Abstract

Consanguineous marriage is a marriage practice that has declined in many parts of the world due to associated taboos and genetic risks; however, in many regions of North Africa, the Near East, and Central Asia, consanguineous marriage and more specifically marriage between first cousins has persisted at significant levels. Inspired by the observations of anthropologists and geneticists, I developed an agent-based simulation that will explain this marriage pattern in terms of the cultural transmission of societal norms and the effect of inbreeding depression. A simple model of a small population with randomized mating confirms the hypothesis that there are higher rates of consanguineous marriages in small populations; however, randomized mating can not explain the high rates of cousin marriage that are found throughout the Middle East. Extensions to the model are needed to better understand the mechanics of the evolution of consanguineous marriage.

INTRODUCTION

Consanguineous marriage has been the topic of many anthropological and biological studies. Consanguineous marriage describes marriages between kin and usually only marriages between relatives that are second cousins or closer. One of the most interesting aspects of the practice is its decline in some areas specifically Europe and North America, and its prevalence in other areas specifically Western and Central Asia. Various hypotheses have been suggested to explain the origins, decline, and persistence of consanguineous marriage; however, clear casual explanations of the persistence of the practice in modern society are not well developed. Some anthropologists such as Holy have suggested that marriages should be considered as individual strategic events and that different cousin marriages must be considered in their individual context rather than as the result of an overarching cause. Consequently, it seems that an agent-based model sharing some of the characteristics of various societies where cousin marriage is prevalent could explain some of the dynamics behind the persistence of cousin marriage. It seems that certain important system features or causal variables could explain cousin marriage in the Near East based on similarities in the nature and prevalence of the practice there.

BACKGROUND

A review of modern cases of cousin marriage identifies important features in areas where cousin marriage is prevalent. Andrey Korotayev examined Murdock's Ethnographic Atlas to determine the prevalence of consanguineous marriage in various societies. He found a universal feature of societies where consanguineous marriage, specifically Father Brother's Daughter marriage, is prevalent - Islamization and inclusion in the eighth century Arab-Islamic Khalifate

with the latter being a stronger predictor of consanguineous marriage within a given society (Koroyatev 2000). Specific studies of various Middle Eastern countries and communities have provided more data about the phenomenon of consanguineous marriage. A 2008 study in Syria found that 30.3% of marriages in urban areas were consanguineous with a mean inbreeding coefficient of 0.0203. Likewise, 39.8% of marriages in rural areas were consanguineous with a mean inbreeding coefficient of 0.265. First cousin marriages were the most popular form of consanguineous marriage representing 20.9% of consanguineous marriages. Patrilateral parallel cousin marriage (FBD marriage) was most popular followed by matrilateral parallel cousin marriage and finally cross-cousin marriage (Othman and Sadat 2009). A 2002 fertility transition study in Iran found that the rate of first cousin marriages fluctuates around 22%. This study also found that consanguineous marriages were lower in urban areas and among more educated women. Most surprisingly the study found that there was no significant decrease in the levels of consanguineous marriage over time (Abbasi-Shavazi 2008). A 1969 randomized survey in Jordan found that 51.25 % of marriages were consanguineous with 38.95% being between first cousins. The following trends also persisted: an increased preference for patrilateral parallel cousin marriage, a negative correlation between education and consanguineous marriage, and a higher prevalence of consanguineous marriages in rural relative to urban areas. In addition, religion was found to be an influential factor with more first cousin marriages occurring among Muslims. This study also found that marriages were typically prearranged. This is a feature that often correlates with a high prevalence of consanguineous marriage (Khoury and Massad 1992). A cross-sectional study was conducted in Saudi Arabia in the city of Dammam, a diverse urban industrial city. 52.0% of marriages were found to be consanguineous with 20.4% being first cousin marriages and 12.5% being double first cousin marriages. The rates of consanguineous marriage were relatively constant from 1950 to the present. (Al-Abdullulkareem and Ballal 1998). Reproductive History interviews were collected from a systematic random sample of Bedouin women living in Bekaa Valley, Lebanon. 46% of marriages in this sample were found to be first cousin marriages holding to the trend of high rates of first cousin marriage in the Middle East. This case is interesting because Bekaa Bedouin practice patrilineal descent and patrilocal, postmarital residence so inheritance and living arrangements may be important factors in determining marriage patterns. (Joseph 2007). A survey in four squatter settlements of Karachi, Pakistan conducted in 1995 in which interviewers

