Queen's Economics Department Working Paper No. 1180

The Origins of the Institutions of Marriage

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8-2008

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August 13, 2008

Abstract

Standard economic theories of household formation predict the rise of institutionalized polygyny in response to increased resource inequality among men. We propose a theory, within the framework of a matching model of marriage, in which, in some cases, institutionalized monogamy prevails, even when resources are unequally distributed, as a result of agricultural externalities that increase the presence of pair-bonding hormones. Within marriage, hormone levels contribute to the formation of the marital pair bond, the strength of which determines a man's willingness to invest in his wife's children. These pair bonds are reinforced through physical contact between the man and his wife and can be amplified by externalities produced by certain production technologies. Both the presence of additional wives and the absence of these externalities reduce the strength of the marital bond and, where the fitness of a child is increasing in paternal investment, reduce a woman's expected lifetime fertility. Multiple equilibria in terms of the dominant form of marriage (for example, polygyny or monogamy) are possible, if the surplus to a match is a function of reproductive success as well as material income. Using evidence from the Standard Cross Cultural Sample and Murdock's Ethnographic Atlas, we find that agricultural production externalities that affect neurological pair-bonding incentives significantly reduce the tendency to polygyny, even when resource inequality is present.

Keywords: Oxytocin, Vasopressin, Neurohormones, Marriage, Monogamy, Polygamy, Development of Institutions, Family structure

1 Introduction

The formalization of family structure through marriage creates a key economic and social institution for distributing resources and for the production of consumption goods as well as children. In this paper we develop a model in which biological factors, social structures and economic systems jointly determine the dominant form the institution of marriage takes, and provide evidence on its evolution from prehistoric times onward. The structure of the marriage may take many forms. General resource equality and a lack of property ownership, such as existed amongst many hunter-gather societies, promoted (at least serial) monogamy (Marlowe, 2003). Wealth inequality, on the other hand, resulting from a transition to an agricultural society, generates economic conditions that foster individual preferences for polygyny (Becker, 1991) by creating different returns to mate choice in both consumption and genetic survivability, and even if a society as a whole is better served by institutionalized monogamy these individual preferences might lead to institutionalized polygyny. The Neolithic transition - the period that generated settled agrarian communities - should, then, in simple theory be accompanied by institutionalization of polygyny. Historically, however, institutionalized *monogamy* and agricultural development are positively correlated across cultures. We hypothesize that the influence of externally generated biological impacts, in particular changes in the levels and/or effects of the hormones and neurotransmitters oxytocin (OT) and arginine vasopressin (AVP), promoted monogamy in spite of increased resource inequality.

Evidence from anthropology and evolutionary biology suggest that there was a period of evolutionary history long prior to the Neolithic revolution where serial monogamy, a likely function of these neurotransmitters, evolved to improve genetic longevity (Fisher, 2004). Certain agricultural technologies appear to influence these neurotransmitters in humans and other mammals. Chiefly, stimulating milk production in dairy agriculture or the ingesting of certain phytoestrogens like soy, tea, and flax should increase the hormone levels and/or amplify their effects (Hartley et al, 2003; Patisaul et al, 1999; Patisaul et al, 2001; Scallet et al, 2003; Wang et al, 2003; Whitten et al, 2002; Zak et al, 2004; Zak et al, 2005). We hypothesize that in some societies the earlier (Pleistocene era) biological adaptation of monogamy was reinforced after the Neolithic revolution by these environmental externalities so that as marital institutions developed, the choice of marriage system was influenced significantly by the presence (or absence) of these factors.

We develop and test the predictions of a matching model in which the dominant form the institution of marriage takes is a function of both the distribution of productive resources and the production technology which drives the biological incentives. The model predicts that polygyny will be increasing in resource inequality and decreasing in external factors that increase pair bonding hormone levels. We investigate the possible economic and biological impacts on societal choice of marital institution by empirically determining the factors that effect the probability that hunter-gatherer and early agrarian cultures throughout the world adopted monogamous marriage institutions. We consider evidence on 1167 cultures described in Murdock's Ethnographic Atlas (Murdock et al, 2000) and, with greater detail, on 186 cultures described in the atlas's better documented subset, the Standard Cross Cultural Sample (Murdock & White, 2006). We find considerable support for our hypothesis that biological externalities accompanied the choice of production technology in the Neolithic era and appear to have had long run societal impacts on the forms of institutionalized marriage, with subsequent impacts on economic growth and well-being.

2 Love and Marriage

Marriage is the original institution, uniting men and women in genetic reproduction and household production. These potentially symbolic actions and gestures, made at the individual and community level, result in the contractual arrangements that define family and a kinship structure for a society. Marriage is preferred by men to no institutional arrangement as the chances that the children they are helping rear carry their genes improves if the women are "wives" in society's eyes, and penalties for infidelity are imposed. Marriage is also preferred by women if they value genetic continuance and if contractual matching increases the consumption levels of both themselves and their offspring. Both men and women prefer marriage in that they receive benefits to bonding that are independent of consumption and childbearing, what we might call 'love'. Finally marriage is preferred at the societal level if unmarried members must be provided assistance from the collective to reach the subsistence level of consumption. Thus we expect social norms will develop that promote a form of the institution of marriage that best meets these objectives. Its structural form, however, varies across cultures, with long run implications for economic growth and well being (Gould, Moav, & Simhon, 2004; Becker, 1991; Singh, 1988). The continued coexistence of male-dominant variations of marriage, polygyny and monogamy, while other household arrangements, for example polyamory and polyandry, are virtually untried throughout history, highlights the importance of biological underpinnings to the institutional structure (Betzig, 1986). In particular, men are more willing to invest in children when the children are their genetic offspring (Geary, 2000) and under polygyny children may face higher mortality (Strassmann, 1997). Economic considerations feature prominently too; polygyny may be preferable both to rich men and most women if wealth inequality is high (Becker, 1991). Despite this, monogamous marital institutions are highly correlated with prosperous, developed nations and higher investments in human capital and higher inequality (Gould, Moav, and Simhon, 2004; Tertilt, 2005; Lagerlof, 2008).

2.1 An Early History of Marriage

The evolution of sexuality and pair bonding among early humans can be traced out from the work of anthropologists, neurologists and paleontologists. Early mating patterns are differentiated over three periods, each distinguished by a particular method of food accumulation: early foragers; hunter gatherers; and agriculturists. Understanding the evolutionary pressures of these distinct periods assists in delineating the trade-offs between polygamy and monogamy more clearly.

2.1.1 Early foragers: 5 million – 1.8 million B.C.E.

Our earliest ancestors (Australopithicus spp.) most likely lived in a "primal horde" (Coontz 2005). In the primal horde there was no long-term pair bonding; males and females copulated with many partners. All genetic competition took place at the sperm level and males made no specific investment in either their offspring or the females in the group. Food was shared but principally in exchange for sexual favors, not only between males and females but other pairings as well. As these early hominoids were quadpedal and infants were more developed at birth than in the later periods, infant care did not impede a mother's ability to gather the fruits, nuts and insects that largely constituted her diet. Living in among trees made it easy protecting the young who were often raised in group nurseries. Males were neither providers nor protectors making the forming of pairs redundant.

In spite of this promiscuity there is evidence of short-lived monogamy even in this period. Attractions did take place, with pairs of separating from the group not only to engage in coitus but also hugging, kissing, feeding and gazing into each other's eyes. These attractions lasted several days or even weeks (Fisher 1992).

As the climate warmed and the forests receded humans began to move out into the fields. Their diet now consisted of gathered vegetation and scavenged meat left behind by predators. Humans became bipeds (homo habilis) because either it made it possible to use tools more effectively, to carry off meat to a safer location, gather more efficiently or hunting possible. Walking upright, however, tied women to their infants more thoroughly. Children were also harder to protect in the open savannah than they had been in the forests. For men, these risks of the savannahs meant that protecting a harem was likely to be too difficult; monogamy suited. The impetus for monogamy grew as the division of labor in child-rearing increased. It is believed that during this period the neuropeptides oxytocin (primarily female) and vasopressin (primarily male) developed their role in promoting male-female attachment (Fisher, 2004).

2.1.2 Hunter-gatherers: 1.8 million forward

Over time our ancestors transformed from scavengers to hunters and began to acquire tools, skills and language. The development of tools and the ability to hunt big game increased the amount of meat in the hominid (homo erectus) diet. The higher protein diet meant that brains and heads grew; infants were born earlier to accommodate the larger head in the birth canal, and required more care from their mothers (Fisher, 2004). Bepedalism meant that mothers could no longer carry their children on their backs or clinging to their chests. The ability of mothers to collect their own food was diminished, at least for the period they were nursing their babies, or about 4 years. In this period there is evidence of pair bonding as well as the additional drive to temporarily "love addictively", which would have increased survivability as males became both providers and protectors. Relationships began with conception and ended when the child became independent of its parents. Resources would have been spread relatively evenly among the males which suggest that most relationships were monogamous, at least over a short period of time.

