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Development and evaluation of an agent-based model of sexual partnership

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Abstract

The agent-based model presented here builds on existing models, allowing for multiple partnerships, including those overlapping in time, to examine sexual partnerships, with the goal of hypothesis testing and guiding data collection. Within each model run, agents are assigned characteristics (including quality, aspiration, courtship duration, and ideal number of lifetime partners) and then search for partners; existing couples choose whether they should break up, remain dating, or become sexual partners. Model behavior was tested across a wide range of parameters and compared with empirical data. The model produces numbers of lifetime sexual partners, and partners in the last year, rates of concurrency, and relationship durations similar to nationally representative data from the US; it also generates correlations in partners' quality similar to those reported for marriage and dating partners. Model results highlight the importance of individual preferences, interactions between individuals, and contextual factors in sexual decision-making.

Keywords

agent-based model; validation; sexual behavior

1. Introduction

1.1 Background

Sexual interactions are bounded by individuals' contacts in their everyday lives and as such strongly responsive to geographical, historical and biographical boundaries (Adimora & Schoenbach, 2005; Fichtenberg, Jennings, Glass, & Ellen, 2010; Laumann, Gagnon, Michael, & Michaels, 1994). Less clear, however, are the ways in which social factors

influence sexual decision-making and give rise to specific patterns of sexual partnership behavior. Evolutionary psychologists have worked to quantify some aspects of partnership preferences and strategies in experimental settings (e.g., Buss, 2006; Shackelford, Schmitt, & Buss, 2005), yet the observational nature of data on the social structures that shape decisions about which partners and types of partnerships are chosen over others complicates causal inference. Computational models have contributed substantially to our understanding of sexual disease transmission (see for example, Garnett & Anderson, 1996; Morris & Kretzschmar, 1997), and have the potential to allow for testing of conceptual frameworks and to guide data collection about the processes that determine sexual decision-making and patterns of sexual behavior.

Computational models of mate choice for first marriage in the US, which use courtship as a period of comparison, have matched observed correlations between partner attributes such as attractiveness and income and the distribution of marriage timing, although it is unclear how detailed measures of mate quality should be, and how best to reflect social norms about dating and sexual decision-making in the models (Alam, Meyer, & Norling, 2008; French & Kus, 2008; Simao & Todd, 2002, 2003). The models previously available in the literature have helped to shape insight about sexual decision-making, but they suffer a substantial limitation: they are described broadly as “partnership” models, but assume that partnering is for life, and that each individual can have only one partner. The model described by Alam et al is an exception here, as it allows for multiple partnerships for men; however, none of the models allow for multiple partnerships for women. It is clear from data from the National Health and Social Life Survey, as well as the National Survey of Family Growth and the National Longitudinal Survey of Adolescent Health, that upwards of 70% of individuals have more than one sexual partner during their lives, and that substantial numbers of individuals have concurrent partners, defined as relationships that overlap in time (Adimora et al., 2002; Adimora, Schoenbach, & Doherty, 2007; Ford, Sohn, & Lepkowski, 2002; Laumann, et al., 1994). The model described here builds on existing models to more accurately reflect sexual partnerships over a 5-year period, rather than simply first marriage. The results show that the model can produce patterns of sexual behavior that are similar to data available from nationally representative surveys from the United States.

1.2 Previous partnership models

Selected characteristics of each model of sexual partnership are shown in Table 1, and informed the development of the model described here. In their model of mate choice in human populations, Simão and Todd (2002) create what they call a “social ecology,” a community of individuals seeking partners, based principally on a one-dimensional quality parameter “ q_i .” This quality parameter represents an aggregate and abstract measure of the objective quality of a potential partner, including attributes such as attractiveness, education, income, and others. Individuals also have an “aspiration level” based on successive encounters with individuals of different qualities (i.e. the aspiration level is lowered if an agent breaks off a relationship with the individual). The aspiration level also lowers gradually with time. Male and female agents meet stochastically with probabilities that depend on both the maximum meeting rate and an individual-specific factor that varies depending on whether the individual is single or not, or whether he/she is courting/dating

someone at each time step. Each agent maintains a list of “alternatives” - opposite-sex individuals the agent has met and can make courting proposals to. Within this list, one individual can be the agent’s current partner. Agents decide whether to make courting proposals based on a fitness function that takes into consideration the quality of the current partner, the quality of the alternative partner, an optimistic estimate of the remaining courtship time required to commit to the current partner, and an optimistic estimate of the required courting time for the alternative partner. Both agents must agree to date, and each individual has a specific “minimum courtship time” before he/she will fully commit to the relationship. After the individuals are fully committed, they mate and do not consider further dating opportunities.

This model of partner formation matches empirical data in several impressive and important ways (Simao & Todd, 2003). The correlation between the quality levels of various individuals is quite similar to actual measurements of similarity between individuals in a couple between nationally representative samples of married couples in the US. Using a normally distributed individual variation in the courtship time K , the model also generates a distribution of marriage timing close to the distribution empirically derived from census data. They also experiment with skewed sex ratios in the population, finding that sex imbalances causes a decrease in mean mating times for those who find mates. This occurs because high quality individuals of the under-represented sex pair quickly and other partners are unable to mate at all. They conclude that this is consistent with a theoretical model postulating that an excess of members of one sex should accelerate the transition to first marriage because of increased opportunities to find a suitable mate. The authors acknowledge, however, that because their partner selection mechanism is based on agents meeting and comparing partners, seeking the best available, it is unlikely that they would find evidence for a theory based on men’s reduced motivation to commit to marriage when women outnumber men, as the only motivations explicitly coded in the model are to find the best possible partner.

