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 paternity uncertainty while women do not face maternity 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 where paternity confidence is high and matrilineal where it is low, and (5) most societies with patrilineal inheritance were patrilocal while most societies with matrilineal inheritance were matrilocal. I explore the following related puzzles: (1) Why were patrilineal-patrilocal societies (PP) more sexually restrictive for women than matrilineal-matrilocal ones (MM)? (2) Why did the older generation in PP and MM societies play starkly different roles in sexual monitoring? (3) Why did most societies emerge as PP while a few became MM? (4) Can the correlation between inheritance and post-marital residence be explained without assuming the exogeneity of either? To answer these questions I look at the simultaneous determination of inheritance, residence, and levels of sexual monitoring/permissiveness.

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

JEL Codes: D02, D82, J12, C72.

1. Introduction

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

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[2] As I study 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.

in with her husband's family, or matrilocal with married daughters staying on in their dotal homes). I develop a hypothesis that unifies a set of curious findings into an intriguing relationship between paternity uncertainty, inheritance, and residence patterns and highlight its superiority over alternatives. Since I model the very long run, my aim is to show how these institutions could have evolved without the support of pre-existing norms. However, I also discuss the effect of norms, highlighting their role in equilibrium selection.

A rich literature in biology, sociology, psychology, and anthropology asserts that (1) paternity uncertainty reduces investment by men and their relatives 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 favour the male line in cultures with high paternity confidence, and the female line in low paternity confidence cultures; (4) in patrilocal societies, in-laws – particularly mothers-in-law – exercise close surveillance over their daughters-in-law, (5) inheritance and residence are strongly associated – most patrilineal societies are patrilocal and most matrilineal societies matrilocal. In fact, most societies developed a patrilineal-patrilocal (PP) system while far fewer developed a matrilineal-matrilocal (MM) system. I know of no theory unifying these disparate findings. This paper seeks to provide such a theory, thus adding to the literature on endogenizing institutions.

The facts above throw up some puzzles. What made PP societies sexually restrictive (for women) while MM societies were comparatively lax? Why, in particular, did the role of the older generation in monitoring co-resident young women differ starkly between the two types of societies? What drove most societies towards PP, while a minority became MM? (As I shall argue, high male productivity in agriculture is not a sufficient explanation in itself; nor is an altruistic model that bypasses paternity uncertainty). Finally, can one explain the strong correlation between inheritance and post-marital residence patterns without assuming the exogeneity of either? My model throws light on these puzzles, studying the simultaneous determination of inheritance, residence, and sexual monitoring levels.

I model an intergenerational game, characterizing a high-paternity-confidence PP equilibrium, as well as a low-paternity-confidence MM equilibrium. Paternity confidence is endogenous: it

depends on the degree of monitoring of the sexual behaviour of the young woman of the family by the older generation ("grandparents").

The intergenerational division of labour whereby only the young work on the heritable asset – the family farm – gives the old the leisure for monitoring – unlike the young women's husbands, who may 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 grandparents may choose to enhance. Monitoring, however, involves effort. So the old monitor only if it benefits them enough. Both young and old care about the value of the farm (which the young can enhance through productive effort) and about the ability to pass this farm to their genetic heirs. Also, 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 men, therefore, paternity confidence (as well as bequest expectations) influences their work incentives. This links the *expected* monitoring effort of the old with the work done by the young on the farm.[4] The old have a direct interest in monitoring, because they care whether the grandchild who inherits is a genetic descendant.

Note a striking asymmetry between the motives of maternal and paternal grandparents. Under MM, 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. The son-in-law anticipates this, generating a misalignment between his interests and those of his parents in law. This may not matter where, due to exogenous conditions, women cultivate [5] Even where sons-in-law cultivate, maternal grandparents do not monitor their daughters, since they cannot credibly pre-commit to do so. In contrast, paternal grandparents in a PP system actively monitor their daughters-in-law. Intuitively, under PP, paternal grandparents have a direct interest in ensuring that any child born

[3] This may be a product of factors such as faith in the marital relationship.
[4] However, as explained in more detail later,, the old cannot precommit to a particular monitoring effort, because young men cannot observe their level of monitoring (if young men had the leisure to do so, they would not require the old to monitor at all, and all sexual monitoring of wives would have been done by the husbands themselves). Therefore, the old could not use their own monitoring choice as a tool to influence young men's effort choices.
[5] We discuss later – drawing on research by Boserup (1970) and Ember and Ember (1971) – when this might be so.

to the daughter in law is really the son's. Therefore, these paternal grandparents' incentive to monitor is stronger. Their sons know that this is so.

Patrilocality and patrilineality are mutually reinforcing. 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 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 work incentives through patrilineal bequest; moreover, since the son knows that his parents have a direct incentive to monitor his wife, this knowledge boosts his work incentives. Patrilocality induces both patrilineality and monitoring. Patrilineality, patrilocality, and high paternity confidence support each other in an equilibrium of the intergenerational game.

I find that there may be multiple PP equilibria, which are Pareto rankable from the viewpoint of the grandparents and their sons. Pre-existing norms about the importance of wifely chastity may then act as selection devices and increase the likelihood of a PP system being preferred to an MM one. Other factors which increase the likelihood of a PP, rather than an MM system being chosen include technological changes in agriculture that favour male productivity.[6] Note that this is not obvious: even if men were more productive, elderly couples could get sons-in-law to cultivate, implementing MM. However, in my model, productivity improvements beyond a threshold boost the incentives of sons more than those of sons-in-law.[7]

In a matrilineal system, the daughter's children inherit, reducing the importance of paternity, the need for monitoring and for patrilocality. In fact, matrilocality is optimal, especially if the daughter cultivates. While matrilineality induces matrilocality, matrilocality creates a need to sustain the daughter's work incentives, which is best done through matrilineal bequest. Moreover, if the daughter cultivates, her parents' incentive to monitor weakens further, in fact they never monitor. However, even if the son-in-law is the primary cultivator, his parents-in-law cannot

[6] For example, dominance of plough based agriculture which requires strength.
[7] Other factors that expand the parameter range over which PP is definitely chosen over MM include a drop in the basal level of paternity confidence (in the absence of monitoring) and a rise in the effectiveness of grandparental monitoring.

influence his incentives by pre-committing to monitoring their daughter, and hence do not bother to undertake costly monitoring, which yields no genetic benefit to them. Thus, matrilineality, matrilocality, and low paternity confidence sustain each other in another equilibrium.

As my model involves the family farm as a heritable asset, my analysis does not apply to non-agricultural societies, such as hunter-gatherer societies.[8,9]

In Section 2, I first present evidence on the importance of paternity confidence to males and their kin, the positive effect of paternity confidence on paternal investment, the relationship between inheritance, residence, and uncertain paternity, the differential role of the older generation in monitoring young women in PP versus MM societies, and the role of the ability to pass on assets to children in inducing efforts to enhance those assets' value. Then, I discuss some related literature. In Section 3, I present my model, results and discuss a few extensions. Section 4 deals with five counter-arguments: (1) Can the facts be explained simply by greater male productivity in agriculture bypassing paternity uncertainty? (2) Can they be explained by the possibility that blood relatives are easier to monitor? (3) Can a model based on grandparental altruism, which bypasses paternity uncertainty, explain the facts? (4) If paternity confidence were wholly exogenous, rather than endogenous, would there be a reverse causation from paternity confidence to residence pattern, patrilocality evolving in high-confidence regions and matrilocality in low-confidence ones? As a related point, even if paternity confidence is endogenous, could it depend solely on economic factors, with no role for grandparental monitoring? (5) Can the facts be explained by a model in which the nature of the warfare threat (internal versus external warfare) determines residence patterns? Section 4 refutes each counter-argument. Section 5 concludes. The appendix contains some additional proofs and data.

[8] Botticini and Siow (2003) similarly qualify the applicability of their model.

[9] Contrary to what was believed earlier, new research on hunter-gatherer societies (Hill et al. 2011) shows that there is very little evidence of a patrilocal bias in such societies.)

2. Evidence and Some Related Literature

2.1 Evidence on Paternity Confidence and Paternal Investment

Evolutionary biology provides the logic for the assumption that genetic descendants are prized over others: natural selection favours 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 investment in putative offspring varies directly with paternity confidence across different species of males – primates as well as humans. Paternal investment is highest among monogamous forest-dwelling arboreals, and lowest among species that live in large groups with multiple males (where therefore other males have access to any male's mate). In human societies, he notes that in cultures with traditionally low paternity confidence (where for instance wives live in their dotal homes with their own parents or siblings, rather than in the husband's home) men direct investment towards their sisters', rather than their wives', children. He attributes this to the certainty that a man must share some genes with his sister's children (since he and his sister 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 behaviour 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. Many men in these cultures explicitly mention low paternity confidence as the reason for their investment strategy. Anderson et al (2007) find that men doubtful about the paternity of their children spend less time with the children, are less involved in their education and more likely to divorce their wives. Apicella and Marlowe (2004) find that men's investment in their children is predicted by the children's resemblance to themselves (a cue of paternity confidence) and by the men's confidence that the children's mothers had been faithful to them.

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.

2.2 Importance of Paternity Confidence for Paternal as opposed to Maternal Kin

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 favour maternal grandchildren over paternal ones. Parents are altruistic in their

model. As men value their children's utility less than women[10], 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 grandparents care about the ability to pass on an asset to a genetic grandchild. They need not be altruistic in the sense of Doepke and Tertilt.[11] However, it makes no difference to the model if the grandparents' concern over their son's paternity is generated by embedded altruistic concerns (i.e. if they care about their son's happiness and know that he is interested in his paternity).

