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Grandparents as Guards: A Game Theoretic Analysis of Inheritance and Post Marital Residence in a World of Uncertain Paternity

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Grandparents as Guards: A Game-Theoretic Analysis of Inheritance and Post-Marital Residence in a world of Uncertain Paternity

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Abstract

I unify the following (1) men face paternal uncertainty while women do not face maternal uncertainty, (2) putative fathers and paternal kin care about true paternity, (3) paternity confidence is systematically lower in matrilocal cultures than in patrilocal ones, (4) inheritance tends to be patrilineal in high paternity confidence cultures and matrilineal in low confidence ones, and (5) most societies with patrilineal inheritance were patrilocal while most societies with matrilineal inheritance were matrilocal. I model the co-evolution of inheritance patterns and post-marital residence patterns - and their relationship with paternity uncertainty. Using a game theoretic model, I examine how a "high paternity confidence" patrilocal-patrilineal equilibrium and a "low paternity confidence" matrilineal-matrilocal equilibrium could emerge. The endogenous choice of the old to monitor the sexual behavior of the young women who reside with them, thereby affecting the paternity confidence of the young women's husbands and hence their productive incentives, is crucial.

Keywords: Uncertain paternity; grandparents; incentives; patrilocality; inheritance; monitoring.

> Sed quis custodiet ipsos custodes? (D Juvenal 1895, Liber secundus, Satura VI, 325, lines 347-8.)

1. Introduction

Women are certain of being biological mothers of any children they bear, but men cannot be certain of having fathered their spouses' children[2]. I exploit this asymmetry to explain the long-run co-evolution of two institutions. These institutions are patterns of inheritance (patrilineal – with sons inheriting, or matrilineal – with daughters doing so) and of post-marital residence

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[2] As I study the evolution of two institutions over the very long run, I am primarily interested in the fact that historically men faced paternity uncertainty. However even given recent access to paternity testing technology, paternity uncertainty remains as conducting such tests is the exception and not the rule. Moreover, the tests themselves are not perfectly accurate.

(patrilocal – with the daughter-in-law moving in with her husband's family, or matrilocal with married daughters staying on in their dotal homes). I develop a hypothesis that takes as its starting point a sequence of curious findings and unifies them to arrive at an intriguing relationship between paternity uncertainty, inheritance and residence patterns. I highlight the superiority of this hypothesis over alternatives. Since I model the very long run, no pre-existing norms are assumed. I show instead how these institutions came into being even before any norms favoring their existence were in place.

A rich literature in biology, sociology, psychology and anthropology, drawing on both historical and current data, asserts that (1) paternity uncertainty significantly reduces the investment that men and their relatives make in the men's putative children; (2) paternity confidence is higher in patrilocal than in matrilocal cultures, matrilocal residence being the strongest predictor of high paternity uncertainty; (3) inheritance rules favor the male line in cultures with high paternity confidence, and the female line in low paternity confidence cultures; (4) there is evidence that in patrilocal societies, in-laws – particularly mothers-in-law – exercised close surveillance over their daughters-in-law, (5) there is a strong association between inheritance and residence patterns – most patrilineal societies are patrilocal and most matrilineal societies matrilocal. In fact, most societies developed a patrilineal-patrilocal (hereafter P-P) system while far fewer developed a matrilineal-matrilocal (hereafter M-M) system. I know of no theory unifying these disparate findings. This paper seeks to provide such a theory. It therefore adds to the literature on endogenizing institutions.

I model an intergenerational game which yields a P-P equilibrium with high paternity confidence for one set of exogenous parameters, and a M-M equilibrium with low paternity confidence for a different set. Paternity confidence is endogenous and is influenced by the degree of monitoring that the older generation (referred to as "grandparents" elsewhere) chooses to exert over the sexual behavior of the young woman who lives with them (their daughter in matrilocality, and their daughter-in-law under patrilocality).

The intergenerational division of labor whereby only the young supply work on the heritable asset – the family farm – gives the old the leisure required for monitoring – unlike the young women's husbands, who may either be busy farming or fighting wars. Of course, even if grandparents do not monitor at all, a husband still has *some* paternity confidence[3] which the grandparents may choose to enhance. Monitoring, however, involves an effort cost. So the old monitor only if it benefits them enough. Both the young and old care about the value of the family farm (which the young can enhance through productive effort) and about the ability to pass on this farm to their genetic descendants. Moreover, these two components of utility are strategically complementary: the young are keener to work on enhancing farm value when surer that the fruits of their efforts will reach their genetic heirs. Where the primary cultivators are (young) men, therefore, paternity confidence (as well as bequest expectations) influences their work incentives. This generates a link between the older generation's (expected) monitoring effort and the productive effort of the young men on the farm. The old may also have a more direct interest in monitoring, because they care whether the grandchild who inherits is a genetic descendant of theirs.

Note a striking asymmetry between the motivations of maternal and paternal grandparents. In a matrilineal-matrilocal system, the (maternal) grandparents know that any child born to their daughter is truly their genetic descendant and so have little incentive to monitor their daughter. The paternity of her child is not their direct concern. While this can alienate the son-in-law and generate a misalignment between his interests and those of his parents in law, this factor may not matter much especially where, due to exogenous conditions, women are primary cultivators[4]. In this event, the maternal grandparents do not have to worry about the impact of their lack of monitoring on the son-in-law's productive incentives. I show that, even in the (off-equilibrium) case where sons-in-law are primary cultivators, maternal grandparents supply a level of monitoring which, though positive, is strictly smaller, under plausible parameter restrictions, than the level of monitoring that paternal grandparents would choose to exercise over their daughter-in-law in a patrilocal system. Intuitively, while in both systems, the grandparents in situ are interested in the paternity of their supposed grandchildren because of its effect on the work-incentives of the fathers, in a PP system, they have an additional and direct interest in ensuring that any child born to the daughter in law is really the son's. Therefore these paternal grandparents' incentive to monitor is stronger.

[3] This may be a product of factors such as faith in the marital relationship and may also be generated by the husband's own monitoring activities.

[4] We will discuss later – drawing on research by Boserup (1970) and Ember and Ember (1971) when this might be so.

Patrilocality and patrilineality are mutually reinforcing – as are matrilocality and matrilineality. In patrilineality, the son's children inherit. This increases the importance of ensuring that his putative children are in fact his – and so of monitoring the daughter in law. Now co-residence is an effective way for paternal grandparents to monitor their daughter in law. Thus patrilineality creates a need for patrilocality. Patrilocality in turn implies that an old couple live with their son and daughter in law and send their daughter off to live with her in laws. Hence their interest in maintaining their son's productive incentives, both through patrilineal bequest and through monitoring his wife. Patrilocality induces both patrilineality and monitoring. Patrilineality, patrilocality and high paternity confidence go together in a mutually supportive loop, and this is one of the equilibria of the intergenerational game.

In a matrilineal system, the daughter's children inherit. This reduces the importance of paternity, the need for monitoring and for patrilocality – in fact, matrilocality is optimal, especially if the daughter is the primary cultivator. While matrilineality induces matrilocality, matrilocality creates a need to sustain the daughter's productive incentives, which is best done through matrilineal bequest. Moreover, if the daughter is the primary cultivator her parents' incentive to monitor weakens further, in fact I show that they never monitor. Thus matrilineality, matrilocality and low paternity confidence sustain each other in another equilibrium – one that obtains for a narrower range of parameters than the first.

1.1 Can Patrilocality Be Explained Simply By Greater Male Productivity?

Consider an alternative, simpler explanation of patrilocality which does not refer to paternity uncertainty. It may be argued that in conditions favoring high male productivity (eg. where plough agriculture requiring strength dominated, and wars were sufficiently infrequent to allow young men to stay on their farms long enough to cultivate), the older generation wanted their sons to stay with them in order to cultivate the family farm. Patrilocality in turn led to patrilineal inheritance; sons had to be given bequests in order to sustain their productive incentives.

The problem with this hypothesis is that even in such conditions, the older generation may just as well keep their daughters at home, bring their sons-in-law to the farm and get them to do the cultivation. As marriages occurred within a limited geographical area, a son-in-law who knew how to cultivate a field in his native village A would presumably also know how to cultivate one in neighboring village B. To sustain the son-in-law's incentives, the farm could then be willed to the daughter and the son-in-law. In short, high male productivity by itself could give rise to a M-M system (with sons-in-law cultivating) just as it could give rise to a P-P one. Where two systems do equally well, how could a random choice between them generate the overwhelming predominance of the P-P system? .

My hypothesis, in contrast, explicitly addresses this issue. I provide a reason for sons-in-law to supply strictly less effort on their parents in law's farm than a son would on his parents' farm (and formally show this in my model). Hence, when male productivity is high, the older generation *strictly* prefers a patrilocal system with sons cultivating over a matrilocal one with sons-in-law working. The son-in-law's low effort is linked to a misalignment between his incentives and those of his wife's parents. As the paternity of their daughter's child does not interest them per se, they supply less monitoring relative to the level at which a set of paternal grandparents would have monitored their daughter-in-law (even after accounting for the impact of this on the son-in-law's effort). This relatively low level of monitoring lowers the son-in-law's paternity confidence affecting his incentives. This effect is absent between a son and his parents; here all want the son's wife to be monitored at a high level.

1.1.1 Playing the Devil's Advocate : Blood Relatives

The argument in the preceding sub-section shows that patrilocality cannot be explained satisfactorily without some factor that makes sons-in-law systematically less effective cultivators than sons. One might then raise the following argument: suppose it is easier to monitor the productive efforts of blood relatives. Then, even where sons and sons-in-law would be equally capable, families might strictly prefer to have their sons live with them and cultivate their land. This could then provide an explanation for patrilocality independent of factors that work through paternity confidence or concerns about genetic descendants inheriting.

However, there are at least four reasons that weaken the explanatory power of this alternative hypothesis relative to the one I propose. First, suppose that, indeed, men were not motivated by concerns over paternity or genetic descendants. In such a world, it should be possible for the older generation to offer young men an output-based contract (like a fixed rent contract) which, by making the young man a residual claimant, maximizes his incentives for exerting effort on the family land. Such a contract would obviate any need for personally monitoring the young man's effort. Now this contract could be applied to a son-in-law just as well as to a son. Moreover, if the cultivator were concerned about whether his children would inherit the land on which he worked, this could be taken care of by bequests making the cultivator the legatee. Again, in the absence of uncertain paternity, this would affect sons and sons-in-law's incentives *identically* and should therefore give rise to matrilocality as often as it would to patrilocality. In contrast, this difficulty is avoided in a world of uncertain paternity, as in my hypothesis. Here, the cultivator – if male - faces uncertain paternity and therefore the grandparents' monitoring of his wife becomes a concern. This concern affects his productive incentives *even if he is made a residual claimant* because his marginal utility from exerting effort depends positively on his assurance of the fruits of his efforts being inherited by his *genetic offspring*. Moreover, making him a legatee would not remove his concern about paternity, because while he would have the ability to pass on the land to his "official" or putative offspring, his overall utility as well as his marginal utility from exerting effort would both be influenced by his paternity confidence, which in turn is linked to grandparental monitoring of his wife. This coupled with the asymmetry between maternal and paternal grandparents' monitoring incentives highlighted earlier then generates an asymmetry between the effectiveness of sons versus sons-in-law.