Although the authors find that their model replicates many of the phenomena observed in actual populations, the assumptions of monogamy and lifetime partnership are quite extreme. It is unclear whether their conclusions hold if individuals are able to partner and then “divorce” (leading to serial monogamy) or are able to have multiple partners at one time. Without a more realistic representation of the possibility of multiple partnerships, the results of this model are only applicable to first marriage markets rather than a broader definition of partnerships that include all sexual relationships.

French and Kus (2008) describe a similar, but slightly more complicated, model of partnering. Two notable differences distinguish their model from the one described above. First, they use a vector of attributes rather than simply a one-dimensional measure of “quality.” These attributes are revealed only gradually, and agents assume average values in those fields they do not yet know about individuals they encounter. Individuals also have differing weighted preferences for the attributes of individuals they marry. It is unclear whether this added complexity is necessary, as their model does not produce results that differ substantially from those of the earlier model. Second, they use “computational temperature” to determine how willing an individual is to give someone a chance, an

attribute that might also be termed “desperation” of the agent. This is similar to the meeting rate set by Simão and Todd, but also influences how an individual perceives the attributes of someone the individual meets. This parameter seems to function in the same way as earlier specifications, but is a unique implementation that facilitates understanding of how the amount of effort an individual puts into finding a partner over the agent’s life course, and in different relationship contexts, influences the types of partnerships that are formed.

In addition to these slightly different specifications, French and Kus address a fundamental assumption made in many models of partnership: that men ask women for a date and women respond relatively quickly, without a great deal of time to amass other offers. They find that only when this assumption is implemented are they able to generate the age-lag differential in marriage hazard rates for men and women (that women typically marry several years earlier than men). When they implement mechanisms through which females always ask males or both males and females can initiate partnerships, the curves change substantially. Though they state that the first model is “traditional Western dating” it is unclear whether empirical data support this assertion.

One model that does address one aspect of multiple partnerships is that described by Alam et al (2008). They build on Simão and Todd’s model, using their method of mate selection, but allow multiple partnerships for men in the model. This model is built very specifically around detailed survey data of the Sekhukhune District in Limpopo, South Africa. Their focus is principally on using this model to predict and explain HIV epidemic behavior in this area. They modify the sexual mixing scheme by allowing male agents to have multiple partners and also by specifying that young female agents prefer males of similar age, while older female agents prefer unmarried suitors who have some employment. Female agents do not have sexual partnerships outside of their primary relationship or marriage. Child agents are born to couples or single mothers with pregnancy only occurring when the male partner is not away on migration. The authors model HIV transmission both sexually and mother-to-child. They also explicitly model a social network and use it to constrain meetings between individuals.

The principle focus of their simulation results is HIV prevalence after 75 simulation-years. They show that increasing the number of random contacts (versus contacts constrained by the social network of the individual) increases the transmission of HIV in the community. In addition, they examine the effect of changing exogenous incidence and different probabilities of HIV transmission. They conclude that introducing new cases from the outside keeps the epidemic going. While they comment on the characteristics of the sexual network between agents in the model, it is only to note that with relatively low numbers of concurrent partners there is not a single large “spanning tree” or giant connected component of the network. They report that “increasing the number of allowable concurrent partners decreases the dyad frequency and increases the frequency of higher sub-graph structures. (p 10)”

These results show that the model is performing in a plausible way but they add relatively little insight to previous models of the separate components (i.e. marriage markets, sexual network structure, etc). The authors examine neither the differences in partnership patterns

that occur when they introduce non-monogamy, (other than to say that there are more higher-order network structures, meaning that there are more individuals with multiple partnerships). Although they do look at the effect of migration in terms of bringing new infections into the community, they do not examine its effects in terms of sexual network structure or partnering decisions. Additionally, their assumptions about concurrent partners in the model limit conclusions and are particularly problematic. Men may report having more partners than women, yet assuming that dating and married women have no concurrent partners is a strong assumption, and is certainly not valid in a US context (Adimora, et al., 2002). They also maintain the convention of only allowing men to ask women for dates.

Another relevant model is that described by Bearman, Moody, and Stovel (2004). Contrasting with the agent-based models described already, they use a p^* statistical network analysis approach which uses Markov processes based on homophily, a preference for partners who share a common or similar attribute, and network structure to generate sets of networks based on defined parameters that can be compared to empirically observed networks. Using network data from 832 high school students living in a midsized Midwestern town, they identify grade in school, smoking status, popularity, and attractiveness as important homophily parameters for this population of young adults. By also implementing a parameter prohibiting network cycles of length 4 (where an individual dates the ex-partner of their own ex-boyfriend or girlfriend's new partner), they achieve networks with very similar structure to those observed in their sample. They argue that this particular prohibition reflects unwillingness on the part of students at the school to date "seconds," which would negatively affect their social standing.