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. 3 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 absence of a double standard regarding extramarital affairs, the incidence of extramarital sex among women or of wife sharing). They find that paternity confidence is best predicted by residential pattern, being significantly lower in matrilocal cultures. Kurland (1979) finds strong correlations between a matrilocal or avunculocal residence pattern (women staying on with their siblings) and measures of low paternity confidence based on high extramarital and premarital sex.

Table 1: Degree of paternity confidence and residence patterns

	Low paternity confidence	High paternity confidence

[10] Due to the presence of paternity uncertainty.
[11] Compatibility with altruistic motives is discussed briefly in section 4.3.

Patrilocal	34	**51**
Matrilocal	**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. Readers are referred to the original table for chi-square and p statistics.

Gaulin and Schlegel also found that important offices (such as that of headman) were 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 patrilineality in high paternity confidence cultures and matrilineality in low confidence cultures. Daly, Wilson, and Weghorst (1982), Alexander (1974), and 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 that men's investments in their sisters' children fell as paternity confidence rose. Thus, there was a strong association between inheritance, residence, and paternity confidence. A strong association between patrilineality and patrilocality, on one hand, and matrilineality and matrilocality on the other, is seen in Table 2, which presents cross-tabulations based on Murdock and White's Standard Cross-Cultural Sample – a controlled sample of world cultures from Murdock's Ethnographic Atlas corrected for regional diffusion effects and auto-correlations.

Table 2

Descent	Patrilineal	Matrilineal	Totals
Residence Shift at Marriage			
Wife to Husband's	**66**	3	69
Optional	4	2	6
Husband to Wife's	2	**24**	26
No Common	0	1	1

Residence			
Totals	72	30	102

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

As Table 2 shows, most cultures with patrilineal descent[12] 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.

2.4 Differential Grandparental Monitoring of Young Women

There is direct evidence of "grandparental" monitoring of young women's sexual behaviour in patrilocal societies. Burgess and Draper (1989) document "female hierarchy" within patrilocal families with mothers-in-law exerting constant surveillance over daughters-in-law, preventing them from meeting other men, and thus boosting the husbands' paternity confidence. 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 studies including Fukutake (1967), Lee (1979), and Draper (1997) which show that parents-in-law monitored the sexual fidelity of their daughters-in-law and would try to end the marriage if this was dubious. Voland and Beise (2005) describe mothers-in-law (in preindustrial Germany) as "daughter-in-law monitoring sensors" explaining that "indifference to the sexual behaviour of daughters-in-law…is also expensive because some of the grandchildren would not be one's own".

There is no parallel evidence of parents monitoring adult daughters in matrilocal societies. On the contrary, where daughters were significant economic contributors, parents often tolerated and certainly did not penalize sexual non-exclusiveness on the daughter's part. Poewe (1981) documents how, in some African M-M societies, girls' mothers and other matrilineal kin taught them that sexual enjoyment "need not be limited to one specific partner"; others were told that "the men are more than one" (Arnfred 2007). Women among the MM Nayars of central Kerala

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

with several simultaneous "unofficial husbands" (*sambandham*) besides their official one were never frowned upon by their kin; these unofficial unions were accepted and the unofficial partners (and *their* maternal kin) invited to ceremonial feasts (Gough 1959).

2.5 Strategic Complementarity

My model assumes that cultivators would be more eager to exert effort on improving the value of the family farm if they are surer of being able to pass it on to their children (the strategic complementarity assumption). There is evidence that real-life cultivators do think this way. Hutson (1987), in his detailed study of family farms in the U.S, finds that the ability to pass on land to one's children was a significant incentive to improve that land. Farmers who had no children, or tenant farmers who did not expect to pass on the land to their children, neglected improvements. In a very different culture (Bangladesh), Ahmed and Timmons (1971) found identical behaviour among cultivators who could not count on passing on land to their children .

When assured that their children can inherit the land they work, cultivators put in more effort on improving it. Moreover, in section 2.1, the direct relationship between paternity confidence and investments has already been emphasized. Combining these two, it is logical to conclude that when paternity confidence is relatively high, and (putative) children are to inherit, men will be more willing to invest in enhancing the value of the family farm. Intriguingly, there is parallel evidence from species of birds where bi-parental care is the norm. Davies (1992) finds that male songbirds increase effort on provisioning for their children in direct proportion to the time they had spent in monitoring their female partner (the children's mother) at the relevant period. The reverse relationship also exists, i.e., a fall in paternity confidence reduces effort; Sheldon and Ellegren (1998) experimentally removed some males from a population of collared flycatchers (a bird species); when they brought them back again, they found that these males sharply reduced efforts in provisioning for the children likely conceived during their absence (compared to control group males who were never removed).

2.6 Related Economics Literature

This subject has been understudied by economists. However, there has been some work by economists on men's preference for paternity assurance, and its implications; more generally,

there has been work on the impact of biological gender differences. The reasons for patrilineality have also been studied elsewhere. This work differs from mine because I study the simultaneous determination of all three issues; patrilineality, patrilocality, and high paternity confidence – while also addressing the puzzles mentioned in the introduction, and offering a rationale for the existence of some MM societies with a greater degree of sexual freedom (for women).

Cox (2007) emphasizes the potential richness of economic implications stemming from biological gender differences, concentrating on two; first, paternity is uncertain while maternity is not; and secondly, women and men differ in the fraction of their lives for which they are fertile. This second source of asymmetry between the sexes, differential fecundity, has also been explored by Siow (1998); he examines its implications for marriage markets, and gender roles in labour markets. There is also some economics literature on the first source of gender asymmetry, exploring the consequences of men's preference for paternity assurance. Doepke and Tertilt (2009) assume that women place a greater weight on children's welfare than men do, and they mention paternity uncertainty as one possible reason for this. Francesconi, Ghiglino, and Perry (2010) show how paternity uncertainty combined with overlapping cohorts of dependent children gives rise to stable families rather than to promiscuous bondings.[13] Both Saint-Paul (2008) and Bethmann and Kvasnicka (2010) treat marriage as a commitment device that removes or reduces paternity uncertainty. In my model, uncertainty is reduced through monitoring by the older generation. (I do not assume that the old can pre-commit to a certain level of monitoring; they may, however, monitor if doing so is in their direct interest). As already mentioned Diamond and Locay (1989) show that risk averse men invest resources in their sisters' children when paternity confidence is low: they also find empirical support for this.

Botticini and Siow (2003) examine why bequests were primarily patrilineal, *given patrilocality.* They reason that patrilineal inheritance was necessary to maintain the son's incentives to exert effort on the 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

[13] 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.

thus crucial to this model, but is treated as exogenous, while it is endogenized in my model. Unlike in my model, paternity uncertainty plays no role in Botticini and Siow. As I will explain in section 4, high male productivity *in itself* is insufficient to explain patrilocality.

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 used hoe cultivation, where women did most of the work, while more densely populated regions developed a system based on ploughing and domestication of draught animals, where men had an advantage. Thus, I treat population density as an exogenous determinant of 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 primary economic contributors. In contrast, if warfare threats are 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.

I consider only monogamous couples for two reasons. First, in societies that allowed polygamy, most men could afford only one wife (*ecologically imposed monogamy*). 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. Here, there is no heritable asset like a family farm, 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. A Model

3.1 Framework

Consider a family with at least one son and one daughter (later we consider additional siblings as well as families with only daughters, or only sons).[14] The family owns a farm (which is actually

[14]For convenience, think of the family having only one son and one daughter in the basic model, as in Botticini and Siow (2003).

owned by the elderly "parents", whom we refer to as "grandparents"). This farm needs to be cultivated by an adult from the younger generation, not by the "grandparents". Farm value v is a concave increasing function of the cultivator's effort e and a productivity parameter z:

$$v = v\,(e, z) \tag{1}$$

where $v_e > 0$, $v_{ee} < 0$, $v_z > 0$, $v_{zz} < 0$, $v_{ez} > 0$ (subscripts denoting derivatives). The positive sign of v_{ez} shows that productivity improvements enhance the marginal benefit of effort.

The cultivator's well-being U is a concave increasing function of this farm value and his perceived probability p of being able to pass on the farm to his genetic successors less the disutility of his/her effort (assumed to be equal to e); further, the marginal utility of farm value increases with p:

$$U = u\,(v, p) - e, \tag{2}$$

where $u_v \geq 0$, $u_{vv} < 0$, $u_p > 0$, $u_{pv} > 0$, the positive sign of the cross-derivative indicating that a cultivator prizes increases in farm value even more when relatively certain that the farm can be passed on to genetic offspring. Where the cultivator is female and inherits the farm, p = 1; but where he is male, p is a concave increasing function of the intensity c with which the sexual behaviour of his wife is monitored:

$$p = p(c) \tag{3}$$

where $p'(c) > 0$ and $p''(c) < 0$. This monitoring must be supplied by the grandparents, as the male cultivator lacks the leisure required to monitor his wife himself. Moreover, $p(0) > 0$; even if grandparents supply no monitoring, the cultivator still has some paternity confidence.

