinship and Low Kin Recognition*)

As in Proposition 3, we have one program faced by older men and another different program faced by younger men. We focus on the problem faced by older men, since younger men cannot make transfers by definition. With the usual notation used so far, the program faced by the older male is to choose $g_1, k_1, g_2, k_2, f_1, z, s_3$ and b to maximize

$$\begin{aligned}
& \frac{1}{2} G_\alpha(g_1, \widehat{k}_1) (f_1 \widehat{m} z)^\alpha + \frac{1}{2} G_\alpha(g_2, \widehat{k}_2) [(1 - \widehat{m})z]^\alpha \left[\widehat{f}_1 \widehat{m} z (s_3 + \widehat{b}) \right]^\alpha \\
& + \frac{1}{2} G_\alpha(g_2, \widehat{k}_2) [(1 - \widehat{m})z]^\alpha \left(1 - \widehat{f}_1^\alpha \widehat{m}^\alpha z^\alpha \right) s_3^\alpha + \frac{1}{2} [1 - G_\alpha(\widehat{g}_1, k_1)] (\widehat{f}_1 \widehat{m} \widehat{z})^\alpha \\
& + \frac{1}{2} [1 - G_\alpha(\widehat{g}_2, k_2)] [(1 - \widehat{m})\widehat{z}]^\alpha (f_1 \widehat{m} z)^\alpha (\widehat{s}_3 + \widehat{b})^\alpha \\
& + \frac{1}{2} [1 - G_\alpha(\widehat{g}_2, k_2)] [(1 - \widehat{m})\widehat{z}]^\alpha \left[1 - \widehat{f}_1^\alpha \widehat{m}^\alpha \widehat{z}^\alpha \right] \widehat{s}_3^\alpha \\
& + \frac{1}{4} \left[(1 + G_\alpha(\widehat{g}_1, \widehat{k}_1) G_\alpha(\widehat{g}_2, \widehat{k}_2)) \right]^\alpha [(1 - \widehat{m})\widehat{z}]^\alpha (\widehat{s}_3 + b)^\alpha \rho
\end{aligned} \quad (\text{A.10})$$

subject to

$$2 = g_1 + f_1 + g_2 + z + s_3 + k_1 + k_2 + b \quad (\text{A.11})$$

$$0 \leq f_1, z, g_1, g_2, k_1, k_2, s_2, s_3, b. \quad (\text{A.12})$$

The transfer b only appears in the constraint and in the last term of the objective function (A.10). Because b cannot be negative, we are concerned with the value of ρ , denoted $\underline{\rho}$, such that in the unconstrained optimization problem the transfer is equal to zero. In such a case, therefore, the

corresponding fixed point when players face the constrained optimization problem (including the sign constraints on the transfer) must yield $b=0$ in equilibrium.

We focus on the first order condition relative to the kin transfer. As mentioned, we ignore the sign constraints on all the control variables, apart from b . Eliminating g_1 and letting $A = 2 - (f_1 + g_2 + f_2 + s_2 + s_3 + k_1 + k_2 + b_M + b_F)$, the first order condition with respect to b is

$$\alpha f_1^\alpha (\widehat{m}\widehat{z})^\alpha \left(\frac{A}{A + \widehat{k}_1} \right)^{\alpha-1} \frac{\widehat{k}_1}{(A + \widehat{k}_1)^2} = \frac{\alpha}{2} \left[1 + G_\alpha(\widehat{g}_1, \widehat{k}_1)G_\alpha(\widehat{g}_2, \widehat{k}_2) \right] (1 - \widehat{m})^\alpha (\widehat{s}_3 + b)^{\alpha-1} \rho. \quad (\text{A.13})$$