interviewed a sample of ever-married women aged 15-49 years found that 56.8% of these women had consanguineous marriages and over 90% of these were first cousin marriages. (Hussain 1999). A study of 9520 families resident from 11 cities in the province of Punjab found that 50.25% of marriages were between individuals related as second cousins or closer. Of these, first cousin marriages were most common form of consanguineous union followed by first cousins once removed and double second cousins. A negligible amount of marriages were between double first cousins and second cousins (Bittles 1993). The preceding studies give a brief survey of the prevalence of consanguineous marriage and the factors surrounding it. A study in Qatar extends this data by giving some information on perceptions about consanguineous marriage. 362 Qatari employees working for two Directorates throughout Qatar were interviewed. In this population, 22% of respondents reported consanguinity among their parents while 35% reported it with their spouse. This study also reported on awareness of potential genetic affects of consanguinity. 35% of children of consanguineous marriages believed such marriages could cause genetic abnormalities and 42 % believed they could cause health problems. In comparison, 63% of those in the non-consanguineous group agreed with these statements (Sandridge et al. 2010) . Tables 1 and 2 summarize important findings on prevalence of consanguineous marriage in various Middle Eastern countries.

Table 1. Summary of Important Statistics on Consanguineous Marriage in Select Middle Eastern Countries

Entry	Year	Country (Region)	Pop.	First Cousin Marriages	Consanguineous Marriages	Society
1	2008	Syria (Damascus)	2,700,000	29.31%	43.3%	
		(Hamah)	1,500,000	24.13%	40.5%	
		(Lattakia)	1,000,000	13.44%	22.1%	
		(Tartous)	800,000	19.2%	31.2%	
		(Al Raqa)	900,000	39.11%	67.5 %	
		(Homs)	750,000	24.3%	43.1%	
		(Edlep)		13.8%	23.9%	
		(Aleppo)	4,600,000	16.65%	31.6%	
2	2002	Iran (Country)		~22%		
		(Sistan and Baluchistan)			77.4%	Low development
		(West			32.6%	

		Azarbaijan)				
		(Gilan)			24%	High development
		(Yazd)			46.3%	High development
3	1963	Jordan (Irbid)	~1,000,000	31.5%	52.0%	Rural
4	1980	Jordan		32.03%	50%	
5	1998	Saudi Arabia (Dammam)	192,370	39.3%	52.0%	Urban
6		Pakistani immigrants in UK (West Yorkshire)		55%		Immigrant
7	1990's	Pakistani immigrants in UK (Oxford)	2,000*	59.0%	76.0%	Immigrant
8		Lebanon (Bekka Valley)		47%		Originally nomadic
9	2004	Qatar	1,696,563	34.8%	54.0%	Wealthy Oil State

Table 2. Frequency of First-Cousin Marriages in Select Middle Eastern Countries, by Location and Time Period (Joseph 2007)

Country	Location	%	Time Period	Source
Egypt	Countrywide	22	2000	Khyat and Saxena (2005)
	Upper Egypt-rural	31		
	Upper Egypt–urban	19		
	Lower Egypt -rural	23		
Iran	Countrywide	28	2001	Saadat, Ansari-Lari, Farhud (2004)
	North	10		
	Northwest	28		
	West	30		
	Central	26		
	East	32		
	South	32		
Jordan	Countrywide	32	1969-79	Khoury and Massad (1992)
Kuwait	Countrywide	26	1996	Alneesf, Al-Rashoud, and Farid (2000)
Lebanon	Coutrywide	18	1996	Ministry of Public Health (1998)
Palestine	Gaza	32	1995	Pedersen (2002)

	West Bank	27		
Qatar	Countrywide	34	1998	Al-Jaber and Farid (2000)
Saudi Arabia	Countrywide	41	1996	Khoja and Farid (2000)
Syria	Countrywide	35	1993	Central Bureau of Statistics (1995)
Turkey	Countrywide	15	1988	Tunçbilek and Koc (1994)
United Arab Emirates	Countrywide	24	1995	Fikri and Farid (2000)
Yemen	Countrwide	34	1997	Jurdi ad Saxena (2003)