Although using network structure comparisons in combination with data analysis to derive preferences is a strength of this study, it is limited in two substantial ways. First, the study population includes only high school students in a town described by the authors as "close-knit, insular, [and] predominantly working-class (p. 53)," in the Midwest. As is acknowledged by the authors, it is unlikely that the particular rules that govern partner selection in a high school setting apply uniformly to adults, particularly given the unique ability of students in a school setting to monitor one another's dating behavior. The second limitation arises from the fact that observed correlation in particular attributes (such as the level of partner experience or attractiveness) may arise directly from homophily or indirectly through the interaction of preferences for "better" attributes (such as attractiveness) across the community. By forcing homophily and a prohibition on cycles of length 4, they demonstrate one potential set of mechanisms for generating the observed network structure, but do not illuminate the sets of individual preferences that could lead to these mechanisms.

2. Research Objectives

The objectives of this project were

- to implement an individual-level algorithm of sexual partnership formation, including multiple and concurrent partnerships, informed by existing models, extant quantitative and qualitative data on heterosexual sexual behavior and sexual decision-making, and theoretical constructs hypothesized to be important

in sexual decision-making, with the goal of hypothesis testing and guiding data collection about patterns of sexual behavior and sexual networks;

- to determine whether a community of agents each using the individual-level algorithm could generate population-level patterns similar to those observed empirically;
- to identify those parameters in the model which most substantially affected the model output in order to increase understanding of the process of sexual decision-making, and to identify sensitive parameters for which additional data might improve the fit of the model.

All of the models described above are limited in their utility in the broader study of sexual behavior in the United States because they are focused on first marriage patterns, and do not allow for multiple partnerships that are either serially monogamous or overlapping in time. This paper describes an agent-based model of sexual decision-making and sexual networks that addresses several of these key limitations by allowing for multiple partnerships over time as well as concurrent partners. While the model presented here is an expansion of current models in several important ways, it is nonetheless still intended to be a simplification to facilitate understanding of partner selection mechanisms underlying observed patterns of sexual behavior. Comparability of model output to real world data suggests that this model may be useful to explore the dynamics of partner selection and sexual decision-making in a variety of US contexts, including not only broadly nationally representative samples, but also urban areas with widely varying sex ratios and partnership markets.

3. Implementation of the model

The model modifies a simplified version of the partnering mechanisms described in Simao and Todd (2002), originally created by Alam et al (2008), shown in Figure 1. A Java-based agent-based modeling platform, Repast J, was used to implement the model. The source code is publicly available at OpenABM (www.openabm.org/models) under the title “Agent-based model of sexual partnership.”

3.1 Model parameters and agent characteristics

Agent-level parameters in the model are outlined in Table 2, and consist of a set of agent attributes that are assigned at the start of the run. Table 3 shows the settable characteristics of the world in which the agents interact and the descriptive statistics for the distributions from which they are drawn. Each agent is assigned several characteristics relating to the partnering mechanism, including quality (a measure of how desirable a given agent is to other agents), aspiration (the level of quality an agent looks for in a partner), courtship duration (how long an agent needs to date another agent before engaging in a sexual relationship), a waiting threshold (how long the agent will go without a partner before decreasing his/her aspiration level), and the ideal number of partners for the agent (how many partners the agent believes he/she should have in a single year). The values of these parameters are assigned randomly from distributions, so there is not a specific default value for each agent. The quality and aspiration values are drawn from either normal (the default)

or skewed distributions, the courtship duration is drawn from a normal distribution, and the waiting times are drawn from a uniform distribution. The ideal number of partners is drawn from a gamma distribution, defined differently for male and female agents using sex-specific lambda and alpha parameters.

The quality and aspiration values assigned to the agents are single values drawn from distributions. Although French and Kus (2008) propose that an array of quality attributes, a separate array of preferences, and limited information about new potential partners more accurately represent the evaluation of dating prospects than single values that are revealed to all potential partners, their parameter-heavy modification to the model does not seem to substantially improve model output relative to empirical data. Though additional parameters defining quality and preferences are intuitively appealing, it is not clear that sufficient data is available to determine reasonable parameter values.

Within the model, the number of agents as well as the sex ratio of male to female agents can be set at runtime. The maximum number of network connections can also be varied.

3.2 Model setup

In each run of the model, the agents start with a community of contacts or friends from which to draw sexual partners. This friend network is created before the run starts, as described by Alam et al (2008). R_0 is defined as the proportion of possible pairs of agents chosen to meet randomly. R_1 is defined as a multiplier to determine the number of nodes chosen for friend-of-a-friend, or network neighbor, meetings. First, the random network is formed: (number of possible pairs * R_0) pairs of vertices are chosen uniformly at random from the network to meet. (Note: The R_0 used here is the notation implemented by Alam et al, and should not be confused with the epidemiological concept of the basic reproductive number.) If a pair meet who do not have a preexisting connection, and if both have fewer than the maximum number of connections then a new connection is established between them. Second, friend-of-a-friend connections are made: (total number of connections in the network * R_1) vertices are chosen at random, with the probability that a particular vertex is chosen proportional to (number of connections it has * number of connections - 1). For each vertex chosen one pair of its neighbors is chosen randomly to meet, and establish one new connection between them if they do not have a preexisting connection and if neither of them already has the maximum number of connections. After the start of the run, at each time step a new random network connection is made, and a new connection is made between an agent and his/her friend-of-a-friend, adding two connections to the overall network at each time step. In addition, at each time step (number of edges * probability of removal) network connections are randomly chosen for removal. This is done by choosing vertices at random, with probabilities proportional to degree. For each vertex chosen, one of its neighbors is chosen uniformly at random and loses the connection to that neighbor. This creates a dynamic community of connections throughout the run of the model, with agents constantly meeting new individuals and losing touch with old contacts.