Secondly, suppose we rule out output-based contracts for the time being and examine whether blood relatives' productive efforts are indeed easier to monitor, or whether blood relatives perform better. Empirical literature on "successions" to important posts in firms by "family heirs" such as the offspring of the founder or the outgoing CEO may lead us to question this assumption. A substantial literature contains empirical evidence that family successors perform *worse* than non-family successors in comparable firms; this includes Villalonga and Amit (2006), Perez-Gonzalez (2006), Schulze et al (2001), Bennedsen et al (2006), Claessens et al (2000), Cronqvist and Nilsson (2003), and Morck et al (2000) [see Bertrand and Schoar 2006 for a partial survey]. As Bertrand and Schoar point out at least some of these studies are also able to control for the endogeneity of family CEO successions. The conclusion that the authors of these studies (for example Perez-Gonzalez 2006) have drawn from their findings is that family heirs' worse performance may reflect lower effort, lower ability or both. These studies therefore cast doubt on the hypothesis that being a blood relative is sufficient to ensure better performance or higher effort for a given level of monitoring, or that it is sufficient to lower the monitoring needed to elicit a given effort level. Most interestingly for our purposes, Perez-Gonzalez 2006 also contains a comparison between sons and sons-in-law. Relative to sons who "inherited" an important post in a firm, sons-in-law who did so actually performed *better* (though the difference was not significant). Certainly, there was no evidence of sons performing better than sons-in-law promoted to similar positions. Theoretical explanations for these contrary findings could, for example, be based on heirs' moral hazard (they are more confident of tolerance if they shirk) and the older generation's reluctance to jeopardize valuable personal relationships with their children through strict discipline. At any rate, these findings call into question the assumption that blood relatives are necessarily more effective.

Thirdly, if sons are intrinsically more effective, or require less monitoring than sons-in-law *independently of concerns about paternity*, they should be relatively more effective in contexts where their effort is not responsible for enhancing the value of a heritable asset (if inheritance is not an issue, paternity uncertainty is not an issue either). A large number of studies on elderly caregiving, help and sharing within families (contexts which required effort, but where the effort did not directly affect the value of a heritable asset) indicates that sons-in-law were no less effective than sons. Sweetser (1984) mentions 15 studies which show that men had *closer* ties with their wife's kin (relative to their own) when it came to contexts like help and caregiving. Later studies like Kivett (1985), Globerman (1996), Shuey and Hardy (2003) and Merrill (2009) come to similar conclusions. Shuey and Hardy showed that when husbands' kin and wives' kin *both* had often competing claims on a couple's investment of effort and help, the wives' kin tended to receive priority.

Fourth, suppose again that it *is* true that blood relatives' productive efforts are intrinsically easier to monitor. Anthropological evidence indicates the existence of a large number of societies where kin marriages (for example to first cousins) was not only allowed but was the *preferred* form of marriage. In a subset of societies with preferential cousin marriage, in those where men usually married their mother's brother's (or sister's) daughter, for example, the son-in-law *was* a blood relative.[5] Therefore, by the argument that blood relatives are easy to monitor, we should observe no marked difference between the frequency of matrilocality and patrilocality, or patrilineal and matrilineal inheritance, in such societies. An old couple might entrust cultivation to a son-in-law who was also a nephew, for example, and will the property to his heirs. However, we find a significant preponderance of patrilocality over matrilocality even

[5] Consider the case where a man marries his mother's brother's daughter. The man's father-in-law would be his maternal uncle. Provided the maternal uncle and the man's mother had the same mother, the man is thus certain to share some genes with his maternal uncle/father-in-law. In societies where men married mother's sister's daughters, they would be sure to be blood relatives of their maternal aunts/mothers-in-law.

in these societies. (Out of 45 societies where sons-in-law were blood relatives because they preferentially married either their mother's brother's daughter or their mother's sister's daughter, 31 were patrilocal. Data on inheritance norms is available for 12 of these societies; of these, 9 followed patrilineal inheritance.[6] Further, according to Murdock (1957), which draws on a larger sample, 31 societies that favored *matrilateral cross-cousin marriage* (in which a man married his mother's brother's daughter) were patrilineal while only 7 were matrilineal). In contrast, under my hypothesis, even sons-in-law who were blood relatives would have to deal with the prospect of uncertain paternity. While a man married to his first cousin would share some genes with her child regardless of whether he is the child's real father[7], the logic of my model would continue to hold as long as the man is either explicitly interested in his paternity, or interested in the magnitude of his genetic relatedness with the child. As long as either of these is true, male cultivators' choice of effort is influenced by the extent to which the older generation monitors the cultivators' wives. If grandparents are also explicitly interested either in their son's paternity or in the *extent* of their genetic relatedness to the grandchild who inherits, an asymmetry will still obtain between maternal and paternal grandparents' motivations, and the logic of the model goes through. Thus, a model which factors in uncertain paternity is better able to explain why patrilocality should dominate even in societies where sons in law tended to be blood relatives.

1.2 Residence and Paternity Confidence : Is Reverse Causation Likely?

My hypothesis addresses the empirical finding of a close association between post-marital residence patterns and paternity confidence. It suggests that high paternity confidence results from patrilocality, reflecting the greater incentive of paternal grandparents to ensure that their daughter-in-law's child is also their son's. The incentive stems both from direct genetic considerations and in order to spur greater effort by the son. Maternal grandparents lack such incentives, especially if their daughter is responsible for cultivation, explaining why low monitoring, and hence low paternity confidence, characterizes matrilocal societies.

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[6] Source: author's calculations based on data from cross-tabulations based on Murdock and White's Standard Cross Cultural Sample available at http://lucy.ukc.ac.uk/cgi-bin/uncgi/Ethnoatlas/atlas.vopts.

[7] For example, consider a husband and wife whose mothers are sisters. The husband's relatedness with his wife's child, even if he is not its real father, is (1+q)/16 where q is the probability that the husband's and wife's mothers were full, rather than half, siblings. If the husband's own paternity confidence is p, his (expected) relatedness to his wife/cousin's child is p/2 + (1+q)/16.

Since in my hypothesis causation runs from residence pattern to paternity confidence, one may wonder whether causation in the reverse direction is likely. I argue below that it is not.

Suppose, that paternity confidence is wholly determined by exogenous factors; would patrilocality then emerge in high confidence regions, and matrilocality in regions with low confidence? In particular, would patrilocality emerge in regions with high paternity confidence, where males are highly productive? Not necessarily so. While grandparents could keep their son at home and make him responsible for cultivation, they could equally well keep their daughter at home and make their (resident) son-in-law responsible for cultivation. If paternity confidence is already high, independently of grandparental behavior, the son-in-law should be as effective as the son. Matrilocality would emerge in high paternity confidence regions as often as patrilocality. Causation running from residence patterns to paternity confidence (as in my model) is thus more plausible than the reverse.

At this point, we might consider two related questions. First, while high paternity confidence does emerge under patrilocality relative to matrilocality (see section 2 for details), is there any direct support for the hypothesis of "grandparental" monitoring of young women's sexual behavior in patrilocal societies? The answer is yes. Anthropologists Burgess and Draper (1996) document how the "female hierarchy" within patrilocally organized families was very helpful to husbands because mothers-in-law exerted more or less constant surveillance over their daughters-in-law, preventing them from meeting other men, and thereby boosting the husbands' paternity confidence. Similarly, Kim (1996), commenting on patrilineal families in ancient Korea, explains that a chief role of mothers-in-law was to "guard daughters-in-law from outsiders". Leonetti et al (2007) cite a number of studies including Fukutake (1967), Lee (1979), and Draper (1997) which show evidence that parents-in-law monitored their coresident daughters-in-law explicitly with regard to the latter's sexual fidelity. They might even try to end the marriage if the daughter-in-law's fidelity to their son was in sufficient doubt. Voland and Beise (2005) show further evidence that coresident mothers-in-law (in preindustrial Germany) sought to exert control and surveillance over their daughters-in-law. They describe the role of mothers-in-law as a "daughter-in-law monitoring sensor" explaining that "indifference to the sexual behavior of daughters-in-law…is also expensive because some of the grandchildren would not be one's own". There is no parallel evidence for parents monitoring co-resident adult daughters in matrilocal societies. On the contrary, there is some evidence that parents, particularly in matrilocal societies where daughters played a significant role as economic contributors, made it clear that they would tolerate and certainly not penalize sexual non-exclusiveness on the daughter's part. [Poewe (1981), for instance, documents how, in some African M-M societies, girls' mothers and other matrilineal kin taught them that their sexual enjoyment "need not be limited to one specific partner"; others were told that "the men are more than one" (Arnfred 2007). Similarly the fact that women among the M-M Nayars of central Kerala often had several simultaneous "unofficial husbands" (*sambandham*) in addition to their official one was never frowned upon by the women's own kin, who indeed accepted these unofficial unions and invited the women's unofficial partners (and *their* maternal kin) to ceremonial feasts (Gough 1959)].

A second related question is, could lower paternity confidence in matrilocal societies simply be a product of matrilineality and the resultant low economic dependence of women on men? In other words, if women inherit, they are assured of some economic support for their offspring, and have less need to assure their partners of their paternity. My response to this question is threefold. First, the question itself presupposes the existence of matrilineality. However, my model assumes no pre-existing institutions, and determines instead under what conditions matrilineality, matrilocality and low paternity confidence/low grandparental monitoring would *simultaneously* evolve (and under what conditions the opposite triad of patrilineality, patrilocality and high paternity confidence/grandparental monitoring would simultaneously evolve). My focus is on how these institutions *originate*, and pre-existing inheritance norms favoring or opposing economic independence for women would not be relevant for this. Secondly, this point would certainly become relevant once either a matrilineal or a patrilineal norm had been established in a particular society. To highlight this, I consider an extension of my basic model which illustrates what happens once a norm is in place. With an established inheritance norm, the differential impact of a patrilineal/matrilineal inheritance norm on women's incentives shows up in differences in the level of paternity confidence which men can expect independently of grandparental monitoring; this level would be lower in societies with a matrilineal inheritance norm in place. (It would however not change the fact that maternal and paternal grandparents would continue to have different incentives to monitor, and that this would continue to affect young men's productive incentives). Third, the point made in the previous paragraph about the evidence indicating grandparental monitoring in patrilocal as opposed to matrilocal societies, emphasizes the special role of grandparents' motivations and their impact on paternity confidence.

1.3 Remarks about Scope and Organization

Other economists have separately discussed the reasons either for patrilineality or for patrilocality; a few others have discussed paternity uncertainty in different contexts. However, I know of no previous attempt to link these three issues together in a model – which at the same time also explains the findings mentioned above, and offers a rationale for the existence of some matrilineal-matrilocal societies with a greater degree of sexual freedom (for women).

The rest of the paper is organized as follows. The first part of section 2 offers details on the findings that form the point of departure for my model (apart from the literature on direct monitoring of women by in-laws, which I have already mentioned). The second part of the section discusses other relevant literature, including some other economists' work on related themes. Section 3 lays out my model, specifying the assumptions and timing of the game. Section 4 solves this game by backward induction and defines and fully characterizes the equilibria, presenting my main results. Section 5 discusses my main results. Section 6 concludes.

2. Some Related Literature

2.1 Evidence that Paternity Confidence matters

Evolutionary biology provides the logic for the assumption that genetic descendants are prized over others: natural selection favors individuals who direct scarce resources to those who share their genes, and away from competing claimants ("nepotism") (Hamilton 1964). Alexander (1974) provides evidence that paternal care and investment in putative offspring varies directly with paternity confidence across different species of males – primates as well as humans. Paternal care is highest among monogamous species of forest-dwelling arboreals, and lowest among species which live in large groups with multiple males (and where therefore other males have access to any individual male's partner). In human societies, he notes that in cultures with traditionally low paternity confidence (where for instance wives lived in their dotal homes with their own parents or siblings, rather than in the husband's home) men directed investment towards their sisters', rather than their wives', children. He attributes this to the certain knowledge that a man must share some genes with his sister's children (since he and his sister undoubtedly have the same mother, and his sister's maternity of her children is also unambiguous) while he only shares genes with his wife's children if he really is their father.