The prevalence of consanguineous marriage is of interest to anthropologists and biologists alike due to the interesting genetic effects of such an arrangement. The main concern of consanguineous marriages is the expression of deleterious recessive alleles. Theoretically, the genetics of close kin are closer due to shared ancestry. Thus, offspring of close kin are more likely to have any recessive allele expressed; however, this is only problematic in the case of deleterious genes. This phenomenon is termed inbreeding depression, and the inbreeding coefficient, the probability of an individual having autozygous genotype due to inbreeding, is a useful measure for determining the amount of inbreeding in a population or between a couple. The situation is slightly complicated by the fact that the amount of deleterious recessive alleles varies with certain population parameters. The number of these recessive genes is higher in larger randomly mating populations because the recessive is masked and thus persists. In contrast, the recessive deleterious genes are often erased in smaller more endogamous populations. The formula for the effect of inbreeding depression (i) is :

$$i = 1 - 1/(e^{nF})$$

This formula represents the reduction of viability in offspring where F is the inbreeding coefficient and n is the number of deleterious recessive genes in the population (Durham 1991).

Many studies have been conducted to asses the effects of inbreeding on fertility and childhood mortality/morbidity. There is also limited data available on adult morbidity. A survey of these results helps elucidate the scope and depth of deleterious effects of inbreeding. A study of mortality of offspring of consanguineous couples in rural East Jordan found that mortality within the first five years of life was positively correlated with the degree of consanguinity of the parents. The results also suggested that most fatalities occurred within the first year of life (Cook and Hanslip 1966). Since demographics often vary among

consanguineous and non-consanguineous couples there may be confounding variables in this study. The Suzanne Joseph study in the Bekaa valley found that rates of infant and child mortality among first cousin unions were 5.6% and 2.3 % respectively while the proportions for non-consanguineous unions were 4.1% and 0.8% respectively. This study is significant because it controlled for socioeconomic and demographic factors and found that infants born to first cousins still have approximately double the odds of dying as infants born to non-first cousin couples. A study of inbreeding in a high resource population found that there were twice as many congenital malformations among first cousin marriages throughout life. This doubling effect is also seen in the offspring of British Pakistanis in the UK versus their British peers (Modell and Darr 2002). A study in Pakistan set out to understand the effects of consanguinity on reproductive behavior and offspring mortality. Consanguinity was found to increase the number of pregnancies and the number of live births between couples; however, this feature could be attributed to other factors common to consanguineous unions. For instance, related couples tend to marry at a younger age meaning they begin reproducing at their most fertile ages (Bittles 1993). In spite of this increase in fertility, the total pre-reproductive mortality of offspring increased with degree of inbreeding. The percentage of abortions/miscarriages, stillbirths, deaths in the first month of life, at 2-12 months and 2-8/10 years increased from 16.36% in non-consanguineous progeny, to 20.09% in second cousins, to 22.91% in first cousins once removed/double first cousins, to 22.13% in first cousins and finally 38.97% in double first cousins. There was the greatest effect in the first year of the child's life. As with other studies, socioeconomic differentials between consanguineous and non-consanguineous could be an explanatory factor as non-consanguineous couples tend to have a higher socioeconomic status. However, access to vaccinations seem to be constant across groups and a study of Pakistani immigrants in the UK confirmed the higher levels of child and infant mortality among children of consanguineous marriages across all socioeconomic levels (Bittles 1993). The main results of this Pakistani study were also found in a case study in South India where higher fertility was linked to all degrees of consanguinity (Bittles et al. 1991). A survey study conducted by Bittles found that evidence of prenatal loss as a result of consanguinity was relatively low. In addition, he found that early postnatal mortality was higher in progeny of consanguineous marriage. In terms of morbidity throughout life, offspring of consanguineous couples are more susceptible to the following single gene disorders: autosomal recessive non-syndromal hearing loss, blindness,