3.3 Model action

The model is a discrete time model in which each step represents one week. At each model step, after the random and friend-of-a-friend meetings have taken place and some friendships are randomly removed, several things happen. The couples in the model are updated, and agents search for partners. In the interest of building a model comparable to existing literature, the starting point for the current model was a simplified partnering model used in an earlier version of the South Africa model by Alam et al (2008). This model implements the mechanism outlined in Simao and Todd (2002), but uses the community network architecture described above. Alam et al (2008) implemented the model in such a way that only male agents make proposals, and in this model a parameter has been added to determine which agents are able to propose a relationship, men, women, or both. The partnering mechanism has also been expanded to include multiple partners.

At each time step, the asking agents get a list of their opposite-sex friends, which includes all connections in the social network to opposite-sex agents. If the asking agent does not already have any partners, then for each friend, he/she determines whether the quality of each friend is higher than the aspiration level of the agent him/herself, and if so, makes that friend a potential date and sends a message to add him/herself to the list of agents proposing to date the friend agent. If the asking agent is already dating other agents, then the perceived quality of the potential date is weighted by the duration of the current relationships as a proportion of the total courtship duration, or how long an agent must date before entering into a sexual relationship, so that if:

$$Q_{\text{current dates}} < Q_{\text{potential date}} * (1 - D)$$

$$Q_{\text{current dates}} = \text{average quality of the current date agents}$$

$$Q_{\text{potential date}} = \text{quality of the potential date}$$

$$D = \text{MIN}([\text{average time dating current partners/courtship duration}], 1)$$

the agent sends a message to the potential date. If all of the current partnerships were past the courtship period, then the new potential date was not considered. The above equation provided a weight that was small enough to allow partner switching during the course of the model, and would multiply the quality of the potential partners by progressively smaller weights as the current relationships increased in duration. In addition, a set of parameters for valuing monogamy in current and potential partners is included. First, a probability of knowing the concurrency status of one's partner is defined based on the actual concurrency status. Second, if an agent believes (correctly or incorrectly) that a partner has other partners, the agent imposes a penalty for non-monogamy in comparisons with potential partners. In addition, the "tolerance change" parameter allows agents to become more tolerant of concurrency the longer they are unable to find a partner who meets their aspirations.

Several other weighting strategies were implemented at various points of model development (including a fixed cost for being a potential rather than a current partner, weighting by a measure of number of partners compared to desired number of partners, weighting by the relationship duration as a fraction of the model run), but none resulted in qualitatively reasonable results.

If the asking agent's quality level is above the aspiration level of the proposed-to agent, and if this agent does not already have any partners, the proposed-to agent adds the asking agent as a potential date. If the proposed-to friend is currently dating other agents, he/she uses the weighted evaluation method, and if the quality measure is high enough, he/she adds the proposer as his/her potential date. If both agents agree, and have each other listed as potential dates, they then become a couple and are dating, moving one another from the potential *date* list to their lists of potential sexual partners. The agent who receives proposals evaluates them in the order in which they arrive. At each step each couple is updated: the number of weeks they have been dating increases by one, and they evaluate the future of their relationship.

In addition to searching for partners within the network of friends, a runtime-settable parameter defines the probability of making the random acquaintance of another agent outside the friendship network. With the defined probability, the agent has the opportunity to evaluate and propose to a random agent outside his/her social network. To allow for comparison with a non-network-based meeting scheme, there is also a parameter which allows agents to meet all of their potential partners randomly, rather than through the friendship network.

In order to update the couples in the model, each couple evaluates the number of weeks they have been dating and determines whether they should break up, remain dating, or become sexual partners. Break-ups occur probabilistically based on the duration of the relationship. In addition to random break-ups, dating relationships can end if an agent meets a new agent who, after weighting, has a higher quality measure than one of the agents it is currently dating. In that case, the agent ends the relationship with the least desirable partner. Sexual relationships can end if a new dating relationship reaches the end of the courtship period and is a better match than one of the current sexual partners, in which case the relationship with the least desirable sexual partner ends. These removal procedures are only necessary in the context where the number of dates an agent may have is limited and/or when the agent already has his/her maximum number of sexual partners. Couples decide to become sexual partners if they have been dating long enough to pass the courtship duration for each partner, and if neither partner already has his/her maximum number of partners.

4. Parameter justification

The final parameterization for the model is shown in Table 8. This set of parameter values was derived based on a combination of empirical studies in the literature from public health, evolutionary and social psychology, and sexual decision-making, theoretical work from psychology and public health, parameter settings inherited from Alam and colleagues (2008), the authors' hypotheses about the process of partner selection, and calibration of the model to achieve the most realistic outcomes as measured by the number of partners over the lifetime in the 5-year run and the past year, rates of concurrency over the 5 year run, and correlation in partner quality values.

The model is set to run for 260 time steps, with each time step representing one week. The 5-year duration of a single run was chosen because it was hypothesized that partner selection

as a young adult (approximately ages 20–25) would be relatively age-independent in this interval and that the mechanisms of partner selection would be more likely to be constant than over a longer time frame (Darroch, Landry, & Oslak, 1999). The number of agents is set to 250, which was chosen to represent the potential dating network of the agents. Lacking empirical data on the number of people an individual may encounter as potential partners, this was chosen as a baseline value. The results were similar when the number of agents was set to 500.