Daly, Wilson and Weghorst (1982) mention similar behavior among the Masai, who had low paternity confidence due to traditions of wife-sharing, and among Naskapi-Montagnais men (citing historical accounts like LeJeune (1634)). Gaulin and Schlegel (1980) document a similar practice in the Trobriand Islands, where women have great sexual freedom. Despite affectionate relationships with their wives' children, Trobriander men prefer to invest in their sisters' children. Moreover, many men in these cultures explicitly mention low paternity confidence as the reason for their investment strategy. Anderson et al (2007) finds that men doubtful about the paternity of their children spend less time with the children, are less involved in their education and are more likely to divorce their wives.

The importance of paternal uncertainty is also emphasized by empirical studies regarding mate guarding among men (Buss 2002), and male jealousy and the sexual double standard (Daly, Wilson and Weghorst (1982), Shackelford, Buss and Bennett (2002)). Shackelford et al show that though a partner's infidelity upsets both sexes, men react more adversely to the sexual aspect of infidelity – with its implication of potential paternity uncertainty. Daly et al bolster this with evidence on spousal abuse and homicides. Gaulin and Schlegel (1980) and Hartung (1985) show that rules of inheritance are influenced by paternity confidence – inheritance is more likely to be patrilineal in cultures of high paternity confidence. Daly and Wilson (1982) using data from videos of live births in the U.S, as well as data from surveys, find evidence of the overwhelming importance placed on paternal resemblance for newborn infants: almost all mothers in their data claimed that the infant resembled the (putative) father while hardly any emphasized the infant's resemblance to herself (or to other maternal relatives). Moreover mothers repeatedly emphasized to putative fathers how much the infant resembled them (the fathers). The authors interpret this as a (mostly subconscious) ploy on the mothers' part to boost paternity confidence in their partners, thereby encouraging the putative father to invest in the child.

Apart from putative fathers, other kin (including grandparents) are also concerned about paternity uncertainty. Smith (1981) and Euler and Weitzel (1996) show matrilineal biases in grandparental solicitude: maternal grandparents are perceived (by their grandchildren) to be significantly more concerned about their welfare than paternal grandparents. The authors' interpretation is that this happens because while maternal grandparents know that their grandchildren share their daughter's genes, paternal grandparents are (consciously or sub-consciously) influenced by paternity uncertainty and are more reluctant to invest in children who are possibly not kin. However, paternal grandparents become more solicitous as their distance from the children's home decreases. Although the authors do not comment on this, this would be compatible with a framework where co-residence enables paternal grandparents to monitor their daughter in law, bolstering the likelihood that their son is the father of the daughter-in-law's children. High paternity confidence would then increase the paternal grandparents' willingness to care for this grandchild. Sear, Mace and McGregor (2000) and Voland and Beise (2002) also document differences between maternal and paternal grandmothers' solicitude.

Among economists, Doepke and Tertilt (2009) have an interesting model in which grandparents favor maternal grandchildren over paternal ones. Parents are altruistic in their model. As men value their children's utility less than women, grandparents value their sons' children's utility less than their daughters' children's (because they know their daughter's children are more important to her than their son's children are to him). In contrast, in my model the ability to pass on an asset to a genetic grandchild enters the grandparents' utility directly, even though parents are not altruistic in the sense of Doepke and Tertilt.

Gaulin, McBurney and Brakeman-Wartell (1997) have also shown that a matrilineal bias exists for aunts and uncles, with a mother's siblings perceived to be significantly more solicitous on average than a father's siblings. This reflects a similar propensity to invest in one's kin: paternal relatives' investments are affected by paternity uncertainty, but maternal relatives' are not. Daly, Wilson and Weghorst (1982) in their account of the tendency of Naskapi-Montagnais men to invest in their sisters' children mention that these men avoided investing in their brothers' children because they were unsure of the true paternity of their brothers' putative children.

2. 2 Paternity Uncertainty, Residence and Inheritance

We also have evidence of a strong significant relationship between residence and "paternity confidence". Gaulin and Schlegel (1980) code cultures with a "paternity confidence" variable based on the degree of women's sexual freedom (indicated for instance by the presence or absence of a double standard regarding extramarital affairs, the incidence of extramarital sex among women or of wife sharing). They find that the strongest predictor of paternity confidence is residential pattern, with significantly lower paternity confidence in matrilocal cultures.[8] Kurland (1979) similarly finds strong correlations between a matrilocal or avunculocal residence

[8] For some numbers, readers are referred to Appendix Table 1, based on data in Table 2 of Gaulin and Schlegel (1980).

pattern (women staying on with their siblings) and measures of low paternity confidence based on high extramarital and premarital sex.

Gaulin and Schlegel also found that important offices (such as that of headman) tended to be inherited by patrilocal kin in high paternity confidence cultures but by matrilocal kin in low confidence cultures. Hartung (1985) also finds that inheritance rules were influenced by paternity confidence with inheritance being patrilineal in high paternity confidence cultures and matrilineal in low confidence cultures. In addition Daly,Wilson and Weghorst (1982), Alexander (1974), Gaulin and Schlegel (1980) also show that resources were transferred to one's sister's children rather than to one's wife's in cultures of low paternity confidence. Among economists, Diamond and Locay (1989) show using anthropological data that men's investments in their sisters' children went down as paternity confidence went up. Thus there was a strong association between inheritance patterns, residence patterns and paternity confidence. That there was a strong association between patrilineality and patrilocality, on one hand, and matrilineality and matrilocality on the other, is evident from the following table which presents cross-tabulations based on the Murdock and White Standard Cross-Cultural Sample (SCCS) – a controlled sample of world cultures from Murdock's Ethnographic Atlas corrected for regional diffusion effects and auto-correlations.

Table 1

Descent	Patrilineal	Duolateral	Matrilineal	Quasi-lineages	Ambilineal	Bilateral	Totals
Residence Transfer at Marriage							
Unknown	0	0	0	0	0	1	1
Wife to Husband's	**66**	7	3	5	6	30	117
Optional for Couple	4	0	2	1	0	21	28
Husband to Wife's	2	1	**24**	0	0	12	39
No Common Residence	0	0	1	0	0	0	1

Totals	72	8	30	6	6	64	186

Source : Author's calculations based on data available at http://lucy.ukc.ac.uk/cgi-bin/uncgi/Ethnoatlas/atlas.vopts.

As Table 1 shows, most cultures with patrilineal descent[9] involve the wife moving to the husband's family at marriage – generating a strong relationship between patrilineality and patrilocality. Conversely, most cultures with *matrilineal* descent involve the husband moving to the wife's family at marriage – so that matrilineality and matrilocality are closely associated. Table 1 also makes it evident that patrilocality was very widely prevalent.[10]

2.3 Related Economics Literature

Botticini and Siow (2003) examine why bequests were primarily patrilineal, *taking patrilocality as given.* They reason that patrilineal inheritance was necessary to maintain the son's incentives to exert effort on the family farm. Had the farm been willed to his sister, who lived away from home (given patrilocality) and therefore suffered a comparative disadvantage in cultivating the plot, the son would no longer be the sole residual claimant of any improvements in productivity achieved through his efforts. His incentives would be dampened. Patrilocality is thus crucial to this model, but is treated as exogenous. Thus my model would help bridge this gap. Unlike in my model, paternity uncertainty plays no role here. As discussed earlier, high male productivity in itself is insufficient to explain the emergence of patrilocality.

Edlund (2001), speculating on the causes of patrilocality, mentions the need to locate multiple women within a husband's household in a polygynous setup. She also speculates that it might reflect the greater bargaining power of men. This explanation however would not address the wide prevalence of patrilocality in primarily monogamous societies. Even in societies where polygamy was permitted, the bulk of the population could just afford one wife – a phenomenon termed *ecologically imposed monogamy* (EIM). Why were these families patrilocal? Nor would it explain why some other societies developed a matrilocal and matrilineal system. As paternity uncertainty plays no role in the story, the empirically observed association between patterns of post marital residence and paternity confidence is not addressed.

[9] "Descent" encompasses both lineage and inheritance.

[10] "Bilateral" descent means that both paternal and maternal kin were equally important for ties and inheritance. Note that such cultures could be either patrilocal or matrilocal.

The notion of uncertain paternity is implicitly considered in Becker (1973) which emphasizes that one obtains utility from one's *own* children. Economics literature which explicitly mentions paternity confidence is fairly limited. Among the papers I am aware of, Doepke and Tertilt (2009) model the evolution of women's rights assuming that women place a greater weight on children's welfare than men do, and they mention paternity uncertainty as one possible reason for this. Some other papers (Edlund 2005, 2006, Edlund and Korn 2002) emphasize "paternity presumption" – the legal presumption that a woman's husband is the presumed father of her child. These papers usually model marriage as a transfer of custodial rights from a woman to her husband, and a man is assumed to care about presumed, rather than true, paternity. In contrast, I do not focus on a father's rights over a child as defined by (modern) law. Instead, I focus on the evolution of inheritance and residence norms – an evolution completely independent of formal institutions like the law – and model men (and their parents) as caring about a child's true, rather than presumed, paternity. I have already mentioned Diamond and Locay (1989) who show that risk averse men will invest resources in their sisters' children when paternity confidence is low: they also find empirical support for this. Saint-Paul (2008) models marriage as a commitment device on the woman's part: in his model marriage removes the husband's paternity uncertainty while the wife, by marrying, sacrifices the opportunity to mate and possibly have children with more attractive men. The focus of this model is on marriage market matching and hypergamy. My model is not concerned with the origin of marriage and also does not view marriage as a complete contract that removes paternity uncertainty. Bethmann and Kvasnicka (2010) also explore the origin of the institution of marriage and view it as a device that reduces paternity uncertainty and promotes paternal investment in offspring. Closer to my paper is Francesconi, Ghiglino and Perry (2010) which shows how paternity uncertainty combined with overlapping cohorts of dependent children gives rise to stable families rather than to promiscuous bondings.[11]

A feature of my model is that exogenous conditions can affect the sexes' relative productivity in agriculture. In this, I follow Boserup (1970) : Boserup describes how sparsely populated regions relied on hoe cultivation, where women did the bulk of the work, while regions with moderate to high population density developed a system based on ploughing and domestication

[11] In their model males in promiscuous bondings expend an inefficiently large amount of time on "mate guarding" thus lowering the food available to dependent children.

of draught animals, where men had an advantage. Thus I treat population density as an exogenous parameter influencing relative productivity across sexes. I also draw on Ember and Ember (1971). They find that matrilocality is the dominant residence pattern in societies with a significant threat of "external warfare" – which required men to be away for long periods, hampering their ability to contribute to subsistence production. Women in these cultures became the primary economic contributors. In contrast, if warfare threats are either local or intermittent, men can continue to tend their plots even while fending off enemies, and patrilocality is more common. Thus the nature of war threats faced by a society is also a parameter influencing which sex is effectively more productive.

Other literature on matrilineal and patriarchal societies includes Gneezy, Leonard and List (2009) who show that women in matrilineal societies compete more often than men while the opposite holds in patriarchal societies.

I consider only monogamous couples for two reasons. First, in most societies which allowed polygamy, most men could afford only one wife. Hence I concentrate on explaining when and why patrilocality, patrilineal inheritance and high paternity confidence emerge in such families. Second, most polygamous societies also involved shifting cultivation, as in much of Africa. Therefore, there is no question of a family farm as a heritable asset, and my analysis would in any case not apply to those societies. (Botticini and Siow 2003, who also consider the farm as a heritable asset, similarly qualify the applicability of their analysis).