2.1.3 Agriculturists: 21,000 B.C.E. and onward

As resources become scarcer, due to greater climate fluctuations, higher population pressures, or other similar shifts, humans sought more energy-intensive food sources. The gathering of cereal grains and other plant foods eventually evolved into early agricultural cultivation (Weiss et al., 2004) and eventually to the domestication of animals. The invention of the plow over 4000 years ago led to a greater division of labor by gender than had been seen in previous periods. Now production required the input of both male and female labor. Agriculture also led to a means to accumulate wealth; both resources and power became more widely dispersed. Despite this redistribution, the evidence does not support a greater movement towards polygamy; in fact the opposite is true, it supports a movement toward long-term stable pair bonding.

2.2 The Science of Love and Bonding

Functional Magnetic Resonance Imaging technology has shown romantic love to be associated with increasing dopamine and norepinephrine levels, and perhaps reduced serotonin levels, all of which activate the nucleus accumbens, prefrontal cortex, and ventral palladium, reward centres of the brain (Fisher, 2004). OT and AVP, and their associated receptors, have been identified as the mechanisms for pair bonding in monogamous mammal species (Young, 1999; Young et al., 1999; Young and Wang, 2004). These reward centres of the brain are also associated with the formation of the OT-AVP pair-bonding attachment or long-term love that can be initiated from dopamine-driven infatuation (Young and Wang, 2004). During the transition from romantic love to attachment, selective increases in certain dopamine receptors (D1 receptors in the nucleus accumbens, shown to prevent pair bond formation in males) may reduce the ability to form new pair-bonds, stabilizing the existing bond and promoting stability of social monogamy (Young and Wang, 2004). OT and AVP levels increase in humans and other mammals through touch, orgasm, massage, and other types of social interaction, including prolonged eye contact. Pair-bonding can be self-reinforcing; oxytocin and vasopressin levels will attach you to your mate, which encourages you to behave towards your mate in a manner which increases your attachment to that mate through higher levels of the hormones (Fisher, 2004). This pair-bond generating mechanism is believed to prevent new pair bonds from forming and as a result solidifies monogamous behaviour (Young and Wang, 2004; Fisher, 2004).

Evidence suggests that this human brain chemistry evolved during the Pleistocene era to promote monogamous pair bonding, an evolutionary change that became a biological drive (Fisher, 2004). Strong pair-bonds were needed to raise an infant in a hunter-gatherer society, where mortality risks were high and specialization of tasks began to promote limited economic dependency (Fisher, 1989). From the Neolithic era forward the established behavioral norms determining family structure became institutionalized (Diamond, 2004).

The link between monogamy and agricultural production occurs when the specific agricultural products initiate a self-reinforcing increase OT levels in humans, bolstering the biological preference for serial monogamy developed in the Pleistocene-era for its value in increasing genetic survival. We hypothesize that both dairy agriculture and the cultivation of certain crops high in phytoestrogens initiate such an increase. Genetic change, in the form of lactose tolerance, has already been attributed to the introduction of dairy agriculture (Check, 2006). Pictorial evidence from around 2000 BCE transmitted information amongst farmers on how gazing into a creature's eyes stimulated oxytocin to promote milk let-down (Rosenstock & Baten, 2006). This, and other tactile human-animal interactions, would also have increased oxytocin levels in the human population in ways that changed social behaviour (Fisher, 2004; Barker et al., 2003).

Recent research also indicates that aerosol delivery of oxytocin can increase trust (Zak et al., 2005; Zak, 2005), reduce social anxiety (Heinrichs et al., 2003), and improve the ability to understand social cues (Domes et al., 2007). In a subset of the cross-cultural data set for which there is evidence on child-rearing (Barry et al., 1976), we find that the need to inculcate trust in children is negatively correlated with the occurrence of milking ($\rho = -.30, n = 138$). In addition, a t-test confirms that the mean level of trust inculcation for milking societies is significantly lower than that of non-milking societies ($t =$

$3.64, n(milk) = 44, n(non - milk) = 94, p = .0002$). We hypothesize that the presence of dairy cattle increased the presence of oxytocin, stimulating human pair bonding in addition to trust.

Consumption of phytoestrogens from flax seed, soy, and teas enhance the effects of oxytocin by increasing the number of oxytocin receptors in the brain and the ability of these receptors to bind the OT (Zak and Fakhar, 2006). Animal studies confirm that soy diets with phytoestrogens change neurological behaviour in areas that are traditionally associated with oxytocin and vasopressin, but studies conflict on how these changes are manifested in terms of social outcomes (Hartley et al, 2003; Scallet et al, 2003; Wang et al., 2003; Whitten et al, 2002; Patisaul et al., 2001; Patisaul et al., 1999). Indeed, while most phytoestrogens do bind to human estrogen receptors, playing an agonistic role in OT effects, some are considered anti-estrogens and are expected to work against OT's socializing effects. Using data for 41 countries, Zak and Fakhar (2006) find an overall significant positive effect of dietary intake of phytoestrogens on trust at the national level, a related social behaviour shown to be increasing in OT (Zak et al, 2004; Zak et al., 2005; Zak, 2005). We hypothesize that increased OT levels from phytoestrogens also reinforced monogamy.

As a further note to the story oxytocin and vasopressin uptake receptors are blocked by stress hormones, particularly adrenaline (Davis et. al, 1998). Thus the uptake of these neuropeptides, and their effectiveness, may have been additionally increased by the transition to agriculture if there was also a reduction in adrenaline, a possibility given the expected change in action from game-hunting to farming.

These biological drives promote temporary responses, so that "marriage" in a state of nature would probably be only of about four years' duration. We argue that externalities affecting biological imperatives worked with economic incentives to support institutions of socially prescribed monogamy. Socially imposed monogamy that evolves institutionally, even if it has biological origins and reinforcement, does not, of course, suggest that men and women will not seek other partners or that men will not sire illegitimate children. It does imply that resources, in particular inheritances, will be distributed differently across generations (MacDonald, 1995; Lagerlof, 2005; Bertocchi, 2006). We leave examination of this latter question for another paper in order to focus on the biological origins of marital structures and their interdependent effects on the distribution of resources within generations.

3 The Model

The standard search and matching framework (Mortensen and Pissarides (1994); Pissarides (1985 and 2001, Ch. 1)) is extended to include heterogenous agents, in terms of wealth, in a market for marriages. In each period every eligible man (defined below) makes an offer of marriage to an unmarried woman. The offer includes a share of family income, which is a function of the wealth of the household, and a promise to contribute to the quality of the children born into the match. This offer to contribute to the quality of children is an increasing function of the expected pair bond between the man and woman, which is in turn a function of the expected number of wives in the household. Finally, the offer is a function of the expected number of children the match will produce. As each man can make only one offer per period, a woman may have to wait several periods to receive an acceptable offer. If her fertility declines over time then the number of children she will expect to have will be a function of the number periods she will have to wait to receive a such an offer. As such, the equilibrium in the marriage market is determined by the lifetime income and fertility, defined over quality and quantity of children, the woman can expect to receive in the marriage relative to her outside option of waiting and marrying in a subsequent period. The solution to the model is the share of men marrying in every period and the number of periods until the market closes and all women are married. The solution with monogamy requires that the share marrying in the first period is one and the market closes after the first period. The solution with polygyny requires that the market lasts multiple periods and, where the number of men and women are equal, some men remain unmarried.

3.1 The Marriage Market

In the first period there is a random draw that matches each man with a woman. The man makes a marriage offer to the woman which includes a promise of future income and a promise to contribute to the quality of children born into the match. The woman rejects or accepts this offer based on the benefits of the match, net of the benefits of an expected future match. If she accepts the offer she becomes married and no longer participates in the marriage market. The man she marries, however, is eligible to return to the market in the next period to look for a second wife. Men whose offers are rejected are eliminated and withdraw from the market. In the second period, there is again a random draw that now matches each eligible man with a woman who remains single. As there may now be unequal numbers of men and women on the market, a woman who refuses her offer in the first period may have to wait several periods to receive a second offer. The market continues until all women are married, at which point the market closes.

There is a large number of men and women, each measured over the unit interval, with infinite multi-period lives and no overlapping generations. All women are ex-ante identical but men vary by the level of resources they control. We assume a discreet uniform distribution of resources such that for male m (where $m \in [0,1]$) his resource share is $r = m\bar{r}$, where $\bar{r}$ is the maximum resources held by one man. Total resources are fixed at $R = \sum_{m=0}^{1} m\bar{r}$.

