

On the Origin of the Family*

Marco Francesconi
University of Essex

Christian Ghiglino
University of Essex

Motty Perry
University of Warwick

Abstract

We present an evolutionary model to explain why people form life long monogamous families. Three special ingredients play a key role in the model, the overlap of different cohorts of children, parental investment, and fatherhood uncertainty. When all three conditions are present, monogamy is the dominant convention over serial monogamy, polygyny, and cenogamy. Monogamy is evolutionarily stable against deviations to any of the other conventions and is the only configuration that fosters altruistic ties among siblings. The model allows us to understand why most religions center around the monogamous fidelity family even though history has witnessed different types of sexual organizations.

Keywords: Overlapping generations; Free riding; Evolutionary Stability; Kinship systems; Religion.

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

First version: June 2011

This version: August 2012

* We thank the editor and three anonymous referees for valuable comments and suggestions. We are also grateful to Gary Becker, Ted Bergstrom, Lena Edlund, Andrea Galeotti, Luigi Guiso, James Heckman, Luis Rayo, Phil Reny, Aloysius Siow, Bertrand Wigniolle, Randy Wright, and seminar participants at Aarhus, Bergen, UBC, Chicago, Cornell, Essex, Hebrew, PSE, Royal Holloway, Warwick, and at the 2009 ESPE Conference (Seville), 2010 SED Conference (Montreal), 2011 SOLE Conference (Vancouver), and 2011 Economics of the Family Conference (Paris). Jianyong Sun provided excellent research assistance.

1. Introduction

Why do humans live in long lasting monogamous families? 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.¹ This paper addresses such a question using a nonco-operative evolutionary model in which males and females care only for the survivorship and propagation of their own genes into future generations (Hamilton 1964). Following Becker's (1973, 1974, 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 monogamous family came about and grew.² We use three special conditions for this purpose, the overlap of different cohorts of offspring, parental investment, and fatherhood uncertainty.

The first special, and perhaps most important, ingredient of our model is the presence of overlapping cohorts of *dependent* children, which is a highly distinctive feature of human behavior. This is tightly linked to our second ingredient, the salience of parental investment (Trivers 1972), which is shared by other non-human species as evidenced, for instance, by the complex non-familial colonies of eusocial insects (Wilson 1975). The third special feature is fatherhood uncertainty. When paternity is uncertain, a man must resort to guard his opposite-sex partner(s) if he wishes to enhance confidence in his biological association with the children he feeds (Hawkes, Rogers, and Charnov 1995).³ 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 (Krützen et al. 2004): most of such species in fact do not form families.

The main set of results of the paper is that, when all three ingredients operate *together*, life long monogamy is the dominant form of sexual organization among humans as opposed to other family types, such as serial monogamy, polygyny, and cenogamy. Dominance here means that the monogamous family grows faster and is evolutionarily stable against deviations to each of the other family conventions, while the other family types are not.

To gain insight into these results consider a large population in which people live for five periods, the first two as children and the last three as adults. As a child, an individual depends on parental investments. All adults strive to maximize the expected number of their biological children who are born in the first two periods of adulthood. There is full

¹Using a looser notion of family 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.

²Biologists 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; Gavrillets 2012).

³Even 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.

intrahousehold labor specialization (Becker 1981/1991), with men being food providers and women (and only women) being in control of the allocation of food to their children.⁴ Men and women can engage in casual sex and, as a consequence, a man guard his mate because he cannot be certain that the children he feeds are his. So, why is monogamy superior to the other family conventions?

In a monogamous environment a man protects his paternity by guarding the same woman for both of her (and his) fertile periods. In the serially monogamous convention instead a man makes does not keep the same mate from the previous period and thus has two groups of children from two different partners. The efficiency difference between these two family types arises because mothers redistribute resources among their children. If a woman receives resources from two different men, there is a free-rider problem in which each man realizes that his contribution to his official children will be shared with other children who are most likely not his.⁵ Consequently, he will shift more of his resources toward cheating and guarding, which are socially wasteful activities.

Life long monogamy dominates serial monogamy precisely because it is socially more efficient and delivers a higher rate of population growth. Interestingly, this result lines up well with the extensive body of contemporary empirical evidence according to which children who live part of their childhood in a blended (serially monogamous) 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). Our notion of evolutionary stability of family conventions builds on the important work by Bergstrom (1995) and Alger and Weibull (2010) and underpins a powerful idea of cultural transmission according to which official parents serve as direct role models for their children.

We show that monogamy also dominates cenogamy — in which all women share all men in the population as partners — as well as polygyny — in which one man has multiple official partners at the same time. In the cenogamy convention, the free-rider problem is more pervasive and leads to a classic tragedy of the commons whereby men shift resources from food production to their own consumption. In polygyny, the polygynous male has to defend his paternity claims from harsher competition by the unmatched men who spend their entire endowment on cheating.

We also show that altruistic ties between siblings are uniquely associated with the monogamous family, in the sense that food transfers among siblings provide survivorship gains only

⁴As long as women are the only food allocators to children, all our results hold true even when we relax the full specialization assumption and women are allowed to be food providers. See the discussion in subsection 6B.

⁵Private underprovision of public goods is a standard result (Samuelson 1955; Becker 1981/1991; Bergstrom, Blume, and Varian 1986). In Weiss and Willis's (1985) model of divorce, the free-rider problem is between former spouses who cannot verify each others' allocative decisions rather than between unrelated men who cannot write down binding verifiable contracts.

in its context and not in the context of the other family conventions. Monogamy is thus the only family configuration in which an adult man, who is uncertain about his paternity and yet cares about reproductive success and invests in children, 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 individual and societal gains obtained through kinship ties, this result identifies the monogamy 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).

A final point worth stressing is on interpretation. In our setup, a family convention specifies the matching protocol defining how many women a man can guard or if he can guard at all. Once the matching protocol is fixed, the other individual activities (hunting, cheating, and food distribution) are determined in equilibrium. Since cheating and guarding turn out to be socially wasteful, a convention that puts pressure on them has an evolutionary advantage over another convention that does not. A convention then can be interpreted as the body of social norms, beliefs, and institutions that may determine evolutionary success or hamper it. One of such institutions is religion, whereby a convention can be seen, in and of itself, as a ‘religion’. This reasoning allows us to use our results to understand why all major world religions have centered around and supported the monogamous fidelity family (Browning, Green and Witte 2006). This remark 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

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

are uncommon. In Becker’s analysis, however, men 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 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 monogamous family. The alternative to marriage, however, is not another form of partnership (such as the serial monogamy family in the present study) but singlehood. The comparison to singlehood, however, is not compelling in an environment in which individuals care for the survivorship of their genetic endowment.

Earlier studies by Becker (1973 and 1974) and Grossbard (1976) show that polygyny can be explained in a world characterized by male inequality in wealth combined with gender differences in the constraints on reproduction. They do not have an explanation, however, of why polygyny has declined over time in those part of the world where it was once more common. Recent work by Gould, Moav and Simhon (2008) does provide an explanation based on the increasing relevance of female human capital. Gould and colleagues argue that educated men increasingly value educated women for their ability to raise educated children, and this drives up the value of educated women to the point where educated men prefer one educated partner to multiple unskilled wives. Our model abstracts from male and female heterogeneity but, while emphasizing the importance of fatherhood uncertainty, establishes the evolutionary dominance of monogamy.

Another important strand of economic research explicitly incorporates biological considerations into individual or household behavior (Bergstrom 1995; 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

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

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), Saint-Paul (2008), and Bethmann and Kvasnicka (2011). 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 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 sister's children decreases with either an increase in the paternity probability or an increase in the number of own official children. As noted, we emphasize 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.

Several recent studies focus 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 religion from a different perspective. In particular, by stressing the role of religion as game setter and, possibly, as a group adaptation mechanism, our model underlines the evolutionary advantage induced by institutions that promote the monogamous family and punish cheating (Wilson 2002).

the physical environment, to the development of specific religions. Our provides a discussion about religion from a different perspective. See subsection 6C.

2. The Model

A. Setup

Consider an overlapping generations model in which individuals live for five periods. In each period 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 each of the first two periods of adulthood (labeled 1 and 2), two opposite-sex individuals from the same cohort are matched and have multiple child. In period 3, instead, individuals are not fertile and use their resources only to support their progeny. Men (and only men) are hunters and provide food for their offspring, while women (and only women) are carers and allocate the food they receive from their partners between their children.⁹ Allowing mothers to be food providers does not alter any of our main results. We shall come back to this issue in Section 6.

In each period 1 and 2, a man divides his resource (or time) endowment into three activities: (a) hunting, which provides food necessary for child survival; (b) mate guarding, which increases the probability that the children he supports carry his genes; and (c) cheating or casual sex, which increases the chance that his genes are represented in the next generation's gene pool. In the last period (labeled 3), men are only food providers because they (as well as all the women in their cohort) are no longer fertile and thus do not engage in guarding and cheating. A fourth activity is own consumption, which improves the man's physical fitness and thus increases his offspring's survivorship. Since most of our results hold irrespective of whether male consumption is modeled or not, for the rest of this section as well as in Sections 3 and 4, we ignore this activity for the sake of notational simplicity and without loss of generality. We will formally introduced it instead in subsection 5B when we analyze the full promiscuity case for which it does play a role.

We consider four alternative and mutually exclusive social configurations (or conventions): (a) the monogamy family, denoted by \mathcal{C}_M , where a female is matched with the same male in periods 1 and 2; (b) serial monogamy, denoted by \mathcal{C}_S , where each female is matched with a male in period 1 and another male in period 2; (c) polygyny, \mathcal{C}_P , where one man mates with more than one woman each period; and (d) full promiscuity (or group marriage or cenogamy), \mathcal{C}_G , in which all men are considered to be officially matched to all women and all group members share equal parental responsibilities. In this context then matching is convention specific, and depending on the family configuration, it expects a given male to guard only his official partner(s).

⁹This full gender specialization in home and market tasks echoes Becker (1981/1991). 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).

In what follows, individuals do not choose among configurations, but abide to one of them. A convention specifies the matching protocol between men and women, i.e., it defines how many women a man can guard or if he can guard at all. For each given convention, we characterize the Nash equilibrium in actions. In particular, Section 3 focuses only on \mathcal{C}_M and \mathcal{C}_S and shows that the two respective Nash equilibria exist. Section 4 compares them and considers their evolutionary stability. It will be shown that \mathcal{C}_M dominates \mathcal{C}_S in the sense that it yields a higher population growth rate and that it is evolutionary stable while \mathcal{C}_S is not. Having established such results, the analysis of \mathcal{C}_P and \mathcal{C}_G becomes quite natural. This will be presented in Section 5. Section 6 extends the model allowing for kin ties among siblings and considering the possibility of maternal food provision and discusses the interpretation of conventions as religions. Section 7 concludes. All proofs are contained in the Appendix.

B. Technologies and Actions

Let g_t denote the amount of time a man devotes to guarding his mate in period t , $t = 1, 2$, k_t be the amount of time he spends in casual sex, and \widehat{k}_t the average amount of time spent cheating by all other men in period t . The probability that guarding is successful is given by $\Pi(g_t, \widehat{k}_t)$ and the probability that an adult man's guarding is not successful is $1 - \Pi(g_t, \widehat{k}_t)$ for any t .

Assumption 1. The function Π exhibits the following properties:

- (i) $\Pi_g(g, k) > 0$, $\Pi_k(g, k) < 0$, for all $k > 0$ and $g > 0$;
- (ii) $\Pi_{gg}(g, k) < 0$, $\Pi_{kk}(g, k) > 0$, for all $k > 0$ and $g > 0$;
- (iii) $\Pi(g, 0) = 1$ for any $g > 0$, $\Pi(0, k) = 0$, for all $k \geq 0$;
- (iv) $\lim_{g \rightarrow 0} \Pi_g(g, k) = \infty$, for all $k > 0$; and $\lim_{k \rightarrow 0} \Pi_k(g, k) = -\infty$, for all $g > 0$;
- (v) there exists a twice differentiable mapping $P : R_+ \rightarrow R_+$ such that

$$\Pi(g, k) = P \circ \gamma(g, k), \quad \text{where } \gamma(g, k) = g/(g + k) \quad \text{for all } g, k > 0. \quad (1)$$

Assumption 1(i)–(iv) states standard regularity conditions according to which Π is increasing and concave in g and decreasing and convex in k and it is well behaved at the boundaries. With Assumption 1(v), which is introduced just for simplicity, Π is parameterized in such a way that the probability of successful guarding is a function of the proportion of time devoted to guarding relative to the total time spent on guarding and cheating.¹⁰

¹⁰It is easy to verify there exists an open set of functions satisfying conditions (i)–(v) of Assumption 1. An example of a class of such functions is given in the Appendix.

This guarantees that, for any given level of guarding, the likelihood of paternity is inversely related to the average level of casual sex of all other men.

Child survival is stochastic and depends only on the amounts of food children receives during the first two periods of life, which are generically denoted by u and v respectively. From the parents' viewpoint, the expected number of children of a given cohort who survive into adulthood is thus given by $F(u, v)$. The function F is assumed to satisfy the following conditions.¹¹

Assumption 2. The function F has the following properties:

- (i) F is increasing and strictly concave;
- (ii) $F(0, v) = F(u, 0) = 0$;
- (iii) $\lim_{u \rightarrow 0} F_u(u, v) = \infty$ for all $v > 0$ and $\lim_{v \rightarrow 0} F_v(u, v) = \infty$ for all $u > 0$;
- (iv) $F_{uv} > 0$ for all $u > 0$ and $v > 0$;
- (v) $F(u, v) = F(v, u)$.

Through Assumption 2(i)–(iii), F shows a number of properties that are similar to those of a standard neoclassical production function. Assumption 2(iv) ensures that F is also supermodular, which in our context is rather natural and amounts to the dynamic complementarity property discussed by Cunha and Heckman (2007). Finally, Assumption 2(v), which is invoked for analytical convenience, imposes a symmetry condition of parental investment timing on survivorship: that is, the probability that a child survives with transfer u in the first period of childhood and v in the second is the same as the survival probability obtained when the time order of the transfers is reversed to v first and u second. This, in the context of the skill formation model proposed by Cunha and Heckman (2007), implies that early and late childhood investments are equally critical and equally sensitive.

An adult man is productive only in periods 1 and 2 and can store food from period to period at no cost. Let x_1 and x_2 be the time equivalent amounts of food a man transfers to the official mother of his first-period children in periods 1 and 2, respectively. Similarly, he gives y_2 and y_3 to the mother of his second-period children in periods 2 and 3. A male then will face the following lifetime resource constraint

$$\omega = g_1 + k_1 + x_1 + g_2 + k_2 + x_2 + y_2 + y_3, \quad (2)$$

¹¹For analytical convenience only, we assume that the actual death of children born in a given period can occur only after the two periods of childhood at the beginning of the adulthood stage. Thus, F can be interpreted as the number of children who are expected to reach adulthood as *fertile* and *productive* individuals. All children reach the adulthood stage but, without adequate parental investment, they will be unfit to mate and (re-)produce. The model also abstracts from other features which are not essential for our results to hold, such as economies of scale in food production.

which is defined over the entire adulthood period.¹² Each man is endowed with ω units of resources, that can be allocated either to seek paternity, or to engage in casual sex, or to hunt and provide food to his mate. The exact timing of such decisions is irrelevant, except that guarding and cheating will not be carried out in the last period because all adults of the same generation (men and women alike) are no longer fertile.