childhood glaucoma, anophtalmos and microphtalmos, bilateral retinoblastoma, and severe learning disability (Bittles 2003). While fertility seems to increase with consanguinity of couples, one study suggests that while this may be true of inbreeding at the level of the couple, inbreeding at the individual level causes a decrease in fertility. A study of inbred women in a small isolated village in the Swiss Alps found that inbreeding of the mother has significant negative effects on the number of children throughout her life (Postma , Martini, and Martini 2010). This study is one of the few to hint at the negative effects of inbreeding on adult fitness. One study found a strong positive association between consanguinity and human susceptibility to the infectious diseases tuberculosis and hepatitis B virus among West Africans (Lyons et al. 2009). A 2004 cross-sectional population study in Qatar conducted across 10 health centers also found significant adverse effects of consanguineous unions on the morbidity of offspring. Consanguineous individuals had higher risk for cancer, mental disorders, heart diseases, gastro-intestinal disorders, hypertension, hearing deficit and diabetes mellitus. This study also found higher mean number of pregnancies among first cousin unions and higher reproductive wastage among the same group (Bener 2007). The broadest study exemplifying the effect of consanguinity while correcting for socioeconomic status was an analysis finding the correlations between inbreeding coefficient and healthy years of life expectancy in 63 countries. The study found a negative correlation between the two variables (Saadat 2011). These studies show that there is an abundance of evidence for the negative effects of consanguineous reproduction on the fitness of offspring.

Various hypotheses have been developed and researched to explain both the phenomenon of consanguineous marriage and the stated preference for such marriages. Due to the correlation between Islamic states and cousin marriage, some believe Islam prescribes the practice. A simple explanation for the high prevalence of consanguineous marriage is population demographics. If the number of available partners is low, the likelihood of choosing a relative as a mate increases. Suzanne Joseph proposes that geographic isolation may restrict the size of the mating pool making consanguineous marriage a default marriage strategy. However, this explanation cannot explain the large percentages of first cousin marriages found across the Middle East. A recurring theme throughout the anthropological literature is the claim that consanguineous marriages lead to more harmonious relationships between husband and wife. R. Hussain found that the most frequently stated reasons for consanguineous reasons were sociocultural explanations such as:

more harmony between a bride and her in-laws, pride from clan endogamy, and shared values between husband and wife. Another perception study in Qatar found that products of consanguineous marriage believed that familiarity of the bride/groom to the spouse was an advantage of consanguinity and that consanguinity promotes stability, traditions, and continuity of a culture and way of life (Sandridge et al. 2010). There is little evidence for this claim, and this explanation lacks any sort of material benefit that could outweigh the genetic costs of these marriages. A more potent social explanation is that consanguineous marriages make marriage negotiations much easier. Thus, a family may have a much higher probability of securing a marriage with a relative than with an outsider. Economic explanations are especially pertinent because economic gains can explain the persistence of a cultural trait from an evolutionary perspective. Islamic inheritance laws mandate that a daughter have a share of the inheritance from her father. This law could divide up families' wealth in agricultural, patrilineal societies unless the daughter also marries into her father's descent line (Koroyatev 2000). This could explain the origin of the practice of Father Brother's Daughter marriage, but it cannot explain its persistence in areas where the law is not respected or other forms of first cousin marriage that are also preferred or highly prevalent in many areas. Suzanne Joseph also suggests that marriage within the family may help facilitate unions among the poor allowing them to circumvent economic payments associated with marriage. For wealthy families, kin marriage helps prevent fragmentation of agricultural property (Joseph 2007). From a strategic point of view, consanguineous marriage is oft explained as a strategy to strengthen ties between within familial groups; however, similar arguments are often made for exogamous marriages. Finally, the cultural preference for first cousin marriage is a strong one. Consequently, status and honor are often given as explanations for the practice because a cousin marriage is generally perceived as a good one. The father brother's daughter right (FBD marriage) is the strongest form of this preference.