To find the critical value of ρ , consider (A.13) and evaluate it at the equilibrium without kin transfers. Since the fidelity equilibrium without kinship (see Proposition 1) is characterized by $g_1 = g_2 = k_1 = k_2 = 1/6$, $f_1 = s_3 = 1/3$, $z = s_2 + f_2 = 2/3$ and $m = 1/2$, we obtain

$$\left(\frac{1}{3} \right)^\alpha \left(\frac{1}{2} \right)^\alpha \left(\frac{1/6}{1/6 + 1/6} \right)^{\alpha-1} \frac{1/6}{(1/6 + 1/6)^2} = \frac{1}{2} \left[1 + \left(\frac{1}{2} \right)^{2\alpha} \right] \left(\frac{1}{2} \right)^\alpha \left(\frac{1}{3} \right)^{\alpha-1} \rho,$$

which implies $\rho = (1/2)^{\alpha-1} [1 + (1/2)^{2\alpha}]^{-1}$, with $\alpha \in (0, \frac{1}{2})$ and $\rho \in [0, 1]$. It is easy to verify that, for any $\alpha \in (0, \frac{1}{2})$, there exists an admissible value of $\rho \in (0, 1)$. Therefore, if the sibling detection parameter, ρ , is below ρ , Proposition 4 is proved. Finally, we checked numerically that the solution to the first order conditions when $b=0$ is a global maximum of the problem with sign constraints. This is confirmed to be the case. Hence, the unique interior Nash equilibrium is as stated.

If, instead, $\rho > \rho$, kin transfers will be positive. But in this case, an analytical solution could not be found. This is the focus of the next proposition.

Proof of Proposition 5 (*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 older men is to choose $g_1, k_1, g_2, k_2, f_1, z, s_3$ and b to

maximize (A.10) under (A.11) and (A.12), taking $\widehat{g}_1, \widehat{g}_2, \widehat{k}_1, \widehat{k}_2, \widehat{z}, \widehat{s}_3, \widehat{m}, \widehat{b}$ and ρ as given, and with $g_1, f_1, k_1, k_2, z, s_3, g_2, b \geq 0$. The solution to this problem is a vector $\{g_1^*, f_1^*, g_2^*, k_1^*, k_2^*, z^*, s_3^*, b^*\}$ in which each component is a function of $\{\widehat{g}_1, \widehat{g}_2, \widehat{k}_1, \widehat{k}_2, \widehat{z}, \widehat{s}_3, \widehat{m}, \widehat{b}, \rho\}$. The solution is obtained from the first step of our two-stage procedure. The mother's optimal allocation rule, m^* , is instead 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 $\widehat{g}_1 = g_1^*$, $\widehat{f}_1 = f_1^*$, $\widehat{g}_2 = g_2^*$, $\widehat{k}_1 = k_1^*$, $\widehat{k}_2 = k_2^*$, $\widehat{z} = z^*$, $\widehat{s}_3 = s_3^*$, $\widehat{b} = b^*$, and $\widehat{m} = m^*$, with the equilibrium allocations depending on the parameters ρ and α . Once this optimization is performed, the second step consists of minimizing the Euclidean distance between $\{\widehat{g}_1, \widehat{f}_1, \widehat{g}_2, \widehat{k}_1, \widehat{k}_2, \widehat{z}, \widehat{s}_3, \widehat{b}, \widehat{m}\}$ and $\{g_1^*, f_1^*, g_2^*, k_1^*, k_2^*, z^*, s_3^*, b^*, m^*\}$, by choosing the 'hat' variables. The fixed point is reached by iteration. The numerical results as ρ increases from ρ to 1 for a given value of α ($\alpha = 0.45$) are shown in the text. Other plots are available upon

request. Finally, we checked numerically that the solution to the first order conditions is the global maximum of the problem with sign constraints. This is confirmed to be the case. Therefore, the unique interior Nash equilibrium is as stated.