A mother has to decide how to allocate the food she receives in a given period between her offspring. This allocation decision is straightforward in period 1, when she gives all the food she receives, x_1 , to her first-period children. In period 3, she also cannot affect the amount of food supplied by the male to the second-born for her children's second stage of childhood, y_3 . Her decision instead is more complex in period 2, when she has two cohorts of children to nurture. In this case, keeping her partner's decisions as given, the mother chooses the food allocation, $m \in (0, 1)$, that maximizes her payoff, which — contrary to the male's — includes neither guarding, because motherhood is certain, nor casual sex, because her total fertility is unaffected. The amounts of food she allocates to her first-period and second-period children are thus given respectively by mR and $(1-m)R$, where $R = x_2 + y_2$ is the total amount of food she receives from her partner(s) in period 2.

We next consider the preference specification conditional on a given family convention. In what follows, the ‘hat’-notation is used to indicate variables that are not a choice under the chooser's control.

C. Preferences

Adult Man in the Monogamous Family Convention — It is important to emphasize again that individuals care only for the survivorship of their genes. A monogamous man chooses $g_1, k_1, x_1, g_2, k_2, R$, and y_3 to maximize his payoff¹³

$$\begin{aligned} & \underbrace{\frac{1}{2} \Pi(g_1, \hat{k}_1) F(x_1, \hat{m}R)}_{\text{“first period children”}} + \underbrace{\frac{1}{2} \Pi(g_2, \hat{k}_2) F((1 - \hat{m})R, y_3)}_{\text{“second period children”}} \\ & + \underbrace{\frac{1}{2} [1 - \Pi(\hat{g}_1, k_1)] F(\hat{x}_1, \hat{m}\hat{R})}_{\text{“first period casual sex”}} + \underbrace{\frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] F((1 - \hat{m})\hat{R}, \hat{y}_3)}_{\text{“second period casual sex”}} \end{aligned} \quad (3)$$

where $R = x_2 + y_2$, subject to (2) and standard nonnegativity constraints $0 \leq g_1, k_1, x_1, g_2, k_2, R, y_3$. The first term in (3) indicates the contribution to the man's payoff from first period offspring. These children are genetically related to the adult male with probability

¹²For simplicity, expression (2) assumes the possibility of free storage and borrowing. However, provided that men are less productive in their last adult period, only saving but not borrowing will occur in equilibrium.

¹³As mentioned in subsection 2A, we ignore own consumption here. Formally this would enter the man's payoff function multiplying each of the F terms in (3). The same remark also applies to the payoff function of serially monogamous men specified below (see equation (4)). Male consumption instead will be explicitly considered when we analyze the \mathcal{C}_G convention in subsection 5B.

$\Pi(g_1, \hat{k}_1)/2$, while $F(x_1, \hat{m}R)$ represents the expected number of such children surviving the first and second periods of childhood. Notice that when casual sex is arbitrarily close to zero, then $\Pi(g_1, \hat{k}_1) = 1$ and the degree of genetic relatedness with own child will boil down to the standard coefficient of $1/2$. The same considerations apply to the second term which captures the payoff obtained by a man through his second period offspring.

The last two terms in (3) refer to the payoff a male can obtain from casual sex. With probability $1 - \Pi(\hat{g}_t, k_t)$, $t = 1, 2$, he is the unofficial father of other children who will not be supported by him. They instead receive food by the 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 the usual ‘hat’-notation.

Adult Man in the Serial Monogamy Convention — Taking into account that the female he guards already has (or will eventually have) children with a different male, a serially monogamous man chooses $g_1, k_1, x_1, g_2, k_2, R', R''$, and y_3 , to maximize

$$\begin{aligned} & \underbrace{\frac{1}{2} \Pi(g_1, \hat{k}_1) F(x_1, \hat{m}R')}_{\text{“first period children”}} + \underbrace{\frac{1}{2} \Pi(g_2, \hat{k}_2) F((1 - \hat{m})R'', y_3)}_{\text{“second period children”}} \\ & + \underbrace{\frac{1}{2} [1 - \Pi(\hat{g}_1, k_1)] F(\hat{x}_1, \hat{m}\hat{R}')}_{\text{“first period casual sex”}} + \underbrace{\frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] F((1 - \hat{m})\hat{R}'', \hat{y}_3)}_{\text{“second period casual sex”}} \end{aligned} \quad (4)$$

where $R' = x_2 + \hat{y}_2$ and $R'' = \hat{x}_2 + y_2$, subject to (2) and the usual nonnegativity constraints. 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 period children) receives x_2 from him and \hat{y}_2 from the (different) male who guards her in period 2 and with whom she begets her second period offspring. The opposite occurs for the mother of his second period children.

Adult Woman — A female must decide on how to allocate food to her progeny. The food is given to her by her official partner(s), i.e., the man (men) responsible to guard her. She cannot affect the amount of food given to the first period children in her first adult period, \hat{x}_1 , nor the amount of food received by the second period children in the third period, \hat{y}_3 . Her problem is thus to choose the food allocation, m , in the second period to maximize her own payoff

$$\frac{1}{2} F(\hat{x}_1, m\hat{R}) + \frac{1}{2} F((1 - m)\hat{R}, \hat{y}_3) \quad \text{for convention } \mathcal{C}_M, \quad (5)$$

$$\frac{1}{2} F(\hat{x}_1, m\hat{R}') + \frac{1}{2} F((1 - m)\hat{R}'', \hat{y}_3) \quad \text{for convention } \mathcal{C}_S, \quad (6)$$

while taking males’ choices as given. Since she has no uncertainty about her motherhood, the degree of genetic relatedness to each of her children is $1/2$.

3. Monogamy and Serial Monogamy Equilibria

As already mentioned, in our model individuals do not choose the type of family structure (either long life monogamy or serial monogamy) in which they live. Rather, this is an exogenous institution. Let us now consider one family convention at a time. We focus on pure Nash equilibria and adopt the following definition.

Definition of Equilibrium. An equilibrium $(\mathcal{C}_j, \sigma_j^*)$, $j = M, S$, is a family convention \mathcal{C}_j and a strategy σ_j^* , with $\sigma_j^* = (m^*, g_1^*, k_1^*, x_1^*, g_2^*, k_2^*, x_2^*, y_2^*, y_3^*)_j$, such that σ_j^* is a pure Nash equilibrium. That is, given \mathcal{C}_j , the equilibrium strategy is a fixed point in actions, whereby each man maximizes his own payoff and each woman maximizes hers, given the partner's actions as well as the actions of everyone else.

We start with a characterization of the equilibrium in the life long monogamy and then present the serial monogamy case.¹⁴

Proposition 1. In the monogamous family configuration, there exists a unique interior Nash equilibrium $(\mathcal{C}_M, \sigma_M^*)$ with the equilibrium strategy σ_M^* characterized by $m^* = 1/2$, $g_1^* = k_1^* = g_2^* = k_2^*$, and $x_1^* = y_3^* = (x_2^* + y_2^*)/2$.

Proposition 1 shows that, in the monogamy family convention, the mother splits resources equally between the two cohorts of her children and both cohorts will receive equal amounts of food in each of their childhood periods, regardless of birth order. As a result of the concavity and symmetry of the F function, this is in fact the only efficient food allocation. An adult male will devote an equal fraction of his resource endowment to guarantee paternity of both cohorts of his children in periods 1 and 2, and this also coincides with the fraction of resources spent on casual sex in both periods.

Repeating the same exercise for the individuals who form families in the serial monogamy convention leads to the next result.

Proposition 2. In the serial monogamy configuration, there exists a unique interior Nash equilibrium $(\mathcal{C}_S, \sigma_S^{**})$ with the equilibrium strategy σ_S^{**} given by $m^{**} = 1/2$, $g_1^{**} = k_1^{**} = g_2^{**} = k_2^{**}$, $x_1^{**} = y_3^{**}$ and $x_2^{**} = y_2^{**}$, with $x_1^{**} > x_2^{**}$ and $y_2^{**} < y_3^{**}$.

It is worth stressing there are three similarities with the monogamous family case: mothers split their resources equally among their children, males spend as much on guarding as

¹⁴We should point out that in the monogamous family convention as well as in the serial monogamy configuration, there will always exist another equilibrium in which parents provide food only to one cohort of children, starving the other cohort to death. For instance, $m^* = 0$ is the mother's optimal response to $x_1^* = 0$, and similarly $x_1^* = 0$ is optimal given $m^* = 0$. Given the purposes of the model, however, we argue this is not an interesting equilibrium and we thus ignore it.

they do on cheating, and children from different cohorts receive an equal total amount of resources over their entire childhood. There is however a notable difference in the amount of the transfers by birth order: first-born children receive more food in their first period of life, while second-born children receive more food in their second stage of childhood. The reason for this difference is simple. In period 2, when both official fathers of the children born to the same woman have to transfer food to her, they essentially free ride on each other and supply less food than what they would have done if they were the sole providers. In the second period, food provision is less efficient from the male's viewpoint because he does not have control over the allocation decision of his (current or former) mate, who could use part of his food provision to care not for his offspring but for the children of the other man. Hence, every man finds it more productive to shift more resources to casual sex, which in turn induces greater guarding in equilibrium. The next section will ascertain whether this reallocation of resources delivers greater or lower payoffs to parents and population growth rates.

4. Evolutionarily Stable Family Conventions

A configuration can only exist if a *group* of individuals adopts its norms. This means that our analysis of stability must focus on group deviations, i.e., deviations of a small population share of men and women rather than individual deviations as it is practice in evolutionary game theory (Weibull 1995). A family convention \mathcal{C}_j , $j = M, S$, is then evolutionarily stable if it resists the invasion of a small group of deviators who adopt the alternative convention $\mathcal{C}_{j'}$, $j' \neq j$.¹⁵

We investigate two different concepts of stability. The first looks at the case when deviators interact only with other deviators. This might happen for instance when the group of deviators isolate themselves entirely from the rest of the population to form and protect families, feed children, and have casual sex, as if they moved to a new separate village or island and cannot migrate and trade so that interactions between the two populations are inhibited or avoided. With the second concept of stability instead we analyze situations in which deviators interact with incumbents as well. In particular, we shall consider interactions that occur only through casual sex.

¹⁵Since any group deviation requires some form of coordination amongst deviators, we assume they can engage in a costless preplay communication as if they used a “secret handshake” when meeting each other (Robson 1990).

A. Stability when Deviators Interact Only with Deviators

If deviators interact only with deviators it is natural to assume that their offspring adopt their parents' family configuration. In this context the convention with the highest population growth is also the convention that is evolutionarily stable, precisely because it will take over the other convention in the long run. We then compute the survival rate for each of the two conventions and establish the following result.

Proposition 3. Survivorship in the monogamous family is always greater than survivorship in the serial monogamy family.

The mechanism underpinning this result is the absence of free riding in the life long monogamy convention. Compared to the serial monogamy convention, in fact, food provision in the monogamous family is more efficient. This comes about through two channels. The first is that the absence of free riding has a direct effect on the individual male incentive to hunt and supply food, because all his food transfers in the \mathcal{C}_M configuration are received by his own official children. The second is a more subtle aspect of the mechanism identified in Propositions 1 and 2. Monogamous men and women distribute food to their offspring equally in such a way that the two childhood periods are perfectly symmetric.¹⁶ This guarantees an equal food distribution for both cohorts in both periods. Since the survivorship function F is concave and symmetric, this distribution turns out to be the most efficient intrahousehold allocation. Now, when greater food provision is efficiency enhancing, each man will have an incentive to shift resources away from casual sex into hunting, a shift that in turn will reduce the need for mate guarding. Since cheating and guarding are wasteful from a societal viewpoint, the equilibrium outcome is therefore efficient in the monogamy family.

B. Example

We illustrate some of the results found so far, including those of Section 3, for the special case in which both Π and F are power functions. In particular, they take the following parametric specifications:¹⁷

$$\Pi(g, k) = \left(\frac{g}{g + k} \right)^\alpha \quad \text{and} \quad F(u, v) = (uv)^\alpha, \quad (7)$$

where the parameter $\alpha \in (0, 1/2)$ is the same in both functions and thus provides a measure of efficiency of both the guarding technology and the food provision technology. With the functions given in (7) and $\omega = 2$, it is easy to show that Proposition 1 holds with $m^* = 1/2$,

¹⁶Recall that the free riding behavior in \mathcal{C}_S occurs only in one period for each cohort of children.

¹⁷It is easy to verify that the function Π in (7) does not satisfy restriction (iv) of Assumption 1. The set of conditions in Assumption 1 in fact is not necessary but only sufficient.

$g_1^* = k_1^* = g_2^* = k_2^* = 1/6$, and $x_1^* = x_3^* = (x_2^* + y_2^*)/2 = 1/3$. Similarly, Proposition 2 holds with $m^{**} = 1/2$, $g_1^{**} = k_1^{**} = g_2^{**} = k_2^{**} = 1/5$, and $x_1^{**} = y_3^{**} = 2/5$ and $x_2^{**} + y_2^{**} = 2/5$. With such equilibrium values, we can check that, on the one hand, the probability of successful guarding is identical in the two conventions and equal to $(1/2)^\alpha$. On the other hand, the expected number of surviving children in the serially monogamous family is $(2/5)^\alpha(1/5)^\alpha$ which, irrespective of α , is always lower than the corresponding number in the life long monogamy family, where instead it is equal to $(1/3)^\alpha(1/3)^\alpha$. This illustrates that child survivorship is greater under the monogamy convention than under the serial monogamy configuration.

C. Stability when Deviators Interact with Incumbents

There might be situations in which deviators interact with incumbents. If the interaction between deviators and incumbents is ‘small’ or ‘local’, in the sense that deviators consume their casual sex predominantly with other deviators, then the previous notion of stability remains valid. This might happen when the degree of isolation between the two populations is high (e.g., they live in separate villages), so the contact rate between individuals of the two groups is low.

If instead the interaction is pervasive, we must be specific about the convention followed by a child born from the casual sex union between a deviating parent and an incumbent parent. In this analysis, we follow and extend the approaches proposed by Bergstrom (1995) and Alger and Weibull (2010). More specifically, we suppose that children propagate the family configuration by copying the role model of the family in which they were born. Family configurations are thus copied from cultural parents. This means, for example, that if in the monogamous configuration a male deviator — who is serially monogamous and has causal sex with a woman of the incumbent convention — has a child with her, the child will adopt the mother’s (and official father’s) family norm and will thus be monogamous. In this environment we find the following result.

Proposition 4. If deviators interact with incumbents, the monogamous convention is evolutionarily stable, whereas the serially monogamous convention is not.

As in the case when deviators interact only with deviators, here too the mechanism that underpins Proposition 4 is the free riding on food provision in the serial monogamy convention. That is, the lower productivity in food provision among serially monogamous men gives them a greater incentive to chase other men’s partners as well as guard their own mates. The negative externality that cheating generates by inducing men to guard their partners plays a key role in generating the result in Proposition 4. In equilibrium, therefore,

overguarding and overheating are socially wasteful activities that prevent serial monogamist mutants to invade a monogamist population successfully.