The sex ratio default is set to 0.5 (an equal number of men and women) as an idealized setting for partner search. This ratio is approximately correct in many communities, though differential mortality (at any point before ages 20–25), incarceration, military service, differential college attendance, and other factors may shift the sex ratio in some settings (for example, see Geronimus, Bound, Waidman, Hillemeier, & Burns, 1996).

The parameters for the friendship network were largely drawn from Alam et al (2008), or set through calibration to achieve distributions of number of partners and rates of concurrency similar to those observed empirically. The parameters that specify network density and clustering (R_0 and R_1) were calibrated by comparing model output to empirical data. However, note that even large changes in friendship network structure do not result in substantial changes in the model results (see supplemental material). The probability of network edge removal was retained directly from Alam et al. as well. A maximum degree of 10 was determined to represent a qualitatively reasonable set of contacts from which an agent can draw potential partners. The literature shows that most sexual networks are constrained by geography and local dynamics, so the default setting for the model is for agents to find partners through their friendship network. Based on the National Health and Social Life Survey, approximately 20% of partners were the result of meetings that took place in bars or other places outside of regular social networks, and so the probability of randomly meeting a potential partner was set to 20% (Laumann, et al., 1994).

The distributions of aspiration and quality levels were arbitrarily retained from Alam et al (2008). Because these measures are proxies for many unmeasured variables, the specific numbers are not important. A normal distribution was chosen because many of the traits that determine attraction are normally distributed in the population.

The selection of “both” (versus men-only or women-only) having the ability to propose partnerships was based on data demonstrating that the dating market is increasingly egalitarian. In one study of undergraduate students in the Midwest, 84–90% of men had been asked out by a women and 63–85% of women indicated that they had asked a man out on a date (Mongeau, Hale, Johnson, & Hillis, 1993).

The courtship duration, or the amount of time that an agent must wait before entering into a sexual relationship, was estimated based on survey research conducted with undergraduate students reported in a review of human mating strategies by Buss (2006). He reports that at every time point men are more willing to have sex than women, though to limit the number of model parameters this was collapsed into a single distribution for both male and female agents. Based on his figure, the average undergraduate student is willing to have sex with

someone he/she finds attractive after between 4 and 12 weeks of knowing him/her, with both men and women reporting being willing to have sex with someone after 6 months. A normal distribution with mean 10 weeks and standard deviation 2 was chosen to roughly approximate this distribution. The minimum and maximum waiting times (defining a uniform distribution of how long an agent will wait without a proposal being accepted before decreasing his/her aspiration) were calibrated to produce reasonable model output, as no data was available to compare them with empirical measurements. The maximum number of potential partners an agent could date at one time was also calibrated, though 10 was also seen as a qualitatively reasonable mean, with a relatively large standard deviation (5).

The distribution of the ideal number of partners was also estimated from data on the preferences of undergraduate students (Buss, 2006). As the review demonstrates, women report that this number ranges from 1–2 partners over the course of 1 month or a year to approximately 5 partners over the lifetime. Men report desiring many more partners, with Buss's data suggesting men wish to have around 2 partners over the course of a month, 10–12 over 5 years, and nearly 20 over the course of the lifetime. This data is likely to suffer from substantial social desirability bias in reporting, with men feeling social pressure to report desiring more partners and women feeling social pressure to report desiring few, but those same social pressures may also in part influence sexual decision-making, and this data is the best available. No distribution over the population was reported in the literature, and so a gamma distribution was chosen to represent a skewed distribution, where most individuals report desiring some number of partners near the expected value (found by dividing alpha by lambda). Since an exact parameterization was unclear, the model was run with the expected value of the ideal number of lifetime partners for men ranging from 6–20 and for women from 2–6. The distribution which appeared closest to empirical data from young adults in the US was produced when the expected value for men was 20 ($\alpha = 20$, $\lambda = 1$) and for women was 2 ($\alpha = 2$, $\lambda = 1$). These values fit reasonably with Buss's empirical data, though clearly more data would improve the selection of parameter values in the model.

Parameters determining whether an agent is able to correctly identify concurrency in a partner were estimated based on empirical data. Several studies comparing adolescents' *beliefs* about the concurrent sexual partnerships of their sexual partners with the actual reports from their sexual partners suggest that only 26–42% of individuals whose partners have other concurrent partners know this, and 14–19% of individuals with monogamous partners believed that their partners had concurrent partners (Drumright, Gorbach, & Holmes, 2004; Lenoir, Adler, Borzekowski, Tschann, & Ellen, 2006). The model parameters were set to fall within the ranges observed: if a partner truly has concurrent partners, the penalty for non-monogamy is applied 30% of the time, and if the partner does not have concurrent partners, the penalty for non-monogamy is applied only 15% of the time, reflecting error in individuals' perceptions of their partners' activities.