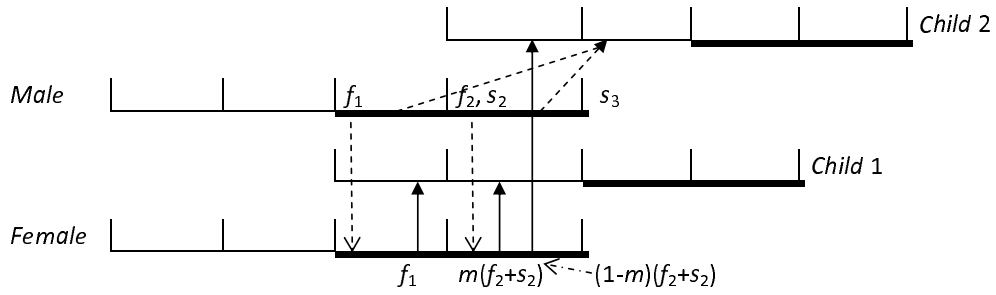
Proof of Proposition 6 (*Religion*)

The problem is to choose $g_1, k_1, g_2, k_2, f_1, z, s_3$ and b to maximize (A.10) under (A.12) and the new resource constraint

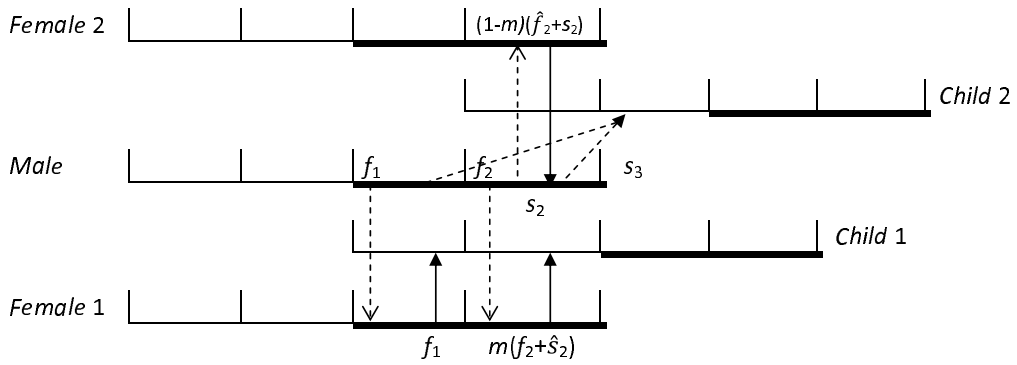
$$2 = g_1 + f_1 + g_2 + f_2 + s_2 + s_3 + (1 + \tau)k_1 + (1 + \tau)k_2 + b.$$

We solve this program numerically, following the same two-stage procedure as that used for Proposition 5. C++ codes of the algorithms are available at <http://privatewww.essex.ac.uk/~cghig/#material>. Numerical results as τ increases from 0 to 1 for a given value of α ($\alpha = 0.45$) are reported in the text. Finally, we checked numerically that the solution to the first order conditions indeed is a global maximum of the problem with sign constraints. This is confirmed to be the case. Therefore, the unique interior Nash equilibrium is as stated.