3.2 The Man's Match Surplus

Total household income in period t, $y(r, w_t)$, is a function of the level of resources (r) of the man and the labor input in period t of w_t wives, and has the usual properties of a production function.[1] If a man is able to make an offer in period t then it must be the case that he already has $w = t - 1$ wives. In that period, the man's offer to the woman will consist of a promise to give her $\lambda(r, w_t)$ of income in every period of her life and a promise to contribute to child quality. We assume that a man offers to invest in his children exactly the amount that he values the children (in this sense his contribution is his shadow price of having children). The present discounted benefit of a successful match for a man making an offer to a wife in period t, net of his contribution to children, is

$$m(r, w_t) = \frac{1}{1-\beta}\left(y(r, w_t) - \sum_{i=1}^{w_t} \lambda(r, i)\right)$$

where β is the subjective discount factor, and the final term is the total income he distributes to his wives.

If he is unsuccessful in period t he will have exactly $t - 1$ wives, is eliminated from future rounds of

[1] $\frac{\partial y(r,w)}{\partial r} > 0$, $\frac{\partial^2 y(r,w)}{\partial r^2} < 0$, $\frac{\partial y(r,w)}{\partial w} > 0$, $\frac{\partial^2 y(r,w)}{\partial w^2} < 0$

the marriage market and will have present discounted benefit

$$b(r, w_{t-1}) = \frac{1}{1-\beta}\left(y(r, w_{t-1}) - \sum_{i=1}^{w_{t-1}} \lambda(r, i)\right).$$

The present discounted surplus of the match from a man making an offer in period t is therefore

$$M(r, w_t, w_{t-1}) = m(r, w_t) - b(r, w_{t-1}). \tag{M}$$

3.3 The Woman's Match Surplus

The match benefit to a woman accepting an offer in period t is

$$w(r, w_t) = \frac{1}{1-\beta}\left[\lambda(r, w_t) + \zeta^t f(\bullet)\right] \tag{1}$$

where ζ^t is a measure of the total number of children she will have if she marries in period t and $f(\bullet)$ (defined below) is the man's offer to contribute to each child's quality.

A woman who rejects her offer in period t chooses to remain unmarried in this period. Her benefit to doing so is

$$s(r, t) = 0 + \beta\left[q_{t+1}E\left[w(r, t+1)\right] + (1 - q_{t+1})\, s(r, t+1)\right],$$

such that she has no income in this period, receives an acceptable offer in the next period with probability q_{t+1}, and remains unmarried in that period with probability $1 - q_{t+1}$.

The total match surplus to the woman receiving an offer in period t is

$$\begin{aligned} W(r, t) &= w(r, w_t) - s(r, t) \\ &= w(r, w_t) - \left[q_{t+1}\beta E\left[w(r, w_{t+1})\right] + \sum_{j=t+2}^{T} \beta^{j-t} \prod_{i=t+1}^{j-1} (1 - q_i)\, q_j E\left[w(r, j)\right]\right] \end{aligned} \tag{2}$$

Where T is the expected total number of periods until all women are matched and the marriage market closes, and the final term is the expected lifetime income of a woman who refuses her offer in this period.

3.4 Child Quality

Child quality will be a function of the level of income that is allocated by the father to the raising of the child. Where

$$f(r, N) = \Lambda(r, N) + O(N, h)$$

is the man's offer to contribute to child quality, the parameter N is the expected total number of wives a man will have. The first term, $\Lambda(r, N)$, is the level of support that a man is willing to give each of his children as a function of his resources and expected number of children.[2] The second term is the level of support he is willing to give each child as a function of his marital bond, $O(N, h)$. We assume that the first effect is strictly increasing in wealth but decreasing in the expected number of wives and the second effect is strictly decreasing in the expected number of wives, for the reasons discussed above; the weaker the marital bond the lower the man's willingness to invest in the care of the children. This marital bond term is also a function of an agricultural production technology, h. Consistent with the evidence, we impose the condition that a production externality strengthens the marital bond if there is only one wife but has a lesser effect otherwise. These conditions imply

$$\left.\frac{\delta O(N, h)}{\delta N}\right|_{N>1} < 0$$
$$\left.\frac{\delta O(N, h)}{\delta N \partial h}\right|_{N>1} > 0.$$

For example, the level of investment per child in a family with two wives relative to the family with only one wife is lower, how much lower will depend on the presence of the pair bonding externality.

3.5 Household Bargaining

The total present discounted value of the match surplus (S) is split according the Nash bargaining solution where ϕ is the measure of the woman's bargaining power. Households solve the problem

$$\max_{W(r,t), M(r,t)} W(r, w_t)^{\phi} M(r, w_t)^{1-\phi}$$

subject to the constraint

$$S = M(r, w_t) + W(r, w_t).$$

The solution to which is

$$M(r, w_t) = (1 - \phi) S$$

$$W(r, w_t) = \phi S,$$

[2]Where his expected number of children is a function of his expected number of wives and is exactly $\sum_{i=1}^{N} \zeta^i$.

where the level of M and W are determined by the levels of $\lambda(r, w_t)$ and $f(r, N)$ and as such are a function of the resources of the man, the number of wives he has at the beginning of the period, and the number of wives he will have in total at the end of the marriage market.

3.6 Probability of a Match

In every period, and for every successful man, the marriage offer is a function of the woman's outside option (which is identical for all women). The expected value of this outside option is a function of the expected distribution of resources of the men making offers in future time periods and the probability of receiving an offer in each of the following periods. In turn the distribution of resources in any one period is a function of the poorest man to marry in the previous period, which we define in period t as being m^*_{t-1}.

The probability a woman receives a successful offer in period two, for example, is a function of the number of women who remain unmarried after period one and the number of men that make successful offers in period two, such that in period two the probability of receiving a successful offer is

$$q_2 = \frac{1 - m^*_2}{m^*_1}.$$

In subsequent periods, the probability of receiving a successful offer is:

$$q_t = \frac{1 - m^*_t}{1 - \sum_{i=1}^{t-1}(1 - m^*_i)}. \tag{3}$$

4 Marriage Market Equilibrium

We turn now to solving for the optimal offers for marriage and the degree of polygyny in a society as a function of the resource distribution and the contribution to child quality. As previously noted, the degree of polygyny is a function of the share of men who marry in each period of the market $(1 - m^*_t)$ and the expected number of periods until the marriage market closes, T.[3]

[3]Note that T denotes both the expected number of periods until the market closes and the expected maximum number of wives that any one man will have.

4.1 Marriage contract offers in each period

Offers of marriage are a function of the level of resources of the man making the offer. In order for the match surplus of a man to be non-negative, without which he would prefer to remain single, it must be that for a man with resources $r = m\bar{r}$

$$\lambda\left(m\bar{r},t\right) \leq \left.\frac{\delta y\left(m\bar{r},w\right)}{\delta w}\right|_{w=1},$$

that is, the offer of income to the wife will not exceed her marginal product. The woman's match surplus will be positive if the offer is such that the benefit to the match is greater than the expected outside option of rejecting the offer and waiting for a future offer, or

$$w(r,t) \geq q_{t+1}\beta E\left[w(r,t+1)\right] + \sum_{j=t+2}^{T} \beta^{j-t} \prod_{i=t+1}^{j-1} \left(1-q_i\right) q_j E\left[w(r,j)\right].$$

Combining this condition with the definition of the woman's match surplus from (1) we have

$$\lambda\left(r,t\right)+\zeta^{t} f\left(r,N\right) \geq q_{t+1}\beta E\left[\lambda\left(r,t+1\right)+\zeta^{t+1} f\left(r,N\right)\right]+\sum_{j=t+2}^{T} \beta^{j-t} \prod_{i=t+1}^{j-1} \left(1-q_i\right) q_j E\left[\lambda\left(r,j\right)+\zeta^{j} f\left(r,N\right)\right]$$

as the condition on a woman's match surplus, with a man with resources r and $t-1$ wives, as being positive. Defining the expected outside option as $\Gamma\left(T\right)$, and since $\Gamma\left(T\right)$ is identical for all women, the poorest man to have an offer accepted in this period, that is, the man with resources $r = m_t^* \bar{r}$, will have a match surplus equal to zero. The offer made to wife number t of such a man will be exactly equal to the value of the outside option of refusing the offer and waiting to marry in a subsequent period,

$$\lambda\left(m_t^*\bar{r},t\right) + \zeta^{t} f\left(\bullet\right) = \Gamma\left(T\right) \tag{4}$$

which implies that the woman receives an offer of income exactly equal to her marginal product;

$$\lambda\left(m_t^*\bar{r},t\right) = \left.\frac{\delta y\left(m_t^*\bar{r},w\right)}{\delta w}\right|_{w=t} \tag{5}$$

and he offers to contribute a total of $\zeta^{t} f\left(m_t^*\bar{r}, N=t\right)$ to support their children. Offers below this threshold will be rejected and these men will leave the market.