Proposition 4 is underpinned by a simple, yet powerful, notion of intergenerational transmission of family norms. As all individuals copy their official parents' family convention, official parents serve as direct role models for their children. This is in line with other recent studies on the transmission of cultural values driven by parents' incentives to foster their children's taste for cooperation (Bisin and Verdier, 2001), honesty (Hauk and Saez-Martí 2002), and work ethics (Lindbeck and Nyberg 2006).

5. Other Family Conventions

A. Polygyny

Polygyny is a family type in which one man has multiple official female partners at the same time. The analysis below will focus on a comparison between polygyny and monogamy, given that the latter convention attains a greater population growth than serial monogamy. A feature of the model so far has been that males and females are homogeneous within a given convention. To have a meaningful comparison, therefore, we continue to do so here. Hence, polygynist men have the same endowment as the other men who, by definition, cannot have official partners. Men are randomly assigned to either the matched or the unmatched group.

To gain an insight as to why such a convention is dominated by monogamy we stress that, since all individuals care only for the propagation of their genes, unmatched men in \mathcal{C}_P will consume their entire endowment in casual sex. Matched men then will have to devote more of their resources to guarding. This, together with the fact that only a fraction of males supply food, will drive the result.

More formally, assume for simplicity that matched polygynists have two women in period 1 and the same two women in period 2. It follows that half of the men are matched while the other half are not.¹⁸ We consider the same stability notion used in subsection 4.A according to which all the individuals of the deviating group isolate themselves from the rest of the population. As before, the objective is to compute the survival rate for individuals of the \mathcal{C}_P convention and compare it to the survival rate obtained under the \mathcal{C}_M configuration. The convention with the highest population growth is deemed to be evolutionarily stable. Our analysis yields the following proposition.

Proposition 5. Survivorship in the monogamous family is always greater than survivorship in the polygynous family.

¹⁸Both this assumption and the condition that matched polygynist men have two partners can be easily generalized respectively to arbitrary fractions of the population being matched and to arbitrary numbers of female partners, provided that a unity sex ratio is preserved.

Let us elaborate this briefly. On the one hand, concavity of F gives men an incentive to divide up their resource among multiple official partners. This could lead the polygynous configuration to enjoy greater population growth than its monogamous counterpart. On the other hand, however, children of polygamous parents can rely on fewer resources than their monogamous counterparts because each family unit has now a greater number of children. This is aggravated by the presence of unmatched males whose only activity is having casual sex that jeopardizes the paternity claims of the officially matched men. To have confidence in their fatherhood, therefore, matched men must increase guarding significantly compared to a world in which homogenous males match monogamously, and this in turn leads to lower population growth. The latter two forces outweigh the first and the net result is thus a smaller survival rate associated with the polygynous family.¹⁹

An important point is in order. Previous studies have typically explained polygyny through both differential fecundity between men and women and male inequality in wealth, whereby richer (and generally older) men tend to have multiple wives (Grossbard 1976; Becker 1991; Gould, Moav, and Simhon 2008). In a world with large endowment inequalities, polygyny is likely to emerge as an evolutionarily stable configuration, even against deviations to monogamy. Proposition 5 shows that, when the differences in resource endowments are not too large, monogamy is evolutionarily stable, while polygyny is not.

B. Full Promiscuity

Another family structure is group marriage (or cenogamy) in which all women share all men in the population as partners and, similarly, all men share all women as partners in fully promiscuous relationships (Morgan 1871; Ingoldsby and Smith 2006; Knight 2008; Allen et al. 2008). In such a convention, labeled \mathcal{C}_G , it is natural for men to supply food to all the women who, in turn, pool it together communally and use it to feed their children. A man in fact does not know which of the women, if any, bear his progeny.

More specifically, all men and women have common dwellings so that guarding is technically impossible. No time is thus devoted to guarding. Likewise, no time is spent in casual sex, since reproductive opportunities are freely available to all fertile men. In each of the three periods 1, 2, and 3, then, every man i supplies food x_{1i} , R_i , and y_{3i} respectively to the common pool. This pool is distributed equally to each woman, who in turn splits it among her children. Each child therefore receives \bar{x}_1 , \bar{R} , and \bar{y}_3 , where $\bar{x}_1 = \frac{1}{N} \sum_{i=1}^N x_{1i}$, $\bar{R} = \frac{1}{N} \sum_{i=1}^N R_i$, and $\bar{y}_3 = \frac{1}{N} \sum_{i=1}^N y_{3i}$, and N is the number of men (and women) in a given

¹⁹It is unsurprising, but still interesting, to notice that this result — unlike that stated in Proposition 3 — is unrelated to the free riding behavior of polygynous men, since they are assumed to be matched to the same women for all their adult life. These men then do not have room to free ride on other men but must protect themselves against the pervasive casual sex of unmatched men by inefficiently increasing mate guarding.

cohort of the promiscuous population. Notice therefore that, while each man's food is equally distributed among all women in the population, on average only one of them is the mother of his children.

As mentioned in Section 2, male consumption does play a role in this convention. Recall that, from Assumption 1 when $g_t = 0$, $t = 1, 2$, Π equals 0 for $k_t \geq 0$. Formally then the optimization problem of a promiscuous man i is to choose x_{1i} , R_i , y_{3i} and C_i to maximize²⁰

$$h(C_i) \left[\frac{1}{2} F(\bar{x}_1, \bar{R}/2) + \frac{1}{2} F(\bar{R}/2, \bar{y}_3) \right] \quad (8)$$

subject to $\omega = x_{1i} + R_i + y_{3i} + C_i$, where C_i is male i 's own consumption and h is an increasing and strictly concave function of C_i .

It could be argued that, compared to the monogamy convention, \mathcal{C}_G is efficiency enhancing, precisely because guarding is a socially wasteful activity. That is, in an environment where guarding is technologically impossible, we may expect that more resources would be made available for food provision and, consequently, child survivorship would improve. This however is not the case when individuals care only for the propagation of their own genes. It is easy to see in fact that each man's best response is to free ride on the other $N - 1$ men's food supply and invest instead in own consumption. Indeed, when the population is large enough (i.e., N increases), every man will devote almost all his entire (time) endowment to own consumption to improve his sexual productivity. In equilibrium, therefore, the fully promiscuous convention will be characterized by no (or very low) food provision and an extremely high level of male consumption. Interestingly, this relationship is in line with some of the available anthropological evidence on cenogamous societies (e.g., Levine and Sangree 1980).

This suggests that \mathcal{C}_G is not evolutionarily stable against deviations to monogamy because, given its exceptionally low level of food provision, it entails a near-zero probability of survival in comparison to life long monogamy. Conversely, an invasion of fully promiscuous deviators in a monogamous population will not succeed in outnumbering the monogamous incumbents in the long run.

6. Extensions and Discussion

A. Kinship

Several studies have shown that individuals care not only for their own progeny but also for other genetically close relatives (Alexander 1974; Kurland 1979; Diamond and Locay 1989; Dunbar, Clark and Hurst 1995; Knight 2008). They have documented a wide array of kinship

²⁰Expression (8) is a suitably modified version of (3) or (4) in which, after accounting for consumption, the first two terms drop out as a result of the fact that $\Pi = 0$.

ties, 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; Bergstrom 1995; Cox 2007).

In this extension we briefly discuss the implications of a simple model in which adult men can make food transfers, denoted by b , to their presumed *younger* siblings.²¹ Notice that, differently from the framework used in previous sections, siblings' birth order matters, so that older males face a different optimization program from that faced by their younger brothers. The Appendix formalizes such programs.

We turn to our main result, which compares serial monogamy to monogamy. This has been obtained with the same parametric specifications as those given in (7) and used in the example of subsection 4.B.

Proposition 6. Assume food transfers between siblings are possible. We characterize two findings:

- (a) In the serial monogamy configuration, there exists a unique interior Nash equilibrium. In this equilibrium the optimal food transfer is $b^{**}=0$ (no kin transfer).
- (b) In the monogamous family convention, there exists a unique interior Nash equilibrium in which: (i) $b^* > 0$ (positive kin transfers); and (ii) compared to the case without kin ties, total survivorship is greater.

For the serial monogamy family, part (a) states that kin ties cannot emerge in equilibrium. The intuition is simple. Because each child has the same likelihood of survival and because any given man is genetically closer to his own children than to any other individual in the population, including his own half-siblings, it is optimal for him to provide food only to his own official offspring.

From part (b) we highlight two points. First, positive kin transfers occur in equilibrium because, given the survival function F is concave, a man in the monogamous convention finds it advantageous to provide food to both his offspring and his siblings since these are equally genetically close to him. Greater efficiency in food provision translates into greater food transfers, lower cheating, and lower guarding.

Second, in comparison to the case without kinship, firstborn receive strictly *more* food from their father in both periods of childhood. Later born children instead receive less food from their father, 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 emerges because fathers, irrespective of whether

²¹The 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.

they made or received food transfers, internalize the possibility that their firstborn will support their younger siblings. By transferring more food to their first born children, fathers spread their investment across children more equally, which, owing again to the concavity of F , increases their payoff.²²

Proposition 6(b) guarantees that a monogamous population in which families are linked through food exchange as opposed to another monogamous population without kin ties will be characterized by greater total food provision, which, in turn, will lead to greater survivorship. 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 younger (still dependent) siblings is efficiency enhancing. Because of this, casual sex goes down and thus the need for guarding recedes too. But lower cheating and lower guarding can only occur within the monogamous convention. The monogamous family therefore allows its members not only to achieve greater survivorship but also to foster altruistic behavior among siblings. Moreover, this result identifies monogamy as a key source of exchange among its members and thus a primary engine of economic growth (Ofek 2001; Chapais 2008; Galor and Michalopoulos 2012).

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 examines the investment of a risk-averse man in his sister's children when he is uncertain about his paternity. 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 (Allen et al. 2008).

B. Food Provision by the Mother

A feature of our model has been that the man is the sole investor, in the sense that he is the only food provider (Kaplan et al. 2000; Robson and Kaplan 2006), while the woman controls the food distribution among children. Mothers nevertheless can be food providers. An interesting question is to see how this possibility would affect our earlier predictions. This extension shows that they do not change.

We focus on the case in which in each period every woman has a given amount of resources that she can use to feed her children. For this case we characterize the following result.

²²Recent 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).

Proposition 7. Suppose an adult woman has a given resource endowment, μ_t , $t = 1, 2, 3$. Then Propositions 1–5 hold true.

As in Propositions 1 and 2, in this extension we consider only interior equilibria.²³ Proposition 7 ensures that, even in a world where mothers are food providers, monogamy continues to dominate serial monogamy, polygyny, and full promiscuity by delivering a greater population growth rate.

The intuition behind this result rests on a simple notion of income pooling (Becker 1981) or, more appropriately for our model, food pooling. Men and women take account of the availability of additional resources and make decisions under their new endowment $\omega + \sum_t \mu_t = \omega'$. The amount of resources received by each child is the same as if the father had a total endowment of ω' with the mother, as usual, being in control of the food allocation among children. This applies not only to monogamy and polygyny but also to the serial monogamy case when there is free riding between the two men linked to the same woman. This is possible because the two men in equilibrium make symmetric food transfers and the woman pools resources with each of them separately. In the cenogamy convention instead the only food given to children in equilibrium comes from the mother, and this convention is thus bound to enjoy the least growth.

C. Religion: Convention or Adaptation?

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 these are socially wasteful activities. A recurring point of the paper is that if, in the presence of such activities, a population behaves according to the monogamous family convention, it will grow more rapidly in equilibrium than in any other family convention and it will also be more likely to promote altruistic links among its members.

Because of the inefficiency they generate, cheating and guarding might induce the development of social norms, beliefs or institutions that can attenuate their negative effects. One of such institutions is religion. It could be argued that each of the family conventions analyzed in the paper can be seen, in and of itself, as a ‘religion’. In our setup, by specifying the matching protocol between men and women, a convention/religion essentially defines how many women a man can guard or if he can guard at all. The matching protocol then defines the game for the group. Once the game is fixed, the other activities (hunting, cheating, and food distribution) are determined in equilibrium by strategic interactions among rational players. Based on the results from Sections 4 and 5, this reasoning allows us to throw light

²³If maternal resources are too large compared to the male resources, men will have no incentive to supply food, and this will lead to a corner solution.

on the remarkable fact that many of the major religions center around the monogamous fidelity family even though history has witnessed all kinds of different sexual organizations (Knight 2008).

With the rules of the game set up, it is hard to affect individual choices further. Yet religions generate moral systems that try to affect equilibrium outcomes also at the margin, by building norms and beliefs that are evolutionarily advantageous and ruling out alternative goals and beliefs that are not (Csikszentmihalyi 1990; Wilson 2002). Our model provides a simple explanation as to why proscribing casual sex does lead to a successful group level adaptation. Reducing casual sex, in fact, has not only the direct effect of freeing up resources for food provision but also the indirect effect of reducing the need for guarding. Both such effects increase survivorship. On the contrary, forbidding mate guarding, independently of the difficulty of its actual implementation, will give rise to increased cheating. Interestingly, almost all major world religions have openly condemned a wide range of sexual sins, including adultery and fornication, and stigmatized the product of casual sex, illegitimate children (Browning, Green, and Witte 2006).

The notion of religion (both as a group selection mechanism and as the convention itself) that promotes fidelity within life long monogamous families is therefore powerfully aligned with the forces underpinning our theoretical insights. Indeed, 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 ethics (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 monogamous family, our model is likely to bring a new perspective to this important debate.

7. Conclusion

This paper presents a new evolutionary model with uncertain paternity and parental investment in overlapping cohorts of children to explain why life long monogamy is the dominant form of sexual organization among humans as opposed to other family types, such as serial monogamy, polygyny, and cenogamy.

A distinctive feature of the model is that men have food provision responsibilities while women (and only women) have allocative responsibilities of the food among their children. Allowing women to provide part of the food to their children does not change our main results.

The efficiency difference between monogamy and serial monogamy (as well as cenogamy) relies on the observation that, if a serially monogamous or cenogamous woman receives resources from multiple men, there is a free-rider problem in which each man realizes that his contribution to his official children will be shared with other children who are most likely not his. In a polygynous environment instead a man must defend his fatherhood claims against the competition of unmatched men who will spend their entire resources on cheating.

Despite its simplicity the model delivers a rich set of insights about the monogamous family and its stability. Here we highlight three. First, we use an interesting notion of evolutionary stability based on group deviations. Looking at stability when deviators interact with incumbents, we can also underpin a powerful notion of cultural transmission according to which official parents serve as role models for their children. Second, altruism between siblings can only emerge with the monogamous family because a man, who is uncertain about his paternity and yet cares about his reproductive success, values his siblings in part because they provide him with the assurance that some of his genes will survive into future generations. Third, by specifying the guarding protocol, a convention essentially sets the norms which individuals follow in equilibrium. A convention is then equivalent to a religion. This insight allows us to construe the striking fact that most of the world religions by and large promote monogamy. We view this paper as a first cut at these three exciting issues and expect that much new work will be done in each of such areas.

Some caution, of course, should be taken before been tempted to use our results 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). The market, the state, and the greater economic independence of women might have influenced the nature of exchange within families in ways that our model cannot capture (Laitner, 1997).