(a) Fidelity Family



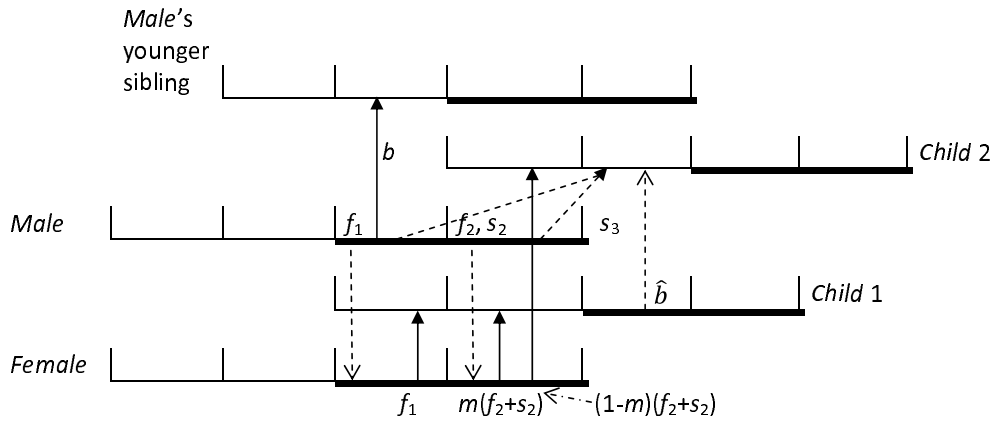
(b) Promiscuous Pair Bonding



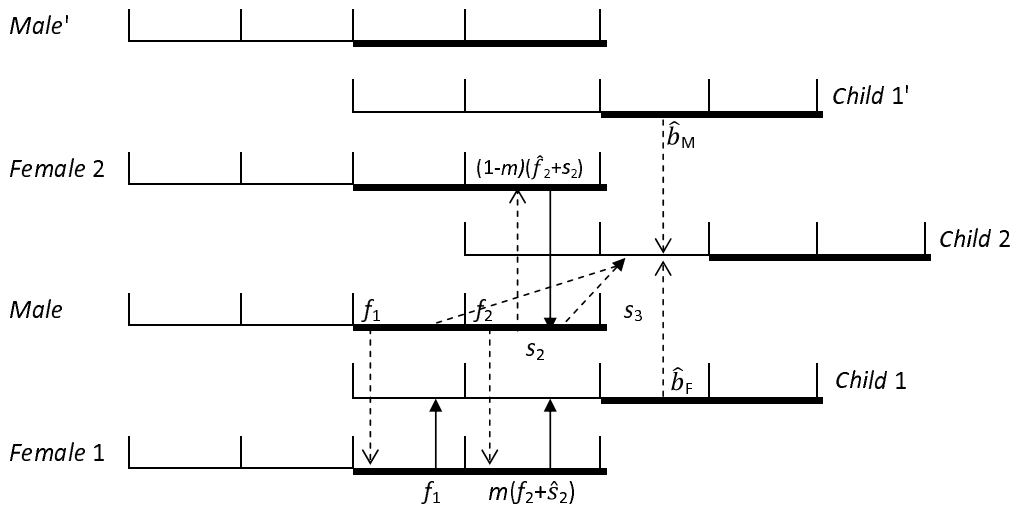
Note: In both panels, the solid thin lines indicate the childhood stage for each individual (corresponding to periods i and ii); the solid bold lines indicate the adulthood stage (periods 1 and 2); the dashed arrow vertical lines denote the food transfer from *Male* to his official partner, while the solid vertical lines denote the allocations made by the mother. The amount of food received by *Child 2* in her/his second period of childhood, s_3 , is perfectly stored by the father in either period 1 or 2. In panel (b), *Female 1* denotes *Male's* partner in the first adult period (period 1), while *Female 2* denotes the male's partner in period 2. For the sake of simplicity, the other male partners involved in the food allocations as well as their offspring have not been represented.

Figure 1: TIMING OF PARENTAL FOOD ALLOCATIONS BY FAMILY CONFIGURATION — BENCHMARK MODEL

(a) Fidelity Family



(b) Promiscuous Pair Bonding



Note: Male is matched to Female 1 in period 1 and to Female 2 in period 2. Male' is Female 2's partner in period 1, with who she has Child 1' (the maternal half-sibling of Child 2). For simplicity, panel (b) does not represent the two half-siblings to whom Male transfers b_M and b_F . See the note to Figure 1 for further details.