A1: *We further assume that for p = p(0), there is a maximum* $\bar{v}(p(0))$ *above which the cultivator loses interest in further increases in farm value. This is defined by*

$$u_v(\bar{v}(p(0)), p(0)) = 0$$

We do not make similar restrictions on u_v for other levels of p; at these higher levels of paternity confidence, cultivators may prize indefinite increase in farm value, so that u_v can be uniformly positive for $p > p(0)$. However, we can also accommodate the possibility that $u_v = 0$ *may* be

reached for other levels of p. Defining $\bar{v}(p)$ analogously to $\bar{v}(p(0))$, for p > p(0), we can check that $\bar{v}'(p) = -{}^{u_{vp}}/_{u_{vv}} > 0$, given[15] $u_{vp} > 0$, $u_{vv} < 0$.

A1 is motivated by the evidence we have presented of the reluctance of many men to pass on substantial bequests to putative heirs of doubtful paternity. Most in fact prefer to invest resources in their sisters' children. Where this option does not exist (perhaps because bequests are decided by the *pater familias*), they may choose not to invest at all, preferring to enjoy the fruits of any excess productivity above a minimum target in the form of increased leisure.

The sexes may differ in the productivity of effort, reflected in gender-specific differences in z, but there are no differences within each sex. We deal only with technological changes affecting male productivity while leaving female productivity unchanged at (say) z = 1. Moreover, we assume that fractional bequests are ruled out due to sufficient economies of scale.

The grandparents derive their utility from (a) farm value and (b) *their* confidence in their ability to bequeath the farm to *their* genetic successors less the disutility of monitoring the sexual behaviour of their daughter or daughter-in-law. Their utility, W, is given by

$$W = w(v, p(c)) - c \tag{4}$$

where $w_v > 0$, $w_p > 0$, $w_{vv} < 0$, $w_{pp} < 0$, $w_{vp} > 0$. The positive sign of this last term indicates that a higher farm value is even more attractive to grandparents when they are relatively certain that this farm can be passed on to a legitimate grandchild.

The grandparents choose the cultivator and the legatee and decide whether their son or their daughter will reside with them after marriage – all decisions observable by the young. They also decide how much to monitor the young married woman who lives with them. However, this monitoring effort is unobservable (except to the young woman` being monitored). The rationale here is that young men do not have the leisure to observe the grandparents monitoring their wives (if they did, they could have monitored their wives themselves). The young cultivator decides on cultivation effort.

[15] We obtain this by totally differentiating the expression $u_v[\bar{v}(p), p] = 0$.

Since young male cultivators with a given level of paternity confidence may, beyond a point, lose interest in further increases in bequest, grandparents too may do likewise for a given level of *grandpaternity confidence.* In a PP system, grandparents know the level of monitoring they supply, and therefore the level of grandpaternity confidence is the same as that of paternity confidence. In contrast, in a MM system the level of grandpaternity confidence is 1 because of the absence of maternity uncertainty. In a PP world, we denote the level of bequest at which grandparents may lose interest in further increases by $\bar{\bar{v}}$ (p), where this solves $w_v(\bar{\bar{v}}(p), p) = 0$ noting that $\bar{\bar{v}}'(p) = -{}^{w_{vp}}/_{w_{vv}} > 0$. In a MM world, grandparents, if they lose interest in further increases in bequest, do so at farm value $\bar{\bar{v}}$ (1), Of course, at levels of p higher than p(0), cultivators do not *necessarily* lose interest in higher bequests for some finite v; nor do grandparents: our results are all compatible with their never doing so. However, if they do, we also make the assumption that:

A2: $\bar{v}(p(0)) < \bar{\bar{v}}$ (1),

This assumption says that young cultivators who know that their wives are not being monitored by grandparents will lose interest in productivity improvements sooner than do grandparents who know for certain that their farm will go to a genetic grandchild. This is a reasonable assumption, considering that the cultivator is much less sure of his genetic link to the inheriting child, and is therefore likely to lose interest in increasing productivity beyond a relatively modest threshold.

3.2 Analysis

Botticini and Siow have proved that the patterns of residence and inheritance must coincide for efficiency. The young resident couple has a cost advantage in cultivation over a non-resident couple and should optimally be the cultivators. But then they should also be the legatees so as to maximize their incentive to invest in the farm. It follows that matrilocality and matrilineality should go together (MM) as also should patrilocality and patrilineality (PP).[16]The choice of the member of the couple who actually does the primary job of cultivation does not follow

[16] For completeness, a formal proof that grandparents never opt for patrilineal-matrilocal or matrilineal-patrilocal structures is included in the Appendix.

automatically: the son-in-law could in principle be the primary cultivator in an MM family and the daughter-in-law the primary cultivator in a PP one.

Lemma 1: Under our assumptions, the daughter-in-law will never be chosen as the cultivator.

Proof: The daughter-in-law's productivity, and therefore her contribution to farm value, will be matched by the daughter and the grandparents can never be as certain of their genetic link with her children as they can of their connection with their daughter's children. Thus, both as heir and primary cultivator, the daughter dominates the daughter-in-law.*QED*

Further, while the grandparents have an incentive to monitor the sexual behaviour of their daughter-in-law (to ensure that her children are indeed their grandchildren), they have no similar reason to monitor their daughter. Of course, if they monitored their daughter and succeeded in conveying this information credibly to their son-in-law (whenever he is the primary cultivator), they would increase the latter's paternity confidence and accordingly his eagerness to invest in the farm, resulting in an increase in farm value. However, as specified in the framework, the son-in-law cannot observe this monitoring effort and there is no way that the grandparents can commit to a given intensity of monitoring. Since monitoring is unobservable, costly and of no direct benefit to the grandparents, the son-in-law believes that they do not monitor – and they, in turn, do not. With no monitoring and perfect confidence in their genetic link to their daughter's children, the grandparents' utility under MM is

$$W_m = w\{v(z, e_m), 1\} \tag{5}$$

where e_m is the effort exerted by the cultivator under MM.

It follows that the grandparent's choices reduce to just three – MM with either daughter or son-in-law cultivating or PP with the son cultivating. Consider each of these options.

With MM, the grandparents have complete assurance of their genetic relatedness to the children who will eventually inherit. However, farm value will differ according to the productivity and effort of the cultivator. Where the daughter cultivates, she is sure that her biological children will inherit and therefore invests a maximum of effort. The son-in-law cannot share this confidence, all the more because he believes that the grandparents will not monitor the

sexual activities of their daughter. So if women suffer no productivity disadvantage, the daughter will add more to farm value than the son-in-law could possibly have done and will therefore be chosen as the cultivator and heir. However, as the productivity advantage of men mounts, this effect will eventually offset the negative impact of lower paternity confidence on effort. The son-in-law thereafter will add more to farm value than the daughter[17] and will be preferred by the grandparents to their daughter in the role of primary cultivator. We now have MM with the son-in-law cultivating. Since the grandparents do not monitor their daughter, c_m, the monitoring intensity under MM is 0, the son-in-law's paternity confidence is at its basal level p(0) and his optimal effort choice is

$$e_m^* = \text{argmax } [u\{v(z, e_m), p(0)\} - e_m] \tag{6}$$

– which, for an interior equilibrium, implies

$$u_v\{v(z, e_m^*), p(0)\}\ v_e(z, e_m^*) = 1. \tag{7}$$

Provided $u_v > 0$, (7) has a unique solution as its LHS is decreasing in effort while its RHS is constant. For the remainder of the paper, we assume that this holds at the farm value that the son-in-law optimally generates in response to his correct expectation that his parents in law do not monitor his wife: $R_1(p(0)) < \bar{v}(p(0))$, where R_1 denotes the cultivator's reaction function – his choice of v in response to a given expected level of paternity confidence, itself a product of grandparental monitoring. Under MM, such a reaction function reduces to a single point as grandparents do not monitor, and consequently p = p(0).

For the rest of the analysis, we concentrate on parameters such that the male productivity advantage (z) ensures that MM with son-in-law cultivating dominates MM with daughter cultivating, and focus on the PP case and a comparison with MM with son-in-law cultivating.

With PP, on the other hand the grandparents are not so sure of their genetic linkage with their eventual heirs. However, they can – and will – increase their confidence in this matter by monitoring the sexual behaviour of their daughter-in-law up to the point where the marginal

[17] Farm value (v) always increases with z (productivity improvements), regardless of the impact of productivity improvements on effort, at least until the satiation output $\bar{v}(p(0))$ is reached. This is formally proved in the Appendix.

benefit to them of additional monitoring matches its cost. Knowing this increases the paternity confidence of the son, induces increased effort, and adds to farm value – which in turn raises the marginal benefit to the grandparents of additional monitoring by them. Under PP, the optimal effort choice of the son is

$$e_p^* = \text{argmax } [u\{v(z, e_p), p(c^*)\} - e_p] \tag{8}$$

while the optimal monitoring intensity of the grandparents, again for an interior equilibrium, is

$$c^* = \text{argmax } [w\{v(z, e_p^*), p(c)\} - c]. \tag{9}$$

For an interior solution, these maximization problems yield

$$u_v\{v(z, e_p^*), p(c^*)\}\ v_e(z, e_p^*) = 1 \tag{10}$$

and

$$w_p\{v(z, e_p^*), p(c^*)\}\ p'(c^*) = 1. \tag{11}$$

which respectively define the effort choice of the son given the monitoring intensity and the grandparents' decision on monitoring given the effort level of the son.

Definition: Define a PP equilibrium as a pair (c*, e*) which solves equations (10) and (11) for a given z. Our equilibrium concept is a Nash equilibrium in pure strategies.

Note: Since v is monotone positive in e (given z) and p in c, we could alternatively define an equilibrium in terms of a pair (p*, v*) where $v^*(z) = v(z, e_p^*)$, $p^* = p(c^*)$. More precisely, (10) and (11) define two reaction functions $v = R_1(p)$ (the cultivator's reaction to a given expected level of p), and $p = R_2(v)$ (the grandparents' reaction to a given farm value) respectively.