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

Appendix

Proofs

We begin with the proof of three technical results that will be used to prove the propositions stated in the paper. Throughout the Appendix, the notation F_i , $i=1, 2$, indicates the first derivative of F with respect to its i -th argument; similarly, F_{ij} , with $i, j=1, 2$, indicates the derivative of F_i with respect to the j -th argument.

Lemma 1. $F_1(x_1, x_2) = F_2(x_2, x_1)$.

Proof. The symmetry condition on F , so that $F(x_1, x_2) = F(x_2, x_1)$, implies that

$$\begin{aligned} F_1(x_1, x_2) &= \lim_{h \rightarrow 0} \frac{F(x_1 + h, x_2) - F(x_1, x_2)}{h} \\ &= \lim_{h \rightarrow 0} \frac{F(x_2, x_1 + h) - F(x_2, x_1)}{h} \\ &= F_2(x_2, x_1). \quad \blacksquare \end{aligned}$$

Lemma 2. If $F_1(x_1, x_2) = F_2(x_1, x_2)$, then $x_1 = x_2$.

Proof. Strict concavity of F implies that for any two points $X = (x_1, x_2)$ and $Y = (y_1, y_2)$ we have

$$F(x_1, x_2) > F(y_1, y_2) + (y_1 - x_1, y_2 - x_2) \nabla F(x_1, x_2)$$

whenever $X \neq Y$. Assume $x_1 \neq x_2$ and let $Y = (y_1, y_2) = (x_2, x_1)$. Then

$$F(x_1, x_2) > F(x_2, x_1) + (x_2 - x_1, x_1 - x_2) \nabla F(x_1, x_2) = F(x_2, x_1) + (x_2 - x_1)[F_1(x_1, x_2) - F_2(x_1, x_2)]$$

which is impossible because $F(x_1, x_2) = F(x_2, x_1)$ and because of the assumption $F_1(x_1, x_2) = F_2(x_1, x_2)$. Then $x_1 = x_2$. \blacksquare

Lemma 3. If $x_1 + x_2 > y_1 + y_2$, then either $F_1(x_1, x_2) < F_1(y_1, y_2)$, or $F_2(x_1, x_2) < F_2(y_1, y_2)$, or both inequalities are true.

Proof. Because $x_1 + x_2 > y_1 + y_2$, then $x_1 - y_1 > 0$ and/or $x_2 - y_2 > 0$. Let:

$$\begin{aligned} \Phi(x_1, x_2) &= F_1(x_1, x_2) \\ \Psi(x_1, y_2) &= F_2(x_1, x_2). \end{aligned}$$

An infinitesimal increase in the value of the images of Φ and Ψ , denoted by $\Delta\Phi$ and $\Delta\Psi$, corresponding to an increase Δ_1 in x_1 and Δ_2 in x_2 can be written as

$$\begin{bmatrix} \Delta\Phi \\ \Delta\Psi \end{bmatrix} = \begin{bmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{bmatrix} \begin{bmatrix} \Delta_1 \\ \Delta_2 \end{bmatrix}$$

By contradiction, assume

$$\begin{bmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{bmatrix} \begin{bmatrix} \Delta_1 \\ \Delta_2 \end{bmatrix} > \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

We now consider the three possible cases.

Case 1. $\Delta_1 > 0, \Delta_2 > 0$.

The system of equations

$$\begin{aligned} F_{11}\Delta_1 + F_{12}\Delta_2 &> 0 \\ F_{21}\Delta_1 + F_{22}\Delta_2 &> 0 \end{aligned}$$

implies that

$$\begin{aligned} F_{12}\Delta_2 &> -F_{11}\Delta_1 \\ F_{21}\Delta_1 &> -F_{22}\Delta_2. \end{aligned}$$

Because all terms are positive, term-wise multiplication of the two equations leads to $(F_{12})^2 > F_{11}F_{22}$, which contradicts the assumption that F is concave.

Case 2. $\Delta_1 > 0, \Delta_2 < 0$.

Since Assumption 2(iv) guarantees that $F_{12} > 0$, the inequality $F_{12}\Delta_2 > -F_{11}\Delta_1$ can never be satisfied because the left-hand term is negative and the right-hand term positive.

Case 3. $\Delta_1 < 0, \Delta_2 > 0$.

The inequality $F_{21}\Delta_1 > -F_{22}\Delta_2$ can never be satisfied because the left-hand term is negative and the right hand term positive.

Notice the supermodularity condition $F_{12} > 0$ is sufficient but not necessary. In addition, the inequalities obtained are for infinitesimal increments Δ_1 and Δ_2 . However, because they hold everywhere, the effect of a change from x_1 to y_1 and from x_2 to y_2 can be obtained by integrating $\Delta\Phi$ and $\Delta\Psi$ over the path from (x_1, x_2) to (y_1, y_2) . The corresponding changes $\Phi(y_1, y_2) - \Phi(x_1, x_2)$ and $\Psi(y_1, y_2) - \Psi(x_1, x_2)$ keep the same signs as those implied by the infinitesimal increments $\Delta\Phi$ and $\Delta\Psi$. Hence, the contradiction holds. ■

Proof of Proposition 1 (Monogamy)

Adult woman. The monogamous woman's problem is to choose z_2 to maximize

$$\frac{1}{2}[F(\hat{x}_1, z_2) + F(\hat{R} - z_2, \hat{y}_3)]$$

subject to $0 \leq z_2 \leq \hat{R}$, where z_2 is the amount of food she gives to her first period children in period 2 and the terms denoted by a 'hat' are exogenous to her decision problem. Because of strict concavity of F the solution is unique. The first order necessary condition associated to an interior solution is

$$F_2(\hat{x}_1, z_2) = F_1(\hat{R} - z_2, \hat{y}_3) \tag{A.1}$$

For $\hat{x}_1 > 0$ and $\hat{y}_3 > 0$ this condition is necessary and sufficient. In this case we denote the solution as $z_2 = m\hat{R}$, where $0 < m < 1$. Now, Lemma 1 guarantees that if $\hat{x}_1 = \hat{y}_3$, then $m = 1/2$.

Adult man. The monogamous man's problem is to choose $x_1, g_1, k_1, R, g_2, k_2, y_3$ to maximize his payoff function ϕ given by

$$\begin{aligned} &\frac{1}{2} \left\{ \Pi(g_1, \hat{k}_1)F(x_1, \hat{m}R) + [1 - \Pi(\hat{g}_1, k_1)]F(\hat{x}_1, \hat{m}\hat{R}) \right. \\ &\quad \left. + \Pi(g_2, \hat{k}_2)F((1 - \hat{m})R, y_3) + [1 - \Pi(\hat{g}_2, k_2)]F((1 - \hat{m})\hat{R}, \hat{y}_3) \right\}, \end{aligned}$$

subject to $\omega = x_1 + R + y_3 + g_1 + g_2 + k_1 + k_2$ and $0 \leq x_1, R, y_3, g_1, g_2, k_1, k_2$, and where, for now, $0 < \hat{m} < 1$. As before, the terms with a ‘hat’ are exogenous. The following first order conditions are necessary but not sufficient for an interior maximum:

$$\frac{\partial \phi}{\partial x_1} \equiv F_1(x_1, \hat{m}R)\Pi(g_1, \hat{k}_1) + \lambda = 0 \quad (\text{A.2})$$

$$\frac{\partial \phi}{\partial R} \equiv \hat{m}F_2(x_1, \hat{m}R)\Pi(g_1, \hat{k}_1) + (1 - \hat{m})F_1((1 - \hat{m})R, y_3)\Pi(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.3})$$

$$\frac{\partial \phi}{\partial g_1} \equiv F(x_1, \hat{m}R)\Pi_g(g_1, \hat{k}_1) + \lambda = 0 \quad (\text{A.4})$$

$$\frac{\partial \phi}{\partial k_1} \equiv -F(\hat{x}_1, \hat{m}\hat{R})\Pi_k(\hat{g}_1, k_1) + \lambda = 0 \quad (\text{A.5})$$

$$\frac{\partial \phi}{\partial y_2} \equiv F_2((1 - \hat{m})R, y_3)\Pi(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.6})$$

$$\frac{\partial \phi}{\partial g_2} \equiv F((1 - \hat{m})R, y_3)\Pi_g(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.7})$$

$$\frac{\partial \phi}{\partial k_2} \equiv -F((1 - \hat{m})\hat{R}, \hat{y}_3)\Pi_k(\hat{g}_2, k_2) + \lambda = 0. \quad (\text{A.8})$$

Next, let us evaluate (A.2)–(A.8) at the fixed point, which we denote with $f^* = (x_1^*, g_1^*, k_1^*, R^*, y_3^*, g_2^*, k_2^*)$. Now, equations (A.4) and (A.5) together with (A.7) and (A.8) imply that $\Pi_g(g_1^*, k_1^*) = -\Pi_k(g_1^*, k_1^*)$ and $\Pi_g(g_2^*, k_2^*) = -\Pi_k(g_2^*, k_2^*)$. Assumption 1 implies that $g_1^* = k_1^*$ and $g_2^* = k_2^*$, which then lead to $\Pi(g_1^*, k_1^*) = \Pi(g_2^*, k_2^*)$. From (A.1) we obtain

$$F_2(x_1^*, m^*R^*) = F_1((1 - m^*)R^*, y_3^*), \quad (\text{A.9})$$

and expression (A.3) becomes

$$F_2(x_1^*, m^*R^*)\Pi(g_1^*, k_1^*) + \lambda = 0. \quad (\text{A.10})$$

From (A.2) and (A.6) evaluated at the fixed point and (A.10) we obtain

$$F_1(x_1^*, m^*R^*) = F_2(x_1^*, m^*R^*) = F_2((1 - m^*)R^*, y_3^*). \quad (\text{A.11})$$

Combining (A.9) and (A.11) we get

$$F_1(x_1^*, m^*R^*) = F_2(x_1^*, m^*R^*) = F_2((1 - m^*)R^*, y_3^*) = F_1((1 - m^*)R^*, y_3^*).$$

Using Lemma 2 we find $x_1^* = mR^*$ and $(1 - m)R^* = y_3^*$, while Lemma 3 applied to $F_1(x_1^*, x_1^*) = F_2(x_1^*, x_1^*) = F_2(y_3^*, y_3^*) = F_1(y_3^*, y_3^*)$ yields

$$x_1^* = y_3^*.$$

With (A.9) this solution leads to

$$m^* = 1/2 \text{ and } x_1^* = mR^* = (1 - m)R^* = y_3^*.$$

The unique symmetric fixed point of the first order conditions (A.2)–(A.8) is then characterized by $x_1^* = y_3^* = R^*/2$, $m^* = 1/2$, $g_1^* = k_1^* = g_2^* = k_2^* = g^*$ and $\omega = 2R^* + 4g^*$.

Existence of equilibrium. To establish that the fixed point σ^* is an equilibrium we need to show that, after fixing the strategies of all players but agent j at $\sigma^* = (m^*, x_1^*, R^*, y_3^*, g_1^*, g_2^*, k_1^*, k_2^*)$, σ^*

is in fact the best response for j . This is not trivial because the problem is not concave. Before getting into the proof, two remarks are in order. First, the allocation implied by σ^* is the only interior solution for (A.2)–(A.8) for player j . This implies that σ^* is the only candidate for an interior equilibrium. Second, we stress that the constraints of the optimization problem define a compact set for each player i and the objective is continuous. As the exogenous parameters, the terms denoted with a ‘hat’, are fixed at the $*$ -values and $\hat{k}_t^* > 0$ and $\hat{g}_t^* > 0$, the ratios $g/(g + \hat{k})$ and $\hat{g}/(\hat{g} + k)$ are well behaved. The optimization problem then must admit a solution. This is either the interior solution σ^* or a corner solution in m , which we now rule out but which we shall turn to at the end of this proof. Below we consider all other possible non-interior alternatives.

- (a) $x_1 = R = y_3 = 0$ and $g_1 > 0$ and/or $g_2 > 0$ is suboptimal because it yields a payoff which is lower than $x_1 = R = y_3 = g_1 = g_2 = 0$ and $k_t = \frac{\omega}{2}$, $t = 1, 2$.
- (b) $x_1 = R = y_3 = g_1 = g_2 = 0$ and $k_i = \frac{\omega}{2}$ is suboptimal because it yields a payoff of $2[1 - \Pi(k_t^*, \frac{\omega}{2})]F(x_1^*, x_2^*)$ which is lower than the payoff obtained following the strategy σ^* , which is $2F(x_1^*, x_2^*)$.
- (c) $R = 0$ and $x_1 > 0$ and/or $y_3 > 0$ is suboptimal because $x_1 = y_3 = R = 0$ will yield higher utility (recall that by assumption $F(u, 0) = F(0, v) = 0$).
- (d) $R > 0$ and $x_1 = 0$ and/or $y_3 = 0$ is suboptimal because $\lim_{x \rightarrow 0} F_1'(x, R/2) = \infty$.
- (e) From (a)–(d), we infer that as a best response to σ^* each individual must set $x_1 > 0$; $R > 0$; $y_3 > 0$.
- (f) Recall that, by Assumption 1(iv), $\Pi(0, \hat{k}_t) = 0$, with $\hat{k}_t \geq 0$. Point (e) implies that in man’s j ’s best response to σ^* we must have $g_t \geq 0$, $t = 1, 2$.
- (g) Assumption (iv), which imposes $\Pi_{k_t}(\hat{g}_t, k_t) = -\infty$ for $\hat{g}_t > 0$, rules out the possibility that $k_t = 0$, $t = 1, 2$. Indeed, for k_t small enough and for all $x_1, R, y_3, g_1, g_2, k_t > 0$, the value of $-\Pi_k(g_t, \hat{k}_t)$ is large enough so that increasing k_t (and decreasing some of the other variables) increases individual j ’s payoff.
- (h) Finally, as $x_1^* = y_3^*$ the optimal response of the mother is $m^* = 1/2$.
- (i) Choosing σ^* is male j ’s best response when all other individuals (men and women) choose σ^* . The same argument holds true for a woman’s best response.

From (a)–(i) we conclude that σ^* is an equilibrium. QED

As mentioned before, there are always two other equilibria in which m is on the boundary. Consider the case in which the mother sets $m = 0$. It is easy to verify that the best response of each man is $x_1 = g_1 = k_1 = 0$. Likewise $m = 0$ is the best response to $x_1 = g_1 = k_1 = 0$. Similarly, $m = 1$ and $x_2 = g_2 = k_2 = 0$ deliver an equilibrium. As emphasized in the text, these equilibria are such that parents provide food only to one cohort of children, starving the other cohort to death. Given the purpose of the paper, we ignore such equilibria.

Proof of Proposition 2 (Serial Monogamy)

Adult woman. The first order condition associated to the woman’s problem is

$$F_2(\hat{x}_1, m(\hat{x}_2 + \hat{y}_2)) = F_1((1 - m)(\hat{x}_2 + \hat{y}_2), \hat{y}_3).$$

For $\hat{x}_1 > 0$ and $\hat{y}_3 > 0$, this condition is necessary and sufficient. Let z_2 be the amount of food a mother gives to her first period children. Then her optimal response is

$$z_2 = m(\hat{x}_2 + \hat{y}_2),$$

where $0 < m < 1$.