Figure 2: TIMING OF PARENTAL FOOD ALLOCATIONS BY FAMILY CONFIGURATION — MODEL WITH KINSHIP

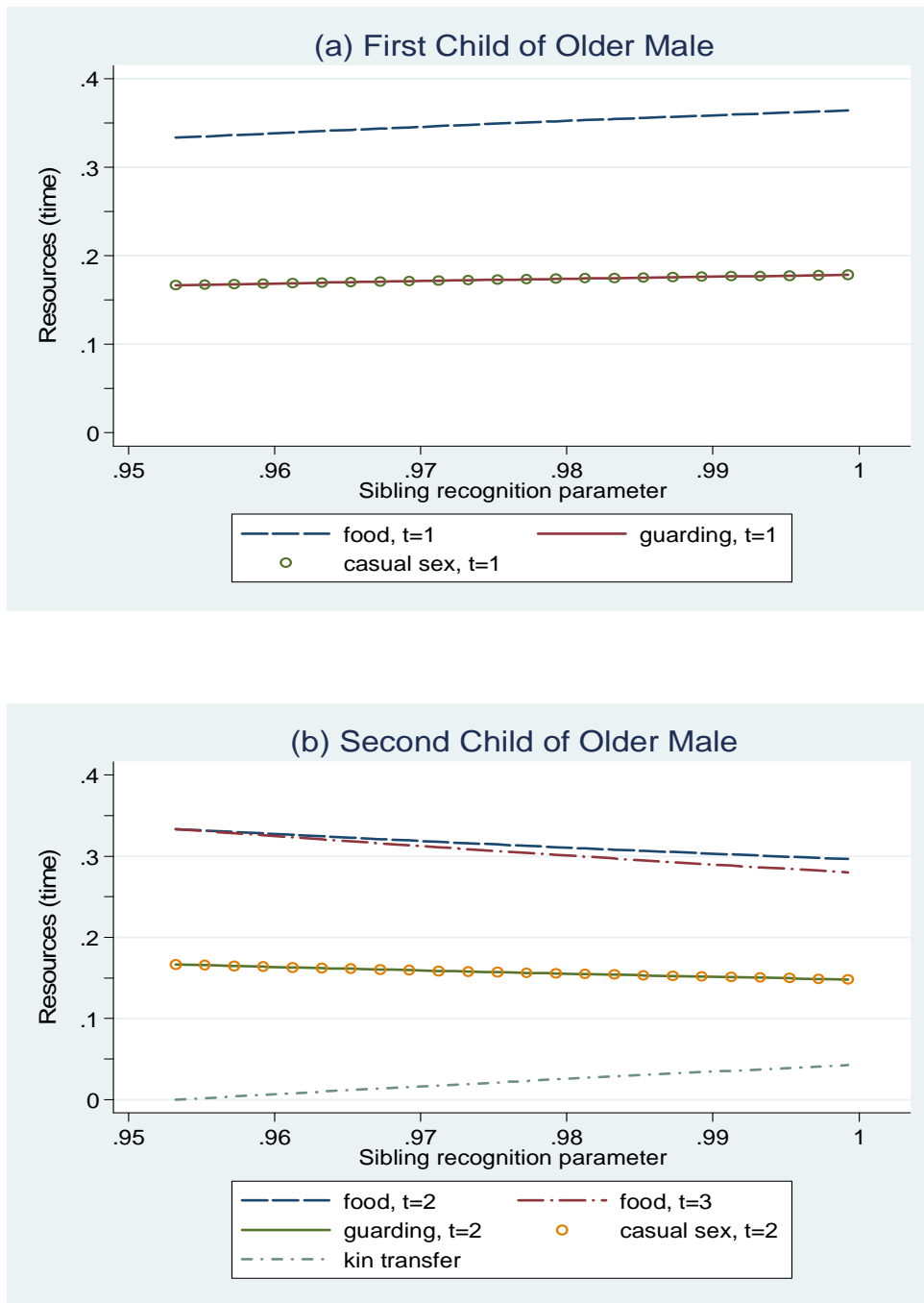


Figure 3: MALE ALLOCATIONS AS THE SIB RECOGNITION PARAMETER, ρ , INCREASES FROM $\underline{\rho}$ TO 1