3. Framework

3.1 Players and timing

My model is an overlapping generations world where each individual lives for two periods. The universe of potential players in my model consists of the members of *N* identical households. Each such household is headed by an old couple (grandparents). As each woman in this model has one son and one daughter, each set of grandparents has one adult son and one adult daughter. Marriage is universal, so adult children all intermarry with adult children from other families, and may then have children of their own. The universe of *potential players* in the game is defined by $\Omega = [\{GF, GM, S, D\}_1, \ldots \{GF, GM, S, D\}_i, \ldots \{GF, GM, S, D\}_N]$ where $\{GF, GM, S, D\}_i$ stands for the grandfather, grandmother and their adult son and daughter in the ith family. Ω includes adult children's spouses, who are the adult sons and daughters of other families. The set of *active players* is, however, a strict subset of Ω. To make this clear, consider the timing of moves in the game:

1. The old couple "grandparents" in each family observes exogenous factors[12] determining the relative productivity of the sexes in cultivation. The couple then announces, by consensus, their decisions on *bequests* (they name the legatee of the family farm), *residence patterns* (they announce which adult child should live with them) and identity of primary cultivator (this has to be either the co-resident child or their spouse). Their decisions on residence patterns are immediately implemented while their decisions on bequests are treated as credible commitments.

2. Simultaneously, the "grandfather" and "grandmother" also reach a consensus on the total intensity with which they monitor the sexual behavior of the young adult woman who lives with them – as well as on the division of this monitoring effort between them. The identity of the young woman (daughter or daughter-in-law) to be monitored depends on the old couple's choice of residence pattern. Total monitoring intensity is split additively between grandfather's and grandmother's monitoring efforts.

3. The young adult chosen as the primary cultivator observes the grandparents' announcements regarding bequests and their monitoring efforts. He or she then decides on *effort choice* – how much effort to expend on enhancing the value of the family land. This choice affects the final value of the land, feeding into the payoffs of both young and old adults.

From the sequence of moves described above, we see that the *active players* in the game are essentially the grandfather, the grandmother and the chosen younger-generation cultivator in each household. Formally, the set of active players is $\Delta = [\{GF, GM, W\}_1, ..\{GF, GM, W\}_i, ..\{GF, GM, W\}_N] \subset \Omega$ where W_i denotes the i[th] family's chosen younger-generation cultivator.

We also note that the game described above is a Stackelberg game. The younger-generation cultivator chooses his effort e as a best response to the grandparents' decisions. This best response function is taken into account by the grandparents during *their* decision-making process.

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[12] Denoted by a composite variable d in the range $[\underline{d}, \bar{d}]$ where $\underline{d} \leq d \leq \bar{d}$ and increasing d denotes factors favoring relatively high male productivity (such as increasing population density with attendant emphasis on plough agriculture, and a move away from external war threats requiring lengthy absences towards local and intermittent warfare).

In the next three sub-sections, I formally present, in turn, (a) these active players' strategy sets, (b) their payoffs and (c) the equilibrium concept used to solve the game. After this I discuss some of the assumptions involved in greater detail.

3.2 Strategy Sets

Subsuming household subscripts, which are not important in what follows, we first focus on the strategy set of W, the younger-generation cultivator nominated by GF and GM. W has to choose how much effort to exert on the land – whose initial value is normalized to V_0. He or she thus chooses effort e - drawn from a continuous interval [0, ě] – so as to maximize his or her own utility, given the older generation's decisions regarding bequests and the level of monitoring applied to the co-resident young woman. Thus, denoting the young cultivator's utility (specified in detail in section 3.3) by U^W, his or her problem is

$$\underbrace{\max}_{e} U^W(e,c,b) \tag{1}$$

In (1), b stands for the old couple's announcement regarding bequests, while c stands for the GF's and GM's combined monitoring of the co-resident young woman in the household. From (1), we see that W's optimal effort choice is influenced by c and b, so that

$$e^W = e^W(c,b) \tag{2}$$

We now specify the older generation's strategy sets. GF and GM **'s** common strategy set is a four-dimensional vector $\Gamma = [b, R, W(R), c(b, R, W(R)), r]$ where b**,** R and W stand for their consensual announcements regarding bequest decisions, post-marital residence and younger-generation cultivator respectively, and c denotes the total intensity at which they agree to monitor the behavior of the co-resident young woman (daughter or daughter-in-law). In addition old couples follow a Pareto-optimal rule r which determines the division of monitoring effort between the spouses into c_{GF} and c_{GM}. The manner of consensus will be specified shortly[13].

Ruling out fractional bequests[14], b amounts to choosing the identity of the young person – son, daughter, son-in-law or daughter-in-law – who inherits the family farm. Thus we have

$$b \in [S, D, SL, DL].$$

[13] The grandfather and grandmother are treated as separate agents as in standard collective household models of households. As in the intra-household bargaining literature, the "sharing rule" – which also applies to tasks which require joint effort – must satisfy Pareto optimality (Chiappori 1988, 1992).
[14] Discussed in section 3.3.

R amounts to choosing either a patrilocal or a matrilocal residence pattern for the younger generation (each old couple chooses this, as no pre-existing norms are assumed):

$$R \in [P, M].$$

Meanwhile, the choice of cultivator is partly constrained by the choice of R:

$$W = W(R) \in \{S, DL\} \text{ if } R = P$$

$$W = W(R) \in \{D, SL\} \text{ if } R = M$$

This reflects the fact that only coresident young can cultivate the family farm.

Total monitoring intensity, drawn from a closed interval [0, č], will vary with b, R and W; different levels of monitoring will be optimally chosen depending on the identities of the co-resident young woman, the chosen cultivator and the legatee. Moreover, the old couple needs to consider the effect of monitoring intensity on W's incentives to exert productive effort, in accordance with (2).

To clarify what is meant by "consensus", we use U^{GF} and U^{GM} to denote GF's and GM's respective utilities. While these utilities are specified in detail in section 3.3, here we simply note that

$$U^{GF} = w^{GF}(b, R, W(R), e(b,c), c) - c_{GF} \quad (3)$$

$$U^{GM} = w^{GM}(b, R, W(R), e(b,c), c) - c_{GM} \quad (4)$$

where

$$c = c_{GF} + c_{GM} \quad (5)$$

and both w^{GF} and w^{GM} are increasing in c. Thus for both grandparents, the function w captures the benefits from monitoring while the second component is their disutility from monitoring, which is taken to simply be the level of monitoring exercised by each of them. Note that total monitoring takes on a "public good" character for the old couple; both derive utility from it but to different extents**.** Now the "optimal monitoring correspondence" $c(b, R, W, e^{W}(c,b))$ maps different feasible choices of b, R and W into levels of total monitoring intensity that the old couple considers optimal, given the young cultivator's best response function $e^{W}(c,b)$. Optimal c is thus agreed on by equating the *sum* of GF and GM's marginal benefits from it with the marginal cost of monitoring, which is unity [the cost of monitoring being simply equal to its level, from (3) and (4)][15]. Thus, $c(b,R,W,e^{W}(c,b))$ is determined by the following condition:

$$\frac{\partial w^{GF}(b,R,W(R),e^{W}(b,c))}{\partial c}+\frac{\partial w^{GM}(b,R,W(R),e^{W}(b,c))}{\partial c}=1 \qquad (6)$$

Grandparents thus use (6) to decide on the total level of monitoring for different feasible choices of b, R and W. The division rule r employed to determine the allocation of individual monitoring efforts is straightforward; its only requirement is that it result in Pareto optimality. As in Lindahl's solution for financing public goods, the requirement for this is that the ratio of the total monitoring cost borne by GF and GM should be equal to the ratio of their respective marginal benefits from monitoring. Thus $c_{GF}=\alpha c(b,R,W(R),e^{W}(b,c))$ where $c(b,R,W,e^{W}(c,b))$ is the solution to (6) while

$$\alpha=\partial w^{GF}/\partial c=\frac{c_{GF}}{c(b,R,W(R),e^{W}(b,c))} \qquad (7)$$

and c_{GM} is determined analogously.[16,17]

Now the couple reaches its "consensus" on bequest, residence and cultivator decisions by maximizing a weighted sum of GF's and GM's utilities given (6) and (7). Thus their problem is

$$\underbrace{\max}_{b,R,W(R)}\ \lambda U^{GF}(b,R,W(R),c(b,R,W,e^{W}(c,b)),\alpha)+(1-\lambda)U^{GM}(b,R,W(R),c(b,R,W,e^{W}(c,b)),\alpha) \qquad (8)$$

subject to (2), (6) and (7), where λ is a parameter that can take values in the closed interval [0,1] and reflects exogenous intra-couple bargaining power.[18]

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[15] The standard condition for efficient public good provision is that the sum of marginal benefits from it be equal to its marginal cost.

[16] This is Pareto-efficient; for any other monitoring cost allocation, readjusting the allocation would have resulted in a Pareto improvement.

[17] Following Browning and Chiappori (1998) and other collective household models, I assume that the couple co-operates in maintaining this allocation. According to Browning and Chiappori, symmetry of information about each other's preferences and the continuous nature of interactions between the couple would suffice to rule out free riding and ensure co-operation on efficient outcomes.

[18] Collective models of households assume that a weighted average of the couple's utility function is maximized where the weights represent exogenous bargaining power. Decisions are assumed to be reached through some form of intrahousehold bargaining. Chiappori (1988) argued for minimal restrictions on this bargaining process. McElroy (1990) explained that the bargaining weights may depend on exogenous "distribution factors", the sex ratio, for instance. See Vermeulen (2002) for a survey.

3.3 Payoffs

In this sub-section I specify the utilities of the players in detail. First I focus on the utility of the young cultivator, W. The cultivator derives utility from the value of the family farm (which he or she may enhance as a result of his/her effort) and the power to bequeathe it to genetic descendants. He or she incurs a disutility of e from an effort choice of e.

First consider the case where W is female. How productive her efforts are is influenced by exogenous factors (like population density and nature of war threats) that determine a composite variable d in the range $[\underline{d},\bar{d}]$ where $\underline{d} \leq d \leq \bar{d}$ and increasing d signifies that men have a greater advantage in cultivation over women. Given d, an effort choice e enables her to enhance the value of the family farm from its initial value V_0 to $V^f(e,d)$, $V_e > 0$, $V_{ee} < 0$ (the value is increasing and concave in effort).Assume that an effort choice of zero adds no value : $V^f(0,.) = V_0$. Hereafter I suppress the dependence on d barring cases where it is important.

This young woman also derives utility from the ability to pass on the family farm to her genetic descendants. This ability is denoted by g. If she knows will be *unable* to pass on this asset to her child – perhaps because the farm is willed not to her but to her brother – g takes on a value of zero. In contrast, if the farm is willed to her, she is *certain* that she can pass on this asset to her genetic child, as maternity uncertainty is not a factor.g then takes on the value $\hat{g}$. Thus the young woman's utility is given by

$$U^f = u(V^f(e,d), g(b)) - e - \kappa(c) \qquad (9)$$

In (5), $\kappa(c)$ is the disutility this young woman faces if her parents or in-laws choose a total monitoring level c: $\kappa(0) = 0$, $\kappa'(c) > 0$. This disutility does not however interact with the woman's effort choice. As explained above, depending on b, g takes on values of either $\hat{g}$ or 0. Thus, for a female cultivator, g is independent of c. Note that d is the only exogenous parameter in (5); she chooses e to maximize (5), given d, b and c. Moreover, denoting partial derivatives of the function u by subscripts, we have $u_1 > 0, u_2 > 0, u_{11} < 0, u_{22} < 0$; u is increasing and concave in both arguments. We now state

Assumption 1: argmax $[\, u(V^f(e),0) - e - \kappa(c)\,] = 0$.

The utility the cultivator gets if she is sure that the asset cannot be passed to her heirs is lower than the cost of incurring any positive effort. Moreover, let Assumption 1 also hold if the cultivator is a male [argmax $[\, u(V^m(e),0) - e\,] = 0$].

Also, assume that for cultivators of either sex, $u(V_0,.) = 0 = U(V_0,.)$: if a young person exerts zero effort gross and net[19] utility are both zero (as is "effort" cost).This assumption amounts to a choice of origin of the utility scale.