The solution to the Nash bargaining problem, with the value of a woman's outside option now represented by the wealth level of the poorest man to marry at t, suggests that all other offers are a weighted average of the woman's own marginal product in that match and the offer made by the poorest man,

$$\lambda(r,t) + \zeta^t f(r,N) = \phi\left(\left.\frac{\delta y(r,w)}{\delta w}\right|_{w=t} + \zeta^t f(r,N)\right) + (1-\phi)\left(\left.\frac{\delta y(m_t^*\bar{r},w)}{\delta w}\right|_{w=t} + \zeta^t f(m_t^*\bar{r},t)\right), \quad (6)$$

where the weights are determined by the woman's bargaining position. The expected offer in period t is therefore:

$$E\left[\lambda(r,t) + \zeta^t f(r,N)\right] = \phi\left(\left.\frac{\delta y(E[r],w)}{\delta w}\right|_{w=t} + \zeta^t f(E[r],N)\right) + (1-\phi)\left(\left.\frac{\delta y(m_t^*\bar{r},w)}{\delta w}\right|_{w=t} + \zeta^t f(m_t^*\bar{r},t)\right) \quad (7)$$

and men with resources $r > m_t^*\bar{r}$ will always have a positive match benefit as long as

$$\left.\frac{\delta y(r,w)}{\delta w}\right|_{w=t} + \zeta^t f(r,N \geq t) > \left.\frac{\delta y(m_t^* r,w)}{\delta w}\right|_{w=t} + \zeta^t f(m_t^*\bar{r},N=t).$$

This implies that there will always be a positive surplus to a match if having more resources increases the investment in children by more than the weaker marital bond reduces it. That is, the sufficient condition is $|f_N(\bullet)| \leq f_r(\bullet)$. If the anticipated marginal product of the woman receiving a successful offer is sufficiently greater than the marginal product of the woman marrying the poorest man then this condition is no longer necessary and the match benefit will be positive for all men with resources $r > m_t^*\bar{r}$.[4]

4.2 Degree of Polygyny

The degree of polygyny is fully described by the series $\{m_1^*, ..., m_T^*\}$ and T itself, which is endogenous. In the final period of the market it must necessarily be the case that $q_T = 1$ which imposes the condition from (3) that

$$m_T^*(T) = \sum_{i=1}^{T-1}(1 - m_i^*(T)); \quad (8)$$

the number of men to marry in period T must be equal to the number of women to remain unmarried in that period. This condition, combined with the condition that in every period the poorest man to marry must offer exactly the expected value of a woman's outside option (the expected value of future offers), is sufficient to fully determine the degree of polygyny. Conditions (4) and (5) imply that in period t that

$$\Gamma_t(T) = \left.\frac{\delta y(m_t^*(T)\bar{r},w)}{\delta w}\right|_{w=t} + \zeta^t f(m_t^*(T)\bar{r},t). \quad (9)$$

[4] Note that for men with wealth levels close to the poorest man to marry in period t their expected number of wives, N, will be equal to t as long as $r < m_{t+1}^*\bar{r}$, they are poorer than the poorest man to marry in the next period. In that case their match benefit will always be positive and for those men $N = t$.

Note now that the determination of the poorest man to marry in the first period, m_1^*, is necessarily a function of number of periods the market is expected to last, such that we use the notation $m_1^*(T)$ to denote that the wealth level of the poorest man to marry in the first period is a function of T. If T were known, the solution to this problem would be found by solving T equations, like the one above, one for each period subject to the condition in (8), so that all women must be married at the end of the final period T.

For example consider the case in which the equilibrium number of periods of the market is $T = 1$ (the case with monogamy). That solution is fully described by $m_1^*(1) = 0$; all men and women will marry in the first period. Alternatively, if in equilibrium the market lasts $T = 2$ periods, then the condition in (8) implies that the number of women who remain single in the first period is equal to the number of men who marry in the second, or $m_1^*(2) = 1 - m_2^*(2)$. In that case $m_1^*(2)$ is determined by the solution to the equation;[5]

$$\Gamma_1(2) = \left.\frac{\delta y\left(m_1^*(2)\,\bar{r}, w\right)}{\delta w}\right|_{w=1} + \zeta f\left(m_1^*(2)\,\bar{r}, 1\right). \tag{10}$$

Likewise for $T = 3$ then $m_1^*(3) = (1 - m_2^*(3)) + (1 - m_3^*(3))$, and there are two equations to be solved simultaneously:

$$\begin{aligned}
\Gamma_1(3) &= \left.\frac{\delta y\left(m_1^*(3)\,\bar{r}, w\right)}{\delta w}\right|_{w=1} + \zeta^1 f\left(m_1^*(3)\,\bar{r}, 1\right) \\
\Gamma_2(3) &= \left.\frac{\delta y\left(m_2^*(3)\,\bar{r}, w\right)}{\delta w}\right|_{w=2} + \zeta^2 f\left(m_2^*(3)\,\bar{r}, 2\right).
\end{aligned} \tag{11}$$

The solution to the problem is therefore found by solving T equations for T unknowns, $m_1^*(T) \ldots m_T^*(T)$, and for that T itself which provides the optimal lifetime benefit for individuals within this society.

Fortunately, the solution is fairly straightforward. There is a unique female-male pair in the first period in which a woman is matched with a man with exactly $m_1^*(1)\,\bar{r}$ of wealth, the minimum level of wealth of a man with a successful match in that period, with the expected number of periods until the market closes equal to $T = 1$. This woman will only accept his offer if the expected lifetime income of marrying the poorest man in this period is no less than the expected value of lifetime income of marrying in the

[5] Where $\Gamma_1(2) = \beta\left(\phi\left(\left.\frac{\delta y(E(r), w)}{\delta w}\right|_{w=2} + \zeta^2\left(E\left[\Lambda(r, 2)\right] + O(2)\right)\right) + (1-\phi)\left(\left.\frac{\delta y\left(m_2^*(2)\,\bar{r}, w\right)}{\delta w}\right|_{w=2} + \zeta^2\left(\Lambda\left(m_2^*(2)\, r, 2\right) + O(2)\right)\right)\right)$

next period, with $T = 2$. This implies that she will accept the offer only if

$$\left.\frac{\delta y\left(m_1^*\left(1\right)\bar{r},w\right)}{\delta w}\right|_{w=1}+\zeta\left(m_1^*\left(1\right)\bar{r},1\right)\geq\Gamma_1\left(2\right).$$

The level of wealth of the poorest man to match in a market with exactly $T = 2$ periods, however, is determined by setting that man's offer exactly equal to the woman's expected benefit of rejecting his offer, or

$$\left.\frac{\delta y\left(m_1^*\left(2\right)\bar{r},w\right)}{\delta w}\right|_{w=1}+\zeta\left(m_1^*\left(2\right)\bar{r},1\right)=\Gamma_1\left(2\right)$$

as in equation (4).[6] The solution with $T = 2$ is only preferred to the solution with $T = 1$ if

$$\left.\frac{\delta y\left(m_1^*\left(1\right)\bar{r},w\right)}{\delta w}\right|_{w=1}+\zeta f\left(m_1^*\left(1\right)\bar{r},1\right)<\left.\frac{\delta y\left(m_1^*\left(2\right)\bar{r},w\right)}{\delta w}\right|_{w=1}+\zeta f\left(m_1^*\left(2\right)\bar{r},1\right)$$

As both the marginal product of female labour and the investment in child quality are increasing in wealth, the condition is simply

$$m_1^*\left(1\right)>m_1^*\left(2\right).$$

This implies that the condition on monogamy, where $m_1^*\left(1\right) = 0$, necessarily, is $m_1^*\left(T\right) < 0$ for all possible $T \in [2, \infty]$. This implies further that for any period t, the condition that $t = T$ is the equilibrium outcome is $m_1^*\left(t\right) > m_1^*\left(T\right)$ for all possible $T \in [1, t]$ and $m_1^*\left(t\right) > m_1^*\left(T\right)$ for all possible $T \in [t + 1, \infty]$.

5 Production Technology and the Marriage Market

For illustrative purposes let $\Lambda\left(r, N\right) = 0$, so that the investment in children is solely a function of the marital bond ($f = O(N)$). The condition in (10) with $T = 2$, and substituting in from (7) and (8), rearranged, is

$$\beta E\left[\lambda\left(\left(1-m_1^*\left(2\right)\right)\bar{r},2\right)\right]-\lambda\left(m_1^*\left(2\right)\bar{r},1\right)=\zeta O\left(1,h\right)-\beta\zeta^2 O\left(2,h\right) \tag{12}$$

with

$$E\left[\lambda\left(\left(1-m_1^*\left(2\right)\right)\bar{r},w\right)\right]=\phi\left.\frac{\delta y\left(\left(1-\frac{m_1^*(2)}{2}\right)\bar{r},w\right)}{\delta w}\right|_{w=2}+\left(1-\phi\right)\left.\frac{\delta y\left(\left(1-m_1^*\left(2\right)\right)\bar{r},w\right)}{\delta w}\right|_{w=2}$$

[6] Note that both of these women, the one who marries the poorest man to marry in a $T = 1$ equilibrium and the one who marries the poorest man to marry in a $T = 2$ equilibrium, will both be the only wife. The poorest man to marry in the first period will not be able to marry in the second as his match benefit is already zero with his first marriage.

