Gambling on Genes: Ambiguity Aversion Explains Investment in Sisters’ Children

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Abstract
Many men invest in their sisters’ children instead of their wives’. Existing theories addressing such behavior depend on the level of paternity probability in such men’s societies being implausibly low. I link this anthropologically observed investment behavior with the experimentally observed phenomenon that some individuals are ambiguity averse. Arguing that men’s decisions are made under ambiguity, I show that an increase in ambiguity aversion results in investment in sisters’, rather than wives’, children. I show that this can happen even under risk neutrality. I also consider the special cases of a SEU maximizer and of extreme ambiguity aversion in the Gilboa-Schmeidler sense. Extremely ambiguity averse individuals invest in sister’s children regardless of risk preference or actual paternity rates. An increase in ambiguity, rather than an increase in ambiguity aversion, in contrast, may affect the investment decision either way. When sufficiently many men are ambiguity averse, inheritance norms could become avuncular, affecting women’s incentives and generating a bias towards actual nonpaternity. This is consistent with, but represents an unusual explanation of, data which show correlations between inheritance norms and actual paternity rates.

1. Introduction
While women can be certain that the children they bear are their own, men throughout history have faced the risk that they may not be the true fathers of their wives’ biological children. As evident from recent court cases² on “paternity fraud” – men suing for damages when paternity testing revealed that they had been financially supporting children who were not in fact theirs – many men are extremely reluctant to invest resources in children whose genetic relatedness to themselves was in doubt. As biologists, anthropologists and psychologists have observed, there exist a number of societies where men direct resources towards their sisters’ children, instead of their wives’ [Alexander (1974), Kurland (1979), Gaulin and Schlegel (1980), Daly, Wilson and

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² The court cases were from several different countries – the US, UK, Australia and South Korea and spanned the period 2000-2008. A summary of some cases can be found at http://en.wikipedia.org/wiki/Paternity_fraud.
Weghorst (1982), Hartung (1985), Wilson (1987)]. This begs the question of why such an avuncular inheritance pattern, or more generally avuncular investment, should obtain. Of course, even in societies which traditionally do not have this pattern – for instance, in developed western countries like the US, the UK and Australia – individual men may remain reluctant to invest in their wives’ or partners’ children. A large number of the court cases mentioned above were in these countries and originated in the men’s urge to ensure that the children they were obliged to support were in fact theirs. Similarly, Anderson et al (2007), studying men in New Mexico, finds that men doubtful about the paternity of their children spend less time with the children, are less involved in their education and are more likely to divorce their wives.

The traditional explanation for why men in some societies invest in their sisters’ children is the expected relatedness theory developed by Alexander, Kurland and others. The theory can be summarized as follows. A man can be sure that he shares some degree of genetic relatedness with his sister’s children, provided he and his sister share the same mother. In this case, his genetic relatedness to her children is bounded between 1/8 (if he and his sister have different fathers) and 1/4 (if the sister is a full sibling). In contrast, his genetic relatedness to his wife’s children is either 1/2 (if he really is their father) or 0 (if he is not). The level of paternity probability in his society enters a man’s calculations of whether his expected relatedness with his wife’s children is higher than that of his sister’s children. A high level of paternity probability, on the one hand, increases his expected relatedness to his wife’s children by raising the likelihood that he is the true father. On the other hand, it could also push up his expected relatedness to his sister’s children simply by raising the likelihood that his sister is a full sibling of his, rather than a half sibling. The theory predicts that men will invest in their sisters’ children if the level of paternity probability in their society is below a certain threshold: for these levels, sisters’ children turn out to have a higher degree of expected relatedness than wives’ children.

This theory however runs into a difficulty. As Diamond and Locay (1989) also point out, the threshold level of paternity probability implied by the Alexander-Kurland model is very low, ranging from .28 to .33. This would imply a much higher nonpaternity rate (.67 to .72) than is observed in any society. [Anderson (2006) surveys 67 studies reporting nonpaternity rates: the highest rate reported was .55. However this was based on samples from paternity testing labs and therefore involved men who were sufficiently doubtful of paternity to request paternity tests.
Median worldwide levels of nonpaternity are estimated to be around .09 (Baker and Bellis 1995), though this is controversial.

Diamond and Locay show that if men are risk averse, they may direct their investments to their sisters’ children even for moderate to fairly high levels of paternity probability (.6-.85). In this paper, I argue that men’s decisions to invest in either wives’ or sisters’ children are made in an ambiguous, rather than a risky, environment. While a detailed discussion on ambiguity is deferred to the next section, in the present context it signifies that men do not know the exact probability that they fathered their wife’s child(ren); they also may not know the probability that they and their sisters were fathered by the same man. In an ambiguous environment, expected utility theory or the expected relatedness model of Alexander and Kurland do not work, as these theories assume that probabilities are known. I then prove that an increase in ambiguity aversion biases men towards investing in sisters’ children in preference to wives’ children, as long as men derive greater utility from giving their assets to an heir with whom they share a greater degree of genetic relatedness. In particular, this result is compatible with risk neutrality or even risk preference. In contrast, an increase in ambiguity, as opposed to an increase in ambiguity aversion, can affect the sister’s child/wife’s child investment decision either way. I contrast these results with alternative results obtained under the assumption that people are subjective expected utility maximizers; the comparison shows that ambiguity aversion can explain investment in sisters’ children over a wider parameter range. I then discuss factors that might influence the frequency of ambiguity averters in the male population, and argue that avuncular inheritance norms would obtain where this frequency is sufficiently high. Such inheritance norms, where they developed, could affect women’s incentives and behavior, generating a link between men’s ambiguity attitudes, inheritance patterns and actual nonpaternity, which as I will discuss is consistent with empirical evidence. In this case, however, the causal link would run from ambiguity attitudes, to inheritance norms to lower than average paternity probability. High nonpaternity might thus be a result of avuncular inheritance norms – while it is traditionally only regarded as a cause of such norms [as in Flinn 1981].