Adult man. Assuming $0 < \hat{m} < 1$, the serially monogamous man's problem is to choose $x_1, g_1, k_1, x_2, y_2, y_3, g_2, k_2$ to maximize his payoff function φ given by

$$\begin{aligned} \frac{1}{2} \Big\{ & \Pi(g_1, \hat{k}_1)F(x_1, \hat{m}(x_2 + \hat{y}_2)) + [1 - \Pi(\hat{g}_1, k_1)]F(\hat{x}_1, \hat{x}_2) \\ & + \Pi(g_2, \hat{k}_2)F((1 - \hat{m})(\hat{x}_2 + y_2), y_3) + [1 - \Pi(\hat{g}_2, k_2)]F(\hat{y}_2, \hat{y}_3) \Big\}, \end{aligned}$$

subject to $\omega = x_1 + x_2 + y_2 + y_3 + g_1 + g_2 + k_1 + k_2$ and $0 \leq x_1, g_1, k_1, x_2, y_2, y_3, g_2, k_2$.

The first order conditions of this problem are:

$$\frac{\partial \varphi}{\partial x_1} \equiv F_1(x_1, \hat{m}(x_2 + \hat{y}_2))\Pi(g_1, \hat{k}_1) + \lambda = 0 \quad (\text{A.12})$$

$$\frac{\partial \varphi}{\partial x_2} \equiv \hat{m}F_2(x_1, \hat{m}(x_2 + \hat{y}_2))\Pi(g_1, \hat{k}_1) + \lambda = 0 \quad (\text{A.13})$$

$$\frac{\partial \varphi}{\partial g_1} \equiv F(x_1, \hat{m}(x_2 + \hat{y}_2))\Pi_g(g_1, \hat{k}_1) + \lambda = 0 \quad (\text{A.14})$$

$$\frac{\partial \varphi}{\partial k_1} \equiv -F(\hat{x}_1, \hat{m}(x_2 + \hat{y}_2))\Pi_k(\hat{g}_1, k_1) + \lambda = 0 \quad (\text{A.15})$$

$$\frac{\partial \varphi}{\partial y_2} \equiv (1 - \hat{m})F_1((1 - \hat{m})(\hat{x}_2 + y_2), y_3)\Pi(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.16})$$

$$\frac{\partial \varphi}{\partial y_3} \equiv F_2((1 - \hat{m})(\hat{x}_2 + y_2), y_3)\Pi(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.17})$$

$$\frac{\partial \varphi}{\partial g_2} \equiv F((1 - \hat{m})(\hat{x}_2 + y_2), y_3)\Pi_g(g_2, \hat{k}_2) + \lambda = 0 \quad (\text{A.18})$$

$$\frac{\partial \varphi}{\partial k_2} \equiv -F((1 - \hat{m})(\hat{x}_2 + y_2), \hat{y}_3)\Pi_k(\hat{g}_2, k_2) + \lambda = 0. \quad (\text{A.19})$$

Let the fixed point of this problem be denoted by $\sigma^{**} = (m^{**}, x_1^{**}, g_1^{**}, k_1^{**}, x_2^{**}, y_2^{**}, y_3^{**}, g_2^{**}, k_2^{**})$. From (A.12) and (A.13), owing to the symmetry of F , it can be verified that

$$F_1(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) = m^{**}F_2(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) = m^{**}F_1(m^{**}(x_2^{**} + y_2^{**}), x_1^{**}).$$

Provided $m^{**} < 1$, we obtain $F_1(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) < F_1(m^{**}(x_2^{**} + y_2^{**}), x_1^{**})$, which leads to

$$x_1^{**} \neq m^{**}(x_2^{**} + y_2^{**}).$$

Assumption 2 guarantees that $F_{11}(u, v) < 0$ and $F_{12}(u, v) > 0$ for all (u, v) . This implies $F_1(u, v)$ is decreasing in the first argument and increasing in the second and thus

$$m^{**}(x_2^{**} + y_2^{**}) < x_1^{**}.$$

Similarly, from (A.16) and (A.17) we find that

$$(1 - m^{**})(x_2^{**} + y_2^{**}) < y_3^{**}.$$

Expressions (A.14) and (A.15) lead to $F(x_1^{**}, m^{**}(x_2^{**} + y_2^{**}))\Pi_g(g_1^{**}, k_1^{**}) = -F(x_1^{**}, m^{**}(x_2^{**} + y_2^{**}))\Pi_k(g_1^{**}, k_1^{**})$, which implies g_1^{**} and k_1^{**} are such that $\Pi_g(g_1^{**}, k_1^{**}) = -\Pi_k(g_1^{**}, k_1^{**})$. Similarly, equations (A.18) and (A.19) yield $\Pi_g(g_2^{**}, k_2^{**}) = -\Pi_k(g_2^{**}, k_2^{**})$. Using Assumption 1, it is easy to verify that

$$g_1^{**} = k_1^{**} \quad \text{and} \quad g_2^{**} = k_2^{**},$$

which leads to

$$\Pi(g_1^{**}, k_1^{**}) = \Pi(g_2^{**}, k_2^{**}).$$

Finally, equations (A.13) and (A.16) give $m^{**}F_2(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) = (1 - m^{**})F_1(m^{**}(x_2^{**} + y_2^{**}), y_3^{**})$. Since in equilibrium the mother chooses m so that $F_2(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) = F_1(m^{**}(x_2^{**} + y_2^{**}), y_3^{**})$, then $m^{**} = 1/2$.

Thus, the fixed point σ^{**} is characterized by $x_1^{**} = y_3^{**}$, $m^{**} = 1/2$, $g_1^{**} = k_1^{**} = g_2^{**} = k_2^{**}$. The existence proof proceed exactly as that used for Proposition 1. Therefore, there exists a unique equilibrium in which $0 < m < 1$ and in which all men use the same strategy and all women use the same strategy. In this equilibrium children are treated in a semi-symmetric fashion. As in the monogamous convention, also here there are two equilibria in which $x_t^{**} = g_t^{**} = k_t^{**} = 0$, $t = 1, 2$. As in the previous convention, we ignore such equilibria. QED

Proof of Proposition 3 (Stability Without Interactions)

Let σ^* denote the equilibrium values in the monogamy convention and σ^{**} the equilibrium values in the serial monogamy convention. By contradiction, assume $F(x_1^*, x_2^*) + F(y_2^*, y_3^*) < F(x_1^{**}, m^{**}(x_2^{**} + y_2^{**})) + F((1 - m^{**})(x_2^{**} + y_2^{**}), y_3^{**})$ or equivalently

$$F(x_1^*, x_1^*) < F(x_1^{**}, x_2^{**}). \quad (\text{A.20})$$

Inequality (A.20) would imply that the total resources devoted to food provision are larger in the \mathcal{C}_S convention, i.e., $2x_1^* < x_1^{**} + x_2^{**}$. As a result, \mathcal{C}_S is stable while \mathcal{C}_M is not. We show that this leads to a contradiction. Indeed, the symmetric allocation (x_1^*, x_1^*) is the most efficient way to use the amount of resources $2x_1^*$. Since $g_1^{**} = k_1^{**} = g_2^{**} = k_2^{**} = g^{**}$ and $g_1^* = k_1^* = g_2^* = k_2^* = g^*$, it follows that, under (A.20), $g^{**} < g^*$.

Using Assumption 1 we obtain that $\Pi_g(g^{**}, k^{**}) > \Pi_g(g^*, k^*)$. Consequently $F_1(x_1^{**}, x_2^{**})\Pi(g_1^{**}, k_1^{**}) = F(x_1^{**}, x_2^{**})\Pi_g(g_1^{**}, k_1^{**}) > F(x_1^*, x_1^*)\Pi_g(g_1^*, k_1^*) = F_1(x_1^*, x_1^*)\Pi(g_1^*, k_1^*)$ and $\frac{1}{2}F_2(x_1^{**}, x_2^{**})\Pi(g_1^{**}, k_1^{**}) = F(x_1^{**}, x_2^{**})\Pi_g(g_1^{**}, k_1^{**}) > F(x_1^*, x_1^*)\Pi_g(g_1^*, k_1^*) = F_1(x_1^*, x_1^*)\Pi(g_1^*, k_1^*)$. Since $\Pi(g_1^{**}, k_1^{**}) = \Pi(g_2^{**}, k_2^{**})$ we obtain

$$\begin{aligned} F_1(x_1^{**}, x_2^{**}) &> F_1(x_1^*, x_2^*) = F_1(x_1^*, x_1^*) \\ F_2(x_1^{**}, x_2^{**}) &> 2F_2(x_1^*, x_2^*) > F_2(x_1^*, x_2^*) = F_2(x_1^*, x_1^*). \end{aligned}$$

Lemma 3 implies that $x_1^{**} + y_1^{**} < 2x_1^*$. A contradiction. QED

Proof of Proposition 4 (Evolutionary Stability With Interactions)

The proof is in two parts. In part 1 we show that deviations from serial monogamy to monogamy increase survivorship of deviators while in part 2 we show that deviations from monogamy to serial monogamy reduce survivorship of the deviators.

1. Deviations to monogamy in the \mathcal{C}_S convention

The problem of a man who deviates to monogamy in the \mathcal{C}_S convention (and thus faces an almost entirely serially monogamous population) is to choose $x_1, g_1, k_1, R, g_2, k_2, y_3$ to maximize his payoff function θ given by

$$\frac{1}{2} \left\{ \Pi(g_1, \hat{g})F(x_1, \bar{m}R) + [1 - \Pi(\hat{g}, k_1)]F(\hat{x}_1, \hat{x}_2) + \Pi(g_2, \hat{g})F((1 - \bar{m})R, y_3) + [1 - \Pi(\hat{g}, k_2)]F(\hat{y}_2, \hat{y}_3) \right\},$$

subject to $\omega = x_1 + R + y_3 + g_1 + g_2 + k_1 + k_2$ and $0 \leq x_1, R, y_3, g_1, g_2, k_1, k_2$, and where the terms with a ‘hat’ indicate quantities that are set at the serial monogamy equilibrium values (in particular, $\hat{k}_1 = \hat{k}_2 = \hat{g}_1 = \hat{g}_2 = \hat{g}$), while \bar{m} is the food allocation chosen by the woman. Because all the ‘hat’ quantities are symmetric in first and second period children as in Proposition 1, then $\bar{m} = \frac{1}{2}$ and the optimal strategies do not depend on whether we consider first period or second period children.

We therefore focus on first period children only, denoting the corresponding problem with $\theta[1]$. Define the endowment corresponding to this program as $w = \frac{1}{2}\omega$. We further decompose the problem $\theta[1]$ into two subprograms. First, we solve the optimization problem given a fixed amount of resources devoted to food provision. Second, given that solution, we look for the optimal amount of resources to be devoted to food provision. Thus, let the function $V : \mathbb{R}_+ \times \mathbb{R}_+ \rightarrow \mathbb{R}_+$ be defined by

$$V(w_0, z) \equiv \text{Max}_{\{g, k\}} \frac{1}{2} \left\{ \Pi(g, \hat{g})z + [1 - \Pi(\hat{g}, k)]F(\hat{x}_1, \hat{x}_2) \right\}, \quad (\text{A.21})$$

subject to $w_0 = g + k$ and $0 \leq g, k$. Let $B^M \subset \mathbb{R}_+^2$ be the budget set corresponding to program $\theta[1]$, that is

$$B^M = \left\{ (w_0, z) \in \mathbb{R}_+^2 \mid z \leq F(R/2, R/2), w = \frac{\omega}{2} = w_0 + R, 0 \leq R \right\}.$$

The second subprogram is then defined by

$$\begin{aligned} \theta[1] &\equiv \text{Max}_{\{w_0, z\}} V(w_0, z) \\ (w_0, z) &\in B^M. \end{aligned}$$

We also consider the program of the incumbent (i.e., the serial monogamist), which is to choose w_0, z to maximize the payoff function ψ given by

$$\begin{aligned} \psi[1] &\equiv \text{Max}_{\{w_0, z\}} V(w_0, z) \\ (w_0, z) &\in B^S \end{aligned}$$

where $B^S = \left\{ (w_0, z) \in \mathbb{R}_+^2 \mid z \leq F(x_1, \frac{x_2 + \hat{y}_2}{2}), w = w_0 + x_1 + x_2, 0 \leq x_1, x_2 \right\}$ is the budget set corresponding to program $\psi[1]$ and \hat{y}_2 is the food provided to the mother of first period children by her second period partner. Note that the function $V(w_0, z)$ is the same in both subprograms, while the budget set is different.

The solution to each of the two subprograms $\theta[1]$ and $\psi[1]$ is a point (w_0, z) that belongs to the relevant budget set and that lies on the highest indifference curve associated with V . A necessary condition for (w_0, z) to be an interior solution is that the tangent to the indifference curves and the boundary of the budget sets coincides at this point. The strategy of the proof is to consider the output $z^S = F(x^S, \frac{x^S + y^S}{2})$ associated with the serial monogamy equilibrium and show that the point (w_0^M, z^M) , for which the tangent to B^M and the tangent to indifference curves of V coincide, lies above the serial monogamy output, that is $z^M > z^S$. For this to be true it is sufficient to show that the tangent to B^M at (w_0^M, z^M) is steeper than the tangent to the indifference curve of V at the same point (w_0^M, z^M) and that B^M is convex.

Because we know that at the serial monogamy equilibrium the tangent to $B^S(w_0, z)$ at (w_0^S, z^S) is also the tangent to the indifference curve of V , we need to prove two properties. First, the slope of the indifference curves associated with V decreases as z remains constant at a given value z^P but w_0 increases. Second, the slope of the tangent to B^M at (w_0^M, z^M) is steeper than the slope to B^S at the original serial monogamy equilibrium (w_0^S, z^S) . These two properties are shown in the following two lemmas.

Lemma 4. The budget sets B^M and B^S are both strictly convex. Furthermore, the slope of the tangent to B^M at (w_0^M, z^M) is steeper than the slope of the tangent to B^S at the original serial monogamy equilibrium (w_0^S, z^S) .

Proof. The point (w_0^M, z^M) satisfies $z^M = z^M(w_0^M)$ where $z^M(w_0)$ maximizes $F(\frac{R}{2}, \frac{R}{2})$ with respect to R subject to $w_0 + R \leq w$ and $0 \leq R$, or equivalently

$$z^M(w_0) = F\left(\frac{w - w_0}{2}, \frac{w - w_0}{2}\right).$$

At w_0^M we have

$$\frac{\partial z^M}{\partial w_0} = -\frac{1}{2}F_1 - \frac{1}{2}F_2 = -F_1,$$

where the arguments are as above and the last equality holds because of the symmetry of F (see Lemma 1). It is also easy to verify that the boundary of B^M is strictly convex. Indeed,

$$\frac{\partial^2 z^M}{\partial w_0^2} = \frac{1}{2}F_{11} + \frac{1}{2}F_{12} < 0,$$

since F is strictly concave, i.e., $|F_{11}| > |F_{12}|$.