The evidence refutes many of the aforementioned hypotheses. Of the hypotheses that could hold true, many of them have become obsolete. R. Hussain from the University of Wollongog led a study in Karachi, Pakistan to elucidate the actual and perceived causes of consanguineous marriage in Pakistan. Although existence of high levels of consanguineous marriage is highly correlated with the existence of Islam, neither the Koran nor the hadith encourage the practice. In accordance with this, Pakistani women hardly ever saw religion as a

motivating factor in arranging consanguineous marriages. Khuri researched in two suburbs of Beirut and used his findings to challenge some of the existing explanations for Father Brother's Daughter marriage in the anthropological literature. He debunks the property argument by pointing out that Middle Eastern countries rarely follow the rules regarding women's inheritance. In addition, he shows that property is rarely exchanged in the case of FBD marriage. He also argues that out-marriages are more effective in consolidating power and that in the 4222 cases of FBD marriage in Chiyah and Ghbairy, only eleven were between people influential enough for power to be a significant factor. The Suzanne Joseph study of Bekaa valley Bedouins provides support for the hypothesis that rates of consanguineous marriage are high in traditional societies where land is inherited through the male line and daughters move in with their husband's families. In traditional agricultural societies such as these, consanguineous marriage can help parents keep their offspring close to home and keep their property within the family line. While consolidation of property seems like a plausible explanation for consanguineous marriage, it was rarely perceived to be a contributing factor among the women interviewed. Dowry price is generally a consideration in arranging a cousin marriage; however, Pakistani women were reluctant to acknowledge this (Hussain 1999). The fact that many of the factors that could have led to the existence of no longer practiced suggests that cultural transmission has played a role in maintaining consanguineous marriage and this sentiment is supported by the results from the Abbasi-Shavazi survey in Iran. One of these hypotheses could explain why the practice of consanguineous marriage originated; however, cultural transmission could have kept the practice alive once it originated.

There are a number of puzzling aspects that emerge from this huge anthropological and biological literature. The first is that the practice of consanguineous marriage persists in spite of deleterious effect to offspring from these marriages. Secondly, the rates of consanguineous marriage found in the Middle East are much too high to be explained as simply a consequence of small population size. Although many anthropologists have predicted a decline in consanguineous marriage over time due to modernization, this is rarely the case and in many instances it has increased over time. This is interesting because a number of factors that could explain the origin of cousin marriage have ceased to be relevant such as the agricultural and property concerns. The rates of consanguineous marriage in the Middle East are especially interesting because the region has remained fairly impervious to the incest taboos that have led to

the decline of kin marriage in other parts of the world. Finally, there is a dearth of valid explanations of the cause of consanguineous marriages. Most arguments assert that Middle Easterners marry their cousins because they have a strong preference for marrying their cousins. This circular argument fails to get at the heart of the driving factors behind consanguineous marriage.

MOTIVATION

The aim of this project is to create an agent-based simulation to help understand the driving forces that could drive a population to high rates of consanguineous, specifically first cousin marriage. In addition, I would like to better understand how the practice could persist and evolve in the face of natural selection against it due to the genetic effects of inbreeding. Finally, I would like to understand how this practice can persist even in the absence of the original factors driving the practice. The simplest model will determine the natural rates of consanguineous marriage among different population sizes and the effect of monogamous versus polygynous marriages on these rates. I expect rates of cousin marriage to be higher in smaller populations. Extensions to the basic model can help elucidate the more complicated questions and problems surrounding the practice of consanguineous marriage.

MODEL

Daniel Bradburd wrote an ethnological account of the Komachi pastoralists, a pastoral nomadic community living in the Kerman Province of south-central Iran from 1974-1975. The Komachi pastoralists provide a metaphor for the agent-based computer simulation because the community is small and effectively a reproductive isolate. Bradburd's ethnological account follows 105 households that can be divided into 2 main socioeconomic groups. The first group consists of wealthy individuals who play an active role in political life and the second consists of poor shepherds who do not play a role in the political arena. The Komachi pastoralists are an Islamic society. In addition, they exhibit an agnatic bias in describing descent and determining inheritance. There are various norms regulating marriage negotiations. Status endogamy is highly preferred among the Komachi as is close kin marriage. In addition, husbands prefer younger wives and vice-versa. While Koranic incest is prohibited amongst the Komachi, marriage with close kin is strongly preferred. To this end, Bradburd observed that 22% of marriages contracted between 1974 were between first cousins. Men of political power among

the Komachi use marriage negotiations as a way to reaffirm critical business and political ties and as a sign of their political power. Thus, public perception plays a crucial role in marriage arrangements. Marriage negotiations are conducted primarily by the parents. The women begin informal negotiations subtly and in private to ensure that any rejection will not tarnish their family's reputation. Once plans become more serious, men engage in more formal, binding and public negotiations. This community motivates the small population sizes in our simulation, and other features provide a basis for extensions to the basic model.