Very little data has been collected about how individuals compare partners, particularly once they are dating. While the data clearly suggest that individuals prefer higher quality partners (with higher quality measured in a variety of domains including attractiveness, income, education, etc.), it is not clear how much better a potential partner must be to motivate

someone to leave a stable relationship, or the extent to which discovering a partners concurrency makes them less attractive. Clearly there is no single estimate of these values, as individuals likely approach each situation in context. To model these decisions, however, it was determined that individuals would weight their evaluations of potential new partners using the current duration of their relationship (as a fraction of their courtship duration), and that partners who were believed to have concurrent partners (either correctly or incorrectly) would be penalized 40% of their quality measure.

The probabilities of random break-ups are hard-coded into the model, meaning that there are not currently parameters defined to set them at run time. If a couple has been dating for less than 2 weeks, 2–4 weeks, 5–6 weeks, 7 weeks, or more than 7 weeks the probability of break-up is 0.01, 0.015, 0.025, 0.015, and 0.010 respectively. These probabilities were chosen to include an element of stochasticity in the partnership formation process, and were retained from Alam et al (2008). There is no empirical data available to determine how likely a relationship is to end based on the duration of the partnership.

5. Model output from one run

Figure 2 demonstrates the average behavior of several measures of agent behavior over the course of 50 model runs, and Figure 3 shows results from a single sample run. Agents have roughly the same number of partners per year throughout the model run, and accumulate lifetime partners as the run continues, though the average remains constant after roughly the first year. In some runs, the average number of lifetime partners decreases slightly when an agent finds a first sexual partner later in the model run, since the average number of partners is only calculated for those who have any partners. The proportion of male agents with concurrent partnerships starts out very high and settles to around 40% after the first year of the run. Concurrent partnerships are also higher for female agents at the start of the model run, and drop to similar levels. As would be expected with no existing relationships at the start of the model, the average relationship duration is quite short. It rises steadily through the first half of the run, and then decreases slightly in the second half of the run. The correlation between agent quality measures in couples generally increases over the course of the run, although in some runs (including the sample shown here), agents randomly find highly correlated partners at the start of the run.

6. Comparison of model outcomes with survey data

As described above, parameter values were set using empirical data and then the model was calibrated using the remaining parameters to produce patterns of partnership that look very much like empirical sexual behavior data gathered in nationally representative surveys, which is described below. In addition to large survey data sets, data from several smaller studies were used to estimate attribute correlation among dating individuals as well as the average duration of young people's dating and sexual relationships. While empirical data is not available to determine values for every parameter, using several sets of data for parameterization and separate data sets to calibrate, or tune remaining parameters, is likely to produce credible model results.

6.1 Empirical data

There are several extant sources for data on the number of sexual partners men and women living in the United States have over the course of a year or the course of a lifetime, and how often their partnerships overlap in time (concurrent partnerships). These sources were used in combination because each of the data sources represent a different population at a different point in time, and there is no clear single data source that best fits the model population. The first of these is the National Health and Social Life Survey (NHSLS) (Laumann, et al., 1994). Completed in 1992, this data is nearly 20 years old, meaning that these data were collected in the early years of the HIV/AIDS epidemic in the US. The comprehensive nature of the survey, as well as the comparative network modeling described in the literature using these data, however, makes it a useful comparison for this model. NHSLS distributions of numbers of partners over the past twelve months, number of partners in the past 15 years, and number of partners since age 18 are presented in Table 9. Based on the population of interest in this model, i.e. young adults, empirical data for individuals aged 18–24 and 25–29 are shown.

The second source of empirical measures of sexual behavior is the National Survey of Family Growth (NSFG) (Chandra, Martinez, Mosher, Abma, & Jones, 2005; Martinez, Chandra, Abma, Jones, & Mosher, 2006). NSFG was designed to describe and explain trends and group differences in birth rates, such as contraception, infertility, sexual activity, and marriage (http://www.cdc.gov/nchs/nsfg/about_nsfg.htm). The first five waves (1973–1995) were conducted only with women, but the most recent available wave of data (Wave 6, 2002) included both men and women. Data on number of partners for this 6th wave are shown in Table 10.

The third source of data about sexual behavior in young adults is the National Longitudinal Survey of Adolescent Health (Add Health). Add Health was developed in response to a mandate from the U.S. Congress to fund a study of adolescent health (Harris & Udry, 2008). Waves I and II focus on the forces that may influence adolescents' health and risk behaviors, including personal traits, families, friendships, romantic relationships, peer groups, schools, neighborhoods, and communities. Wave III was conducted when respondents were between 18 and 26 years old and focuses on adolescent decisions, behavior, and health outcomes in the transition to adulthood. Data on number of sexual partners reported in Wave III are shown in Table 11 below.

Of these sources, only NSFG and Add Health estimate rates of concurrency, or the proportion of individuals who have overlapping partnerships over a particular period of time. Concurrency was defined slightly differently depending on the study. For men, NSFG-defined concurrency included any instance where the first date of sexual intercourse occurred before the last date of sexual intercourse with another partner. This same definition was used for both men and women using the Add Health data set. For women, NSFG-defined concurrency included instances where there were two or more partnerships were defined as “current” or where first sexual intercourse with one partner occurred before the month of last sexual intercourse with another partner. In the model, concurrent partnerships were sexual partnerships that overlapped by at least one week. These estimates are shown in Table 12.