The serial monogamy equilibrium (w_0^S, z^S) satisfies $z^S = z^S(w_0^S, \hat{y}_2)$ with $z^S(w_0, \hat{y}_2)$ being the solution of the maximization of $F(x_1, \frac{x_2 + \hat{y}_2}{2})$ with respect to x_1 and x_2 subject to $w_0 + x_1 + x_2 \leq w$ and $0 \leq x_1, x_2$, or equivalently

$$z^S(w_0, \hat{y}_2) = \text{Max}_{x_2} F\left(w - w_0 - x_2, \frac{x_2 + \hat{y}_2}{2}\right). \quad (\text{A.22})$$

By the envelope theorem we establish that

$$\frac{\partial z^S}{\partial w_0} = -F_1\left(w - w_0^S - x_2, \frac{x_2 + \hat{y}_2}{2}\right).$$

The set B^S is strictly convex. Indeed,

$$\frac{\partial^2 z^S}{\partial w_0^2} = F_{11} + F_{11} \frac{\partial x_2}{\partial w_0} + \frac{1}{2}F_{12} \frac{\partial x_2}{\partial w_0} = F_{11} + \left(F_{11} + \frac{1}{2}F_{12}\right) \frac{\partial x_2}{\partial w_0}.$$

The first order condition associated with (A.22)

$$\Theta(x_2, w_0) = -F_1\left(w - w_0 - x_2, \frac{x_2 + \hat{y}_2}{2}\right) + \frac{1}{2}F_2\left(w - w_0 - x_2, \frac{x_2 + \hat{y}_2}{2}\right) = 0$$

implicitly defines x_2 as a function of w_0 and \hat{y}_2 . The implicit function theorem then implies that

$$\frac{\partial x_2}{\partial w_0} = -\frac{\frac{\partial \Theta}{\partial w_0}}{\frac{\partial \Theta}{\partial x_2}} = -\frac{F_{11} - \frac{1}{2}F_{12}}{F_{11} - \frac{1}{2}F_{12} - \frac{1}{2}F_{21} + \frac{1}{4}F_{22}} = -\frac{(< 0)}{(< 0)} < 0.$$

Furthermore, because of the supermodularity of F , i.e., $F_{21} > 0$, we have that $\left| \frac{\partial x_2}{\partial w_0} \right| < 1$. Therefore,

$$\left| F_{11} + \frac{1}{2} F_{12} \right| < |F_{11}|.$$

In sum then

$$\frac{\partial^2 z^S}{\partial w_0} = F_{11} + \left(F_{11} + \frac{1}{2} F_{12} \right) \frac{\partial x_2}{\partial w_0} < 0.$$

The level of w_0 associated with the level of output z^S depends on whether we consider B^M or B^S . Imposing the same level of output, the relevant relationship is

$$F \left(w - w_0^S - x_2, \frac{x_2 + \hat{y}_2}{2} \right) = F \left(\frac{w - w_0^{FM}}{2}, \frac{w - w_0^{FM}}{2} \right) = z^S,$$

which, by concavity of F , implies

$$\frac{w - w_0^M}{2} + \frac{w - w_0^M}{2} < w - w_0^S - x_2 + \frac{x_2 + \hat{y}_2}{2}.$$

Now Lemma 3 implies that

$$F_1 \left(w - w_0^S - x_2, \frac{x_2 + \hat{y}_2}{2} \right) < F_1 \left(\frac{w - w_0^M}{2}, \frac{w - w_0^M}{2} \right) \quad (\text{A.23})$$

and/or

$$F_2 \left(w - w_0^S - x_2, \frac{x_2 + \hat{y}_2}{2} \right) < F_2 \left(\frac{w - w_0^M}{2}, \frac{w - w_0^M}{2} \right). \quad (\text{A.24})$$

From both (A.23) and (A.24), it is straightforward to see that

$$\left| \frac{\partial z^M}{\partial w_0} \right| > \left| \frac{\partial z^S}{\partial w_0} \right|. \quad \blacksquare$$

Lemma 5. The absolute value of slope of the indifference curves associated with V decreases with w_0 as z is kept constant at $z = z^S$.

Proof. Consider the program (A.21) that defines V . Letting $k = w_0 - g$, the associated first order condition is

$$\frac{\partial}{\partial g} [\Pi(g, \hat{g})z + [1 - \Pi(\hat{g}, w_0 - g)]F(\hat{x}_1, \hat{x}_2)] = \Pi_g(g, \hat{g})z + \Pi_k(\hat{g}, w_0 - g)F(\hat{x}_1, \hat{x}_2).$$

Applying the implicit function theorem to

$$\Lambda(z, w_0) = \Pi_g(g, \hat{g})z + \Pi_k(\hat{g}, w_0 - g)F(\hat{x}_1, \hat{x}_2) = 0$$

we obtain

$$\frac{\partial g}{\partial w_0} = - \frac{\frac{\partial \Lambda}{\partial w_0}}{\frac{\partial \Lambda}{\partial g}} = - \frac{\Pi_{kk}(\hat{g}, w_0 - g)F(\hat{x}_1, \hat{x}_2)}{\Pi_{gg}(g, \hat{g})z - \Pi_{kk}(\hat{g}, w_0 - g)F(\hat{x}_1, \hat{x}_2)} > 0$$

Each indifference curve associated to V is defined by a real number $c \in \mathbb{R}_+$ and the equation

$$V(w_0, z) = c.$$

Consider a point $(w_0, z) \in \mathbb{R}_+^2$. Let s_T denote the slope of the tangent to the indifference curve passing through (w_0, z) and evaluated at this point. Using the envelope theorem this is given by

$$s_T = -\frac{\partial V}{\partial w_0} = -\frac{-\Pi_k(\hat{g}, w_0 - g)F(\hat{x}_1, \hat{x}_2)}{\Pi(g, \hat{g})}.$$

At the maximum it must be the case that

$$\Pi_k(\hat{g}, w_0 - g)F(\hat{x}, \hat{y}) = -\Pi_g(g, \hat{w}_0 - \hat{g})z.$$

Therefore

$$s_T = -\frac{\Pi_g(g, \hat{w}_0 - \hat{g})z}{\Pi(g, \hat{g})}$$

As we have shown above, g increases with w_0 . Thus, $\Pi(g, \hat{g})$ increases with w_0 . Furthermore, $\Pi_g(g, \hat{w}_0 - \hat{g})z$ decreases with g since Π is concave in g . Hence, the absolute value of s_T decreases as w_0 increases, keeping z constant. ■

Lemmas 4 and 5 imply that $z^M > z^S$. QED

2. Deviations to serial monogamy in the \mathcal{C}_M convention

We now analyze the opposite exercise, i.e., a deviation to serial monogamy. Consider the point (w_0^M, z^M) such that the tangent to B^M and the tangent to the indifference curve associated with V coincide. Of course, the ‘hat’ quantities in V now denote the monogamous equilibrium values. Because of concavity of F , the w_0 associated to the z^M is such that $w_0 < w_0^M$. From Lemma 4 we know that the absolute value of slope of the tangent to B^M decreases as w_0 is reduced from w_0^M . On the other hand, Lemma 5 implies that the indifference curves become steeper as w_0 falls, keeping z at z^M . This means that at the point $(w_0, z^M) \in B^M$ the tangent to B^S is flatter than the tangent to the indifference curves. Because of the convexity of the set B^S , the point (w_0^S, z^S) , where the tangent to the set B^S and the tangent to the indifference curves coincide, must lie below z^M , i.e., $z^S < z^M$. QED

Proof of Proposition 5 (Polygyny)

Men have an incentive to cheat. We prove Proposition 5 by assuming that polygynists are not allowed to cheat. The result is thus stronger than what stated in Proposition 5. The program of an unmatched man is simple, as he spends his entire resource endowment on casual sex. A (matched) polygyny man who spend g on guarding faces a probability $\Pi(g, \omega/4)$ that the children he feeds are his. His problem is then to choose x_1, g_1, R, g_2, y_3 to maximize his payoff ϑ given by

$$\frac{1}{2} \left\{ \Pi(g_1, \omega/4)F(x_1, \hat{m}R) + \Pi(g_2, \omega/4)F((1 - \hat{m})R, y_3) \right\}$$

subject to $\omega/2 = x_1 + R + y_3 + g_1 + g_2$ and $0 \leq x_1, R, y_3, g_1, g_2$, where we assume $0 < \hat{m} < 1$ and, as usual, the ‘hat’ denotes exogenous parameters. The following first order conditions are necessary but not sufficient for an interior maximum.

$$\frac{\partial \vartheta}{\partial x_1} \equiv F_1(x_1, \hat{m}R)\Pi(g_1, \omega/4) + \lambda = 0 \tag{A.25}$$

$$\frac{\partial \vartheta}{\partial R} \equiv \hat{m}F_2(x_1, \hat{m}R)\Pi(g_1, \omega/4) + (1 - \hat{m})F_1((1 - \hat{m})R, y_3)\Pi(g_2, \omega/4) + \lambda = 0 \quad (\text{A.26})$$

$$\frac{\partial \vartheta}{\partial g_1} \equiv F(x_1, \hat{m}r)\Pi_g(g_1, \omega/4) + \lambda = 0 \quad (\text{A.27})$$

$$\frac{\partial \vartheta}{\partial y_3} \equiv F_2((1 - \hat{m})R, y_3)\Pi(g_2, \omega/4) + \lambda = 0 \quad (\text{A.28})$$

$$\frac{\partial \vartheta}{\partial g_2} \equiv F((1 - \hat{m})R, y_3)\Pi_g(g_2, \omega/4) + \lambda = 0 \quad (\text{A.29})$$

$$\frac{\partial \vartheta}{\partial \lambda} \equiv x_1 + R + y_3 + g_1 + g_2 - \omega/2 = 0 \quad (\text{A.30})$$

Using $F_2(x_1, \hat{m}R) = F_1((1 - \hat{m})R, y_3)$ from the first order condition of the mother's problem, (A.26) becomes

$$F_2(x_1, \hat{m}R)[\hat{m}\Pi(g_1, \omega/4) + (1 - \hat{m})\Pi(g_2, \omega/4)] + \lambda = 0.$$

From now on we focus on fixed point values and, as in the monogamous case, we consider only interior equilibria so that $x_1 = y_3$, $m = 1/2$, $g_1 = g_2 = g$, and $x_1 = x_2 = y_2 = y_3 = R/2$. Using these values, the system (A.25)–(A.30) allows us to solve for the equilibrium value of R given by

$$F_1(R/2, R/2)\Pi(\omega/4 - R, \omega/4) - F(R/2, R/2)\Pi_g(\omega/4 - R, \omega/4) = 0. \quad (\text{A.31})$$

Recall that the relevant expression determining R^M for monogamous males is

$$F_1(R^M/2, R^M/2)\Pi(\omega/4 - R^M/2, \omega/4 - R^M/2) - F(R^M/2, R^M/2)\Pi_g(\omega/4 - R^M/2, \omega/4 - R^M/2) = 0. \quad (\text{A.32})$$

Assume by contradiction that $F(R^M/2, R^M/2) < F(R/2, R/2)$, or equivalently $R^M < R$. Under this inequality, using (A.31) and (A.31) we conclude

$$\frac{F_1(R^M/2, R^M/2)\Pi(\omega/4 - R^M/2, \omega/4 - R^M/2)}{\Pi_g(\omega/4 - R^M/2, \omega/4 - R^M/2)} < \frac{F_1(R/2, R/2)\Pi(\omega/4 - R, \omega/4)}{\Pi_g(\omega/4 - R, \omega/4)}.$$

Assumption 1(v) implies that $\Pi_g(g, k) = P'\left(\frac{g}{g+k}\right) \frac{k}{(g+k)^2}$. Then $\Pi(\omega/4 - R^M/2, \omega/4 - R^M/2) = P\left(\frac{1}{2}\right) > P\left(\frac{\omega/4 - R}{\omega/2 - R}\right)$, as P is increasing. This, together with the concavity of F , implies

$$F_1(R^M/2, R^M/2)\Pi(\omega/4 - R^M/2, \omega/4 - R^M/2) > F_1(R/2, R/2)\Pi(\omega/4 - R, \omega/4).$$

Therefore, we must have $\Pi_g(\omega/4 - R^M/2, \omega/4 - R^M/2) > \Pi_g(\omega/4 - R, \omega/4)$. Provided P is concave in the region $\left[\frac{\omega/4 - R}{\omega/2 - R}, \frac{1}{2}\right]$, then

$$\frac{1}{\omega - 2R^M} > \frac{\omega/4}{(\omega/2 - R)^2} = \frac{\omega}{(\omega - 2R)^2}.$$

Recalling that by assumption $R > R^M$, we obtain $2\omega > 4\omega - R$ which implies $R > 2\omega$. A contradiction. QED

Proof of Proposition 6 (Kinship)

We adopt the use functional specifications as those used in the example reported in subsection 4B. We begin with the characterization of the problems in the monogamy convention and then turn to the serial monogamy convention. The comparison is for such two conventions only.

Monogamy

Adult Woman. Taking into account that her second period children may receive food from their older brothers, denoted by \hat{b} , a woman chooses m to maximize

$$\hat{x}_1^\alpha (m(\hat{x}_2 + \hat{y}_2))^\alpha + \mathbb{E} \left\{ [(1-m)(\hat{x}_2 + \hat{y}_2)]^\alpha (\hat{y}_3 + \hat{b})^\alpha \right\}. \quad (\text{A.33})$$

The expectation operator $\mathbb{E}[\cdot]$ in (A.33) arises because older brothers might not survive to adulthood, and this means $\hat{b} = 0$. Letting $\hat{x}_2 + \hat{y}_2 = \hat{z}_2$, the woman's objective is to choose m to maximize

$$m^\alpha (\hat{x}_1 \hat{z}_2)^\alpha + (1-m)^\alpha \hat{z}_2^\alpha \mathbb{E} \left[(\hat{y}_3 + \hat{b})^\alpha \right]. \quad (\text{A.34})$$

As food can be supplied only by men, the sex of a child matters. In order to keep a balanced sex ratio and avoid useless complications, every couple is assumed to give birth to an equal number of boys and girls in each period. Siblings' birth order also matters now, so that the optimization problem faced by older males will differ from that faced by their younger brothers. This is because older children, when adult, can support their younger siblings but not vice versa. Rearranging (A.34), the female's problem becomes that of choosing $m \in (0, 1)$ to maximize

$$m^\alpha (\hat{x}_1 \hat{z}_2)^\alpha + (1-m)^\alpha \hat{z}_2^\alpha \left[m^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha (\hat{y}_3 + \hat{b})^\alpha + (1-m^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha) \hat{y}_3^\alpha \right].$$

The first order necessary condition for an interior solution is then

$$\left(\frac{m}{1-m} \right)^{\alpha-1} \hat{x}_1^\alpha - \hat{y}_3^\alpha - m^{\alpha-1} (2m-1) \left\{ \hat{x}_1^\alpha (\hat{x}_2 + \hat{y}_2)^\alpha \left[(\hat{y}_3 + \hat{b})^\alpha - \hat{y}_3^\alpha \right] \right\} = 0. \quad (\text{A.35})$$

The implicit equation (A.35) gives all equilibrium candidates to interior maxima. As in the case without kin ties, however, there are always two other inefficient non-interior solutions, in which males and females choose $x_1 = 0$ and $m = 0$ or $y_3 = 0$ and $m = 1$, which are ignored. Finally, we numerically checked that for the values of the exogenous variables evaluated at the fixed point, i.e., the candidate Nash equilibrium, the solution to (A.35) delivers the global maximum for the mother.