We now prove an intermediate result that we need for Proposition 1.

Lemma 2: Suppose cultivators may reach $u_v = 0$ even at higher levels of $p > p(0)$. Given $R_1(p(0)) < \bar{v}(p(0))$, the cultivator's reaction function $R_1(p)$ must never cross $\bar{v}(p)$.

Proof: Suppose it does. Then, since the two functions are continuous and $R_1(p(0)) < \bar{v}(p(0))$, at the point of intersection, $R_1'(p) > \bar{v}'(p)$. But differentiating (10) with respect to both v and p, and simplifying,

$$R_1'(p) = v'(p) = -u_{vp}v_e^2/[u_{vv}v_e^2 + u_v v_{ee}] > 0 \quad (12)$$

while $\bar{v}'(p) = -{}^{u_{vp}}/_{u_{vv}} \geq R_1'(p)$ recalling that , at the common point, both arguments, v and p, are identical for both functions. This is a contradiction. QED

Lemma 2 does not however rule out the two functions touching tangentially: insertion of $u_v = 0$ in (12) makes the two slopes equal

In Proposition 1 below, we prove the existence of at least one equilibrium under PP. For the bulk of the proof, we look at the case where $u_v > 0$ for $p > p(0)$. Towards the end of the proof, we show that the result also holds for cases where $u_v = 0$ is reached at some finite level $\bar{v}(p)$.

Proposition 1: Under PP, the system has at least one equilibrium for any given z. An interior equilibrium (where the satiation constraint is not binding) is guaranteed if $R_1(p(0)) < \bar{v}\{p(0)\}$

Proof: From (12), we know the reaction function of the cultivator $v = R_1(p)$ in (v, p) space is positively sloped.

Now differentiate (11) with respect to e_p and c:

$$w_{pv}v_e p'de = -[w_p p'' + w_{pp}(p')^2]dc \quad (13)$$

$$\text{or } w_{pv}p'dv = -[w_p p'' + w_{pp}(p')^2]dp/p'$$

reducing to

$$dp/dv = p'(v) = -w_{pv}p'^2/[w_p p'' + w_{pp}(p')^2] > 0 \quad (14)$$

The reaction function of the grandparents $p = R_2(v)$ is also positively sloped.

Now, when the grandparents do not monitor at all, the cultivator still has some basal paternity confidence, p(0): he therefore still makes some effort and produces some output: $R_1(p(0)) > 0$.

On the other hand, as grandparents intensify monitoring indefinitely, paternity confidence rises to some finite maximum $\hat{p} \leq 1$, and the cultivator's effort is given by the e that solves

$$u_v\{v(z, e), \hat{p}\}\, v_e(z, e) = 1 \tag{15}$$

Both terms on the LHS are decreasing in e, the other quantities are constant, so there is a unique finite e (say $\hat{e}$) that solves this equation and an associated $\hat{v} = v(z, \hat{e})$. $R_1(\hat{p}) = \hat{v}$. Thus, R_1 hits the vertical through p(0) at a positive output level and makes a finite positive intercept $\hat{v}$ on the vertical through $\hat{p}$ (Fig. 1).

What about R_2? When the cultivator makes no effort, he generates no output. His parents might nonetheless have an incentive to monitor his wife, simply for genetic considerations. Thus, $R_2(0) \geq 0$ (call it $\underline{p}$, where $w_p\{0, \underline{p}\}\, p' = 1$).[18] Further, whatever the level of output, the cultivator's paternity confidence cannot be increased above the ceiling $\hat{p}$. So R_2 is asymptotic to the vertical through $\hat{p}$. $R_2(\hat{v})$ lies between $\hat{p}$ and $\underline{p}$ and is given by the p that solves

$$w_p\{\hat{v}, p)\}p' = 1 \tag{16}$$

Suppose $R_2(\hat{v}) = \tilde{p}$. Since R_2 is continuous and monotonic, $\tilde{p}$ is unique.

Now consider Fig. 1 which portrays the reaction functions in (v, p) space. In particular, consider the rectangle bounded by the p-axis, the verticals at p(0) and $\hat{p}$ and the horizontal at $\hat{v}$. R_1 rises in this region from a positive $R_1(p(0))$ to $\hat{v}$. R_2 increases from $R_2(0) = \underline{p} > p(0)$ to $R_2(\hat{v}) = \tilde{p} < \hat{p}$. Since both functions are continuous and monotonic, R_1 must intersect R_2 at least once in this region – and it must intersect it from the left to the right. Thus, there exists at least one equilibrium.

So far, we have ignored the constraints due to $u_v = 0$ and $w_v = 0$, if they exist for $p > p(0)$. If they do, the relevant constraint is the cultivator's, as this determines a ceiling on farm value. As Lemma 2 shows, given $R_1(p(0)) < \bar{v}\{p(0)\}$ (the condition in the Proposition and the same condition that ensures existence of an interior solution to the son-in-law's effort choice problem)

[18] Note that this is not necessary for the Proposition to hold. All that is necessary for the Proposition is that grandparents find it worthwhile to supply some positive monitoring as long as their son's effort is not too small (specifically, not smaller than $v^{-1}\{R_1(p(0))\}$).

the cultivator's reaction function R_1 never enters the region above $\overline{v}$ (p). In this case, the constraint shrinks the feasible set to a smaller region than the rectangle in Fig. 1; however, it does not affect the reaction functions or the proof that R_1 must intersect R_2 at least once, from left to right. **QED**

Though the analysis up to this point has been static, we may be interested in the stability (and not just the existence) of equilibrium in a dynamic version of this model. A simple dynamic extension that retains the Cournot-Nash spirit of the analysis would define (1) v_{t+1} as the farm value that maximizes U for given z and $p = p_t$, and (2) p_{t+1} as the paternity confidence level that maximizes W for given z and $v = v_t$.

$$v_{t+1} = R_1(p_t) \tag{17}$$

$$p_{t+1} = R_2(v_t) \tag{18}$$

An equilibrium of this system would be a self-perpetuating pair (p*, v*). Such an equilibrium would be locally stable if the system converged to it after a small disturbance. It can readily be seen that the analysis of our Proposition remains valid even in this variation. Also, if R_1 intersects R_2 from left to right, the relevant equilibrium (as at S in Fig. 1) would be locally stable. The reaction functions divide the region in the neighbourhood of their intersection into four sectors: as the arrows demonstrate, from any point in the north-west or south-east sectors, the system will move towards the reaction functions themselves while from any point on R_1 or R_2 or any point in the north-eastern or south-western sectors, it will converge monotonically on equilibrium. The equilibrium whose existence is established by the Proposition is locally stable.

Remark 1. The equilibrium may not be unique. But a consideration of the endpoints of the two functions in this region shows that if there are multiple equilibria, they must be odd in number, with each pair of stable equilibria separated by an unstable one between, as in Fig. 3. In particular, the initial and terminal equilibria will both be locally stable.

3.2.1 Multiple equilibria, Pareto rankability, and norms as a selection device

Multiple PP equilibria may occur for a given z, as noted in Remark 1, and shown in Fig 3, if there are multiple intersections between R_1 and R_2. This has implications both for selection between these equilibria, and selection of a PP versus an MM system.

A co-ordination problem exists in this case, because while the young know from the grandparents' announcements about the legatee, the residence system etc. that they are in a PP world, the grandparents cannot precommit to a particular equilibrium choice of monitoring level. Therefore, absent selection devices, none of the equilibria can be ruled out.

We first ask whether these multiple equilibria can be ranked. From Fig 3, there is a positive association between the equilibrium levels of v and p in the various equilibria; there are equilibria with low levels of both farm output and paternity confidence, and equilibria with high levels of both. This brings us to

Proposition 2: Grandparents as well as their cultivator sons prefer equilibria with higher levels of both cultivator effort and sexual monitoring (e and c), or equivalently, equilibria with higher levels of both farm value (v) and paternity confidence (p).

Proof: Totally differentiate the grandparents' utility function, (4), with respect to both v and c:

$$dW = w_v dv + (w_p p'(c) - 1)dc$$

From the envelope theorem, the terms pre-multiplying dc cancel out (given (11)), so that

$$dW/dv = w_v > 0. \tag{19}$$

Therefore, grandparents become better off at equilibria with higher levels of both v and c (and therefore p), despite supplying more monitoring effort. Similarly, totally differentiating the son's utility function, and using the envelope theorem and equation (10),

$$dU = (u_v v_e - 1)de + u_p\, dp = u_p dp > 0 \tag{20}$$

The sons are also better off at high v, high p equilibria despite supplying more effort. **QED**

Proposition 2 implies that multiple equilibria under PP are Pareto rankable from the point of view of the active players in the game under PP – the grandparents and their cultivator son.

This suggests the importance of a selection device that would enable the old couple and their son to co-ordinate on an equilibrium which satisfies all of them. Norms may play a role as a co-ordinating device here. For example, if a society has a norm stressing the importance of a wife's chastity, the son may expect his parents to choose a relatively high equilibrium level of sexual monitoring, to ensure compliance with this norm, and this induces him to make the correspondingly high effort choice. His parents know that, because the son is aware of the norm, he will choose high effort, and accordingly choose high monitoring as their best response.