Next we look at the utility of W when W is male. A male cultivator's utility is different in four respects from that of a female cultivator. First, as productivity differs between the sexes, for a male an effort choice of e, for given d, results in a final land value of $V^m(e,d)$. Secondly, a male experiences no sexual monitoring and hence the $\kappa(c)$ term is missing. Third, and strikingly, for a male g can take on different values depending on the extent of the older generation's monitoring of the cultivator's wife. More specifically, g = $p(c)\hat{g}$, where 0< $p(c) \leq 1$ is the cultivator's *paternity confidence*[20] (or the probability that he is the true father of his putative offspring), $p(0) = \underline{p}$ is the level of paternity confidence *in the absence of grandparental monitoring*, $p'(c) > 0$ and p (č) = 1 recalling that č represents the maximum possible total monitoring effort. Thus, a young male cares not only whether bequests are in his favor so that he can pass on the land to his putative offspring; he also cares about the probability that these offspring are really his, a probability that is influenced by the old's monitoring decisions. His utility is given by

$$U^m = u(V^m(e,d), g(b,c)) - e \tag{10}$$

Fourth, this concern about paternity – and hence grandparental monitoring - feeds into the young man's incentives to exert effort. This is reflected in the fact that $u_{12} > 0$. The two arguments of a young male cultivator's u function are "strategic complements". Strategic complementarity implies that a cultivator derives a higher utility from being able to add to the value of his asset (via his efforts) the more confident he is of passing on this high-value asset to his genetic heirs. Thus high grandparental monitoring increases a young male's marginal benefits from exerting effort on the land. As usual we have $u_1 > 0, u_2 > 0, u_{11} < 0, u_{22} < 0$.

[19] It can be checked that c will always be zero if e=0. This is due to Assumption 2 (see the end of this sub-section) which guarantees that grandparents can never experience a strictly positive utility when W chooses e=0. As long as e=0, therefore, grandparents gain nothing from monitoring.

[20] This is the case if the male cultivator is also the legatee, so that he can pass on the land to his putative offspring; he then cares about the probability that these offspring are really his. If he is not the legatee, on the other hand, g = 0 as he is then not in a position to pass on the land to his offspring, putative or otherwise.

Next we turn to GF and GM 's payoffs. First I focus on GM 's payoffs, discussing (4) in greater detail. Both grandparents derive utility from enhancements in the value of the family farm (as a result of $e^{W}(c,b)$) and from the ability to pass on the farm to their genetic grandchild. I denote this ability by *G*. *G* can take on a maximum value of Ĝ; this can obtain for GM if, for instance, the farm is willed to her daughter. [In that event, the daughter's children inherit and GM can be certain they are her genetic heirs as there is no maternity uncertainty in either generation]. If GM is unsure of whether the "grandchild" is really a genetic descendant (which could be the case if the "grandchild" is her daughter-in-law's child), $G = p(c)\hat{G}$. While monitoring can thus feed positively into her utility (both directly through the genetic component and indirectly via the effect of monitoring on effort choice), monitoring – as described in (4) - also involves a disutility or cost equal to the level of monitoring intensity c_{GM} that GM chooses. Thus we have

$$U^{GM} = w(V^{W(R)}(e(b,c)), G(b,c)) - c_{GM} \tag{11}$$

We have $w_1 > 0$, $w_2 > 0$, $w_{12} > 0$. Thus while the function w is increasing in both its arguments, the two arguments are also strategic complements. GM derives greater marginal utility from enhanced farm value (resulting from high effort by W) the more confident she is of the farm being passed on eventually to her genetic grandchild.

GF 's payoffs are very similar to GM 's. The only point of departure is his own uncertainty about the paternity of his (putative) children. However, his choices at this point in the game cannot affect his own paternity confidence, which we treat as given and designate simply by p . The effect of this is to lower the genetic component of GF 's utility relative to GM 's for similar choices of monitoring effort; so we have

$$U^{GF} = w(V^{W(R)}(e(b,c)), pG(b,c)) - c_{GF} \tag{12}$$

Without loss of generality, normalize $U^{GF}(V_0,.) = U^{GM}(V_0,.) = 0$ for the utility either grandparent gets when the young do not exert any effort: for convenience, I designate this Assumption 2.

Assumption 2: $U^{GF}(V_0,.) = U^{GM}(V_0,.) = 0$.

3.4 Equilibrium Concept

We focus on symmetric subgame perfect equilibria in pure strategies for the game described in the previous sub-sections. Consider a five-dimensional vector for the i[th] family $\varphi_i = \{b, R, W(R), c, e^W(b,c)\}_i$ such that GF, GM and W are optimizing as captured by equations (2) and (5)-(12). Let $U_i^{GF}(\varphi,..\varphi,..\varphi)$ and $U_i^{GM}(\varphi,..\varphi,..\varphi)$ denote the utilities of the i[th] family's GF and GM respectively, when the choices made by all N families are denoted symmetrically by φ .

Definition: We say that $\varphi = \{b, R, W(R), c, e^W(b,c)\}$ constitutes a symmetric subgame perfect Nash equilibrium if $\forall i$,

there is no φ'_i such that

(1) $\lambda U_i^{GF}(\varphi,..\varphi_i^{'},..\varphi) + (1-\lambda)U_i^{GM}(\varphi,..\varphi_i^{'},..\varphi) > \lambda U_i^{GF}(\varphi,..\varphi,..\varphi) + (1-\lambda)U_i^{GM}(\varphi,..\varphi_i,..\varphi)$

(2) $\lambda U_i^{GF}(\varphi_i^{'},..\varphi_i^{'},..\varphi_i^{'}) + (1-\lambda)U_i^{GM}(\varphi_i^{'},..\varphi_i^{'},..\varphi_i^{'}) > \lambda U_i^{GF}(\varphi,..\varphi,..\varphi) + (1-\lambda)U_i^{GM}(\varphi,..\varphi_i,..\varphi)$

and $\forall i$, W_i is choosing effort optimally according to $e^W = e^W(c,b)$.

3.5 Discussion of some Assumptions

Consider the timing of the game described in section 3.1. Can the old alter their bequest decision (made *before* the young choose effort levels) *after* observing the effort choices of the young? If so, they could try to enforce any given effort level by threatening to reverse a favorable prior bequest if lower effort were supplied by the legatee. However, this threat would not be subgame perfect. As the old have approached the end of their lifetime, they cannot gain by implementing the threat (they will not be around to experience the benefits of a higher farm value at this point)**.** And if reversing a prior bequest decision is even slightly costly, the old would only stand to lose by doing so [see Bruce and Waldman (1990) for a similar "finite period" argument made in a different context]. I therefore rule out this possibility and focus on the more interesting situation where effort is not strictly enforceable.[21] Moreover, as highlighted in section 1.1.1, the cultivators can be made residual claimants. What is important for this model is not whether effort is "low" or "high", but that with $u_{12} > 0$, a young male cultivator's marginal

[21] An implication is that the bequest announcements are credible commitments. This explains their timing : if the announcement is made in advance it can spur productive effort by the future bequest recipient.

benefits from exerting effort are increasing in his paternity confidence and hence in grandparental monitoring [so he would supply even higher effort if assured of high grandparental monitoring of his wife]**.**

As mentioned in section 3.2, I rule out fractional bequests. This is partly for tractability, and partly because dividing the productive asset is undesirable (Alexander (1974) discusses how many societies sought to avoid division of the family farm into inefficiently small units) and may also be impractical (for example, if one sibling lives away from home, it may not be possible for her to regularly return home to cultivate her share of the farm). I also assume that a child who has left the household to live with his or her spouse cannot work on the family farm; a weaker assumption that he or she can, but at a disadvantage, retains the spirit of the analysis but complicates it greatly. Hence the choice of R also constrains W.

The assumption that young men rely on the old to monitor their spouses (which the old may or may not do) reflects the advantage of the old in monitoring the sexual behavior of young women in the household, while the husbands may be too busy to do so themselves (equivalently, the paternity confidence of men have in the *absence* of monitoring by the old may be thought of as generated by their own necessarily limited monitoring). It is also supported by some empirical and anecdotal evidence as highlighted in section 1.2.

It will be convenient to discuss additional assumptions – such as the assumption that the grandparents in each family nominate only one young cultivator - once the main results from the model are presented in the next section.

4. Results

In this section, I first present some results relating to the Stackelberg aspects of the game described above. These relate to the chosen cultivator W's effort choice – specifically on how it reacts to grandparental monitoring c (observed by W) – and on how anticipating W's "reaction function" $e^W(c)$ affects the grandparents' monitoring decisions. Next, I use the equilibrium concept laid out in section 3.4 to illustrate the emergence of two specific equilibria (which obtain for different parameter zones). The first of these describes a M-M system and the second a P-P one.

4.1Results on Stackelberg aspects of the game

Proposition 1: In any equilibrium with *matrilocality* ($R = M$) where the daughter does the cultivation ($W = D$), and where either she or her spouse is the legatee ($b \in \{D, SL\}$), her parents never monitor her sexual behavior.

Proof: Recall that the daughter's utility function is given by (9). As either she or her spouse is the legatee, and as she has no maternity uncertainty, she is sure of being able to pass on the farm to her genetic children, hence has $g = \hat{g}$. Her problem therefore is

$$\underbrace{\max}_{e} u(V^f(e), \widehat{g}) - e - \kappa(c)$$

yielding effort choice e^f which satisfies the first order condition

$$V_e^f u_1(V^f(e^f), \widehat{g}) = 1 \qquad (13)$$

Note that e^f does not depend on c.

Now, grandparents – the daughter's parents – have to decide on the total level of monitoring using (6). GF's utility is now $w(V^f(e^f), p\widehat{G}) - c_{GF}$. As the grandchild who will inherit will be his daughter's child and there is no maternity uncertainty, the only factor which dampens the genetic component of GF's utility is his *own* paternal uncertainty *p*, which cannot now be affected through monitoring. The marginal benefits of monitoring to GF are

$$\frac{\partial w^{GF}}{\partial c} = w_1(V^f(e^f), p\widehat{G})V_e^f \frac{\partial e^f}{\partial c} = 0$$

as $\partial e^f / \partial c = 0$. Similarly, GM's utility is $w(V^f(e^f), \widehat{G}) - c_{GM}$. $G = \widehat{G}$, its maximum possible value, for GM due to the absence of maternity uncertainty in either generation. The marginal benefits of monitoring to GM are

$$\frac{\partial w^{GM}}{\partial c} = w_1(V^f(e^f), \widehat{G})V_e^f \frac{\partial e^f}{\partial c} = 0$$

Since the marginal benefits of monitoring for any positive c are zero, while its marginal cost is 1, grandparents optimally choose never to monitor their daughter. *QED*

The intuitions underlying Proposition 1 are twofold. First, maternal grandparents' genetic closeness to their daughter' child cannot be affected by their monitoring her behavior, due to the absence of maternity uncertainty. Secondly, the daughter's own incentives to exert effort on the family farm do not interact with monitoring, as she does not need to worry about the genetic relatedness of her own child, who reaps the benefits of her efforts. Therefore, her parents realize that monitoring her sexual behavior cannot improve her productive efforts. Since monitoring is costly and yields no benefits, they dispense with it.

Corollary 1: If grandparents want the cultivator to be female, (and plan to bequeathe the farm to her or her spouse) they always prefer her to be a daughter rather than a daughter-in-law.