Elder Male. Taking account of the possibility that his younger children might receive food transfers from his older children and letting $x_2 + y_2 = z_2$, the elder male's program is to choose $g_1, k_1, g_2, k_2, x_1, z, y_3$ and b to maximize

$$\begin{aligned} & \frac{1}{2} \Pi(g_1, \hat{k}_1) (x_1 \hat{m} z_2)^\alpha + \frac{1}{2} \Pi(g_2, \hat{k}_2) [(1-\hat{m}) z_2]^\alpha \left[\hat{x}_1 \hat{m} z (y_3 + \hat{b}) \right]^\alpha \\ & + \frac{1}{2} \Pi(g_2, \hat{k}_2) [(1-\hat{m}) z_2]^\alpha (1 - \hat{x}_1^\alpha \hat{m}^\alpha \hat{z}_2^\alpha) y_3^\alpha + \frac{1}{2} [1 - \Pi(\hat{g}_1, k_1)] (\hat{x}_1 \hat{m} \hat{z}_2)^\alpha \\ & + \frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] [(1-\hat{m}) \hat{z}_2]^\alpha (x_1 \hat{m} z_2)^\alpha (\hat{y}_3 + \hat{b})^\alpha \\ & + \frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] [(1-\hat{m}) \hat{z}_2]^\alpha [1 - \hat{x}_1^\alpha \hat{m}^\alpha \hat{z}_2^\alpha] \hat{y}_3^\alpha \\ & + \frac{1}{4} \left[(1 + \Pi(\hat{g}_1, \hat{k}_1) \Pi(\hat{g}_2, \hat{k}_2)) \right]^\alpha [(1-\hat{m}) \hat{z}_2]^\alpha (\hat{y}_3 + b)^\alpha \end{aligned} \quad (\text{A.36})$$

subject to $2 = g_1 + x_1 + g_2 + z_2 + y_3 + k_1 + k_2 + b$ and $0 \leq x_1, z_2, g_1, g_2, k_1, k_2, y_2, y_3, b$ and taking $\hat{g}_1, \hat{g}_2, \hat{k}_1, \hat{k}_2, \hat{z}_2, \hat{y}_3, \hat{m}$ and \hat{b} as given. Note that the transfer b only appears in the budget constraint and in the last term of the objective function (A.36). The problem faced by younger males is similar to that discussed in Sections 2 and 3.

We first ignore the sign constraints on all the control variables, allowing us to focus on interior solutions, and check afterward that these are positive. Here we focus on the first order conditions relative to the kin transfer. Eliminating g_1 and letting $A = 2 - (x_1 + g_2 + z_2 + y_3 + k_1 + k_2 + b)$, the first order condition with respect to b is

$$\alpha y_1^\alpha (\hat{m} \hat{z}_2)^\alpha \left(\frac{A}{A + \hat{k}_1} \right)^{\alpha-1} \frac{\hat{k}_1}{(A + \hat{k}_1)^2} = \frac{\alpha}{2} \left[1 + \Pi(\hat{g}_1, \hat{k}_1) \Pi(\hat{g}_2, \hat{k}_2) \right] (1 - \hat{m})^\alpha (\hat{y}_3 + b)^{\alpha-1} \quad (\text{A.37})$$

The issue is to evaluate the sign of the transfer b the agent would like to make at the fixed point. As a preliminary step, consider (A.37) and evaluate this expression at the equilibrium without kin transfers, as derived in subsection 4B. As this fixed point is characterized by $g_1 = g_2 = k_1 = k_2 = 1/6, x_1 = y_3 = 1/3, z_2 = x_2 + y_2 = 2/3$ and $m = 1/2$, we obtain

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

It can be verified that, for $b = 0$, the right-hand is larger than the left-hand term for any $\alpha \in (0, \frac{1}{2})$. Therefore, we expect the unconstrained interior fixed point to be characterized by $b > 0$ and consequently the kin transfers to be operative even in the original constrained model.

The full characterization of the equilibrium with positive kin transfers is analytically not possible. We perform a numerical analysis using 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 elder man solves his problem taking $\hat{g}_1, \hat{g}_2, \hat{k}_1, \hat{k}_2, \hat{x}_1, \hat{z}_2, \hat{y}_3, \hat{m}$ and \hat{b} as given. The solution is a vector $\{g_1^*, x_1^*, g_2^*, k_1^*, k_2^*, z_2^*, y_3^*, b^*\}$ in which each component is a function of $\{\hat{g}_1, \hat{g}_2, \hat{k}_1, \hat{k}_2, \hat{x}_1, \hat{z}_2, \hat{y}_3, \hat{m}, \hat{b}\}$. The mother's optimal allocation rule, m^* , is instead obtained using the secant algorithm, as a root of the implicit equation (A.35). The second step uses 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. More precisely, the second step consists of minimizing the Euclidean distance between $\{\hat{g}_1, \hat{x}_1, \hat{g}_2, \hat{k}_1, \hat{k}_2, \hat{z}_2, \hat{y}_3, \hat{b}, \hat{m}\}$ and $\{g_1^*, x_1^*, g_2^*, k_1^*, k_2^*, z_2^*, y_3^*, b^*, m^*\}$, by choosing the 'hat' variables. The equilibrium is a fixed point, which occurs when $\hat{g}_1 = g_1^*, \hat{x}_1 = x_1^*, \hat{g}_2 = g_2^*, \hat{k}_1 = k_1^*, \hat{k}_2 = k_2^*, \hat{z}_2 = z_2^*, \hat{y}_3 = y_3^*, \hat{b} = b^*$, and $\hat{m} = m^*$, with the equilibrium allocations depending on the parameter α . Finally, we checked numerically that the solution to the first order conditions is the global maximum of the problem with sign constraints. Therefore, the $*$ fixed point is the unique interior Nash equilibrium.

Serial Monogamy

In this configuration second-born children may receive transfers from the older half-brothers on the maternal side, denoted by b_M , as well as from the older half-brothers on the paternal side, b_F . Let $b = b_M + b_F$.

Adult Woman. As a mother can only affect survivorship of her own children, and not that of her nieces and nephews, her choice of m can only affects the probability of her second period children receiving a transfer from her first period children, b_M . Her objective is then to maximize

$$m^\alpha (\hat{x}_1 \hat{z}_2)^\alpha + \hat{m}^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha (1 - m)^\alpha \hat{z}_2^\alpha \left[m^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha (\hat{y}_3 + \hat{b}_M + \hat{b}_F)^\alpha + (1 - m^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha) (\hat{y}_3 + \hat{b}_F)^\alpha \right]$$

$$+[1 - \hat{m}^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha](1 - m)^\alpha \hat{z}_2^\alpha \left[m^\alpha \hat{x}_1^\alpha \hat{z}^\alpha (\hat{y}_3 + \hat{b}_M)^\alpha + (1 - m^\alpha \hat{x}_1^\alpha \hat{z}_2^\alpha) (\hat{y}_3)^\alpha \right]$$

A solution to this optimization exists and is a function of the parameters exogenous to the mother's decision.

Elder Male. Taking account of the possibility that his younger children might receive food transfers from their older brothers, his problem is to choose $g_1, x_1, k_1, g_2, x_2, y_2, k_2, y_3, b_M$ and b_F to maximize

$$\begin{aligned} & \frac{1}{2} \Pi(g_1, \hat{k}_1) x_1^\alpha (\hat{m}(x_2 + \hat{y}_2))^\alpha + \frac{1}{2} \Pi(g_2, \hat{k}_2) [(1 - \hat{m})(\hat{x}_2 + y_2)]^\alpha \hat{x}_1^\alpha \hat{m}^\alpha (\hat{x}_2 + y_2)^\alpha (y_3 + \hat{b}_M + \hat{b}_F)^\alpha \\ & + \frac{1}{2} \Pi(g_2, \hat{k}_2) [(1 - \hat{m})(\hat{x}_2 + y_2)]^\alpha [1 - \hat{x}_1^\alpha \hat{m}^\alpha (\hat{x}_2 + y_2)^\alpha] y_3^\alpha + \frac{1}{2} [1 - \Pi(\hat{g}_1, k_1)] \hat{x}_1^\alpha [\hat{m}(\hat{x}_2 + \hat{y}_2)]^\alpha \\ & + \frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] [(1 - \hat{m})(\hat{x}_2 + \hat{y}_2)]^\alpha x_1^\alpha [\hat{m}(\hat{x}_2 + \hat{y}_2)]^\alpha (\hat{y}_3 + \hat{b}_M + \hat{b}_F)^\alpha \\ & + \frac{1}{2} [1 - \Pi(\hat{g}_2, k_2)] [(1 - \hat{m})(\hat{x}_2 + \hat{y}_2)]^\alpha [1 - \hat{x}_1^\alpha \hat{m}^\alpha (\hat{x}_2 + \hat{y}_2)^\alpha] \hat{y}_3^\alpha \\ & + \frac{1}{4} [(1 - \hat{m})(\hat{x}_2 + \hat{y}_2)]^\alpha (\hat{y}_3 + b_M + \hat{b}_F)^\alpha \\ & + \frac{1}{4} \Pi(\hat{g}_1, \hat{k}_1) \Pi(\hat{g}_2, \hat{k}_2) [(1 - \hat{m})(\hat{x}_2 + \hat{y}_2)]^\alpha (\hat{y}_3 + \hat{b}_M + b_F)^\alpha \end{aligned}$$

subject to $2 = g_1 + x_1 + g_2 + x_2 + y_2 + y_3 + k_1 + k_2 + b_M + b_F$ and $0 \leq x_1, x_2, g_1, g_2, k_1, k_2, y_2, y_3, b_M, b_F$. The first order conditions for this problem are formally identical to those without kin ties, except those relative to b_M and b_F . Eliminating g_1 and letting $A = 2 - (x_1 + g_2 + x_2 + y_2 + y_3 + k_1 + k_2 + b_M + b_F)$, the first order conditions with respect to b_M and b_F are respectively given by

$$Q = \frac{\alpha ((1 - \hat{m})(\hat{x}_2 + \hat{y}_2))^\alpha}{2} (\hat{y}_3 + b_M + \hat{b}_F)^{\alpha-1} \quad (\text{A.38a})$$

$$Q = \frac{1}{2} \alpha \Pi(\hat{g}_1, \hat{k}_1) \Pi(\hat{g}_2, \hat{k}_2) ((1 - \hat{m})(\hat{x}_2 + \hat{y}_2))^\alpha (\hat{y}_3 + \hat{b}_M + b_F)^{\alpha-1}, \quad (\text{A.38b})$$

where $Q = \alpha x_1^\alpha [\hat{m}(x_2 + \hat{y}_2)]^\alpha \left(\frac{A}{A + \hat{k}_1} \right)^{\alpha-1} \frac{\hat{k}_1}{(A + \hat{k}_1)^2}$. Proceeding as in the monogamous case, we evaluate (A.38a) and (A.38b) at the equilibrium without kin transfers, which is $g_1 = g_2 = k_1 = k_2 = 1/5, x_1 = y_3 = 2/5, x_2 + y_2 = 2/5$ and $m = 1/2$ (see subsection 4B), and obtain

$$\left(\frac{2}{5} \right)^\alpha \left(\frac{1/5}{1/5 + 1/5} \right)^{\alpha-1} \frac{1/5}{(1/5 + 1/5)^2} = \frac{1}{2} \left(\frac{2}{5} + b_M + \hat{b}_F \right)^{\alpha-1}$$

and

$$\left(\frac{2}{5} \right)^\alpha \left(\frac{1/5}{1/5 + 1/5} \right)^{\alpha-1} \frac{1/5}{(1/5 + 1/5)^2} = \frac{1}{2} \left(\frac{1/5}{1/5 + 1/5} \right)^{2\alpha} \left(\frac{2}{5} + \hat{b}_M + b_F \right)^{\alpha-1}.$$

It easy to verify that at $\hat{b}_M + b_F = b_M + \hat{b}_F = 0$ the right-hand terms of these last two expressions are both smaller than the left-hand side term. Therefore, the optimal transfers that the older male would like to make is negative, at least when everybody else behaves as in the equilibrium without kinship. Hence, kin transfers are never positive. In fact, 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. Hence, the unique interior Nash equilibrium is as stated. QED

Proof of Proposition 7 (Food Provision by the Mother)

A key feature of the model is that the mother has full control over distribution of resources to her children. As long as this feature is retained, whether or not she has resources of her own does not matter. Assume the woman has a given stream of food endowment in her three adult periods, denoted by μ_1, μ_2 and μ_3 respectively. The optimization program of the mother is then to choose z_2 to maximize

$$\frac{1}{2} \left[F(\hat{x}_1 + \mu_1, z_2) + F(W - z_2, \hat{y}_3 + \mu_3) \right],$$

subject to $0 \leq z_2 \leq W = \hat{R} + \mu_2$, where $(\hat{x}_1, \hat{R}, \hat{y}_3)$ are the amounts of food she receives from her official partner(s) and z_2 is the amount of food she distributes to her first period children in the period 2. Because of strict concavity of F , the solution is unique. The first order necessary condition associated to an interior solution is

$$F_2(\hat{x}_1 + \mu_1, z_2) = F_1(W - z_2, \hat{y}_3 + \mu_3).$$

In this case we denote the solution as $z_2 = m(\hat{R} + \mu_2)$, where $0 < m < 1$. Now, because of the symmetry of F , if $\hat{x}_1 + \mu_1 = \hat{y}_3 + \mu_3$ then $m = 1/2$.

Let the food allocations that take account of the mother's contribution be denoted by $\tilde{x}_1 = x_1 + \mu_1$, $\tilde{\mu} = R + \mu_2$, and $\tilde{y}_3 = y_3 + \mu_3$. Let also $\mu = \sum_{t=1}^3 \mu_t$. The budget constraint of the monogamous man becomes

$$\omega + \mu = g_1 + k_1 + \tilde{x}_1 + \tilde{\mu} + \tilde{y}_3 + g_2 + k_2,$$

while that of the serial monogamous males is

$$\omega + \mu = g_1 + k_1 + \tilde{x}_1 + x_2 + y_2 + \mu_2 + \tilde{y}_3 + g_2 + k_2$$

Allowing the mother to be food provider modifies the original problems for \mathcal{C}_M , \mathcal{C}_S , \mathcal{C}_P , and \mathcal{C}_G only through additive changes in the variables. Hence, the first order conditions do not change. As an example, consider \mathcal{C}_S . For this case, we have

$$m^{**} F_2(\tilde{x}_1^{**}, m^{**}(x_2^{**} + y_2^{**} + \mu_2)) = (1 - m^{**}) F_1(m^{**}(x_2^{**} + y_2^{**} + \mu_2), \tilde{y}_3^{**})$$

and

$$F_2(\tilde{x}_1^{**}, m^{**}(x_2^{**} + y_2^{**} + \mu_2)) = F_1(m^{**}(x_2^{**} + y_2^{**} + \mu_2), \tilde{y}_3^{**}),$$

which, as in the original problem, leads to $m^{**} = 1/2$. Similar results hold for the other family conventions. Therefore, the results and properties reported in the text carry over with ω being replaced by the total resources allocated to food, $\omega + \mu$, and provided the solution is interior. Focusing on interior solutions means not only that $0 < m < 1$ but also ensure that all transfers from the father(s) are positive. A sufficient condition for this to hold is that the mother's own endowments are small relative to ω . Importantly, in \mathcal{C}_S , as long as $\hat{R} > 0$ there will always be free riding between two competing men and, although the solution might be such that children from different cohorts are not treated symmetrically in equilibrium, the results here are qualitatively the same as those found earlier. QED

A Class of Functions Satisfying Assumption 1

The set of functions $\Pi : \mathbb{R}_+ \times \mathbb{R}_+ \rightarrow \mathbb{R}_+$ that satisfy Assumption 1 is non-empty and contains open and dense subsets in the appropriate topology. For example, consider

$$P(z) = \frac{1}{2} \left[z^\alpha - (1 - z)^\alpha + 1 \right]$$

where $\alpha \in (0, 1/2)$. In this case, it is easily verified that Π satisfies Assumption 1 for all $\alpha \in (0, 1/2)$.