The LHS of equation (12) is the expected surplus in terms of income of waiting to be a second wife in period two in a market that will last two periods. This is decreasing in $m_1^*(2)$ for all $m_1^*(2) > 0$; the richer the poorest man to marry in the first period is, the smaller the match surplus in waiting to be the second wife. The RHS is equal to the surplus in terms of child quality of being the only wife of the poorest man to marry in period one in a market that will last two periods. The level of resources of the poorest man to marry conditional on $T = 2$ occurs when the surplus in terms of income to waiting is equal to the surplus in terms of total child quality to not waiting (and accepting the offer in the first period). Plotting both sides of equation (12) separately, with the expected surplus to marrying in the second period on the vertical axis, Figure I illustrates a determination of $m_1^*(2)$ in which the equilibrium with $T = 2$ is preferred to that with $T = 1$, that is $m_1^*(2) > m_1^*(1)\,(= 0)$.

5.1 Hunter Gatherer Production Technology

In the hunter-gatherer society the defining quality is that resources are equally distributed among men. In this case, there is a negative surplus in terms of income to rejecting the first offer and waiting to the next period. All offers are accepted in the first period, $m_1^*(1) = 0$. $T = 1$, monogamy ensues, and pair bonds are immaterial in terms of incentive to marry. Figure II below illustrates this case.

5.2 Agriculture Production Technology

Consider two possible cases in the agricultural society. In the first case the specific production technology used does little to enhance the pair bonding beyond that which is evolutionarily determined; that is the level of bonding that developed in the Pleistocene era in response to the increased survivability of the children of monogamous marriages. In the second case the evolutionarily determined bond is enhanced by the agricultural technology. Figure III illustrates both these cases with the surplus to child investment in the second case, with the pair bonding enhancing technology, labeled ‘Child Quality (M)’. There is a natural tendency to polygyny in the case with skewed resources, even when child quality matters. This tendency is mitigated, however, by the reduction in investment in child quality when marital bonds are enhanced by the technology used. If the increase in the surplus to being the only wife in the first period in terms of child quality is sufficient, there will be no solution in which $m_1^*(2) > 0$, and even in the presence of skewed resources monogamy is preferred.

In either case, we note that reduction in the bargaining power of women will reduce the incidence of polygyny. Figure IV illustrates such a case. A reduction in the female bargaining power (ϕ) reduces the incidence of polygyny by reducing the income surplus at every level of $m_1^*(2)$ by decreasing the expected offer in the next period. This implies that if society can impose the level of female bargaining power, the social planner can chose the level of ϕ to achieve an optimum. This also implies that the presence of a hormone externality might reduce the tendency to decrease female bargaining power, if society perceives monogamy to be socially optimal, as the effect of skewed resources is already mitigated by this effect.

6 Empirical Support of the Model

6.1 Data and Variables

We empirically investigate the probability of prescribed monogamy as the dependent variable in a standard logistic regression using the Standard Cross Cultural Sample (SCCS) as collected electronically from World Cultures: The Journal of Cross-Cultural and Comparative Research. The data set contains ethnographic data on 186 pre-industrial cultures around the world. These data have been coded according to the standard, vetted definitions widely used by anthropologists and other researchers as new researchers use the sample, originally published by Murdock and White in Ethnology in 1969 (Murdock & White, 2006). The SCCS was created in order to reduce problems of collinearity among variables in Murdock's Ethnographic Atlas ($n = 1167$) and to allow more in depth analysis for better-studied communities.

The SCCS has several different variables that identify family structure and marital institutions. White (1988) attempts to clarify the differences and provide greater context. We use prescribed monogamy (as coded in v860) to generate a binary dependent variable, with monogamous societies equal to 1. We choose this definition because it codes the cultural rules underlying the marital institutions. Monogamy is prescribed in the sense that concubines or mistresses, and their children, if any, do not inherit intestate. Other reasonable choices, such as whether men in societies are observed as having more than one wife, generally have less complete data ($n = 145$, for example). Measures of monogamy in practice are in any case more difficult to verify, so we choose the prescription of monogamy as an indicator of the goals of the society, reflecting their biological and economic motivations jointly. In the larger sample of the ethnographic atlas, no distinction is made between 'monogamous' and prescribed monogamy. We are the first to test that production technologies and biological impeti for monogamy may be endogenous, leading to the societal prescription of monogamy.[7]

We also use a larger subset of the full atlas ($n = 1040$) to corroborate our hypothesis on the broader scale in spite of the collinearity problems. We do this to compensate for the fact that Africa has no communities with prescribed monogamy in the SCCS. Figure V maps communities and the primary form of their marital institutions, as well as whether or not the societies engage in dairy agriculture. Societies in green match our theory; they are either milking communities with monogamy, or non-milking societies with polygyny. While we do not have direct data on whether societies consumed high levels of phytoestrogens or not, the monogamous, non milking societies (red squares) do appear to be spatially correlated in locations where phytoestrogens may have entered the diet directly through soy, tea, or flax consumption, particularly Asia.

Many of the polygamous, milking societies in Africa overlap or are close to Tsetse fly habitat and other environmental stressors that reduce cattle viability, so that milking may not have a long local history for some of these societies, a hypothesis further corroborated by the high levels of lactose intolerance among many present day Africans and African-Americans. In Eastern Africa, where lactose tolerance is high, confirming a longer history of dairy agriculture, the genetic mutations for this tolerance evolved differently than those in Europe (Tishkoff et al, 2007). It is possible that the evolutionary history of the pair-bonding benefits are different as well.

Furthermore, differences in milking methods may not have instigated biological reinforcement of pair-bonding hormones greatly in some communities. Societies that used prolonged eye contact to increase

[7] Others have used these datasets to investigate social monogamy as a function of female contributions to subsistence, excess male mortality in war, and pathogen stress (Sanderson, 2001; White, 1988; Ember et al., 2007), and Quinlan and Quinlan (2007) use a subset of the data to investigate the "stability of pair-bonds" by examining divorce correlates.

oxytocin levels in the cattle to facilitate milk let-down (Rosenstock and Baten, 2006) would have experienced a more direct impact on human pair bonds, since this eye contact primes the neurotransmitters to act (Morhenn et al, 2008). Other methods for stimulating milk let down, prevalent in pastoral Africa in the 19th and 20th centuries (Mourant and Zeuner, 1963), increased oxytocin levels primarily through stimulating vaginal contractions in the cattle and may not have had as direct an influence on the human hormonal systems.

Alternatively, the significant returns to polygyny in pastoral East Africa may simply outweigh any hormonal benefits. The Standard Cross-Cultural Sample includes data on the roles of bride and groom choice in marriage partner for a subset of the cultures. There is no statistically significant relationship between the ability to choose one's mate and prescribed monogamy. The need for the bride's consent does not differ when there is prescribed monogamy from when there is not ($t = .83, \rho = .40, n = 57$), nor does the need for the groom's consent ($t = .26, \rho = .79, n = 54$). The level of say that a bride or groom has in creating the match also does not vary statistically with prescribed monogamy. In societies without monogamy, there is actually slightly more opportunity for the bride and groom to either choose or have the right to refuse matches, though the difference from those societies without monogamy is not statistically significant. For example, in none of the twelve cases where the woman has full autonomy in spousal determination is there prescribed monogamy ($n = 151$). Of the 46 cases where the man has full autonomy in spousal determination, monogamy is statistically significantly lower ($t = 1.71, \rho = .09, n = 148$).

We focus on prescribed monogamy because we do not expect the biological impacts to entirely preclude polygamy or extramarital sexual relations, rather we anticipate that societies will institutionalize the idealized social norm, which is influenced by the biological conditions. The societies in the sample for Africa, however, do not include any cases of prescribed monogamy. We therefore present the results both with and without the inclusion of Africa.

Quinlan and Quinlan (2007) suggest that high degrees of polygyny are correlated with low levels of divorce and thus signify stability of pair-bonds. Upon examination of the same data, we find the opposite for the subset of Africa included, where the correlation between common divorce and degree of polygyny is .18 ($n = 11$; for all communities with available data $\rho = .04, n = 85$). Separately, we find that for a sub-sample of the dataset where a Guttman scale indexes polygamy by the amount of co-wife autonomy that the correlation between this autonomy and milking is positive ($\rho = 0.25, n = 177$). This fits our model as it allows that co-wives may need more compensation for polygamy where pair bonds are expected to be stronger.