The possibility of multiple PP equilibria, and Proposition 2, also have implications for whether the grandparents select a PP system or a MM one to start with. Which one they select depends on their anticipated utility under the rival systems – a comparison of (4) (substituting in the equilibrium levels of e and c under PP) – and (5). We will look at the factors governing this choice in more detail in Propositions 3 and 4 and Remarks 2 and 3 below. For now, we use Example 1 to illustrate our point.

Example 1. Consider a system with multiple PP equilibria as in Figure 3. Suppose that, given z, we have $w\{R_1(p_1),p_1\}-p^{-1}(p_1) < w\{v(p(0)),1\} < w\{R_1(p_3),p_3\}-p^{-1}(p_3)$. This simply states that grandparental utility under a MM equilibrium with sons-in-law cultivating lies between the utility the grandparents would obtain in the stable low level PP equilibrium at $(R_1(p_1), p_1)$ and that which they would get at the stable high level PP equilibrium at $(R_1(p_3), p_3)$.[19] If the initial level of paternity confidence is at a level above p_2 –that associated with the unstable root—the PP process will converge to the high level stable PP equilibrium at $(R_1(p_3),p_3)$, and knowing this, the grandparents will choose a PP system. They will also do so if norms stressing the importance of wifely fidelity serve as a co-ordination device leading sons to expect co-ordination on the high-level equilibrium, and to supply a correspondingly high level of effort. In the absence of such norms, or of other co-ordination devices, an initially low level of paternity confidence (below p_2) and a correspondingly low level of cultivator effort will lead the PP process to converge to the low-level PP equilibrium. In this case, pessimistic expectations would dictate a grandparental choice of a MM system instead.

3.2.2 Male Productivity Improvements: effects on Equilibria and Choices

[19] In the expressions above, we are using $c = p^{-1}(p(c))$ to denote the level of monitoring associated with a given p.

We first look at the impact of improvements in male productivity, z, on equilibrium under PP.

Proposition 3. As z increases under PP, the son will create more farm value while the grandparents intensify monitoring. A rise in z increases the equilibrium utility levels under PP.

Proof. Differentiating (1),

$$dv = v_z\, dz + v_e\, de$$

For given p (or c), differentiate (10) with respect to z and e:

$$u_v(v_{ez}dz + v_{ee}de) + v_e u_{vv}(v_z dz + v_e de) = 0$$

Eliminating de from these two equations,

$$dv/dz = u_v(v_{ee}v_z - v_{ez}v_e)/(u_{vv}v_e^2 + v_{ee}u_v) > 0.$$

The son's reaction function $R_1(p)$ shifts upward to a position like $R_1'(p)$ in Figs. 2 and 3 under these conditions. Note that, as z increases, $\hat{v} = v(z, \hat{e})$, also shifts upward.

The grandparents' reaction function expressed in (p, v) space, $p = R_2(v)$, is however independent of z. z affects its defining equation (11) only through v: changes in z imply movements along the reaction function, not shifts of it.

Now, if we are initially in a stable equilibrium (in the sense of Remark 1 above) at S in Fig. 2, the new equilibrium will occur to the north-east of the old at S', and the dynamics of equations (17) and (18) would lead to a monotonic convergence to the new equilibrium where both paternity confidence/grandparental monitoring and farm value would be intensified.

If, on the other hand, we start at an unstable equilibrium at U in Fig. 3, the shift in reaction functions with increase in z would move this equilibrium to the south west to U'. However, our starting point would now be in a zone from which expansion to an upper stable equilibrium at S' is automatic according to equations (17) and (18). Since every unstable equilibrium is flanked by stable equilibria, it follows that, in either event, an increase in male productivity advantage increases both paternity confidence and farm value in equilibrium.

A third possibility is that, if multiple PP equilibria initially existed, the shifts in the reaction functions following a rise in z could lead to the multiplicity vanishing, with only one intersection surviving, at a higher level of paternity confidence and farm value (Fig 4).

As z increases, the PP equilibrium slides up the grandparents' reaction curve to successively higher levels of farm value and paternity confidence. Further, by Proposition 2, grandparents (and their sons) enjoy successively higher levels of utility in consequence.[20] **QED**

Proposition 3 establishes that male productivity improvements increase the equilibrium utility obtainable under PP. The next result shows that male productivity improvements beyond a threshold tend to favor PP being chosen over MM.

Proposition 4. Suppose there exists a $\hat{z}$ such that $w\{\bar{v}(p(0)),1\} = w\{v(\hat{z}, e_p^*), p^*(c^*)\} - c^*$, where asterisks denote equilibrium values (of effort, paternity confidence, and monitoring) under PP. Then, PP is always chosen in preference to MM with son-in-law cultivating for all $z > \hat{z}$.

Proof: Consider the equation

$$w\{\bar{v}(p(0)),1\} = w\{v(\hat{z}, e_p^*), p^*(c^*)\} - c^* \tag{21}$$

The LHS represents the upper bound on grandparental utility under MM with the son-in-law cultivating. This reflects the upper bound $\bar{v}(p(0))$ on farm value in these circumstances, as from A2, the binding constraint on farm value is due to the cultivator's reluctance to produce more at p(0), rather than to any grandparental constraint. As this upper bound is invariant to increases in z, the LHS of (21) does not increase with z. However, the RHS denotes equilibrium grandparental utility under PP; from Proposition 3, this increases in z. We now consider two cases.

(i) If $u_v > 0$ for $p > p(0)$, and there are no bounds on the grandparental utility function, the grandparents' equilibrium utility under PP increases without bound with z; in this

[20] While Proposition 2 was for a given z, exactly the same envelope-theorem based proof shows us that even with z changing, we have $dW = w_v dv > 0$ as we have shown in Proposition 3 that $dv/dz > 0$. Grandparental utility goes up even though they are monitoring more. Similarly, we have $dU = u_p dp > 0$ as the upward shift of R_1 results in higher equilibrium levels of p.

case, $\hat{z}$ always exists. As z increases beyond $\hat{z}$, grandparents would obtain more equilibrium utility under PP than the finite maximum $\{\bar{v}(p(0)), 1\}$ attainable under MM, and choose the former.

(ii) Next, suppose that constraints $u_v = 0$ and $w_v = 0$ are in place for higher levels of p, for both cultivators and grandparents, and define $\tilde{v}(p) = \min[\bar{v}(p), \bar{\bar{v}}\ (p)]$. Then, the maximum attainable grandparental utility under PP is limited by the maximum feasible level of paternity confidence under PP, $\hat{p}$, and the bequest level at which $w_v = 0$ sets in for this level of paternity confidence; thus this upper bound is $w(\tilde{v}(p), \hat{p}) - p^{-1}(\hat{p})$**.** If this upper bound exceeds that under MM, $\{\bar{v}(p(0)), 1\}$, $\hat{z}$ will exist. PP is chosen over MM for further increases in z, as grandparental utility initially increases beyond the upper bound possible in MM and eventually becomes fixed at a strictly higher level. However, if the upper bound under PP is smaller than that under MM, $\hat{z}$ does not exist. **QED**

To sum up, when men and women are equally productive, MM prevails with daughters cultivating. But as male productivity advantage z increases, sons-in-law may replace daughters as primary cultivators. This will remain the dominant system if grandparents did not monitor the sexual activities of their wards; PP would never have evolved. Grandparents however have an incentive to monitor their daughters-in-law under PP – but none under MM.

As z increases, farm value v rises under both MM and PP through direct productivity effects. Under PP however there is an additional indirect effect. The initial rise in farm value induces grandparents to intensify monitoring, since $w_{vp} > 0$ This raises the son's paternity confidence and prompts him to work harder, further increasing farm value. The indirect effect on farm value adds to grandparental utility under PP but not under MM, making the former system relatively more attractive as z increases.

Under MM, the plausible cap that paternity uncertainty puts on farm value also sets a ceiling on grandparental utility. As z rises, can PP do better? The maximum feasible level of monitoring sets a ceiling on paternity confidence. Under PP, this ceiling imposes either a limit on farm value (and hence on grandparental utility), or directly on the grandparental

utility function (if lim w(v, $\hat{p}$) is bounded). If this limit exceeds the ceiling under MM, there will always be a value of z above which PP is preferred to MM.

How likely is $\hat{z}$ to exist? This depends largely on $\hat{p}$, and so, on monitoring technology. Given availability of devices such as segregation of sexes, confinement of married or post-pubescent women within the home and their restriction to household activities (as soon as productivity is high enough to permit it), dress codes that prescribe concealment of female figures, hair and even faces, all of which depend for their effectiveness on grandparental surveillance, there could be little difficulty in most societies in raising $\hat{p}$ almost to 1 as z rises. But if $\hat{p}$ approaches 1, the upper bound on grandparental utility approaches $w(\tilde{v}(1), 1) - p^{-1}(1)$ which, by Proposition 2, must exceed $\{\bar{v}\big(p(0)\big), 1\}$.

3.2.3 Further comparative statics: changes in basal paternity confidence and monitoring technology,

First, we consider the impact of changes in p(0), the basal level of paternity confidence without monitoring, holding other parameters constant. For instance, if young men get busier than usual, reducing the time and attention they can give their wives, this might reduce p(0), without impacting the effectiveness of grandparental monitoring.

Remark 2. A reduction in p(0) reduces equilibrium grandparental utility under MM with son-in-law cultivating, but has no effect on grandparental utility in a PP equilibrium (or in a MM equilibrium with daughter cultivating), *ceteris paribus.* Moreover, a reduction in p(0) increases the range of z over which PP is definitely chosen over MM with son-in-law cultivation.