My analysis thus offers a solution to the difficulty with the expected relatedness theory mentioned above that differs from Diamond and Locay’s.

At this point I clarify why men who invest in an avuncular fashion direct their resources to their sisters’ children and not their brothers’ children. Even if a man and his brother share the
same mother and are hence genetically related, there is no guarantee that the brother is in fact the father of his putative children. Hence there is a risk that one may be genetically unrelated to one’s brother’s putative children. In fact, 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 – according to the men’s own accounts - they were unsure of the true paternity of their brothers’ putative children. All the studies mentioned earlier involving avuncular investment involve investment in sisters’ children.

This paper adds to a growing economics literature on the implications of uncertain paternity and more generally on themes like incentives motivating inheritance patterns. The notion of uncertain paternity is implicitly considered in Becker (1973) which emphasizes that one obtains utility from one’s own children. Bishai and Grossbard (2007) model bride price as payment for marital fidelity on the wife’s part, and use Ugandan data to demonstrate a robust negative relationship between the level of bride price and the incidence of extramarital sexual relations among women (and by implication potential higher nonpaternity). Saint-Paul (2008), Francesconi, Ghiglino and Perry (2010) and Bethmann and Kvasnicka (2010) all discuss uncertain paternity in the context of theories about the origin of marriage or of the family. Doepke and Tertilt (2009) discuss paternity uncertainty as a reason for why men may place lower weight on children’s welfare than women do. Korn (2000) discusses the disutility men in polyandrous arrangements face from uncertain paternity. Some other papers (Edlund 2005, 2006, Edlund and Korn 2002) emphasize “paternity presumption” – the legal presumption that a woman’s husband is the presumed father of her child. These papers usually model marriage as a transfer of custodial rights from a woman to her husband, and a man is assumed to care about presumed, rather than true, paternity – in contrast to my paper as well as the literature just cited which focuses on the importance that men place on true paternity. In addition, economists have studied inheritance norms. For instance, Botticini and Siow (2003) discuss the origin of patrilineal inheritance. None of these papers focus specifically on ambiguity, however, unlike mine.

This paper also adds to the literature on applications of ambiguity aversion (the theoretical and experimental literature on ambiguity aversion is partially discussed in sections 2 and 4). Etner et al (2011) provides a recent survey of work on ambiguity and ambiguity aversion ; Camerer and Weber (1992) provides an older one. The idea of ambiguity aversion has been
applied to fields like financial markets [Condie and Ganguli 2011, Ozsoylev and Werner 2011, Dow and Werlang 1993, Neilson 2007 are a few examples among many], game theory [Eichberger and Kelsey 2011, Jungbauer and Ritzberger 2011], auctions [eg Dickhaut et al 2011], insurance [eg Hogarth and Kunreuther 1985,1989], and problems of trade in general equilibrium models with asymmetric information [eg De Castro and Yannelis 2010, De Castro and Chateauneuf 2011]. By linking investment in sisters’ children to ambiguity aversion I highlight an important application of ambiguity aversion for which anthropological evidence exists. I also show how attitudes to ambiguity could explain how individuals make these investment decisions and discuss how this relates to inheritance norms favoring sisters’ children.

The plan for the rest of the paper as follows. In Section 2 I provide more background and facts on (a) paternal behavior and men’s investment decisions, and (b) ambiguity and ambiguity aversion. During the discussion I highlight the continued relevance of these issues. In Section 3 I explain how my problem ties these two areas together, and derive my results. Section 4 contains a detailed discussion while Section 5 concludes.

2. More on paternal behavior and ambiguity

2.1 More on paternal behavior

Evolutionary biology provides the driving force for genetic descendants being prized over others: natural selection favors individuals who direct scarce resources to those who share their genes, and away from competing claimants (a pattern of behavior biologists term “nepotism”). Accordingly, men faced a dilemma when deciding how much to invest in their partners’ children. If they were the real fathers of these children, the children would represent a better genetic investment than other, more distantly related, children. The problem however was that paternity was never certain, and men had to be wary of investing in unrelated children.

Evidence that paternity confidence influences the extent of paternal care and investment in offspring for all species of males was provided by Alexander (1974). He showed that among animals, males of species who lived in large groups where multiple males had access to any one male’s partner showed the least paternal involvement. Among humans, he noted that in cultures where, for instance, women lived on in their parents’ or siblings’ homes after marriage (instead of in their husbands’ homes) and so had greater freedom – men directed investments towards
their sisters’ children, instead of in their wives’. He attributes this to lower or variable paternity confidence among these men.