Proof: A daughter-in-law would be just as productive as a daughter, as members of the same sex share the same productivity. However, if a daughter-in-law is the cultivator, grandparents face two choices. First, they may choose not to monitor. If they do this, GF 's utility will be

$$w(V^f(e^f), p\underline{p}\widehat{G}) < w(V^f(e^f), p\widehat{G}) \tag{14}$$

where the RHS of inequality (14) represents GF 's utility if the cultivator were his daughter, and recalling that $\underline{p}$ represents the son's paternity confidence *in the absence of grandparental monitoring*. Similarly, for GM , we have

$$w(V^f(e^f), \underline{p}\widehat{G}) < w(V^f(e^f), \widehat{G}) \tag{14'}$$

Inequalities (14) and (14') show that with a daughter-in-law or son as legatee, the grandchild who inherits will be the son's putative offspring. Hence grandparents would need to factor in the possibility that this grandchild may not really be the son's child, a factor which is absent if the cultivator/legatee is their daughter as her maternity is never in question. Their other option if they make a daughter-in-law responsible for cultivation while willing her or their son the farm is to supply a positive level of monitoring. For any positive monitoring levels, GF 's utility will be

$$w(V^f(e^f), pp(c)\widehat{G}) - c_{GF} < w(V^f(e^f), p\widehat{G}) \tag{15}$$

The corresponding inequality for GM is

$$w(V^f(e^f), p(c)\widehat{G}) - c_{GM} < w(V^f(e^f), p\widehat{G}) \tag{15'}$$

Inequalities (15) and (15') show that even with positive monitoring, both grandparents would be worse off choosing the daughter-in-law, rather than their daughter, as cultivator/legatee, on two grounds. First, the monitoring effort itself involves disutility, while from Proposition 1 they would not need to monitor their daughter. Secondly, even after monitoring, the grandparents might still be somewhat uncertain of whether their son is really the father of their daughter-in-law's child, while this factor is absent with a maternal grandchild. Thus this option is never chosen. *QED*

From Proposition 1 above, we note that in a M-M equilibrium with daughters working the land, we would have $\varphi = \{D, M, D, 0, e^f\}$ *or* $\varphi = \{SL, M, D, 0, e^f\}$. It makes no difference to the daughter's productive incentives whether she or her spouse is the legatee, because in both cases she is confident that the land can be passed on to her children (and his putative children).

We now derive some results which obtain when *W* is male. Recall that $w_{12} > 0$, reflecting that grandparents value increases in productive effort leading to increases in land value relatively more when surer that this land will be passed on to their genetic grandchild (ie when surer that the grandchild who is to inherit is really their child's offspring). The *magnitude* of w_{12} measures the extent to which a small increase in the grandparents' expected genetic relatedness with the putative genetic grandchild who is to inherit the farm will raise the grandparents' marginal utility from a higher final value of their land. In contrast, recall that w_1 measures grandparents' direct marginal utility from higher final land value (reflecting higher cultivator effort), while w_2 reflects their marginal utility from an increase in their expected genetic relatedness with the grandchild who is to inherit. We now state

Proposition 2: Consider any arrangement in which *W* is male and either he or his spouse is the legatee. Provided w_{12} is not too large relative to w_1, w_2 and $p'(c)$, the sensitivity of paternity confidence to grandparental monitoring, greater productive effort is always supplied if *W* is the grandparents' son rather than their son-in-law.

Proof: If *W* is male and either he or his spouse is the legatee, he knows he can pass on the fruits of his efforts to his putative children, but may be unsure of their paternity, which is a function of grandparental monitoring. Such a male cultivator's problem, from (10), is

$$\underbrace{\max}_{e} u(V^m(e), p(c)\hat{g}) - e$$

This yields an effort choice e^m which solves the first order condition

$$V_e^m u_1(V^f(e^m), p(c)\hat{g}) = 1 \tag{16}$$

From (16) optimal effort choice is a function of monitoring; $e^m = e^m(c)$. Totally differentiating the first order condition (16) with respect to e^m and c, and simplifying, we obtain

$$\frac{\partial e^m}{\partial c} = -\frac{V_e^m p'(c)\hat{g}u_{12}}{V_e^m u_{11} + V_{ee}^m u_1} > 0 \tag{17}$$

given $u_1 > 0, u_{11} < 0, V_e > 0, V_{ee} < 0, u_{12} > 0, p'(c) > 0$. Therefore, if grandparents monitor their daughter less when the cultivator is the son-in-law relative to the extent that they monitor their daughter-in-law when the cultivator is the son, less effort will be supplied when W is the son-in-law rather than when he is the son. Now consider the grandparents' choice of monitoring when W is the son; let the optimal level of total monitoring of the daughter-in-law be denoted by C. From (6), C solves

$$V_e^m \frac{\partial e^m}{\partial c}[w_1(V^m(e^m), pp(c)\widehat{G}) + w_1(V^m(e^m), p(c)\widehat{G})] + p'(c)\widehat{G}[pw_2(V^m(e^m), pp(c)\widehat{G}) + w_2(V^m(e^m), p(c)\widehat{G})] = 1 \quad (18)$$

The LHS of (18) sums both grandparents' marginal benefits from monitoring. Their marginal benefits stem from two sources; first, from the effect of monitoring on their son's productive incentives; and secondly, from the direct effect of monitoring on increasing their son's paternity confidence thereby boosting the genetic component of the grandparents' utility. The RHS of (18) is the marginal cost of monitoring. For C to be optimal, the second-order condition must ensure that the marginal benefits of monitoring are declining in monitoring intensity. Similarly, when W is the son-in-law, let $\underline{c}$ denote the grandparents' choice of the level at which they monitor their daughter. From (6), $\underline{c}$ solves

$$V_e^m \frac{\partial e^m}{\partial c}[w_1(V^m(e^m), p\widehat{G}) + w_1(V^m(e^m), \widehat{G})] = 1 \quad (19)$$

Note two differences between (18) and (19). First, in (19), grandparents derive no genetic benefits from monitoring their daughter, as maternity uncertainty is absent. This factor tends to lower the LHS of (19) relative to the LHS of (18). However, grandparents will still monitor their daughter at some positive level when their son-in-law is the cultivator so as to affect his incentives to exert effort. The second difference is that the grandparents' genetic component of utility is at a higher level in (19), as they know that the grandchild who will inherit will be their daughter's child and genetically related to her with probability 1, while in (18) the grandchild who inherits will be their son's putative child and genetically related to him with less than probability 1. Since $w_{12} > 0$, this second factor in itself however tends to increase the grandparents' incentive to monitor their daughter by increasing the marginal utility that they derive from increased farm value, therefore encouraging them to incentivize the cultivator. We shall show that under the conditions specified in the Proposition, the first effect dominates the second.

Now we evaluate the LHS of (18) *at the monitoring level optimally chosen when the cultivator is the son-in-law*, that is, at $\underline{c}$. We find that the LHS of (18) when evaluated at this level of monitoring is higher than the LHS of (19) provided

$$V_e^m \frac{\partial e^m}{\partial c}(1-p(\underline{c}))\widehat{G}[pw_{12}(V^m(e^m), p\widehat{G}) + w_{12}(V^m(e^m), \widehat{G})] < p'(\underline{c})\widehat{G}[pw_2(V^m(e^m), pp(\underline{c})\widehat{G}) + w_2(V^m(e^m), p(\underline{c})\widehat{G})]$$
(20)

where we have used the approximation

$$(1-p(\underline{c})\widehat{G}w_{12}(.,\widehat{G}) \approx w_1(.,\widehat{G}) - w_1(., p(c)\widehat{G})$$

Simplifying (20) using (19) and rearranging, it can be expressed as

$$\frac{p'(\underline{c})}{1-p(\underline{c})} > \frac{w_{12}(.,\widehat{G}) + pw_{12}(., p\widehat{G})}{[w_1(.,\widehat{G}) + w_1(., p\widehat{G})][w_2(., p(\underline{c})\widehat{G}) + pw_2(., pp(\underline{c})\widehat{G})]} \quad (21)$$

where the first argument of all the functions on the RHS of (21) is $V^m(e^m(\underline{c}))$ and has been suppressed for economy of notation. We see that (21) is likely to hold provided the conditions specified in the statement of this Proposition hold, that is, w_{12} is not too large relative to w_1, w_2 and $p'(c)$. In this event, the marginal benefits that (paternal) grandparents derive from monitoring their daughter-in-law at intensity $\underline{c}$ *exceed* the marginal cost of monitoring. By the second order condition, marginal benefits are declining in monitoring intensity, hence the optimal level of monitoring for these paternal grandparents necessarily exceeds $\underline{c}$: $C > \underline{c}$. Hence provided (21) holds, the effort supplied when W is the son-in-law is lower than that supplied when W is the son, or

$$e^m(\underline{c}) < e^m(C) \quad (22)$$

QED

For the rest of the analysis, we assume that the grandparents' utility parameters are such that the cross partial is relatively small compared to the direct partial effects and monitoring technology is not too ineffective so that (21) holds.

Lemma 1: Suppose grandparents' utility function w is *additively separable* in the "land value" and "genetic" components, so that $w^{GF} = f(V^W(e(b,c))) + h(pG(b,c))$,

$w^{GM} = f(V^W(e(b,c))) + h(G(b,c))$. Then it is *always* the case that if the cultivator/legatee is male, he supplies strictly more effort if he is the son rather than if he is the son-in-law.

Proof: With additive separability we have w_{12}=0. The lemma then follows from Proposition 2.

Remark: From Propositions 1 and 2, the extent to which grandparents monitor the sexual behavior of the young woman who lives with them is lowest (zero) when the cultivator/legatee is the daughter, highest when the cultivator/legatee is the son, and intermediate when he is the son-in-law.

Observation 1: If a set of maternal grandparents is monitoring their daughter (at level $\underline{c}$) when the son-in-law is cultivating, the grandfather always monitors less than the grandmother. If a set of paternal grandparents is monitoring their daughter-in-law (at level C) when the son is cultivating, the grandfather monitors less than the grandmother does, provided w_{22} is not too large.

Proof: First consider the case where a set of maternal grandparents is monitoring their daughter to maintain the incentives of their cultivator son-in-law. Denoting GF's share in total monitoring by $\widetilde{\alpha}$, and using (7) and (19), we have

$$\frac{\widetilde{\alpha}}{1-\widetilde{\alpha}} = \frac{w_1(V^m(e^m(\underline{c})), p\widehat{G})}{w_1(V^m(e^m(\underline{c})), \widehat{G})} < 1$$

given p<1 and $w_{12} > 0$. This proves the first part of Observation 1. Now consider the case where a set of paternal grandparents is monitoring their daughter-in-law to maintain the incentives of their cultivator son *and* to directly boost the genetic component of their utility by increasing the probability that the daughter-in-law's child (who inherits) is also the son's. Denoting GF's share in total monitoring by α^*, and using (7) and (18), we have

$$\frac{\alpha^*}{1-\alpha^*} = \frac{V_e^m \dfrac{\partial e^m}{\partial c} w_1(V^m(e^m(C)), pp(C)\widehat{G}) + pp'(C)\widehat{G}w_2(V^m(e^m(C)), pp(C)\widehat{G})}{V_e^m \dfrac{\partial e^m}{\partial c} w_1(V^m(e^m(C)), p(C)\widehat{G}) + p'(C)\widehat{G}w_2(V^m(e^m(C)), p(C)\widehat{G})} \tag{23}$$

Comparing the first term in the numerator of the RHS of (23) with the first term in the denominator, it is clear that the latter is greater given p<1 and $w_{12} > 0$. Comparing the second term in the numerator and the second term in the denominator, the latter is greater if w_{22} is not too large. A *sufficient,* but not *necessary*, condition for the paternal grandfather to monitor the daughter-in-law less than the paternal grandmother does, is that w_{22} should be small enough that

$$\frac{w_2(V^m(e^m(C)), pp(C)\widehat{G})}{w_2(V^m(e^m(C)), p(C)\widehat{G})} < \frac{1}{p} \tag{24}$$

That is, the genetic component of grandparental utility should not decline very fast. *QED*

Intuitively, maternal grandfathers will always monitor their daughters less than maternal grandmothers do. Their own paternity uncertainty with respect to their daughters lowers the marginal utility they obtain from an enhanced farm value because they are less certain (relative to their wives) that the daughter's child, who will inherit the farm, is their genetic descendant. Thus their incentives to influence the cultivator son-in-law's efforts are weaker. As paternal grandfathers are also uncertain of their paternity with respect to their sons, while paternal grandmothers are certain of being their sons' mothers, a similar effect obtains for paternal grandparents. However, here there is an additional benefit of monitoring the daughter-in-law, because by doing so, paternal grandparents directly boost the genetic component of their utility. Since the paternal grandfather's genetic component of utility is lower than the paternal grandmother's (because of his own paternity uncertainty with respect to his son), he has higher incentives to boost this component of his utility via monitoring. The first effect will dominate, though, unless marginal utility from the genetic component declines very sharply. Interestingly, this ties in with observations that women often play a more important role than men in monitoring the sexual behavior of younger women.