The first part of the remark follows from totally differentiating (7), the first-order condition with the son-in-law cultivating, with respect to v and p(0) ; we obtain $dv/dp(0) = -u_{vp}v_e^2/[u_{vv}v_e^2 + u_v v_{ee}] > 0$, so that output under MM with the son-in-law cultivating falls with a fall in p(0). Clearly, this also reduces grandparental utility from a MM system with sons in law as the cultivators (w{v(p(0)),1}). However, p(0) does not enter grandparental utility under PP, or under MM with daughters cultivating. The second part of the remark follows from the definition

of $\hat{z}$ in (21). As $\bar{v}'(p) > 0$, a reduction in p(0) reduces the LHS of (21), $w\{\bar{v}(p(0)), 1\}$. However, p(0) does not affect the RHS; thus, maintaining the equality requires a fall in $\hat{z}$, as the RHS increases in z. But then, from Proposition 4, this implies that the threshold above which PP is chosen over MM falls with a fall in p(0), proving the second part of the remark.[21]

Next, look at an increase in effectiveness of grandparental monitoring—so that p rises for each level of c. For example, this could happen if the mother-in-law habitually participates in (or supervises) activities that her daughter-in-law does, making it easy for her to monitor.

Remark 3. An increase in effectiveness of grandparental monitoring increases equilibrium grandparental utility in PP while leaving that under MM unaffected, *ceteris paribus.* It also increases the range of z over which PP is preferred to MM with son-in-law cultivating.

Graphically, the rise in the effectiveness of grandparental monitoring can be shown in (v,p) space as a rightward shift of the grandparents' reaction function R_2; the relationship between output (v) and monitoring (c) remains unchanged, but each level of monitoring now results in higher p. The cultivator's reaction function does not shift; there is a movement along R_1 rather than a shift of the curve. The new equilibrium must then be at a higher level of both v and p. From Proposition 2, this implies that grandparental utility in the new equilibrium is also higher. Since grandparental monitoring is not a factor in MM, we have proved the first part of the remark; equilibrium grandparental utility under PP rises, while that under MM is unaffected. As for the second part, the LHS of (21) is unaffected, while, since equilibrium grandparental utility rises, its RHS rises holding $\hat{z}$ constant. Thus, to maintain the equality, $\hat{z}$ must fall, since the RHS is increasing in $\hat{z}$. Therefore, from Proposition 4, this implies that the threshold above which PP is chosen over MM falls as grandparental monitoring becomes more effective.

Combining our results so far, we see that PP tends to be favoured over MM if (i) male productivity advantage intensifies, (ii) social norms stressing wifely fidelity serve as a co-

[21] Note that a fall in p(0) implies that for low z, now MM with daughters cultivating will dominate MM with sons-in-law cultivating over a greater range, as well. This is because, while sons-in-law's productivity falls as shown when p(0) falls, the productivity of daughters is unaffected. Therefore, the range of z over which MM with son-in-law cultivating obtains shrinks at both ends.

ordination device, (iii) paternity confidence without grandparental monitoring falls, and (iv) the efficacy of grandparental monitoring rises.

3.3 Extensions: multiple children, families with only sons or only daughters, and changes in longevity

We have so far discussed the incentive structure of family heads with at least one son and one daughter. What about additional sons and daughters? Goldschmidt and Kunkel (1971) show that patrilineal societies either established impartible land inheritance (with primogeniture imposed in land-scarce economies or those where a feudal class sought to maintain the concentration of landholdings as in Japan and Western Europe)[22], or partible land inheritance with multiple sons jointly inheriting but living in an extended family, thus delaying the actual partition and with each brother working on the land that he is due to inherit[23](as in China, India, and much of Asia). My model can accommodate both setups. First, impartible inheritance is restricted to one son with the others leaving the family to seek fortunes and brides elsewhere. Then, the analysis of the model can be applied to this son's incentives, and to the grandparents' choice between a son and a daughter (or her husband) as cultivator-legatee. On the other hand, partible patrilocal inheritance involves a joint family with multiple married sons staying on the land, each cultivating the piece of land he is to inherit. Thus, this can be regarded as a blow-up of the problem we model, since the incentives governing these sons' actions will be unchanged. Alternatively, if matrilocality were to emerge, partible inheritance would involve multiple daughters inheriting and staying on in their dotal families after marriage. The incentives determining the choice between these options will be essentially the same as described above. The only change from the viewpoint of the grandparents is that, with partible inheritance under patrilocality, they would now have to monitor multiple daughters-in-law.

What about families that have only sons or only daughters? Families without daughters have no problems if the parameters favour PP, nor do families without sons if the parameters favour MM. But what if the situations are reversed? In an MM environment, a family without

[22] This was an incentive for the nobility. However, the authors note that commoners did not necessarily adopt the practices of the nobility. Many stuck to partible inheritance. Thus, individual choice continued to play a role.
[23] The partition did not take place while the grandparents were living.

daughters would have to acquire a daughter-in-law as co-resident and legatee. It can acquire her only by compensating the dotal family for the loss of a productive (and reproductive) asset of high value in an MM environment – thus leading to the emergence of a bride price. And, while in the bride's paternal home, her parents could be sure that her children were indeed their grandchildren, no such assurance is available for her in-laws unless they incur a monitoring cost. This will therefore be an inefficient arrangement and one that is unlikely to be achieved by bargaining between the parties – unless there are special circumstances that depress the value of the bride. In an MM environment, a Pareto-superior arrangement would be for the family without daughters to send their son to live with and work for his in-laws (possibly taking a share of his patrimony with him): a deviation from MM to PP would be avoided even in this case.

On the other hand, a family without sons – where the circumstances favour PP – needs a resident son-in-law who will inherit. This too is a Pareto-inefficient arrangement. The resident son-in-law will be low in paternity confidence and incentive to work: the gain that the family that imports him can expect will be less than the contribution that he was making in his parental home, so that his in-laws will be unable to compensate his parents for the loss of his services. A better device would be for the family without sons to send its daughters to reside with their in-laws, transferring its property to them at the time of marriage in the form of a dowry. Thus, in neither of these cases are the accidents of birth likely to cause a deviation from the dominant patterns of residence and inheritance that our earlier argument predicts.

It has been asserted that post-marital residence and inheritance are matters of social norms rather than individual choice. However, a social norm cannot persist for long if deviations from it are profitable for the parties concerned. Thus, if at least one family in the marriage transaction finds PP profitable and the other does not find it unprofitable, the transaction is unlikely to yield an MM outcome, whatever the prevailing norm. Sufficient such transactions will change the prevailing norm.

Finally, we might be interested in the impact of greater uncertainty about longevity on grandparents. If grandparents anticipate – whether correctly or incorrectly – a relatively short lifespan, they fear they will not have long to play their monitoring role. Accordingly, in a PP society, they would want their sons to marry early so that they (the grandparents) had more time

to monitor their daughters-in-law, with a greater probability of ensuring that most of the children born to her were really their son's. Of course, an emphasis on early marriage for men would also translate into early marriage for women (even more so, if there is a preference for wives to be younger than husbands).

4. Counter-Arguments

I now consider five possible counter-arguments, arguing against each separately.

4.1 Can Patrilocality Be Explained Simply By Greater Male Productivity?

Consider an alternative, simpler explanation of patrilocality that bypasses paternity uncertainty. It may be argued that in conditions favouring high male productivity (e.g. 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 here, the older generation may just as well keep their daughters at home, bring their sons-in-law to the farm, and entrust cultivation to them. As marriages occurred within a limited geographical area, a son-in-law who knew how to till a field in his native village A would presumably also know how to till one in neighbouring village B. To sustain his 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 an MM system (with sons-in-law cultivating) just as well as to a PP one. Where two systems do equally well, how could random choice between them generate the overwhelming predominance of the PP system?

My hypothesis, in contrast, explicitly addresses this issue. I explain why sons-in-law work less on their parents-in-law's farm than a son would on his parents' farm – an effort difference which, moreover, would intensify rather than disappear as male productivity improved. Hence, when the technology favours male productivity, 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 reflects a misalignment between his incentives and those of his wife's parents. As the paternity of their daughter's child does not interest them, they cannot credibly pre-commit to

monitor their daughter, eroding the son-in-law's paternity confidence and incentives. This effect is absent between a son and his parents; here all want the son's wife to be intensively monitored.

4.2 Playing Devil's Advocate: Blood Relatives

The above argument shows that patrilocality cannot be explained satisfactorily without some factor that makes sons-in-law systematically less effective cultivators than sons. One might of course claim that it is easier to monitor the work of blood relatives. Families might then prefer to have their sons, rather than their sons-in-law, live with them and cultivate their land. This could then explain patrilocality independently of genetic concerns.

However, there are at least four reasons to doubt this alternative hypothesis. First, if sons are intrinsically more effective, or require less monitoring than sons-in-law *independently of paternity concerns*, 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). Many studies on elderly care giving, help and sharing within families (contexts that require effort which does not directly affect the value of a heritable asset) indicate 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 (than their own) in matters like help and care giving. 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 received priority. Thus, though one might be tempted to argue that grandparents who own a farm might want it cultivated by their son, rather than son-in-law, in order to receive more care from him, it is not immediately clear that the old couple would receive less care from their daughter and son-in-law, than from their son and daughter-in-law. My hypothesis, however, is able to explain the dominance of patrilocality without relying on this argument.