As noted by Aberle (1961), 84 out of a total of 565 societies listed in Murdock’s World Ethnographic Sample (a representative sample of all world cultures) had a matrilineal inheritance norm whereby a man would leave his assets not to his partner’s children, but to his sister’s children. If he did not have a sister with children, he would instead leave his assets to a brother who shared the same mother (but not to this brother’s children, for reasons explained in the introduction). (Note that a brother who shared the same mother was also certain to share some of the man’s genes, because of maternity being certain). Diamond and Locay (1989) use Flinn’s dataset listing a total of 150 societies which had matrilineal inheritance. According to ethnographers, societies where maternal uncles routinely passed on assets to their sisters’ children were quite varied in their characteristics. For instance, in many of them, either the sister or her children also lived with the maternal uncle³ (Aberle 1961). However there were others where men lived with their wives and children but nevertheless passed on their land and their titles (for example, offices as chiefs/headmen) to their sisters’ children, with whom they maintained a close relationship. Societies with matrilineal inheritance were also quite varied with respect to geographical location (a few examples being the Navaho of Arizona, Utah and New Mexico, the Nairs of Kerala – in southwestern India, the Trobriand Islanders – near New Guinea, the Tuareg of Mediterranean Africa, the Garos of the hills bordering Burma, the Ashanti of Ghana, the Na of southwestern China, and the Minangkabau of western Indonesia.) They also varied with respect to the dominant mode of economic activity (for instance, some were pastoral, while others were agrarian with hoe cultivation, while yet others were agrarian with plough cultivation or terraced farming).

As evident from the account above, men in a significant minority of world cultures chose to invest not in their partners’ children but in their sisters’ children (or failing that, in other matrilineal relatives, such as brothers sharing the same mother). Daly, Wilson and Weghorst (1982) mention similar behavior among the Masai, who had low paternity confidence due to traditions of wife-sharing, and among Naskapi-Montagnais men. Moreover, many men in these cultures explicitly mention paternity uncertainty as the reason for their investment strategy. It is

³ To put it another way, men lived with their sisters and the sisters’ children, while paying periodic nightly visits to their own wives or lovers.
interesting to note that in those matrilineal cultures where women traditionally lived with their husbands, the husbands usually had several wives (each wife lived in a semi-independent “hut” with her children). Therefore, the husband was often unable to monitor the sexual activities of an individual wife (Hughes 1982). Hence, there was more room for doubts regarding paternity. Gaulin and Schlegel (1980) and Hartung (1985) both found that men’s investment in their wives’ children was significantly negatively correlated with women’s sexual freedom, as measured by either (a) the absence of a sexual double standard, (b) the incidence of extramarital and premarital sex or (c) traditions of wife-sharing. Similarly, Diamond and Locay (1989), using Flinn’s dataset, find that while father’s kin constituted the major source of inheritance in 96% of societies with “very high” paternity confidence (where the index of paternity confidence was constructed by Flinn based on the prevalence of extramarital sex), they did so only in 14% of societies with “very low” paternity confidence.

I now briefly turn to some other work on paternal behavior. Anderson et al (2007) – studying men in modern New Mexico - finds that men doubtful about the paternity of their children spend less time with the children, are less involved in their education and are more likely to divorce their wives. 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 the mothers repeatedly emphasized to the putative fathers how much the infant resembled them (the fathers). The authors interpret this as a (mostly subconscious, and in some cases conscious) ploy on the mothers’ part to boost paternity confidence in their partners, thereby encouraging the putative father to invest in the child. Gaulin and Schlegel (1980) emphasize that even in cultures with a patrilineal inheritance norm, where fathers traditionally leave their property to their (putative) children, individual men who are doubtful about paternity remain reluctant to do so.

Turning to the preference that men have for investing in their sisters’ children as opposed to their brothers’ children, Gaulin, McBurney and Brakeman-Wartell (1997) have also shown that a matrilineal bias exists for uncles, with a mother’s siblings perceived to be significantly more solicitous on average than a father’s siblings. Interestingly, Gaulin et al’s study is not based on anthropological data but on experimental data collected from contemporary western college
students. A tendency to invest in sisters’ children, if not to share one’s inheritance with them, therefore persists in some degree even in modern western societies lacking an avuncular inheritance norm. 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 – from their own accounts - they were unsure of the true paternity of their brothers’ putative children.

It may sometimes be objected that individuals in modern society do not place any importance on genetic relatedness – citing the prominence of families with step children and adopted or foster children. However, the prominence of these family types does not prove that people no longer value genetic relatedness, or that men have stopped disliking the notion of ambiguous paternity. The issue of a step or adopted child differs from the problem under study. First of all, there is no ambiguity involved. Agreeing to raise a step or an adopted child involves an individual knowingly agreeing to raise another’s child, either (in the case of step parenting) driven by “mating effort” directed to the child’s biological parent, or (in the case of adopted children) due to lack of biological children, among other motives. Secondly, making a conscious decision to raise such children does not prove that biological children would not receive even more care. For instance, there is evidence that suggests that people on average favor biological over non-biological children in households where both are present (Case et al (1999), Wilson and Daly (1987), Daly and Wilson (1985)) : biological children receive more nourishment, and are less likely to be neglected or abused. Daly and Wilson (1985) found using Canadian data that children living with a mother and a stepfather were 40 times more likely to face child abuse than children living with both biological parents: in the vast majority of cases, abusive stepfathers never abused their own biological children. On a slightly different issue, there is also evidence of an investment bias towards sisters’ children (but not brothers’ children) in contemporary western societies (as in Gaulin et al 1997). Moreover, while paternity tests are available in modern times, their use has not become a norm, (instead of being used whenever a child is born, they are used on very rare occasions) and is in many countries and states subject to the consent of the child’s mother, and therefore cannot be used at will by the (putative) father. While avuncular inheritance norms were clearly developed by men in older societies before the advent of paternity testing technology, the advent of paternity testing by itself does not remove paternal ambiguity entirely.
2.2 More on Ambiguity