Explanatory variables used in the regression include measures of production technology, wealth, division of labour, and societal structure, as suggested by our hypothesis and previous research outlined above. Sex-ratio imbalances, certainly a factor in polygamy, are not sufficiently documented in either dataset and cannot be included.

To capture the effects of various production technologies, we include the level of dependence on hunting and agriculture.[8] We expect that increased dependence on hunting should decrease the likelihood of prescribed monogamy, while increased dependence on agriculture has an uncertain effect. If the agricultural landscape increases oxytocin levels or the brain's oxytocin receptors, through milking or soy or oilseed production and consumption, then agriculture should be correlated with monogamy. If not, it should decrease the probability of monogamy as it allows for wealth accumulation. Thus we include whether animals are milked regularly to capture human-animal interactions that would increase oxytocin levels and promote pair bonds. The level of fixedness of the residence (from 1-5) is included as a measure of wealth accumulation. In the complete ethnographic atlas data, fixity of residence is replaced with a similar ranking of settlement patterns (from 1-7).

To identify wealth, we control for societies that were able to store surplus food as well as the fixity of residence (described above) and population density. We would expect these variables to negatively influence the probability that the society has prescribed monogamy through the wealth effect.

Class distinctions indicate social stratification that should enable polygamy similarly to physical wealth. We include a ranked measure of class stratification, from 1-5, where 1 indicates no class stratification and 5 represents complex stratification.

[8] The levels range from 0-9, with 0 being less than 5%, 1 being 6-15%, 2-8 increasing by 10%, and 9 including dependence levels over 85%.

Intergenerational wealth is perhaps fostered and preserved by prescribed monogamy. Thus monogamy may be expected to occur more frequently if there exist inheritance rules for land, though inequal distribution of this land would favor polygamy. We include the existence of inheritable property rights for land to control for this possibility.

As mentioned, the data set has no direct evidence on soy or oilseed crops. Phytoestrogen consumption increases receptors for oxytocin and vasopressin in the brain, amplifying their effects (Zak, Kurzban and Matzner, 2004; Zak, 2007) and flax and soy have several thousand times higher levels of phytoestrogens than other crops; with flax having about 3 times more than most soy uses (Thompson et al, 2006). Flax cultivation is ancient in Europe and the Near East, though much of this cultivation is for producing linen rather than food. Soy cultivation is ancient and limited to Asia until the end of the 19th century. While soy may have been cultivated as many as 4000 years ago in Northern China and Inner Mongolia, and was certainly a staple part of the diet from 1000 BCE forward, it did not reach the west until the late 1800s and has only recently become a food source there. Thus geography may instrument for phytoestrogen consumption sufficiently for our analysis of long run institutional choice. Figure V provides support for the hypothesis that monogamy in Asia has non-dairy agriculture, yet region-specific, origins as well. We use a regional indicator for Asia, or East Eurasia in the full ethnographic atlas, to see if likely soy cultivation affected the probability of monogamy, relative to the rest of the world. We expect a positive influence on the probability of monogamy, though such a result may of course reflect cultural factors other than simply diet.

Finally, we include the female contribution to subsistence. Higher contributions by wives to family consumption have been shown to increase the probability of polygyny (Singh, 1988). We use an average of three studies' calculations that ranges from 0 to 80 percent contribution (Divale, 2004). In the complete ethnographic atlas data, this variable is replaced by an indicator of whether or not women contribute at least 50% of household agricultural production.

6.2 Empirical Results

Table 1 shows the results of the logistic regressions. We use three samples: the full SCCS data (with one lost observation from incomplete information on female contribution to subsistence), the SCCS data excluding Africa, which has no cases of prescribed monogamy, and the Ethnographic Atlas ($n = 1040$) due to missing observations on class distinctions). For each sample, the coefficients (with their standard errors below) are in the first column, and for interpretability, the log odds ratio is shown in the second column. Odds ratios greater than one indicate the explanatory variable contributes to explaining monogamy, because the odds of the dependent variable being one are that many times greater, while coefficients less than one indicate the explanatory variable contributes to explaining the absence of monogamy. Thus, milking activities increase the odds of monogamy 3.32 times over no milking for the SCCS societies, 4.58 times over no milking for the SCCS societies excluding Africa, and 1.56 times for the Ethnographic Atlas, holding constant the other explanatory variables.

Most of the variables have the expected directional impact in all regressions. Milking activities, inheritable land, and agricultural dependence all significantly increase the probability of institutionalized monogamy ($\alpha = 0.1$). Milking activities increase the probability of monogamy 1.56 to 4.58 times above chance, depending on the specification. This is less than the positive impact of inheritable land, but more than any other explanatory variable other than the Asian indicator variable. Asian communities also increase the probability of monogamy as compared to the rest of the world by 8.4-10.15 times in the SCCS data; the full ethnographic atlas may contain more diverse societies as the variable is not significant at $\alpha = 0.1$. African societies have significantly less incidence of monogamy in the Ethnographic Atlas data, as one would expect since there are no cases of prescribed monogamy in Africa in the SCCS sample.

Population density, fixity of residence, and female contribution to subsistence all significantly reduce the probability of prescribed monogamy in the full SCCS data but not when eliminating African societies or in the Ethnographic Atlas, while storable food surpluses and class distinctions do not have any significant effect under any specification. Thus the greater social structure seems less important than household level activities and net benefits.

These findings corroborate our hypothesis that biological externalities accompanied the choice of production technology in the Neolithic era and appear to have had long run societal impacts on the forms of institutionalized marriage, with subsequent impacts on economic growth and well-being.

6.3 Discussion and Conclusions

Throughout the evolution of humanity, two basic structures of familial organization have competed: polygamy (mainly polygyny) and monogamy. Economies in which resources are evenly distributed tend to lead to monogamy as men compete equally for wives. If an economy transitions to one in which resources are distributed unequally, however, and storage of wealth becomes viable, the joint utility at the family level for consumption and assurance of gene continuance asserts polygamy as pareto-superior strategy. From the male's perspective more wives will provide more opportunities for genetic continuation. Women also stand to gain in polygamous systems when resources or skills are unequally distributed because it may be more advantageous to be the second or third wife of a rich or powerful man than the only wife of a poor man. When women contribute significantly to the family consumption levels, men are more capable of maintaining multiple wives and polygamy itself contributes to the imbalance in the income distribution. Women also may have greater impetus to participate in polygyny if they contribute significantly to family support since they can share the burden (Marlowe, 2003). Thus, we expect a rise in polygyny to be correlated with increases in inequality (Becker, 1991; Kanazawa and Still, 1999; Sanderson, 2001; Gould, Moav and Simhon, 2004). Pair bonds, however, may temper this increase in polygyny.

Ceteris paribus, the evolution of ancient man from hunter-gather to agriculturalist should have increased polygyny. With agriculture came greater impetus to define and protect private property, the ability to store wealth and an eventual reallocation of resources to a more unequal distribution (Pryor, 2005). This tendency toward wealth inequality is represented in our data: societies that have more rich, more poor, and more dispossessed individuals are more likely to be agricultural.[9] Instead of leading to polygynous marriage institutions, however, in many societies monogamous marriage emerged. We argue

[9] The correlation between the number of rich people and agricultural dependence is .15 ($n = 98$) ,the correlation between the number of poor people and agricultural dependence is .15 ($n = 88$) ,and the correlation between the number of dispossed people and agricultural dependence is .12 ($n = 88$) ,signifying greater wealth dispersion in agricultural communities.

that the transitions to some forms of agriculture were accompanied by an increase in levels and/or effects of the neuropeptides oxytocin (OT) and arginine vasopressin (AVP) that promoted the institutionalization of biologically reinforced monogamy. OT and AVP are present and have a wide variation of roles in all mammalian systems. OT is most well known for its role in promoting parturition (labor) and lactation, but it plays many other roles, including regulation of many social behaviors and in particular male-female pair-bonds and mother-child bonds (Young and Wang, 2004). OT's role in lactation has been indirectly understood and utilized since the beginnings of dairy agriculture (Mourant and Zeuner, 1963; Rosenstock and Baten, 2006) and we link releases of OT in dairy cows to increases in pair-bonding and monogamy.

We link the biological imperative to mate with the institutional evolution of marriage. We argue that monogamy is not a new phenomenon, nor is it inevitably linked to resource equality. A countervailing force to the economic drive toward a woman marrying the wealthiest man, regardless of the number of wives he already has, is hormonal benefits that come from pair bonding and children. These hormonal benefits are linked to particular types of agricultural production, in particular dairy production and soy, tea, and flax crops, as well as lower levels of stress-related adrenaline. These connections lead us to believe that the transition to these types of agriculture has a different expected impact on marital institutions than simple resource inequality and accompanying well-defined property rights would; we expect more monogamy.