The correlation in partner quality measured here is an approximate measure that is a simplification of measures of correlation between partner income, looks, education, and other factors. Hitsch and colleagues (2006) compare the correlation structure of online matches made through an online dating service to that of married couples. They review the literature and report observed correlations by education ($\rho = 0.64$), income ($\rho = 0.13$), height ($\rho = 0.31\text{--}0.63$), weight ($\rho = 0.08\text{--}0.32$), and looks ($\rho = 0.34\text{--}0.54$). For matches made through the online dating service, the correlations are slightly lower, with looks, height, BMI, income, and years of education having correlation coefficients of 0.33, 0.16, 0.13, 0.15, and 0.13 respectively (Hitsch, et al., 2006). The authors suggest that online dating matches are likely to be less correlated as they reflect “first date” partnerships rather than marriage partnerships, and it is reasonable to suppose that correlation for sexual relationships would fall somewhere between first date partnerships and marriages. These data are also shown in Table 13.

In addition to the number of partners and correlation in partnership attributes, the average duration of relationships in the model was compared with average duration of sexual relationships reported in the literature. Reported data are available for adolescents and young adults between 13 and 20 years of age (Howard, Fortenberry, Blythe, Zimet, & Orr, 1999; Manlove, Ryan, & Franzetta, 2007; Sturdevant et al., 2001). These estimates are for populations slightly younger than the model target population of 20–25 years, but nonetheless provide a useful comparative estimate of relationship duration. Using data from the first two waves of the National Longitudinal Study of Adolescent Health (Add Health), Manlove and colleagues (2007) report that the average duration of pre-sexual relationships (the time between when the pair begin dating and sexual initiation) is approximately 5 months, with the subsequent sexual relationship lasting 5–6 months, for a total relationship duration of approximately 10–11 months. Among women 13–19 years of age enrolled in a prospective HIV study, the average relationship duration was measured only for primary partnerships, and was between eleven and twelve months, and this did not differ by HIV status (Sturdevant, et al., 2001). In both of these studies, the range of relationship durations was substantial; for example, in the Add Health data, sexual relationships lasted between 1 and 42 months. Howard and colleagues (1999) report that among their sample of young women (15–20 years old) using STD clinic services, 76% had had at least one relationship that lasted less than 21 days. Even if this group has a higher frequency of short relationships, it suggests that measures of current partnership duration, or even relationship duration (with the associated connotations), rather than dates of first and last intercourse, may overestimate relationship duration slightly. Measures of variance in these means were not reported.

6.2 Comparison with model results

Based on the survey data discussed above, as well as theoretical considerations and the range of model output demonstrated across reasonable ranges of parameters, a set of parameter values was chosen to represent a base model, shown in Table 8.

Model output and empirical distributions of the number of lifetime partners and partners over the past year are compared in Tables 9, 10, and 11. To visualize these comparisons, the distribution of number of partners in the model output was divided into bins corresponding

with those presented in the survey data and Figures 4 and 5 show the model distribution of numbers of partners compared to empirical distributions, with the difference between model and empirical proportions on the x-axis. The model data match most closely with those from men and women aged 20–24 from the NSFG (Table 10) and men and women aged 18–26 in Add Health (Table 11). The most notable deviation from the empirical data is in the number of male agents that report not having any partners in the past year and those having only one partner in the past year: there are more agents without partners than appear in the empirical data, and there are fewer male agents who report having had one partner in the past year than in the empirical data. Overall, however, the model produces distributions of partners in the last year and over the lifetime that are qualitatively similar to those distributions observed in empirical data.

Rates of concurrency in the United States reported in the literature range from 11–29%, with reporting time frames ranging from 1–5 years (Adimora, et al., 2002; Adimora, et al., 2007; Ford, et al., 2002). The rates of concurrency in the model are slightly higher than those reported in the empirical data, with 41% and 43% respectively for men and women over the 5 year run. These are compared in Table 12.

The couples produced in the model have an average quality correlation of 0.14. This is much closer to the correlations in partner attributes observed in matches made through an online dating service, though it is not much lower than the correlation observed in marriages (Hitsch, et al., 2006). Correlations from the literature and model output are compared in Table 13.

The average relationship duration of agents in the model is 45.9 weeks, which is approximately 11.5 months. This matches estimates reported in the literature (11–12 months), for young adults and includes both the pre-sexual and sexual parts of the relationships (Howard, et al., 1999; Manlove, et al., 2007; Sturdevant, et al., 2001).

7. Evaluating model fit

Based on traditional survey measures of sexual behavior, correlation between partners, and relationship duration, the model produces qualitatively reasonable results for sexual partnerships. The model is able to generate distributions of partnership counts and other population-level patterns that are similar to empirical data, using simple algorithms for individual decision-making with realistic parameter values. The model also behaves reasonably when the sex ratio is altered, as well as when the objective “quality” measures of male and female agents come from different distributions. Though these changes make it more difficult for individuals to find partners, they ultimately change their expectations (and sometimes their tolerance for generally undesirable behaviors like partner concurrency) and find partners even in difficult contexts.