Knight (1921) first raised the distinction between “measurable uncertainty” or risk and “unmeasurable uncertainty” or ambiguity. Risk refers to a situation where an action is associated with a range of possible outcomes but the probability of each outcome is precisely known. Thus, one could calculate the expected utility arising from an action as

\[
E(U) = \sum_{s=1}^{N} p_s u_s
\]

where \( E(U) \) denotes expected utility, the action can yield a state-specific utility \( u_s \) in state \( s \), the total number of states is \( N \) (with states being numbered from 1 to \( N \)), and where the probability of state \( s \) occurring is \( p_s \), with \( \sum_{s=1}^{N} p_s = 1 \) (i.e., states 1 to \( N \) exhaust the set of possible outcomes).

In contrast, ambiguity refers to a situation where an action can lead to different possible outcomes, but the probability of each outcome is unknown. Therefore, it is not possible to compute expected utility as in (1). Accordingly, individuals making decisions under ambiguity must use some decision criterion other than maximization of expected utility.

Ambiguity was also mentioned by Keynes (1921) who believed that entrepreneurs’ profits represent a reward to their taking on ambiguity (as distinct from risk taking). Research on ambiguity gained prominence with the Ellsberg paradox (1961). The Ellsberg Paradox is best illustrated through the following example.

Example: Consider an urn with 90 balls. 30 of these balls are red while the remaining 60 are some combination of black and yellow. However, the number of black balls or of yellow balls is unknown. A ball can be drawn from the urn and a bet placed on its color. Now consider the following 4 bets (a) you win $50 if the ball drawn is red, (b) you win $50 if the ball drawn is black, (c) you win $50 if the ball drawn is either red or yellow, and (d) you win $50 if the ball drawn is either black or yellow. Ellsberg found that many people preferred (a) to (b) and (d) to (c), and argued that this was a violation of expected utility theory. To see this, note that for (a) to yield greater expected utility than (b), we must have

\[
p_{RR} u_R > p_{BB} u_B
\]
where the subscripts R and B denote red and black balls respectively, p denotes probability and $u$ a von Neumann-Morgenstern utility function defined over outcomes. Given the specific example, we note that $u_R = u_B = u(50), p_R = 1/3$. Now, note that the probability of a ball being either red or yellow is simply the sum of the probabilities of the ball being red and of the ball being yellow (and similarly for the probability of its being black or yellow). For (d) to yield greater expected utility than (c), we must therefore have

$$p_Bu_B + p_Yu_Y > p_Ru_R + p_Yu_Y$$

(3)

However, canceling the common term from both sides of (3), we get

$$p_Bu_B > p_Ru_R$$

which contradicts (2).

The explanation of the Ellsberg Paradox lies in ambiguity aversion. Ambiguity averse individuals dislike situations where probabilities are unknown. Note that while $p_R$ is known (to be 1/3), $p_B$ is unknown. In an extreme case, the subject may be afraid that all 60 of the “black or yellow” balls may be yellow. Therefore, an ambiguity averse individual will prefer bet (a) to bet (b). At the same time, however, while the probability of being black or yellow is known ($p_B + p_Y = 2/3$, since 60 of the balls are either black or yellow), the probability of being red or yellow is not (since while $p_R$ is known, $p_Y$ is not). Hence this same ambiguity averse individual will prefer bet (d) to bet (c). [See Machina (2009) for an analysis of how the Ellsberg urn experiment involves both subjective uncertainty (with regard to the color of the ball) and objective uncertainty (related to the draw itself) and associated theoretical implications].

Subsequently, there has been a large experimental literature on attitudes to ambiguity [Hogarth and Kunreuther 1989, Heath and Tversky 1991, Fox and Tversky 1995, Chua and Sarin 2002, Dominiak and Schnedler 2011, among others] which confirms that many individuals are, indeed, ambiguity averters. There has also been some work on the determinants of ambiguity aversion. For instance, Heath and Tversky (1991) and Fox and Tversky (1995) find that a feeling of incomplete information increases ambiguity aversion while individuals who are very confident of their knowledge are ambiguity-seeking.

What decision criteria do individuals use in the presence of ambiguity? The axiomatic foundation for the decision-making criterion I use in this paper was developed by Klibanoff,
Marinacci and Mukerji\textsuperscript{4} (2005) “the smooth ambiguity model”; somewhat similar models are also developed by Nau (2006), Chew and Sagi (2008) and Ergin and Gul (2009). [Other recent theoretical work on ambiguity includes Cerreia-Vioglio et al (2011), Klibanoff et al (2011), Nau (2011). Jewitt and Mukerji (2011) examines the comparative statics of an increase in ambiguity. More generally, theoretical work on violations of expected utility, or “subjective” expected utility – where the underlying idea is that although probabilities are unknown, individuals have prior beliefs about possible distributions of probabilities - includes Machina and Schmeidler (1992), Machina (2004) and Machina (2005), among others. Machina (2005) summarizes other theoretical approaches to violations of expected utility].