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Table I

	SCCS		SCCS, Excl. Africa		Ethnographic Atlas	
Prescribed Monogamy	Coefficient	Odds ratio	Coefficient	Odds Ratio	Coefficient	Odds Ratio
Milking Activities	1.20 (0.66)	3.32*	1.52 (0.72)	4.58**	0.44 (0.24)	1.56*
Inheritable land	1.69 (0.90)	5.44*	1.77 (0.91)	5.87*		
Surplus stored food	-0.06 (0.68)	0.94	-0.15 (0.69)	0.86		
Class distinctions	-0.53 (0.74)	0.59	-0.75 (0.84)	0.47	-0.02 (0.07)	0.98
Population density	-0.49 (0.25)	0.61*	-0.41 (0.25)	0.66*		
Fixity of residence	-0.52 (0.28)	0.59*	-0.45 (0.28)	0.64		
Settlement Intensity					0.02 (0.06)	1.02
Hunting dependence	-0.56 (0.37)	0.57	-0.45 (0.37)	0.64	-0.15 (0.10)	0.86
Agricultural dependence	0.37 (0.17)	1.45**	0.34 (0.17)	1.41**	0.16 (0.06)	1.17**
Female contribution to subsistence	-0.03 (0.02)	0.97*	-0.02 (0.02)	0.98		
Female contribution to agriculture > 50%					-0.08 (0.21)	0.93
Asia	2.31 (0.65)	10.11***	2.15 (0.66)	8.57***		
E. Eurasia					-0.43 (0.28)	0.65
Africa					-3.86* (0.60)	0.02
Constant	-0.19 (0.65)		-0.85 (1.79)		-1.83 (0.43)	
Log Likelihood	-53.41		-50.70		-360.18	
LR statistic	39.71		36.27		155.4	
Probability LR>X2	0		0.00		0	
Pseudo-R2	0.27		0.26		0.18	
Number of Observations	185		157		1040	

Figure I

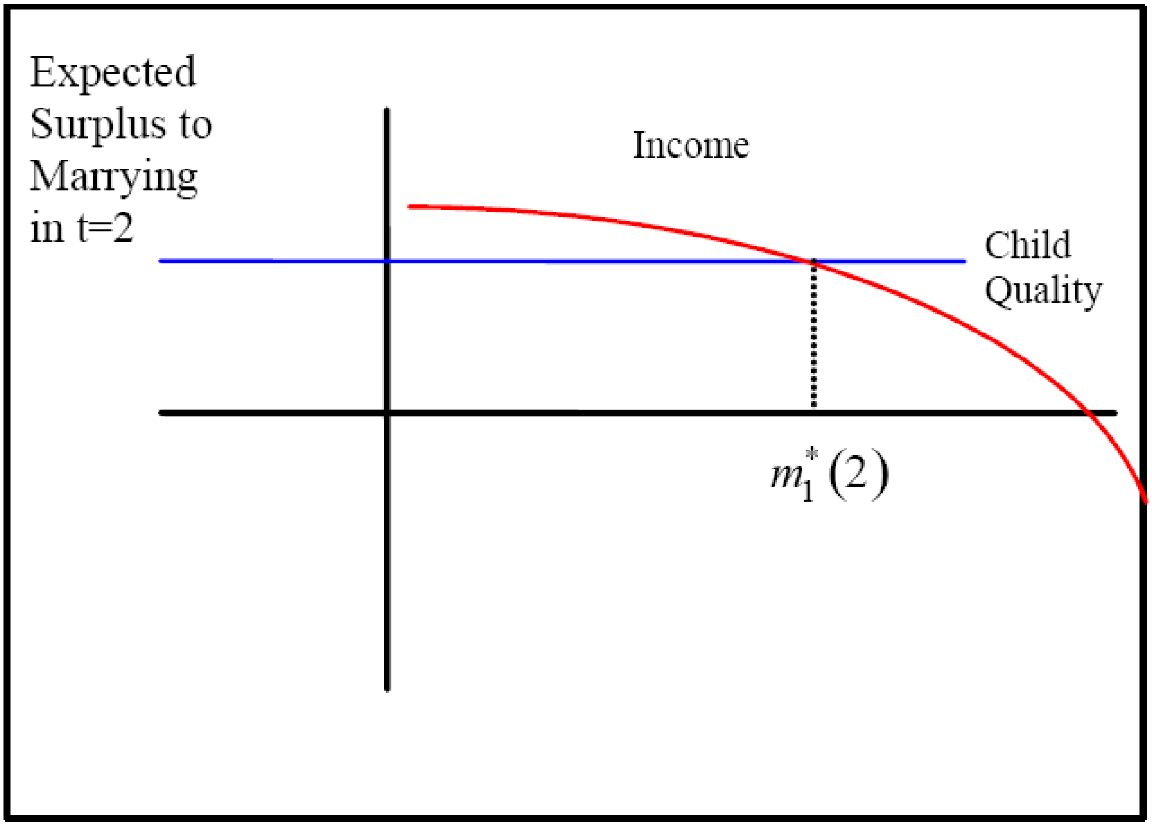


Illustration of an equilibrium in which the decision of some women to reject their offers in the first period is a function of both the surplus to income and the surplus in terms of child quality relative to case in which all women marry in the first period. The x-axis measures the share of men marrying in the first period which is a function of the number of periods until the market closes (T).

Figure II

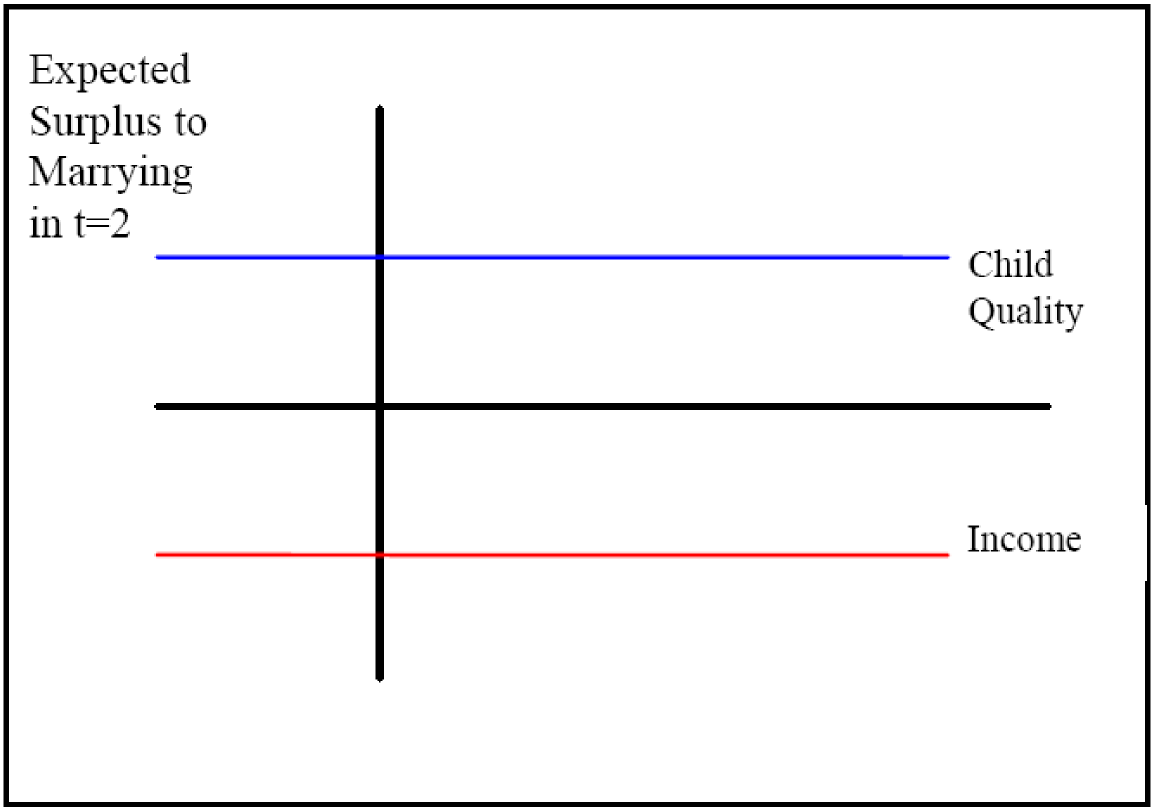


Illustration of an equilibrium in the hunter gatherer case when resources are evenly distributed. In this case all women accept their offers in the first period and monogamy is the norm.