Secondly, to assess whether blood relatives' productive efforts are indeed easier to monitor, or whether blood relatives perform better, we can examine the empirical literature on "successions" to important posts in firms by "family heirs" such as the offspring of the founder or the outgoing CEO. There is substantial evidence that family successors perform *worse* than

non-family successors in comparable firms – e.g. 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]. Bertrand and Schoar point out that some of these studies 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 ensures 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 offspring's 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.

Third, suppose that, nonetheless, blood relatives' productive efforts *are* intrinsically easier to monitor. Anthropological evidence indicates the existence of a large number of societies where kin marriage (e.g. to first cousins) was not only allowed but was *preferred*. In a subset of societies with preferential cousin marriage, in those where men usually married their mother's brother's (or sister's) daughter, the son-in-law *was* a blood relative.[24] Therefore, if 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 here. (Out of 45 societies where men preferentially married either their

[24] 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.

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 which 9 were patrilineal.[25] Further, according to Murdock (1957), which draws on a larger sample, 31 societies that favoured *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 must deal with paternity uncertainty. 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[26], the logic of my model would hold as long as the man is either explicitly interested in his paternity, or 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 interested either in their son's paternity or in the intensity of their genetic relatedness to the grandchild who inherits, an asymmetry will still obtain between maternal and paternal grandparents' motivations, and the model goes through. Thus, a model that factors in uncertain paternity is better able to explain why patrilocality should dominate even in societies where sons-in-law were blood relatives.

Finally, there is another argument against a model that completely bypasses paternity concerns. Suppose paternity concerns do not matter. Then, the old could offer young men output-based contracts (like fixed rent contracts) which, by making the young residual claimants, maximize their work incentives. Now this contract could be applied to a son-in-law just as well as to a son. The cultivator's concerns about whether his children would inherit the land he tilled 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 give rise to matrilocality as often as to patrilocality. This difficulty is avoided in a world of uncertain paternity. Here, the cultivator – if male - faces uncertain paternity and therefore his expectation about the grandparents' monitoring of his wife becomes a concern. This concern affects his work incentives *even if he is a residual claimant* because his marginal utility from exerting effort depends on his assurance of the fruits of his efforts being inherited by his genetic

[25] 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.

[26] Eg, If a husband's and wife's mothers are sisters, the husband's relatedness to 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 relatedness to his wife's child is p/2 + (1+q)/16.

offspring ($u_{vp} > 0$)**.** Moreover, making him a legatee would not remove his concern about paternity, because even if he could pass on the land to his "official" offspring, his overall utility as well as his marginal utility from exerting effort would be influenced by his paternity confidence, which is linked to *expected* 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.

4.3 Altruism

How about an alternative model based on altruistic grandparental preferences and high male productivity in agriculture, but bypassing paternity uncertainty? Suppose grandparents care about both their son's and their daughter's utility. Assume no gender bias. They can will the farm to only one child. Then, they will prefer to will the farm to their son since, being more productive, he can generate more utility from the farm than the daughter could, had she been given the farm.

However, the grandparents could equally well will the farm to their daughter, and have it cultivated by their resident son-in-law. Since the daughter benefits from the son-in-law's effort, she can achieve as high a utility gain from this arrangement as the son could have, if he were willed the farm. Therefore, the preponderance of PP could not be explained by such a model.

As a tangential issue, however, note that altruism is not incompatible with the model presented in this paper. For example, suppose that grandparents care about whether their paternal grandchildren share their genes because they are altruistic and know that their son will care about his paternity. This is completely compatible with our framework; we merely require grandparents to have some direct interest in monitoring daughters-in-law and boosting paternity confidence. Whether this is generated by an intrinsic preference for genetic grandchildren, or by an embedded altruistic concern for their sons, is irrelevant.

4.4 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 from direct genetic concerns.

Maternal grandparents lack such incentives. Even if their son-in-law, not their daughter, is responsible for cultivation, they cannot pre-commit to monitor their daughters, and hence do not use monitoring as a tool to influence the son-in-law's work incentives. This explains why low monitoring, and hence low paternity confidence, characterizes matrilocal societies.

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 exogenous; 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. While grandparents could keep their son at home and entrust him with cultivation, they could equally well keep their daughter at home and make their (resident) son-in-law the cultivator. If paternity confidence is already high, independently of grandparental behaviour, 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.

In addition, the evidence on the differential role of the older generation in monitoring young women in PP versus MM societies (section 2.3), is supportive of my model and casts doubt on the exogeneity of paternity confidence.

A related question: could lower paternity confidence in matrilocal societies simply reflect matrilineality and the resultant low economic dependence of women on men? 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 the conditions for the simultaneous origin either of MM and low paternity confidence/low grandparental monitoring or of PP and high paternity confidence/grandparental monitoring. My focus is on how these institutions *originate*, and pre-existing inheritance norms favouring or opposing economic independence for women are not relevant. Secondly, this point would certainly become relevant once matrilineality or

patrilineality had been established in a particular society. With an established inheritance norm, the differential impact of patrilineal/matrilineal inheritance on women's incentives shows up in the form of differences in p(0), the base level of paternity confidence which young men have *in the absence* of grandparental monitoring – which may then change. It would have fallen in a MM society, because young women have realized that matrilineal inheritance has reduced their economic dependence on their husbands and that they therefore had no need to assure them of their fidelity. It would however not change the fact that maternal and paternal grandparents would continue to have different incentives to monitor – with different effects on 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.

4.5 Warfare

Consider yet another explanation of post-marital residence pattern in terms of the nature of warfare threats faced by a society. Anthropologists such as Ember and Ember (1971), and Divale (1974) note a correlation between patrilocality and internal warfare and between matrilocality and its absence (with any existing war threats being purely external, that is, wars were fought with other societies and not within the same society). This may suggest that when warfare threats are at least sometimes internal, parents prefer to live with their sons for defensive purposes. They trust them more than their sons-in-law, for fear of an internal fight breaking out with the son-in-law's clan. Thus, internal warfare may give rise to patrilocality. If however, there is very little infighting in the society, and warfare is mostly external, sons-in-law have no disadvantage because they may be expected to cooperate against a common external enemy, just as sons would. Matrilocality may emerge in such circumstances, especially if women's contribution to subsistence is high. Moreoever, if warfare is external, men may have to spend much time away from home, leading to low paternity confidence. Not so if warfare were mostly internal. Thus, this alternative theory suggests a correlation between internal warfare, patrilocality, and high paternity confidence, and one between purely external warfare, possible matrilocality, and low paternity confidence, while bypassing the role of older adults in sexual monitoring.

However, a correlation between warfare and residence pattern is completely consistent with my theory. Consider a matrilocal society in which matrilocality is determined as in my model. Men of the same natal family are geographically scattered, having moved to their own wives' families. These men are then reluctant to initiate internal fighting, as they wish to avoid a conflict between their natal clans and the clan in which they currently live with their wives and children. In patrilocal societies, fraternal kin are clustered in the same area, and are more willing to initiate fights against other clans in the same society, giving rise to the association between patrilocality and internal warfare. Thus, residence pattern determines the nature of warfare, rather than being determined by it (reverse causation). Indeed Ember and Ember (1971) themselves mention precisely this possibility as a motivation for their investigation of the relationship between warfare and residence. Otterbein (1968) and Ross (1985) conclude that patrilocality, with its clustering of fraternal kin, tends to encourage internal warfare, and interpret their empirical findings as indicating a causality from residence patterns to warfare, rather than the reverse. (Ross (1985) involves regression analysis rather than correlations).

I now discuss two reasons to doubt the theory that warfare is the main determinant of post-marital residence patterns. First, if this were the case, predominantly peaceful societies should not be overwhelmingly patrilocal. Ember and Ember (1992) identifies societies that have been peaceful throughout their history; and Murdock's Ethnographic Atlas (1967) tells us about postmarital residence patterns in these societies. I find however that out of 37 peaceful societies, only 9 were matrilocal, while the rest were patrilocal (see Appendix B). (The proportions remain similar when we exclude non-agricultural societies from the sample of peaceful societies—we are then left with 28 societies of which 21 were patrilocal and 7 matrilocal.) As there was no warfare and there appear to have been no marked warfare threats in these societies, we need some other explanation for the importance of patrilocality even for these societies.

Secondly, suppose the warfare explanation is correct, and consider societies with purely external warfare threats. If the contribution of men to subsistence is high in such societies, grandparents will want men to cultivate, but will have no reason to prefer sons to sons-in-law, since the latter can be trusted against a common external enemy. Therefore, there should be no marked dominance of patrilocality in such societies; matrilocality with sons-in-law cultivating

should emerge as often. However, this is not the case. As shown in Korotayev (2003, Table 11), patrilocality increases with men's contribution to subsistence *even controlling for the nature of the warfare threat.* Thus, even among societies with purely external warfare, patrilocality rather than matrilocality emerged when men's contribution was sufficiently important. However, as just explained, a warfare-based theory is insufficient to explain this. Instead, we need some factor that makes the grandparents strictly prefer sons to sons-in-law, regardless of the nature of warfare. My theory provides such a reason. Paternal grandparents' genetic concerns provide them with an incentive for monitoring which maternal grandparents lack; knowing this, sons work harder for their parents than sons-in-law do for their parents-in-law. In turn, this knowledge induces grandparents to choose sons rather than sons-in-law as cultivators when male productivity advantage is high, regardless of the nature of the warfare threat.

Finally, the evidence mentioned in Section 2.3 on the differential role of grandparental monitoring in patrilocal versus matrilocal societies supports a model in which paternity confidence *is* in fact influenced by the role of the older generation.