When the program is initialized, a set number of males and females are created. The user can change the number of individuals in the initial population. There are exactly half males and half females. The agents are distributed at random locations across space. There is no spatial component to the simple model. The simulation employs Mendelian genetics to model the inheritance of traits among consanguineous couples. Each agent posseses one trait for which it can have one of three combinations of alleles: AA, Aa, and aa. The allele are randomly assigned with a 50% chance of getting A for the first allele and A for the second allele at initialization. There are dominant and recessive phenotypes. The phenotypes are the two different colors of agents.

In order to reproduce, males randomly choose a female from the population. Each female has an equal probability of being chosen by a given male. Once the male chooses a female, they create a lifelong union. There is one limitation on the choice of mate that is determined by whether the world is monogamous or polygynous. In the monogamous world, males can only mate with a female who is unmarried. Once they are married he may no longer search out a new mate. In addition, no other male can create a union with his wife. In the polygynous world, males may only mate with an unmarried female; however, he may mate with as many unmarried females as he can find. Each union reproduces once and has a number of children determined by the family size chosen by the user. Children receive traits from their parents and express the phenotype coded by their genetics. In addition, children track relationships. They keep track of their parents, grandparents, and siblings. In addition, after the second generation, agents keep track of the relationships of their marriages. In the monogamous world, agents keep track of whether their relationship is a first cousin marriage or not. A first cousin marriage is a marriage where the grandparents of the turtle are the grandparents of the turtle's mate. In the polygynous world, half first cousin marriages are tracked in addition to first cousin marriage. A half first

cousin marriage is defined as a marriage where the partners share a grandfather but have different grandmothers.

Finally, agents die in order to keep the population at carrying capacity. Once an agent dies, it is hidden and it no longer runs the main procedures of the simulation. It is possible to select against the recessive phenotype. This causes agents expressing the recessive phenotype to die at a slightly higher rate than the other agents. The strength of this selection can be varied by varying s in the following equation:

(N – (1-s) * K) / N where N is the population size at time t, K is carrying capacity, and s is the selection against the recessive phenotype. This equation represents the probability that a recessive individual dies when the population is over carrying capacity. This models the deleterious recessive genetic disorders that plague offspring of consanguineous unions disproportionately.

Experiments were run in behavior space to determine the differences in the rates of consanguinity among the monogamous and polygynous worlds. The simulation was run for 20 time steps at the following carrying capacities: 25, 50, 75, 100 and 200. For each carrying capacity, the simulation was run with initial populations at 25% and 75% of the carrying capacities. For the experiments, each family had four offspring and there was no selection against recessive phenotypes. For each set of parameters, the experiment was run ten times.

RESULTS

There was a negative correlation between carrying capacity and percentage of first cousin marriage for both initial population sizes. This result also held in both the monogamous and polygynous world. There was a higher rate of full first cousin marriage in the monogamous population than there was in the polygynous population at every initial population size and carrying capacity. For the polygynous world, there was consistently a lower rate of half first cousin marriage than full first cousin marriage. Finally, the total consanguinity, the sum of first cousin and half first cousin marriages, in the polygynous world was consistently higher than the first cousin marriage in the monogamous world. Variance in the rates of cousin marriage tended to decrease as carrying capacity increased. One interesting result is that initial population size affects the monogamous world more than it affects the polygynous one. In addition, there was

more variance when initial population size was 75 % of carrying capacity. Table 3 and Table 4 pressent summary statistics for these results.