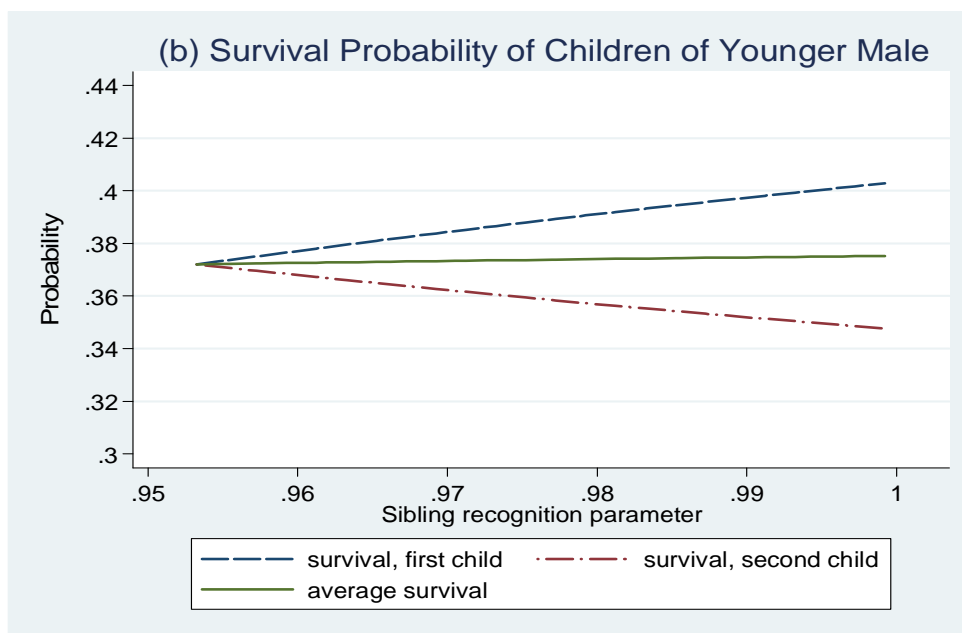
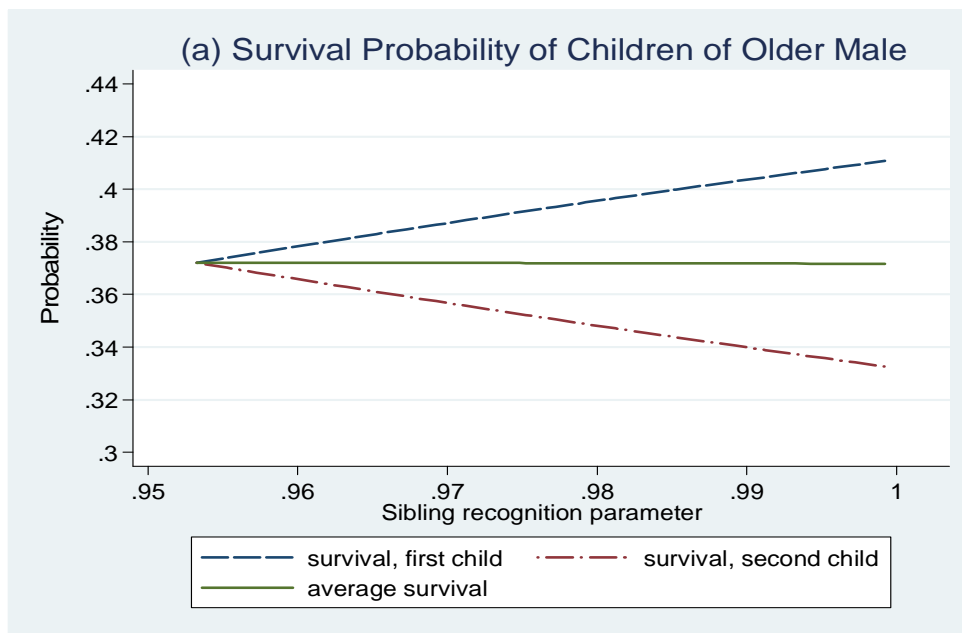


Figure 4: CHILD SURVIVAL BY BIRTH ORDER AS THE SIB RECOGNITION PARAMETER, ρ , INCREASES FROM $\underline{\rho}$ TO 1