How does warfare affect my model? If men often leave home to fight, thus reducing their ability to produce, grandparents may prefer women as cultivators. Daughters may then be chosen as cultivators under MM (by Lemma 1, they are always preferred to daughters-in-law).

5. Conclusion: Back to Juvenal

Juvenal, the first-century Roman poet and satirist, is famous for the question "Who will guard the guardians?" Juvenal was referring to the need to guard one's wife from "immoral behaviour". He adds "My friends advise me: 'Bolt her in, constrain her!' But who can watch the watchman?"

In PP societies, patrilocality functioned as a mechanism designed to solve Juvenal's problem: 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 were the "guards" – guards whose self-interest coincided with their son's. In MM societies, however, young men – sons-in-law residing with their wives' families – faced precisely Juvenal's problem. They could not credibly rely on maternal grandparents to monitor their daughters: the ostensible "guardians" did not do their job, and there was no one to watch over them!

Appendix A

Suboptimality of matrilineal-patrilocal or patrilineal-matrilocal structures. We normalize the cultivators' utility when certain that his or her children will definitely not inherit to zero: $u(.,0) = 0$. Consider an arrangement where the old couple live with their son, who cultivates; however, the daughter and her children inherit. Since the son's children cannot inherit, he avoids the disutility of effort ($e = 0$); this results in farm output of $v(0)$.[27] The grandparents' utility is then $W = w\{v(0),1\}$ reflecting the fact that while farm output remains at $v(0)$, grandparents benefit from passing on the farm to their daughter's children (matrilineality), with whom their genetic connection is unambiguous. However, note that $w\{v(0),1\} < w\{v(e_m),1\}$, which, by (5), is grandparental utility under MM, since e_m (the effort choice of a resident son-in-law, or a resident daughter) is strictly positive. Therefore, MM dominates matrilineality with patrilocality. The argument for the suboptimality of patrilineality with matrilocality is similar except that the grandparents' utility here is even lower, at $w\{v(0),p(0)\}$; this reflects the fact that their son's children inherit, but they cannot monitor their son's wife (since they do not live together), and therefore are unsure of a genetic link with these children. It is easy to see that this arrangement, too, is dominated by MM.

Proof that dv/dz >0 under MM with son-in-law cultivation. Suppose, on the contrary, that farm value v goes down with a rise in productivity, z. Consider a rise of dz in z. Then, we must have $dv < 0$. Now we have $dv = v_z dz + v_e de$. Since $v_z > 0$, we have $v_z dz > 0$. The impact of a rise in z on effort choice e incorporates two effects; a substitution effect and an income effect. The substitution effect encourages more effort by raising the marginal productivity of effort, given $v_{ez} > 0$. However, the income effect must also encourage more effort; as $dv < 0$, the value of total output has fallen, making more effort necessary. But then, the substitution and income effects reinforce each other and result in $de > 0$. But since $v_e > 0$, and $v_z dz > 0$, we then obtain $dv = v_z dz$

[27] In the text, we have chosen units such that $v(0) = 0$. Of course, if output were zero, exercising this option would also give the grandparents a utility of zero and would never be chosen as an option. The proof here is designed to show that the argument holds even if we allowed farm output to remain at some low positive level when zero effort is exerted.

+ $v_e de > 0$, a contradiction. Therefore, a rise in productivity can never induce a fall in output. Moreover, as long as the satiation output $\bar{v}(p(0))$ has not been reached, we cannot have dv = 0 when dz > 0. If we did, the rise in z would have no income effect on e, since output remains constant, while the substitution effect would induce greater effort by raising the marginal productivity of effort. Thus both the terms $v_e de$ and $v_z dz$ would be positive, resulting in their sum being positive; since the sum is dv, we have arrived at a contradiction. Thus dv/dz is necessarily positive until the satiation constraint becomes binding.

Appendix B.

The peaceful societies I extract from the Ember and Ember (1992) data are the Quiche, Bribri, Warrau, Carib, Cayapa, Siriono, Mapuche, Montagnais, Saulteaux, Slave, Kaska, Havasupai, Papago, Kimam, Manus, New Irelanders, Trobrianders, Tikopia, Pentecost, Marshallese, Copper Eskimos, Burusho, Lepcha, Garo, Semang, Vedda, Alorese, Turks, Irish, Lapps, Gond, Toda, Santal, !Kung, Nyakyusa, Wolof, and Tallensi. Of these 37, the Ethnographic Atlas (Murdock 1967) shows that matrilocality or bilocality (no fixed pattern) is the prevalent form in only 9 (the !Kung, Vedda, Garo, Marshallese, Bribri, Warrau, Carib, Siriono, and Kaska). Patrilocality is dominant in the rest.

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Figure 1: Existence and stability of PP equilibrium, unique equilibrium case

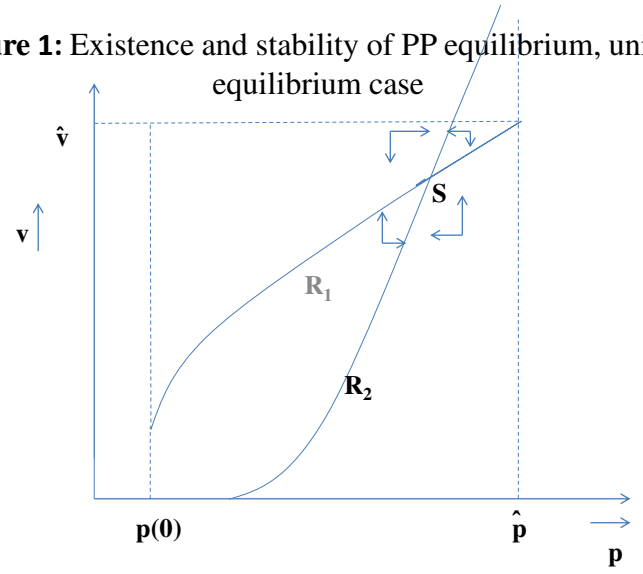

Figure 2: Comparative Static Effects of a rise in z, unique equilibrium case

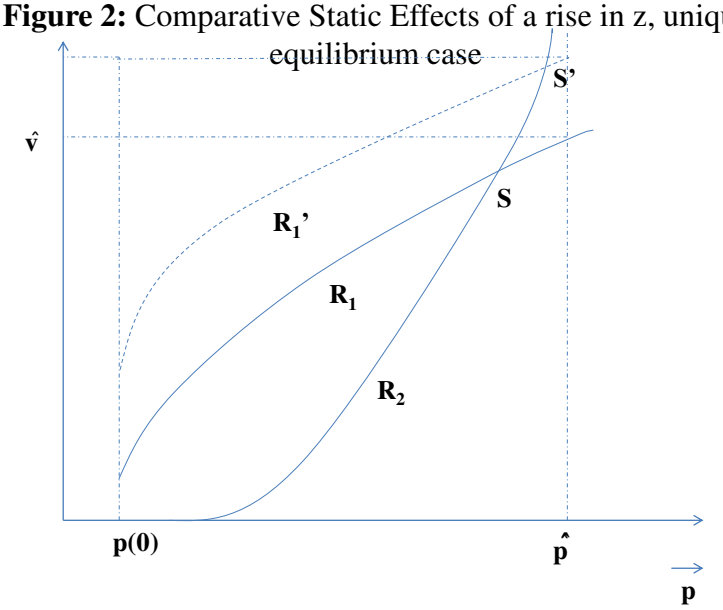

Fig. 3: Multiple P-P equilibria and the effects of a rise in z

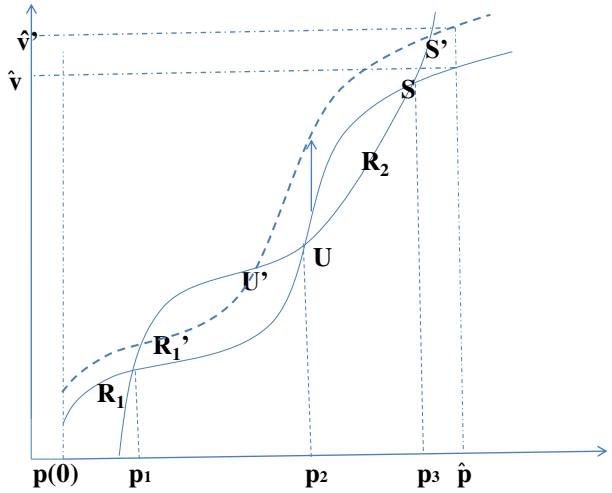

Figure 4: Multiplicity of P-P equilibria vanishing after a rise in z

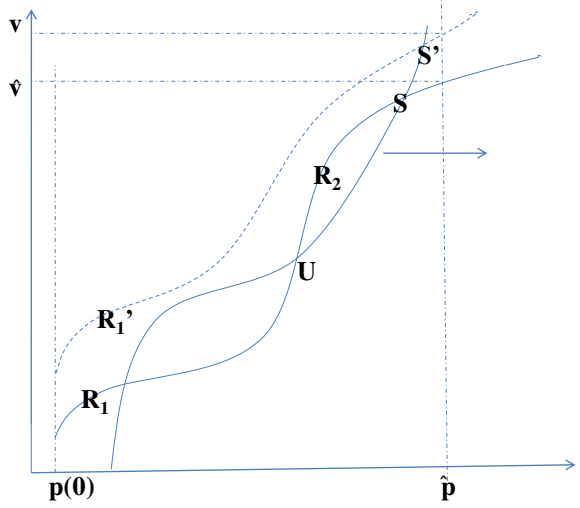

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Fig. 5