In the KMM model, ambiguity aversion is modeled as a dislike of uncertainty over expected utility; an ambiguity-neutral individual would simply be a subjective expected utility (SEU) maximizer who maximizes the expected utility over a distribution of priors about probabilities. In mathematical terms, individuals maximize a function $E_{\mu} G(E_{\pi} uof)$, where $E$ is the expectations operator, $f$ is an act, $u$ is a von Neumann-Morgenstern utility function, $G$ is an increasing transformation, and $\mu$ is the decision-maker’s subjective distribution over the set $\Pi$ of probabilities $\pi$ that the decision-maker considers relevant based on his information. Klibanoff et al prove that ambiguity aversion is equivalent to concavity of the function $G$. In contrast (as also argued by KMM), if $G$ is linear, the decision criterion reduces to subjective expected utility maximization; the only difference from expected utility maximization being that expectations need to be taken over priors regarding probabilities. Convex $G$ represents ambiguity-seeking behavior. In addition, another well-known formulation of ambiguity aversion – the Gilboa-Schmeidler or MEU (minimax expected utility) model, can be regarded as a special case of the KMM formulation. Gilboa and Schmeidler’s (1989) model is built on Wald’s minimax criterion and argues that uncertainty averse people will take the minimal expected utility (over all possible priors) into account while evaluating bets. Hence they prefer the act which entails a better worst case scenario. Ambiguity aversion in the Gilboa-Schmeidler sense represents an “extreme” form of ambiguity aversion in the KMM sense. Since the formulation described above is fairly general, and accommodates SEU and MEU as special cases, I apply it to my analysis.

\textsuperscript{4} Henceforth KMM.
3. Ambiguity Aversion and Investment in Sisters’ Children

In tune with theories of evolutionary biology, according to which men seek to maximize the survival of their genes and therefore invest in genetically related individuals, I start off by considering a simple utility function for men:

\[ u = u(r), u'(r) > 0 \]  

Here, \( u(r) \) is simply genetic, and denotes the satisfaction that a man gets from giving his inheritance to a child whose genetic relatedness to him is given by \( r \). Utility is increasing in \( r \), but we have imposed no restrictions as yet on second derivatives. Linear utility would imply that men are risk neutral. Thus, a fall in genetic relatedness will not cause a greater utility loss than the utility gain from an equivalent gain in genetic relatedness. A risk averse individual would have \( u'(r) < 0 \), while a risk lover would have \( u''(r) > 0 \).

Is ambiguity relevant to a man’s problem of investing in his wife’s or his sister’s children? I argue that it is. A man is unlikely to know the precise probability that his wife’s child is really his own. If she has a number of children, he is similarly unlikely to know for sure how many of these children are his. Most men will also not know the precise level of nonpaternity in their society, and even if they do, this may not tell them much about the paternity of their own wife’s children. Therefore, this is a situation more relevant to ambiguity than to risk. While a man might certainly have priors with regard to his probability of being the real father of a child, it was not possible for him to assign a known probability to the event of paternity. (While paternity tests provide men with a statistic known as “probability of paternity”, recall that we are discussing the origin of norms of investing in sisters’ children, at a time when such statistics would not have been available. Moreover even in modern times, not all men would request such a test, or would be in a position to do so – for example, if the wife’s consent is required – but may still face some uncertainty regarding paternity).

Turning to investment in sisters’ children, provided the man and his sister share the same mother, some degree of genetic relatedness with her children is unambiguous (as explained in the introduction, the lower bound of relatedness here is 1/8), however, there is some ambiguity about the exact extent of relatedness, because the man may be unsure if his sister is a full sibling. To be
consistent with the fact that a man does not know the probability that he has fathered his wife’s children, it seems reasonable to assume that he similarly does not know the probability that he and his sister were fathered by the same man.

I now state my main result.

**Proposition 1:** Fixing information sets and beliefs (distributions over probabilities), an increase in ambiguity aversion increases the likelihood that men will invest in their sisters’ children, in preference to their wives’ children. Moreover, the result holds even for risk neutral preferences.

**Proof:** For any hypothetical level of paternity probability $p$, denote a man’s expected utility from investing in a sister’s child and investing in a wife’s child by $EU_p(S)$ and $EU_p(W)$ respectively.\(^5\) We have

\[ EU_p(S) = pu\left(\frac{1}{4}\right) + (1 - p)u\left(\frac{1}{8}\right) \tag{5} \]

And

\[ EU_p(W) = pu\left(\frac{1}{2}\right) + (1 - p)u(0) \tag{6} \]

(5) reflects the fact that if a man’s sister is a full sister, which is the case with probability $p$, he is related to her child by a coefficient of $\frac{1}{4}$, while if she is a half-sister, which is the case with probability $1-p$, he is related to her child by a coefficient of $\frac{1}{8}$. (6) reflects the fact that a man is related to his wife’s child by a coefficient of $\frac{1}{2}$ if he is the real father, and 0 if not. Note that (5)=(6) at $p=p^*$, such that

\[ p^* = \frac{u\left(\frac{1}{8}\right) - u(0)}{u\left(\frac{1}{2}\right) - u\left(\frac{1}{4}\right) + u\left(\frac{1}{8}\right) - u(0)} \tag{7} \]