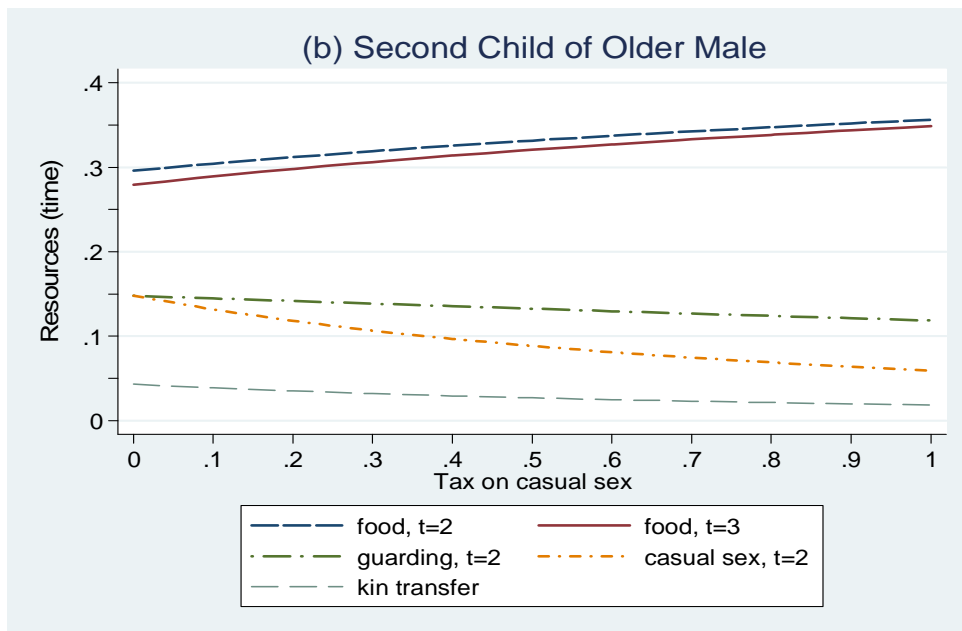
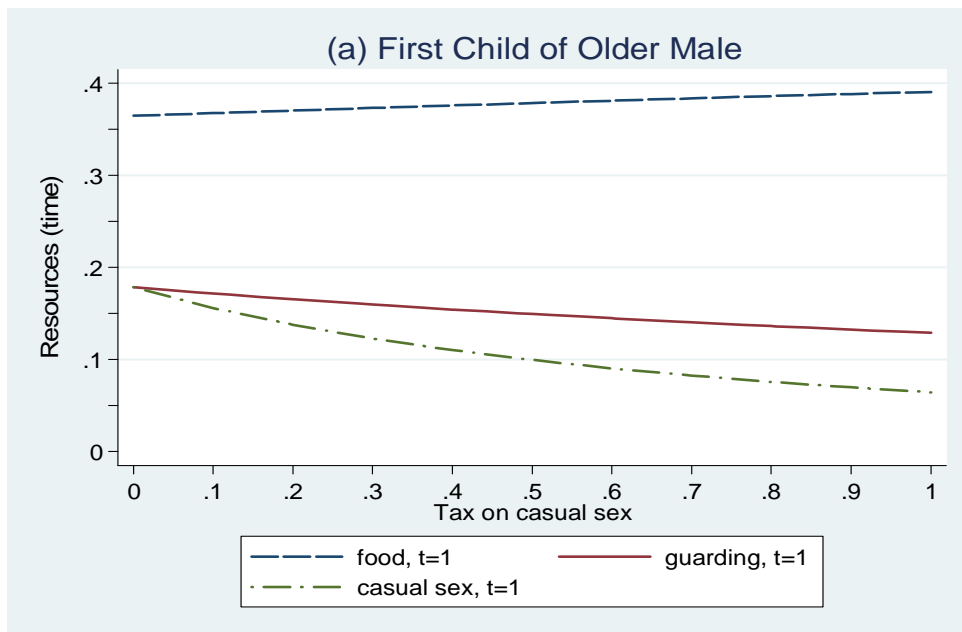