From Proposition 2 above, we note that in a P-P equilibrium with sons working the land, we would have $\varphi = \{S, P, S, C, e^m(C)\}$. GF's utility in this system would be $w(V^m(e^m(C)), pp(C)\widehat{G}) - \alpha^* C$ while GM's would be $w(V^m(e^m(C)), p(C)\widehat{G}) - (1-\alpha^*)C$ where α^* is determined by (23).

Next I turn to deriving the conditions that support the emergence of (i) a low paternity-confidence M-M equilibrium with daughters working the land with the ability to pass it on to their offspring, and (ii) a high paternity-confidence P-P equilibrium with sons working the land, with the ability to pass it on to their (putative) offspring. I use the equilibrium concept (symmetric subgame perfect Nash equilibrium) specified in section 3.4.

4.2 Results on M-M and P-P equilibria

So far I have been suppressing the exogenous variable *d* which determines relative effectivness in cultivation between the sexes. Now consider *d** such that

$$\begin{aligned}&\lambda w(V^f(e^f,d^*),p\widehat{G})+(1-\lambda)w(V^f(e^f,d^*),\widehat{G})\\&=\lambda\{w(V^m(e^m(C),d^*),pp(C)\widehat{G})-\alpha^*C\}+(1-\lambda)\{w(V^m(e^m(C),d^*),p(C)\widehat{G})-(1-\alpha^*)C\}\end{aligned} \tag{25}$$

From (8) and the previous sub-section's results, we see that *d** is the value of *d* at which the ratio of male to female productivity in agriculture is such that grandparents' utility (weighted in accordance with their exogenous bargaining power) is identical in a M-M system with daughters working the land and no monitoring, and in a P-P system with sons working the land while grandparents monitor daughters-in-law at intensity C. For *d>d**, the LHS of (25) would become lower than its RHS, so that grandparents would derive relatively greater weighted utility in the P-P system: the opposite holds true for the M-M system.

Proposition 3: Suppose *d<d**. A symmetric M-M equilibrium with $\varphi=\{D,M,D,0,e^f\}$ obtains either if (a) $\underline{c}$, the level at which maternal grandparents need to monitor the daughter to sustain the son-in-law's productive incentives is high, *or* (b) output is relatively unresponsive to male efforts for low or moderate levels of grandparental monitoring.

Proof: As *d<d**, there is no incentive for all *N* families to collectively deviate to $\varphi'=\{S,P,S,C,e^m(C)\}$: doing so would lower the weighted grandparental utility function for all of these families.

Now consider deviations by an individual family i to some $\varphi_i^{'}\neq\varphi$ when the other *N-1* families are implementing $\varphi=\{D,M,D,0,e^f\}$. Any deviation in the bequest recipient *b* to the non-resident sibling (here, the son) or his spouse lowers the cultivator-daughter's effort to zero by Assumption 1, as she is now certain that her children will not inherit the fruits of her effort. By Assumption 2, this in turn lowers her parents' utility to zero, therefore this is not a profitable deviation. Switching *b* to *SL* is not profitable either; as long as the daughter is the cultivator, it makes no difference to her incentives and therefore this deviation does not help the grandparents in any way. Similarly, switching *R* (to *P* instead of *M*) while retaining the daughter as the legatee is counter-productive. Now the resident sibling would be the son; neither he nor his wife would have any incentives to exert effort, knowing that the farm would not go to their children, lowering grandparental utility to zero by Assumption 2.

A more interesting deviation involves keeping b and R unchanged but switching to $W = SL$. As shown in the previous sub-section, if grandparents did this they would optimally monitor their daughter at a total intensity of $\underline{c}$, inducing an effort level of $e^m(\underline{c})$. The GF's share in total monitoring would be $\widetilde{\alpha}$ (specified in the proof of Observation 1 above). Given that grandparents are maximizing a weighted utility function, this deviation can be ruled out if

$$\lambda w(V^f(e^f), p\widehat{G}) + (1-\lambda) w(V^f(e^f), \widehat{G}) > \lambda\{w(V^m(e^m(\underline{c})), p\widehat{G}) - \widetilde{\alpha}\underline{c}\} + (1-\lambda)\{w(V^m(e^m(\underline{c})), \widehat{G}) - (1-\widetilde{\alpha})\underline{c}\} \quad (26)$$

This is likely to hold if the conditions of Proposition 3 are met. If $\underline{c}$ is relatively high, so that a lot of monitoring needs to be done to incentivize the son-in-law, *or* if male productivity responds only sluggishly to grandparental monitoring unless monitoring is very high (lowering $V^m(e^m(\underline{c}))$, the RHS of (26) falls, while the LHS is unaffected.

By Corollary 1, grandparents never find it worthwhile to replace their daughter's role as cultivator with the daughter-in-law. Another possible deviation involves family i grandparents switching b and R simultaneously – bringing their son to live with them while simultaneously nominating him as the cultivator/legatee. However, from (25), as *d<d** this would decrease their weighted payoff. In fact, their utility would fall even below the RHS of (25). While they would need to monitor their daughter-in-law at intensity C to sustain their son's incentives, they would in addition need to pay some compensation to their son's in-laws, who would be losing *their own daughter's* labor (recalling that other families follow a M-M system). Hence, this is an unprofitable deviation. Their other possible alternative is to bring only their son but not their daughter-in-law to live with them, while nominating him as the cultivator/legatee. However, without coresidence, grandparents are unable to monitor their daughter-in-law. Since paternal grandparents would optimally like to monitor their daughter-in-law at levels $\alpha^* C$ and $(1-\alpha^*)C$ respectively, their weighted utility now falls *below* the RHS of (25), to

$$\lambda(V^m(e^m(0)), p\underline{p}\widehat{G}) + (1-\lambda)(V^m(e^m(0)), \underline{p}\widehat{G})$$

Since this is lower than the RHS of (25), and since the RHS of (25) is lower than the grandparents' weighted utility in the M-M equilibrium for *d<d**, this deviation is not profitable either. Thus we have ruled out all possible deviations by the ith family's grandparents. The

cultivators never deviate because we have already derived they are already responding optimally in equilibrium.

We note that (26) also rules out the possibility of a simultaneous deviation by all *N* families to a system which is matrilocal but where sons-in-law cultivate. If (26) holds, the equilibrium payoff in this new system would be lower for each set of grandparents, and therefore would not be a profitable deviation. *QED*

We now focus on a different parameter zone, with $d>d^*$.

Proposition 4: Suppose $d>d^*$. A symmetric P-P equilibrium with $\varphi = \{S, P, S, C, e^m(C)\}$ obtains if the difference in monitoring costs between the P-P case and a case where the son-in-law is the cultivator/legatee is not too large relative to the differences in effort induced by these differences in monitoring levels.

Proof: As $d>d^*$, there is no incentive for all *N* families to collectively deviate to $\varphi' = \{D, M, D, 0, e^f\}$: doing so would lower the weighted grandparental utility function for all of these families. Moreover, there is no incentive for all *N* families to collectively deviate to a matrilocal equilibrium where sons-in-law cultivate and where their (putative) offspring ultimately inherit, provided

$$\begin{aligned}&\lambda\{w(V^m(e^m(C)), pp(C)\widehat{G}) - \alpha^* C\} + (1-\lambda)\{w(V^m(e^m(C)), p(C)\widehat{G}) - (1-\alpha^*)C\}\\ &> \lambda\{w(V^m(e^m(\underline{c})), p\widehat{G}) - \widetilde{\alpha}\underline{c}\} + (1-\lambda)\{w(V^m(e^m(\underline{c})), \widehat{G}) - (1-\widetilde{\alpha})\underline{c}\}\end{aligned} \tag{27}$$

If (27) holds, the weighted grandparental utility for all families would fall as a result of such a deviation. Note that (26) is a *sufficient*, but not *necessary*, condition for (27) to hold, given that the RHS of (25) exceeds its LHS as $d>d^*$. Even if (26) does not hold, (27) is likely to hold under the conditions specified in Proposition 4: the difference in extra monitoring costs between the two cases must not be too large compared to the induced differences in cultivator effort.

Now consider deviations by an individual family i to some $\varphi_i' \neq \varphi$ when the other *N-1* families are implementing $\varphi = \{S, P, S, C, e^m(C)\}$. Changing the bequest recipient *b* to the non-resident daughter or her spouse lowers the cultivator-son's effort to zero by Assumption 1, as he knows that his (putative) children will not inherit. Thus this deviation would lower grandparental utility to zero by Assumption 2. Switching *b* to *DL* is not profitable either; as long as the son is the cultivator, it makes no difference to his incentives and therefore this deviation does not help the grandparents in any way. Similarly, switching *R* (to *M* instead of *P*) while retaining the son as the legatee is counter-productive. Neither the resident daughter nor her husband would have any incentives to exert effort, knowing that the farm would not go to their children, lowering grandparental utility to zero by Assumption 2.

Another possible deviation involves switching W from S to DL. However, we know from Corollary 1 that grandparents always get less utility from entrusting cultivation to their daughter-in-law (while willing the farm to the son) relative to their utility when their daughter is the cultivator/legatee. And as $d>d^*$, we know from (25) that the grandparents' equilibrium utility in the P-P system is higher than the utility they would obtain by making their daughter the cultivator/legatee. Hence this deviation is unprofitable. By exactly the same token, this is also not profitable as a collective deviation by all *N* families; it would lower weighted grandparental utility for each family.

Another possible deviation involves family i grandparents switching *b* and *R* simultaneously – bringing their daughter and son-in-law to live with them while simultaneously nominating either as the cultivator/legatee. First, we note that given $d>d^*$, making the daughter the cultivator is not a profitable deviation; the difference in productivity between the sexes is large enough to outweigh any benefits due to reduced monitoring costs. Moreover, given (27), making the son-in-law the cultivator is also an unprofitable deviation. In particular, note that the grandparents' weighted utility from making the son-in-law the cultivator would be even lower than the RHS of (27). While they would need to monitor their daughter at intensity $\underline{c}$ to sustain their son-in-law's incentives, they would in addition need to pay some compensation to their son-in-law's parents, who would be losing *their own son's* labor (recalling that other families follow a P-P system).

Thus we have ruled out all possible deviations by the i^{th} family's grandparents. The cultivators never deviate because we have already derived they are already responding optimally in equilibrium. *QED*

In the parameter zone $d>d^*$, male productivity is sufficiently high relative to female productivity to cancel out the disutilities grandparents incur from having to monitor their son's wife and from suffering some genetic "grandparental uncertainty" (relative to the M-M equilibrium of Proposition 3 above where the cultivator is the daughter).

Remark 2: A P-P and a M-M equilibrium cannot coexist. They exist in different parameter zones ($d>d^*$ and $d<d^*$ respectively).