Table 3. Mean Rates of Consanguineous Marriage in Monogamous World

	Initial Population = 25 %	Initial Population = 75% CC
Carrying Capacity	% FCM	% FCM
25	11.05 ± 1.92	5.08 ± 2.17
50	4.48 ± 1.4	3.20 ± 1.67
75	3.55 ± 0.90	1.85 ± 0.84
100	2.34 ± 0.63	1.53 ± 0.48
200	1.26 ± 0.42	0.82 ± 0.24

Table 4. Mean Rates of Consanguineous Marriage in Polygynous World

	Initial Population = 25% CC			Initial Population = 75% CC		
Carrying Capacity	% FCM	% Half FCM	% Consang	% FCM	% Half FCM	% Consnag
25	5.68 ± 0.82	4.31 ± 1.79	9.99 ± 2.25	4.68 ± 1.48	1.87 ± 1.00	6.55 ± 1.60
50	3.38 ± 0.80	2.01 ± 0.68	5.39 ± 0.88	2.48 ± 0.41	1.29 ± 0.59	3.77 ± 0.57
75	2.60 ± 0.50	1.28 ± 0.43	3.89 ± 0.42	1.91± 0.42	0.74 ± 0.33	2.65 ± 0.44
100	1.81 ± 0.48	1.04 ± 0.26	2.86 ± 0.50	1.75 ± 0.32	0.70 ± 0.22	2.45 ± 0.30
200	1.12 ± 0.18	0.62 ± 0.10	1.75 ± 0.24	1.09 ± 0.20	0.30 ± 0.11	1.38 ± 0.25

These results are expected. As population size increases, the number of relatives to non-relatives decreases. Thus, there will be a decrease in consanguineous marriage when marriage is completely random in such a population. In addition, it makes sense that the rate of first cousin marriage is lower in the polygynous world than the monogamous world. This is a simple probability problem. In a polygynous world, there are more mates available because each male is allowed more than one wife. The number of prohibited mates decreases thus the ratio of first

cousins to all eligible mates decreases. Since polygyny does not change the number of total available mates, the number of consanguineous marriages is still comparable to the number of first cousin marriages in the monogamous world.

EXTENSIONS

The results of the agent-based are relatively simple; however, it is possible to add layers of complexity to the model to answer more difficult questions. The goal of the first round of future iterations of this simulation would be to add more realistic population and mating dynamics. This simple model made several unrealistic assumptions about population demographics. The first was deterministic family size. Stochastic family size would be a more realistic model and could be accomplished by making family size a random variable with a normal distribution. This could further enhance the simulation because fertility can also be varied across different degrees of consanguinity. Adding a spatial element to the model could be informative giving agents an increased probability of mating with agents who are nearer to them on the grid space. The current simulation does reflect the small communities after which it's modeled. In a society of only a couple 100 people or less, location does not play a very large role in choosing with whom to interact. In a larger population size, this could play an important role. It could also aid in exploring different habitation patterns such as patrilocal where wives move in with their father's husband's family.

A second layer of complexity involves adding wealth and fitness to the model. In the real world, individuals can have wealth that they can pass down to their offspring. In addition, overall health is influenced by factors such as wealth and genetics, which can in turn increase the wealth of an agent and its offspring. A model that incorporates these features would capture how economic factors and health can influence the fitness of offspring of different kinds of marital unions. Agents could preserve a certain amount of fitness that is positively correlated with his health and wealth. If death were a function of fitness, one could see how various cultural elements evolve. Such a model could show a gene-culture co-evolution with marriage decisions being the main cultural artifact of interest.

Finally, a model with changing parameters and cultural transmission would be interesting. For instance, it would be interesting to see how marital patterns evolve in the face of the evolution of society as a whole. If societies begin small and grow larger, will marriage

patterns change or remain the same. It would also be interesting to examine the evolution of marriage patterns as positions of power, habitation patterns, and occupations change. These could all be modeled by changing the influence of agent and the way agents acquire fitness. This last layer of models would focus on capturing the possibility of adaptation of agents in light of environmental pressures.

CONCLUSION

The cultural evolution of first cousin marriage is a unique and complex problem. The agent-based simulation described in this paper provides one approach to tackling this problem. The strength of this approach is that we can understand the dynamics between costs and benefits and the role of cultural transmission in the evolution of this phenomenon. The current model must undergo the aforementioned extensions in order to be useful in modeling realistic populations and better understanding the mechanics of the process.

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