Also, observe that

\[ \frac{\partial EU(W)}{\partial p} = u\left(\frac{1}{2}\right) - u(0) > u\left(\frac{1}{4}\right) - u\left(\frac{1}{8}\right) = \frac{\partial EU(S)}{\partial p} \]

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\(^5\) While I focus on the decision to invest in a wife’s child versus a sister’s child, the decision to make mixed investments (for example, whether to invest in 2 children of one’s wife, or in 1 child of one’s wife and 1 of one’s sister) can also be accommodated in this framework. Results are qualitatively similar, and available on request.
as \(u\left(\frac{1}{2}\right) > u\left(\frac{1}{4}\right), u(0) < u\left(\frac{1}{8}\right)\). Therefore, it is clear that \(EU(W) \geq EU(S)\) for \(p \geq p^*\), while the inequality is reversed for \(p < p^*\). Now, using the formulation described in the previous section, a man invests in his sister’s child in preference to his wife’s if and only if

\[
\int [G(EU_p(S)) - G(EU_p(W))]d\mu > 0
\]

where the man’s information set and beliefs tells him that \(p\) is in the range \([p, \bar{p}]\) and distributed with cdf \(\mu\). Now note that for an ambiguity averse individual, \(G\) is concave; an increase in ambiguity aversion is represented by an increase in concavity. That is, if \(B\) is more ambiguity averse than \(A\), \(G_B = h(G_A), h' > 0, h'' < 0\); the \(G\) function for \(B\) is a concave transformation of the \(G\) function for \(A\). Now note that the property of a concave function is to give greater weight to lower values; more precisely, if \(G\) is concave,

\[
G(x) - G(y) > G(x+z) - G(y+z)
\]

Relative to a linear \(G\), which reduces to SEU maximization, a concave \(G\) gives greater weight to lower values of \(p\) in the information set, for which as we have shown, the difference \(EU_p(S) - EU_p(W)\) is positive. It gives relatively low weight to higher values of \(p\), for which this difference is negative. Therefore, the effect of this weighting is to bias men in favor of investing in their sisters’ children, relative to the case of ambiguity neutrality (linear \(G\) or SEU maximization). Moreover, the more concave \(G\) is, the more likely is it that the positive terms in (8) outweigh the negative ones, and hence an increase in ambiguity aversion makes men more likely to invest in sisters’ children. Moreover, note that we have never needed to use the second derivative of \(u\) in this proof. Hence, the proof holds for risk neutral preferences as well, which as can be easily checked involves \(p^* = 1/3\). QED

Proposition 1 involves a contrast of the ambiguity aversion case with the case of ambiguity neutral preferences, which, as KMM have shown, essentially reduces to subjective expected utility maximization. The former is thus able to explain investment in maternal kin over a larger range of parameters than the latter.

**Corollary 1:** Risk aversion and ambiguity aversion work in the same direction.

**Proof:** As shown in Proposition 1, ambiguity aversion increases the likelihood of investing in sisters’ children. Now consider a framework where individuals are ambiguity neutral (to
eliminate the effects of ambiguity aversion) so that $G$ is linear. Next, first consider the case of risk neutrality. Setting $u(r)=r$ in (7), we obtain $p^*=1/3$. Meanwhile the expression in (8) reduces to $\int [EU_p(S) - EU_p(W)]d\mu$, which is positive only for $p<1/3$. However, now consider risk aversion, so that $u''<0$, and $p^*$ continues to be given by (7). Note that due to the concavity of $u$, we have

$$u(\frac{1}{2}) - u(\frac{1}{4}) < 2[u(\frac{1}{8}) - u(0)]$$

implying $p^*>1/3$. Now, with risk aversion, the increase in $p^*$ means that the range of $p$ over which $p<p^*$ and therefore men invest in sisters’ children increases. In other words, the terms in (8) are positive over a greater range than before. Thus, risk aversion, like ambiguity aversion, increases the tendency to invest in sisters’ children, given information sets and beliefs. QED

**Example 1**

Consider $\mu$ to be such that three probabilities – $p=0$, $p=1/3$ and $p=1$ – are all equally likely; $\mu(0)=\mu(1)=\mu(1/3)=1/3$, and risk neutral preferences. Individuals are ambiguity averse, with $G(x)=\sqrt{x}$. Now the LHS of (8) reduces to

$$\frac{1}{3}\left[\sqrt{\frac{1}{4}} - \sqrt{\frac{1}{8}} + \sqrt{\frac{1}{8}} - \frac{\sqrt{2} - 1}{3(2\sqrt{2})}\right] > 0$$

so that men prefer to invest in their sisters’ children. To illustrate the comparative static effect of a reduction in ambiguity aversion, consider a less concave $G$ function, with $G(x)=x^{3/4}=(\sqrt{x})^{3/2}$. Now the LHS in (8) has the same sign as

$$\left(\frac{1}{4}\right)^{3/4} - \left(\frac{1}{2}\right)^{3/4} + \left(\frac{1}{8}\right)^{3/4} = \frac{1}{2\sqrt{2}}\left[1 + \left(\frac{1}{2\sqrt{2}}\right)^{1/2} - (2\sqrt{2})^{1/2}\right] < 0$$

on calculation. This example illustrates a case where men invest in wives’ children under low levels of ambiguity aversion, but in sisters’ children when more ambiguity averse.