Figure 5: MALE ALLOCATIONS AS THE TAX ON CASUAL SEX, τ , INCREASES FROM 0 TO 1

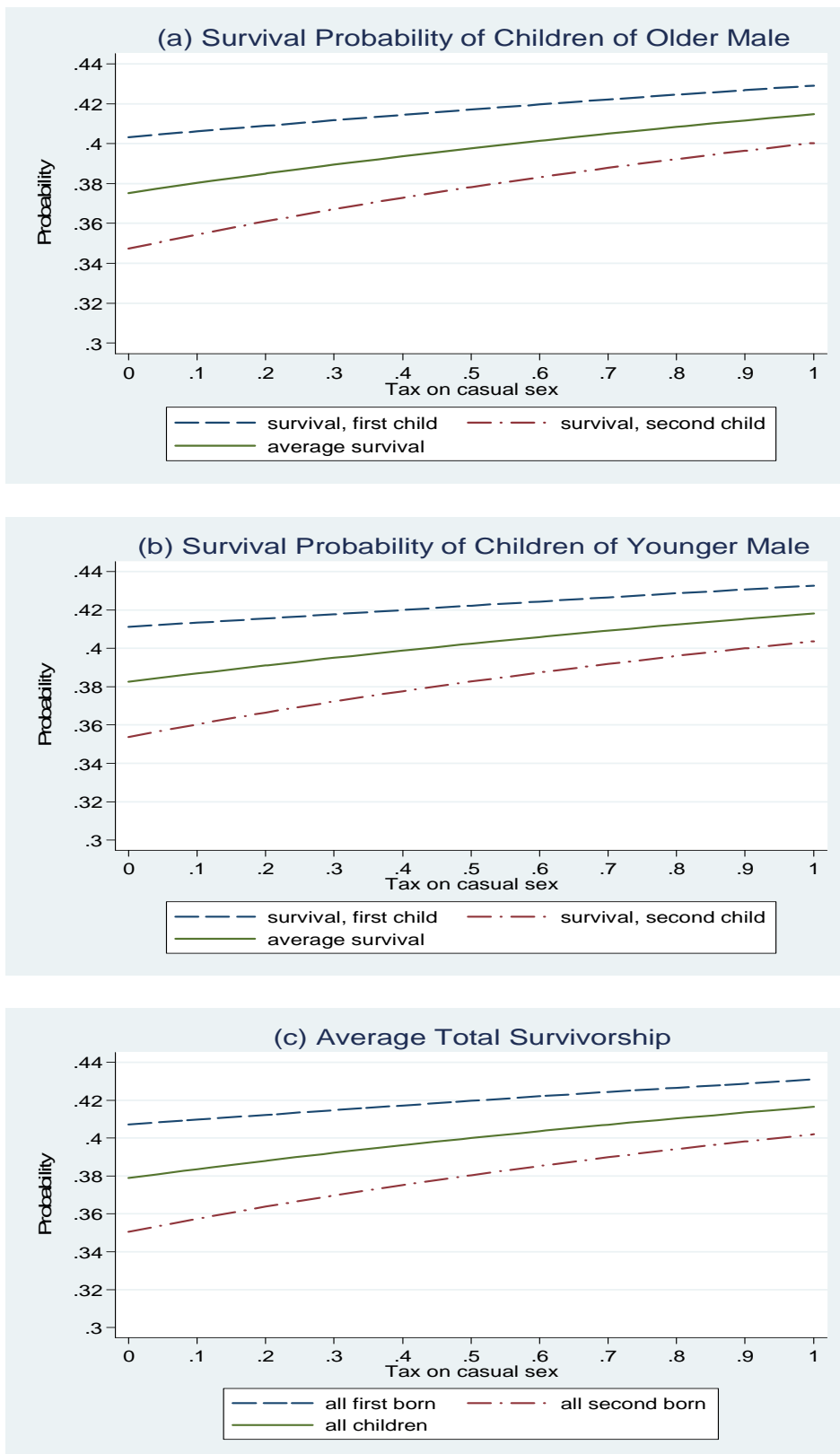


Figure 6: CHILD SURVIVAL BY BIRTH ORDER AND TOTAL SURVIVORSHIP AS THE TAX ON CASUAL SEX, τ , INCREASES FROM 0 TO 1

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