Figure III

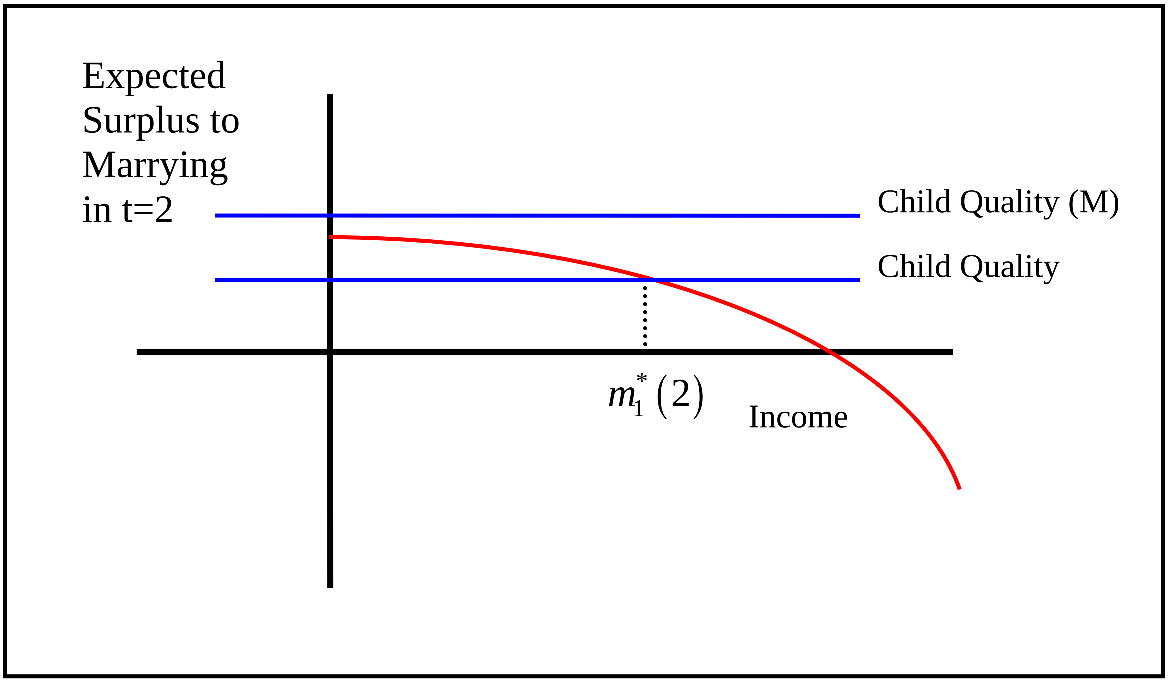
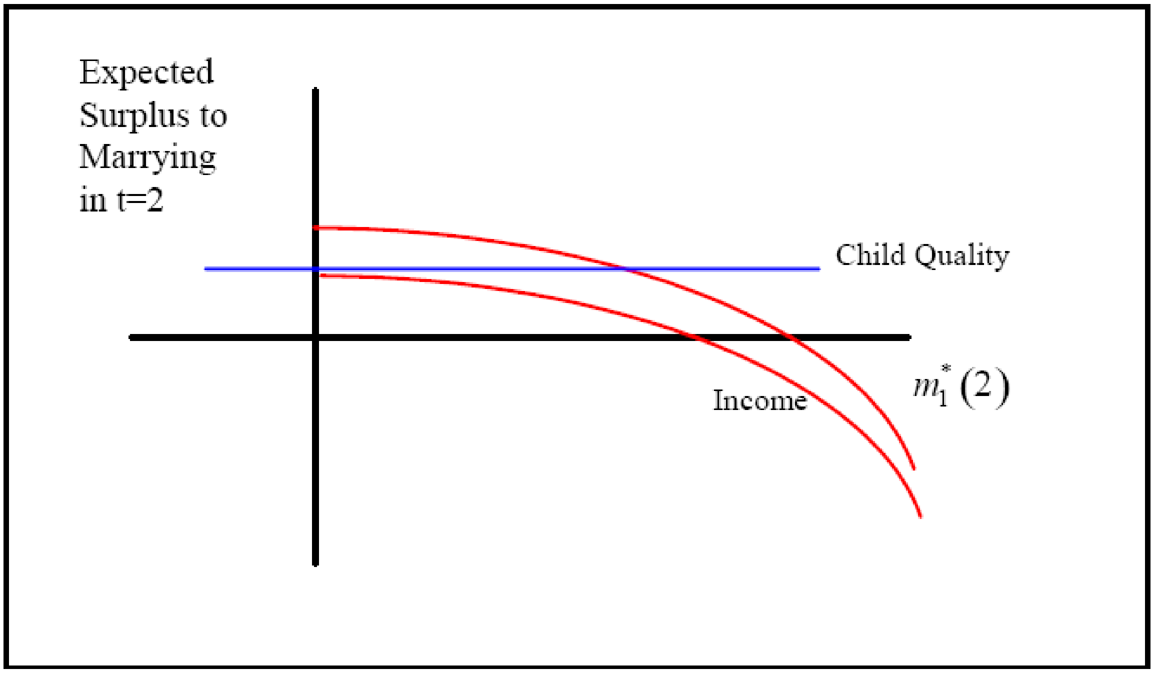


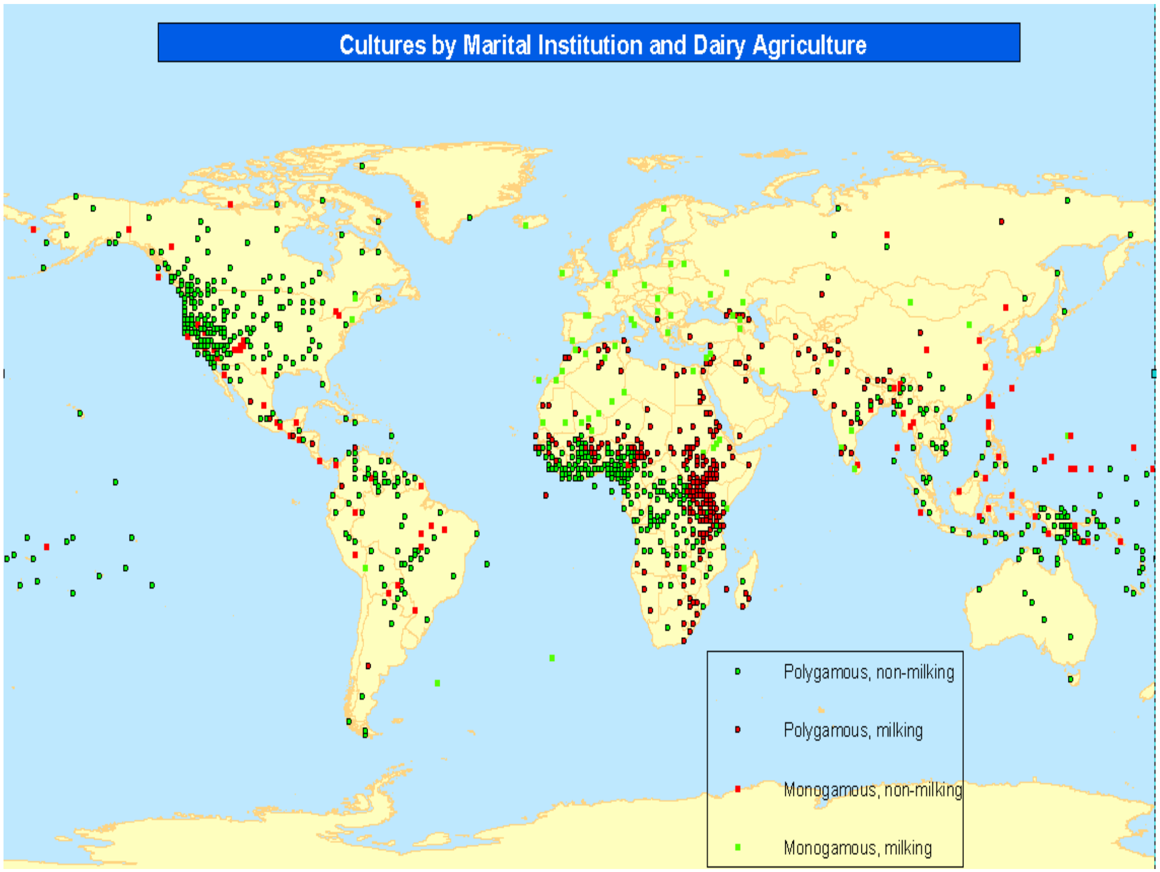
Illustration of two cases, one in which there is no pair-bond enhancing production technology (and there are incidences of polygyny) and one in which there is a pair-bond enhancing production technology and the tendency to polygamy is reduced.

Figure IV



A decrease in female bargaining power reduces the incidence of polygyny in this case by reducing the surplus income to waiting to be a second wife relative to being the only wife of a poor man.

Figure V


Cultures by Marital Institution and Dairy Agriculture
Polygamous, non-milking
Polygamous, milking
Monogamous, non-milking
Monogamous, milking