**Example 2: Ambiguity aversion in the Gilboa-Schmeidler sense (MEU)**

Investing in a wife’s child gives a risk-neutral man a payoff of $\frac{1}{2}$ in state $s$, where $s$ is defined as the state in which “the man is really the father of the child”, and a payoff of $0$ in state $s^C$ which is the complement of state $s$. That is, the man gets a payoff of $0$ from a genetically unrelated child.
Thus the minimal expected utility, over all possible priors, from investing in a wife’s child is $u(0)$. Investing in a sister’s child gives this same man a utility of $u(\frac{1}{4})$ in state $q$, where $q$ is defined as the state in which “the man and his sister share the same father” (it is already assumed that they share the same mother), and a utility of $u(\frac{1}{8})$ in state $q^C$, the complement of state $q$. Thus the minimal expected utility from investing in a sister’s child is $u(\frac{1}{8})$. As $\frac{1}{8}>0$, men who are ambiguity averse in the Gilboa Schmeidler sense would invest in sisters’ children in preference to wives’ children. This is independent of risk attitudes, or actual paternity rates.

In contrast to an increase in ambiguity aversion, an increase in ambiguity can affect the investment decision either way. Holding ambiguity attitude, or the function $G$, constant, and an increase or reduction in ambiguity can be represented in terms of the decision-maker’s information set about possible paternity probabilities.

**Definition:** We say that there has been a reduction in ambiguity from state $A$ to state $B$ if $\Pi_{(A)} \subset \Pi_{(B)}$; the decision maker’s information set in state $B$ is a strict subset of his information set in state $A$.6

**Proposition 2:** Holding ambiguity attitude and risk preferences fixed, a reduction in ambiguity may either increase or decrease the likelihood of investing in a sister’s child versus a wife’s child.

**Proof:** If the reduction in ambiguity is accomplished by eliminating low values of $p$ from the information set, ie eliminating values in the range $[0,p^*]$, this reduces the mass of positive terms in the LHS of (8), making it more likely to be negative, so that it is better for men to invest in their wives’ children. However, if the reduction in ambiguity is accomplished by ruling out some high values of $p$ (in the range $[p^*,1]$), this has the opposite effect, reducing the mass of negative terms in the LHS of (8) and tending to make it positive. In this case, a reduction in ambiguity could increase the tendency to invest in a sister’s child. Thus the results depend on whether the information obtained indicates paternity to be relatively probable or not. QED

Summarizing, in the standard expected relatedness model of Alexander and Kurland, there is no ambiguity, people are risk-neutral and ambiguity-neutral and each individual knows his own exact risk of nonpaternity. As mentioned in the introduction, in that framework, men invest in sisters’ children only if paternity probability is implausibly low. I have considered an

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6 Jewitt and Mukerji (2011) formulate two different notions of what is meant by “more ambiguous”. My definition is closer to their “more ambiguous II” concept than to their “more ambiguous I”.
ambiguous environment, and shown that an increase in ambiguity aversion makes it more likely that men will invest in sisters’ children. This happens even if men are risk neutral, and is reinforced if they are risk averters. Moreover men who are ambiguity averse in the Gilboa-Schmeidler sense will always invest in sisters’ children regardless of the actual level of nonpaternity in their societies – even if they are risk neutral or risk loving. Unlike an increase in ambiguity aversion, an increase in ambiguity holding ambiguity attitudes constant can make investment in sister’s children either more or less likely. Results on decisions involving mixed investment (should one invest in two children of one’s wife’s, or in only one while investing in one child of a sister’s?) are qualitatively similar and are omitted here in the interests of brevity. I now turn to a discussion of what factors could influence ambiguity aversion in this genetic context and relate my finding to other results on ambiguity aversion.

4. Discussion
The preceding section shows that the decision of whether to invest in one’s wife’s or one’s sister’s children is made in an ambiguous environment, and an increase in ambiguity aversion biases men to investing in their sisters’ children, even for men who are neutral to known risks. Interestingly, experimental evidence suggests that attitudes to ambiguity and to risk are not highly correlated (Camerer and Weber 1992 survey such studies), therefore, it is plausible that ambiguity averters may display a wide variation in their risk preferences.

What affects the frequency of “genetic ambiguity averters” in any given population of males? Such factors may include a woman’s participation in activities outside the home – possibly in agriculture or other economic activities – which would increase her access to other men, patterns of residence that would have the same effect (for example, matrilocal or avunculocal residence patterns, where the husband or his kin’s ability to monitor her activities is reduced), and frequent warfare threats which necessitate prolonged absences from home on the husband’s part. While none of these factors necessarily lead to higher nonpaternity the crucial fact is that they provide women with the opportunity to cheat and reduce the husband’s information about paternity. Heath and Tversky (1991) and Fox and Tversky (1995) have shown that a feeling of incomplete information increases ambiguity aversion while individuals who are very confident of their knowledge are ambiguity-seeking. Hence, one could plausibly argue that
the presence of factors that reduce the husband’s information about paternity might increase the proportion of ambiguity averters. Conversely, genetic ambiguity aversion would only plague relatively suspicious or fearful individuals in cultures where even women’s opportunities to cheat were minimal.