Observation 2: Condition (26) – which says that the monitoring intensity required to incentivize sons-in-law is relatively high, *or* that sons-in-law's efforts respond only sluggishly to low or moderate levels of grandparental monitoring – is sufficient to ensure that *either* a low paternity confidence M-M equilibrium with daughters cultivating *or* a high paternity confidence P-P equilibrium with sons working always exists.

Proof: Proposition 3 showed that condition (26) is necessary and sufficient for a low paternity confidence M-M equilibrium with daughters cultivating to exist when $d<d^*$. Proposition 4 showed that condition (26) is sufficient, but not necessary, for a high paternity confidence P-P equilibrium with sons cultivating to exist when $d>d^*$. *QED*

5. Discussion

The model shows how residence and inheritance patterns reinforce each other. Patrilineality, for instance, enhances the importance of ensuring that a putative heir is truly a genetic descendant – thereby enhancing the need to have patrilocality as a monitoring mechanism. Patrilocality, in turn, results in the need to sustain the incentives of a son to exert effort on the land (since he is the sibling who resides with his parents) – emphasizing the roles both of patrilineal bequests and of monitoring. Similarly, with a matrilineal system, establishing a child's paternity is less vital – especially if the woman is the prime economic contributor, in which case a son-in-law's co-operation is not of primary importance. This fits in perfectly with a matrilocal living arrangement: matrilocality in turn emphasizes the need to sustain the daughter's incentives, but not the son's or even the son-in-law's: thus monitoring is not needed. The fact that patrilocal-patrilineal arrangements were more common than matrilocal-matrilineal ones would reflect the fact that men were relatively more productive on the family farm under a wider set of exogenous conditions: in terms of the model, condition (25) was relatively likely to hold.[22]

[22] Drastic changes in exogenous conditions over time could lead a M-M society to transit to a P-P one as documented by Ember (1974), who links these changes to changes in war threats. Other types of shifts could also happen. For example, some matrilocal tribes in North East India have been transiting to patrilocality as *wet cultivation* – a mode of agriculture in which men play the dominant role – is becoming more common. The reverse

Paternity uncertainty continues to motivate modern men. Many societies – particularly western ones – have broken away from the extended family pattern, now that children no longer inherit their parents' occupations and can move beyond the family farm. In these societies, paternal kin can no longer play the role of "monitors". Men however must still confront a degree of paternity uncertainty and in this case

, their investment decisions in their putative offspring would then respond to subconscious cues of shared genes, such as facial resemblance.

5.1 Some additional issues

I have assumed that only one younger-generation adult – whether a young man or a young woman – cultivates each household's farm. While this assumption undoubtedly simplifies my analysis, dropping it does not change the essential results (as clarified shortly). Before discussing that, however, I discuss the motivation underlying the assumption.

First, this assumption is motivated by the fact that in the past labor in agriculture supplied by *family members* involved *either* a very large role for men – with women staying off the field and confining themselves to household duties, *or* predominantly female labor while their men did not play a part in farming but occupied themselves either in war or hunting (or occasionally in simply whiling away their time). (Boserup 1970). In fact this was true to such an extent that Boserup classified farming systems as "male systems" or "female systems".

Secondly, in the context of my model, it is not possible for a pair of grandparents to have *both* their children cultivate the land. This would imply that at least one sibling would not be able to stay with his or her spouse. Moreover, if a pair of grandparents tried to keep both their children *and* their spouses on the farm, this would not be acceptable to at least one of the spouses' parents who would lose their source of farm labor.

As a robustness check, I have checked the results with a more general formulation where *both* members of the young couple living with the grandparents (son and daughter-in-law in P-P, daughter and son-in-law in M-M) contribute to cultivation, with male and female efforts being (weakly) complementary. The results are essentially similar. Proposition 2 still holds so that grandparents monitor more when they live with their son and daughter-in-law (inducing greater effort on the son's part, and possibly on the daughter-in-law's part as well if male and female

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transition could also occur. Murphy (1956) mentions a patrilocal tribe in South America – the Mundurucu – who were initially patrilocal but shifted to matrilocality when trade shifted towards crops in whose production women had an advantage.

efforts are strict complements) than when they live with their daughter and son-in-law. Observation 1 on grandfathers' and grandmothers' relative monitoring goes through. We still obtain a high-confidence P-P equilibrium for some parameters and a low-confidence M-M equilibrium for another set of parameters. We find that the P-P equilibrium is more likely to obtain when male productivity is high relative to female productivity and when male and female efforts in agriculture are strongly complementary. Due to space constraints, I omit the mathematical results here, but they are available on request.

A second issue to highlight is that there are no "types" in my model. No one is inherently lazy or inherently responsible: every one chooses their effort levels – either in production or in monitoring – as rational optimizers.[23]

In Appendix B, I consider what happens when we extend this model to future periods when either a P-P or a M-M system has already been established, and discuss the dynamics of sexual monitoring and paternity confidence.

6. Conclusion : Back to Juvenal

The quotation with which I begin this paper is from the first-century Roman poet and satirist, Juvenal. Translated, the question asks "Who will guard the guardians?" Juvenal was referring to the need to guard one's wife from "immoral behavior". He adds "I know the plan that my friends always advise me to adopt : 'Bolt her in, constrain her!' But who can watch the watchmen?"

My model represents a partial solution to Juvenal's problem. In patrilocal-patrilineal societies, patrilocality functioned as a monitoring device: paternal grandparents and putative fathers shared a common interest in ensuring that any child born to a wife was not sired by an outsider. The grandparents would be the "guards" –guards who would not be easy to sway, as their self-interest coincided with their son's. In matrilocal-matrilineal societies, however, young men – sons-in-law residing with their wives' families – would face precisely Juvenal's problem. They could not credibly rely on maternal grandparents to monitor the behavior of their daughters

[23] Thus, for example, in the (out-of-equilibrium) event that paternal grandparents in a P-P system fail to monitor their daughter-in-law adequately, their son would, quite rationally, choose to supply low effort. However, in the next generation this same son would become a "grandfather" and would optimally like to monitor *his* daughter-in-law. Both of these reactions on the son's part are consistent with rationality; it is not the case that he was "lazy" when young and becomes "diligent" in his old age.

(the young men's wives): the ostensible "guardians" did not do their job, and there was no one to watch over them!

Appendix A : Appendix Table 1 : degree of paternity confidence and residence patterns

	Low paternity confidence	High paternity confidence
Patrilocal/virilocal	34	**51**
Matrilocal/uxorilocal/avunculocal	**18**	7

Source : Author's calculations from Table 2 of Gaulin and Schlegel (1980) , page 305. I group together all societies where couples reside with paternal kin – and likewise those where they reside with maternal kinsmen.

Thus the majority of mother-centered residence patterns entailed low degrees of paternity confidence, while the majority of father-centered residence patterns entailed high paternity confidence. Readers are referred to the original table for chi-square and p statistics.

Appendix B: *What happens once either patrilocality or matrilocality is established?*

The model in the text has focused only on the simultaneous *origin* of a particular set of inheritance patterns, post-marital residence patterns and levels of sexual monitoring. Here I very briefly consider what happens once a particular equilibrium – either a high confidence P-P equilibrium, or a low-confidence M-M one – establishes itself in a particular region.

Denote the period when the grandparents in the model in the text were monitoring while the young adults were working by period 0. Now consider the next period, period 1. Now the young adults of period 0 are the grandparents. There are two main differences from period 0. First, period 1 "grandfathers'" paternity confidence has been affected by the level of monitoring endogenously chosen in period 0; it is therefore $p(C)$ in a P-P society and $p(0) = \underline{p}$ in a matrilocal one. Secondly, in period 1, the *base level* of paternity confidence – which young men have *in the absence* of grandparental monitoring – may have changed. It could have become lower in a M-M society, because, for example, young women may have realized that with matrilineal inheritance, their economic dependence on their husbands had become insignificant and that they therefore had no need to assure them of their fidelity. For opposite reasons (greater economic dependence of women on men in a P-P society), it could have become higher in a P-P society. Denote this new base level by $\underline{p}_1$.

Subject to these changes, conditions similar to those in the text would ensure the maintenance of either type of equilibrium. However, we can say some interesting things about the dynamics of paternity confidence.

Appendix Result 1: Consider a P-P society. Suppose that at period 0, the conditions of Observation 1 hold, i.e, w_{22} is not too large, so that grandfathers monitor their daughters-in-law less than grandmothers do. Then over time, both grandparental monitoring and paternity confidence increase, converging to an upper bound in finite time. Paternity confidence at the upper bound may or may not be 1.

Proof: As argued above, in period 1, the new "grandfathers" in a P-P equilibrium have higher paternity confidence relative to period 0 grandfathers ($p(C) > p$). Now consider equation (18) which sums grandparents' marginal benefits from monitoring their daughter-in-law in period 0 to determine optimal period 0 monitoring, C. The parallel to that equation in period 1 determines period 1 monitoring C_1;

$$V_e^m \frac{\partial e^m}{\partial c}[w_1(V^m(e^m), p(C)p(c)\widehat{G}) + w_1(V^m(e^m), p(c)\widehat{G})] + p'(c)\widehat{G}[p(C)w_2(V^m(e^m), p(C)p(c)\widehat{G}) + w_2(V^m(e^m), p(c)\widehat{G})] = 1$$

(A1)

Moreover, it is clear that while grandmothers' marginal benefits to monitoring have not changed, grandfathers' have gone up. Since grandfathers' marginal benefits from monitoring were less than grandmothers', they have now – with the increase in *grandfathers'* paternity confidence – become closer to the grandmothers' marginal benefits. Thus total marginal benefits from monitoring increase. Given that marginal benefits are declining in monitoring levels (by the second order condition), this implies $C_1 > C$ and a corresponding rise in paternity confidence. Moreover, this pattern of rising monitoring and rising paternity confidence continues until either one of two things happens

(i) Grandfathers' and grandmothers' marginal benefits from monitoring become *equal* so that grandfathers and grandmothers share the burden of total monitoring equally. Say this happens at a total monitoring intensity of $c^* <$ č. Then monitoring *stabilizes* at this level from this period on while paternity confidence stabilizes at $p(c^*) < 1$.

(ii) Grandfathers' marginal benefits from monitoring remain lower than grandmothers' at the point where total monitoring intensity reaches č. In this case paternity confidence reaches 1 and further monitoring stops.

Appendix Result 1 thus shows that as long as mothers-in-law initially bear most of the burden of sexual monitoring in a P-P system, the system favors progressive increases in sexual restrictions and paternity confidence; these stabilize at a very high level. (Of course, this will be so only as long as a drastic shift in exogenous factors (for example, in wars or agricultural conditions favoring a transition to a M-M system, or in economic factors leading to the breakup of the joint family system) does not break up the P-P system. The shift would need to be drastic because by this time P-P would have become the established norm for this society.)

Appendix Result 2: Consider a M-M system. After an initial drop in paternity confidence, paternity confidence will stabilize at a (low) level. Parents will never monitor their daughters as long as the latter are the cultivators.

Proof: Since there is no monitoring in a M-M system where daughters cultivate the land (by Proposition 1), the level of paternity confidence is always the base paternity confidence in the absence of monitoring. As argued earlier, there is an initial drop in this level as young women adjust their behavior to their reduced economic dependence on their partners. After this, however, paternity confidence stabilizes at this new base level $\underline{p}_1$. Parents never monitor their daughter as the logic of Proposition 1 does not depend on the base level of paternity confidence.

Thus P-P and M-M systems evolve asymmetrically over time. While P-P ones are likely to become progressively more restrictive at least for a while, M-M ones do not become progressively more lax after some initial increase in laxity. Again, it is possible that changes in exogenous factors might lead a society out of M-M either into P-P or towards a modern urban setup with couples living away from their parents. The changes necessary to trigger a transition would need to be strong for the society to break out of the by-now-established norm of matrilocality.

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