References

- Acemoglu, Daren, Simon Johnson, James A. Robinson. 2001. "The Colonial Origins of Comparative Development: An Empirical Investigation." *American Economic Review*, 91(5): 1369–1401.
- Acemoglu, Daren, Simon Johnson, James A. Robinson. 2005. "Institutions as a Fundamental Cause of Long-Run Growth." In *Handbook of Economic Growth*, Volume 1A, edited by Philippe Aghion and Steven N. Durlauf. Amsterdam: Elsevier, pp. 385–472.
- Alger, Ingela, and Jörgen W. Weibull. 2010. "Kinship, Incentives, and Evolution." *American Economic Review*, 100(4): 1725–58.
- Alexander, Richard D. 1974. "The Evolution of Social Behavior." *Annual Review of Ecology and Systematics*, 5(November): 325–83.
- Allen, Nicholas J., Hilary Callan, Robin Dunbar, and Wendy James, eds. 2008. *Early Human Kinship: From Sex to Social Reproduction*. Oxford: Blackwell.
- Anderson, Kermyt G. 2006. "How Well Does Paternity Confidence Match Actual Paternity? Evidence from Worldwide Nonpaternity Rates." *Current Anthropology*, 47(3): 513–20.
- Ashraf, Quamrul and Oded Galor. 2011. "The 'Out of Africa' Hypothesis, Human Genetic Diversity, and Comparative Economic Development." MIT Department of Economics Working Paper No. 11-08.
- Baker, R. Robin, and Mark A. Bellis. 1995. *Human Sperm Competition: Copulation, Masturbation, and Infidelity*. London: Chapman and Hall.
- Barro, Robert J., and Rachel M. McCleary. 2003. "Religion and Economic Growth Across Countries." *American Sociological Review*, 68(5): 760–81.
- Becker, Gary S. 1973. "A Theory of Marriage: Part I." *Journal of Political Economy*, 81(4): 813–46.
- Becker, Gary S. 1974. "A Theory of Marriage: Part II." *Journal of Political Economy*, 82(2, pt. 2): S11–S26.
- Becker, Gary S. 1981. *A Treatise on the Family*. Cambridge, MA: Harvard University Press. Enlarged Edition, 1991.
- Becker, Gary S. 1989. "On the Economics of the Family: Reply to a Skeptic." *American Economic Review*, 79(3): 514–518.
- Becker, Gary S. 1993. "Nobel Lecture: The Economic Way of Looking at Behavior." *Journal of Political Economy*, 101(3): 385–409.
- Becker, Sasha O., and Ludger Woessmann. 2009. "Was Weber Wrong? A Human Capital Theory of Protestant Economic History." *Quarterly Journal of Economics*, 124(2): 531–96.
- Bergstrom, Theodore C. 1995. "On the Evolution of Altruistic Ethical Rules for Siblings." *American Economic Review*, 85(1): 58–81.
- Bergstrom, Theodore C. 1996. "Economics in a Family Way." *Journal of Economic Literature*, 34(4): 1903–34.
- Bergstrom, Theodore C. 2007. "Some Evolutionary Economics of Family Partnerships." Unpublished.

- Bergstrom, Theodore, Lawrence Blume, and Hal Varian. 1986. "On the Private Provision of Public Goods." *Journal of Public Economics*, 29(1): 25–49.
- Bethmann, Dirk, and Michael Kvasnicka. 2011. "The Institution of Marriage." *Journal of Population Economics*, 24(3): 1005–1032.
- Bisin, Alberto, and Thierry Verdier. 2001. "The Economics of Cultural Transmission and the Dynamics of Preferences." *Journal of Economic Theory*, 97(2): 298–319.
- Black, Sandra E., Paul J. Devereux, and Kjell G. Salvanes. 2005. "The More the Merrier? The Effect of Family Size and Birth Order on Children's Education." *Quarterly Journal of Economics*, 120(2): 669–700.
- Botticini, Maristella, and Zvi Eckstein. 2007. "From Farmer to Merchant, Conversions, and Diaspora: Human Capital and Jewish History." *Journal of the European Economic Association*, 5(5): 885–926.
- Browning, Don S., M. Christian Green, and John Witte Jr, eds. 2006. *Sex, Marriage, and Family in World Religions*. New York, NY: Columbia University Press.
- Browning, Martin, Pierre-André Chiappori, and Yoram Weiss. *Family Economics*. Cambridge: Cambridge University Press, forthcoming.
- Chapais, Bernard. 2008. *Primeval Kinship: How Pair-Bonding Gave Birth to Human Society*. Cambridge, MA: Harvard University Press
- Cox, Donald. 2007. "Biological Basics and the Economics of the Family." *Journal of Economic Perspectives*, 21(2): 91–108.
- Csikszentmihalyi, Mihaly (1990). *Flow: The Psychology of Optimal Experience*. New York: Harper and Row.
- Cunha, F. and J.J. Heckman. 2007. "The Technology of Skill Formation." *American Economic Review Papers and Proceedings*, 97(2): 31–47.
- Cunha, F. and J.J. Heckman. 2010. "Investing in Our Young People." IZA Discussion Paper No. 5050, Institute for the Study of Labor: Bonn.
- Diamond, Arthur M., Jr. and Luis Locay. 1989. "Investment in Sister's Children as Behavior Towards Risk." *Economic Inquiry*, 27(4): 719–35.
- Dunbar, Robin I.M., Amanda Clark, and Nicola L. Hurst. 1995. "Conflict and Cooperation among the Vikings: Contingent Behavioural Decisions." *Ethology and Sociobiology*, 16(3): 233–46.
- Duncan, Greg J., and Jeanne Brooks-Gunn (eds.). 1997. *Consequences of Growing Up Poor*. New York: Russell Sage Foundation.
- Edlund, Lena. 2006. "Marriage: Past, Present, Future?" *CESifo Economic Studies*, 52(4): 621–39.
- Edlund, Lena, and Evelyn Korn. 2002. "A Theory of Prostitution." *Journal of Political Economy*, 110(1): 181–214.
- Emlen, Stephen T. 1994. "Benefits, Constraints and the Evolution of the Family." *Trends in Ecology and Evolution*, 9(8): 282–85.
- Emlen, Stephen T. 1995. "An Evolutionary Theory of the Family." *Proceedings of the National Academy of Science of the USA*, 92(August): 8092–99.

- Freeman, Richard B. 1986. "Who Escapes? The Relation of Churchgoing and Other Background Factors to the Socioeconomic Performance of Black Male Youths from Inner-city Tracks." In *The Black Youth Unemployment Crisis*, edited by Richard B. Freeman and Harry J. Holzer. Chicago: University of Chicago Press, pp. 353–76.
- Galor, Oded and Stelios Michalopoulos. 2012. "Evolution and the Growth Process: Natural Selection of Entrepreneurial Traits." *Journal of Economic Theory*, 147(2): 759–80.
- Gavrilets, Sergey. 1995. "Human Origins and the Transition from Promiscuity to Pair-Bonding." *Proceedings of the National Academy of Science of the USA*, 109(June): 9923–28.
- Ginther, Donna K., and Robert A. Pollak. 2004. "Family Structure and Children's Educational Outcomes: Blended Families, Stylized Facts, and Descriptive Regressions." *Demography*, 41(4): 671–96.
- Goldin, Claudia. 2006. "The Quiet Revolution that Transformed Women's Employment, Education and Family." *American Economic Review Papers and Proceedings*, 96(2): 1–21.
- Gould, Eric D., Omer Moav, and Avi Simhon. 2008. "The Mistery of Monogamy." *American Economic Review*, 98(1): 333–57.
- Grossbard, Amyra. 1976. "An Economic Analysis of Polygyny: The Case of Maiduguri." *Current Anthropology*, 17(4): 701–707.
- Guiso, Luigi, Paola Sapienza, and Luigi Zingales. 2006. "Does Culture Affect Economic Outcomes?" *Journal of Economic Perspectives*, 20(2): 23–48.
- Hamilton, William D. 1964. "The Genetical Evolution of Social Behaviour. I, II." *Journal of Theoretical Biology*, 7(1): 1–52.
- Hamilton, William D. 1967. "Unusual Sex Ratios." *Science*, 156(3774): 477–88.
- Hauk, Esther, and Maria Saez-Martí. 2002. "On the Cultural Transmission of Corruption." *Journal of Economic Theory*, 107(2): 311–35.
- Hawkes, Kristen, Alan R. Rogers, and Eric L. Charnov. 1995. "The Male's Dilemma: Increased Offspring Production is More Paternity to Steal." *Evolutionary Ecology*, 9(6): 662–77.
- Iannaccone, Laurence R. 1998. "Introduction to the Economics of Religion." *Journal of Economic Literature*, 36(3): 1465–95.
- Ingoldsby, Bron B., and Suzanna D. Smith, eds. 2006. *Families in Global and Multicultural Perspective*. Thousand Oaks, CA: Sage Publications.
- Kaplan, Hillard, Kim Hill, Jane Lancaster, and A. Magdalena Hurtado. 2000. "A Theory of Human Life History Evolution: Diet, Intelligence, and Longevity ." *Evolutionary Anthropology*, 9(4): 156–85.
- Knight, Chris. 2008. "Early Human Kinship Was Matrilineal." In *Early Human Kinship: From Sex to Social Reproduction*, edited by Nicholas J. Allen, Hilary Callan, Robin Dunbar, and Wendy James. Oxford: Blackwell, pp. 61–82.
- Kurland, Jeffrey A. 1979. "Paternity, Mother's Brother, and Human Sociality." In *Evolutionary Biology and Human Social Behavior*, edited by Napoleon A. Chagnon and William Irons. North Scituate, MA: Duxbury Press, pp. 145–80.

- Krützen, Michael, Lynne M. Barré, Richard C. Connor, Janet Mann, and William B. Sherwin. 2004. "O Father: Where Art Thou?" – Paternity Assessment in an Open Fission-Fusion Society of Wild Bottlenose Dolphins (*Tursiops* sp.) in Shark Bay, Western Australia." *Molecular Ecology*, 13(7): 1975–90.
- Laitner, John. 1997. "Intergenerational and Interhousehold Economic Links." In *Handbook of Population and Family Economics*, edited by Mark R. Rosenzweig and Oded Stark. Amsterdam: Elsevier Science, pp. 189–238.
- Levine, Nancy, and Walter H. Sangree. 1980. "Asian and African Systems of Polyandry." *Journal of Comparative Family Studies*, 11(3): 385–410.
- Lindbeck, Assar, and Sten Nyberg. 2006. "Raising Children to Work Hard: Altruism, Work Norms, and Social Insurance." *Quarterly Journal of Economics*, 121(4): 1473–503.
- Lott, Dale F. 1991. *Intraspecific Variation in the Social Systems of Wild Vertebrates*. Cambridge: Cambridge University Press.
- Lundberg, Shelly, and Robert A. Pollak. 2007. "The American Family and Family Economics." *Journal of Economic Perspectives*, 21(2): 3–26.
- McCleary, Rachel M., and Robert J. Barro. 2006. "Religion and Economy." *Journal of Economic Perspectives*, 20(2): 49–72.
- McLanahan, Sara, and Gary Sandefur. 1994. *Growing Up with a Single Parent: What Hurts, What Helps*. Cambridge, MA: Harvard University Press.
- Morgan, Lewis H. 1871. *Systems of Consanguinity and Affinity of the Human Family*. Washington, DC: Smithsonian Institute.
- Ofek, Haim. 2001. *Second Nature: Economic Origins of Human Evolution*. Cambridge: Cambridge University Press.
- Poirier, Nicole E., Linda A. Whittingham, and Peter O. Dunn. 2004. "Males Achieve Greater Reproductive Success Through Multiple Broods Than Through Extrapair Mating in House Wrens." *Animal Behaviour*, 67(6): 1109–16.
- Reichard, Ulrich H., and Christophe Boesch. 2003. *Monogamy: Mating Strategies and Partnerships in Birds, Humans and Other Mammals*. Cambridge: Cambridge University Press.
- Robson, Arthur J. 1990. "Efficiency in Evolutionary Games: Darwin, Nash and the Secret Handshake." *Journal of Theoretical Biology*, 144(3): 379–396.
- Robson, Arthur J. 2001. "The Biological Basis of Economic Behavior." *Journal of Economic Literature*, 39(1): 11–33.
- Robson, Arthur J., and Hillard S. Kaplan. 2006. "The Economics of Hunter-Gatherer Societies and the Evolution of Human Characteristics" *Canadian Journal of Economics*, 39(2): 375–98.
- Samuelson, Paul A. 1955. "Diagrammatic Exposition of the Theory of Public Expenditure." *Review of Economics and Statistics*, 37(4): 350–56.
- Saint-Paul, Gilles. 2008. "Genes, Legitimacy and Hypergamy: Another Look at the Economics of Marriage." CEPR Discussion Paper No. 6828, May.
- Siow, Aloysius. "Differential Fecundity, Markets and Gender Roles." *Journal of Political Economy*, 106(2): 334–54.

- Trivers, Robert L. 1972. "Parental Investment and Sexual Selection." In *Sexual Selection and the Descent of Man*, edited by Bernard G. Campbell. Chicago: Aldine, pp. 136–79.
- Weibull, Jörgen W. 1995. *Evolutionary Game Theory*. Cambridge, MA: MIT Press.
- Weiss, Yoram. 1997. "The Formation and Dissolution of Families: Why Marry? Who Marries Whom? And What Happens Upon Divorce." In *Handbook of Population and Family Economics*, edited by Mark R. Rosenzweig and Oded Stark. Amsterdam: Elsevier Science, pp. 81–123.
- Weiss, Yoram, and Robert J. Willis. 1985. "Children as Collective Goods and Divorce Settlements." *Journal of Labor Economics*, 3(3): 268–292.
- Wilson, David S. 2002. *Darwin's Cathedral: Evolution, Religion, and the Nature of Society*. Chicago, IL: University of Chicago Press.
- Wilson, Edward O. 1975. *Sociobiology: The New Synthesis*. Cambridge, MA: Harvard University Press.