Chua and Sarin (2002) have shown that people are more averse to “unknown” than to “unknowable” uncertainty. That is, they display more aversion to taking bets about which they realize that someone else may possess greater information than they do. These same individuals may not mind taking on an uncertain bet provided they know that no one else has more information than they do (an “unknowable” uncertainty). Note that paternity uncertainty falls in the “unknown” rather than the “unknowable” category as presumably a man’s wife would have more information about the paternity of her children than her husband would, and the husband would be aware of this.

When the proportion of ambiguity averse men is sufficiently high, men might decide to vote for an avuncular inheritance pattern. This critical proportion would be $\frac{1}{2}$ for a democracy where decisions are taken by majority voting. However, it could be lower if, for instance, decisions were taken by a small minority (for example local chiefs) and more than $\frac{1}{2}$ the members in this minority were averse to ambiguity. Interestingly, there is evidence that avuncular inheritance patterns develop in cultures with the characteristics mentioned above. For instance, the Nairs of Kerala had a matrilocal residence pattern (with women staying on in their dotal homes after marriage) and their men traditionally spent much of their time away from home fighting wars. The Nairs had an avuncular inheritance pattern. Similarly, cross-tabulations based on Murdock and White’s Standard Cross-Cultural Sample (SCCS) (a controlled sample of world cultures from Murdock’s Ethnographic Atlas corrected for regional diffusion effects and auto-correlations) demonstrate a strong correlation between matrilocal residence and inheritance patterns that involved men giving their property to their sisters’ children. For instance, in a sample of 30 cultures where maternal kin inherited, 24 involved matrilocal residence. In others, as mentioned in section 2.1, even though women might live with their husbands, polygyny – the practice of husbands often having several wives – meant limited capacity on the husband’s part to supervise any one wife.

In societies where the proportion of men with ambiguity aversion remained very low, avuncular inheritance would not develop. However, in societies which did develop the avuncular
inheritance norm, women’s incentives to assure their partners of their paternity would drop. As social norms would now ensure that they could rely on their brothers for financial support for their children, the importance of securing their husband’s investment in his (putative) children would diminish. Hence, once such a norm were in place it might well encourage some women to take advantage of their opportunities to have extramarital affairs. Thus, nonpaternity rates in societies with avuncular inheritance patterns would rise above the average. This seems to accord with empirical evidence [Wilson 1987]. Gaulin and Schlegel (1980) find a strong correlation between such nonpaternity rates as measured by incidence of extramarital sex, and inheritance patterns, with cultures in which important offices were inherited by maternal rather than paternal kin displaying higher nonpaternity. Kurland (1979) similarly finds strong correlations between a matrilocal or avunculocal residence pattern and the incidence of nonpaternity as measured by a high incidence of extramarital and premarital sex. However, the logic here shows that irrespective of the initial level of nonpaternity in these societies, the existence of opportunities to cheat could ensure that a significant proportion of men were ambiguity averse. This could then generate an avuncular inheritance norm which in turn would raise nonpaternity above normal through its incentive effects on women. Meanwhile, societies where only a few men were driven by ambiguity aversion retained a patrilineal inheritance norm (inheritance in the male line of descent) which weakened women’s incentives to cheat by increasing the importance of boosting their partners’ paternity confidence in order to promote paternal investment. Therefore, nonpaternity rates in these societies remained low – even when women’s opportunities increased due to, say, greater participation in the formal labor force. This explains why some men – those who remained particularly ambiguity averse - would refrain from investing in their wives’ children even in societies with high paternity probability and patrilineal inheritance. It also shows that high nonpaternity might be the result of an avuncular inheritance norm, and not necessarily the cause, as is traditionally assumed.

5. Conclusion
I link two phenomena – the anthropologically supported phenomenon that some men invest in their sisters’ children rather than their wives’, and the experimentally supported phenomenon that some individuals display ambiguity aversion – to develop a theory of how an increase in
ambiguity aversion can induce men to invest in their sisters’ children, rather than their wives’. This result holds even when individuals are indifferent to known risks. The tendency to invest in sisters’ children is more pronounced than in a SEU framework. Moreover, the special case of extreme ambiguity aversion in this model reduces to the Gilboa-Schmeidler MEU framework wherein men would always invest in sisters’ children regardless of actual paternity rates or risk preferences. The model in this paper avoids the problems of the expected relatedness models which imply that societies must have implausibly high nonpaternity rates to justify investment in sisters’ children. At the same time it differs from Diamond and Locay’s solution. Its most basic difference from both these models is that it emphasizes that men make these decisions in an ambiguous, rather than a risky, environment.

This paper can thus be viewed in two ways. First, it sheds light on an unusual application of ambiguity aversion, one for which a body of anthropological evidence exists. Secondly, it provides behavioral underpinnings – in terms of ambiguity aversion – for the phenomenon of some men investing in their sisters’ children in preference to their wives’ children. At an institutional level, it highlights the behavioral factors underlying avuncular inheritance norms.

I also offer a theory of circumstances which could increase the occurrence of “genetic ambiguity averters” and create an avuncular inheritance norm (though I do not argue that mine is the only possible explanation for the rise of such a norm) – a norm which in turn could boost actual nonpaternity. This would generate the observed link between higher nonpaternity and inheritance through maternal rather than paternal kin. However in this case the link is generated through a channel not usually considered in the literature.

References


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