Although using empirical data to validate model output is a critical step in model development, it is worth considering the potential limitations to these data. It seems likely that some portion of the discrepancy in number of sexual partners may be a result of over-reporting of sexual partners in the past year by male respondents on surveys of sexual

behavior due to (1) social desirability bias, in this case, reporting a higher number of partners than is true to conform to societal perceptions about male sexuality likely contributes to the discrepancy (Fenton, Johnson, McManus, & Erens, 2001) and (2) telescoping, in which a respondent recalls a relationship that occurred 13–14 months prior to the survey as having taken place in the past year, is also a likely contributors to an empirical underestimate of the number of young men who have no sexual partners in a given year. In addition, at least one study has suggested that in responding to surveys, more men than women include non-penetrative sex in the definition of “sexual intercourse,” which is another source of potential bias (Jeannin, Konings, Dubois-Arber, Landert, & Van Melle, 1998). For the measures of concurrency, the time scale of measurement, as well as the fact that the model data captures true rates of concurrency in the model, where the survey data are self-reported, may also be important. In addition, because of the cumulative nature of the model measure (where each instance of concurrent partnership is captured) and the cross-sectional nature of survey data, it would be expected to see slightly higher rates of concurrency in the model output. These potential inaccuracies do not render the data useless, but instead encourage a qualitative assessment of model fit, rather than striving to perfectly match survey data. It is encouraging that all of the deviations of model output from empirical data are in the anticipated directions based on known limitations of surveys of sexual behavior.

8. Sensitivity analysis: model behavior across parameter values

The model was run under a wide range of parameter settings to determine not only the sensitivity to change in the parameters, but also to identify a parameterization that would generate the most realistic descriptive statistics of sexual behavior in the agent population compared with empirical data analysis. Full descriptions of the parameter sweeps and numerical results are given in the online supplemental materials. The reported values for number of partners in the past year, lifetime partners, rates of concurrency, and partner quality correlation are averages based on 50 model runs each. The averages were calculated using data from the final time step of the model, attempting to most closely approximate survey data which is cross-sectional. These particular measures were chosen because they are commonly used measures of sexual behavior and are available in many of the nationally representative US surveys.

8.1 Lifetime partners

The changes in the number of lifetime partners (over the 5-year model run) observed as parameter values were varied are shown in Table 4. Only those parameters that caused a greater than one standard deviation change in the number of lifetime partners between the highest and lowest parameter values are listed.

Parameters that determined the availability of partners had the expected results: increases in the number of desired partners on the part of female agents (who on average desired fewer partners than male agents) and in the sex ratio (more men available) increased the number of lifetime partners for female agents, while increasing the sex ratio decreased the number of lifetime partners for male agents. Similarly, drawing quality values from skewed (Chi-

squared) distributions, or having male and female agents draw from different distributions decreased the number of lifetime partners because fewer high quality partners were available.

Varying those parameters which defined the search process also gave expected outcomes for the most part. Increasing the number of dates an individual could consider at one time increased the number of lifetime partners, while increasing the courtship period decreased the number of lifetime partners. Notably, when agents used the weighted mechanism to consider new partners (and thus gave more weight to those partners of longer duration), they increased the number of lifetime partners, though it is unclear why this would be the case.

It is interesting to note that when agents have a higher probability of suspecting and punishing concurrency (whether they are correct that their partner has outside partners or not) they ultimately have a higher number of lifetime partners. For female agents, the increase in the number of partners occurred between having no probability of punishing concurrency and 0.20 probability, with little change when the probability of punishing was increased further.

8.2 Partners in the last year

The results of varying parameters on the number of partners in the past year (measured at the end of the run) is shown in Table 5, with only those parameters that caused a change in the number of partners larger than one standard deviation between the lowest and highest parameter values listed. These results show short term effects of variation in parameter values, and in many respects are similar to the results for lifetime partners. For example, increased availability of partners also increases the number of partnerships that occur in a given year. However, contrasting with the trends observed in lifetime partnerships, punishing true concurrency decreases the number of partners that male agents have. Several other parameters also have opposite effects on the number of partners in the past year compared with their effect on the number of lifetime partners: increasing courtship duration and using the friendship network to find partners both increase the number of partners in the past year, but decrease the number of lifetime partners.

8.3 Concurrency

Parameters that caused a change in the rate of concurrency larger than one standard deviation (between the highest and lowest parameter values) are listed in Table 6. Punishing concurrency decreases its frequency, as expected. Decreasing the availability of partners (as evidenced by the effects of decreasing the average number of potential dates, drawing male and female quality values from different distributions, and increasing the lambda values for the distributions of the ideal number of partners, a parameter which ultimately decreases the expected value of the distribution by making it more broad) also reduce rates of concurrency. Increases in rates of concurrency suggest that several parameters can be interpreted as increasing tolerance for concurrency: when agent quality values are drawn from a skewed distribution such that high quality partners are relatively scarce, or when courtship duration is long, requiring individuals to wait before engaging in sexual behavior, rates of concurrency increase for men (but do not change for women); when a weighted switching

mechanism is used and agents preferentially maintain existing relationships, rates of concurrency increase.

8.4 Correlation in partner quality

There are very few parameters that caused a change in the quality correlation larger than one standard deviation between the highest and lowest parameter values, and they are listed in Table 7. As expected, increasing the mean number of dates an agent can have at once increases the correlation, as agents can do a better job of comparing available partners. The largest increase in quality correlation, however, occurred between having only a single date at once and having 6 at once, with little change as the number of dates was increased further. When the quality values are drawn from a skewed distribution the correlation also increases, likely because all of the quality values are lower and thus closer together when this distribution is used. Quality correlation decreases substantially, but unsurprisingly, when male and female quality values are drawn from different distributions. It also decreases when only men propose relationships (compared to women proposing relationships, or both being able to propose), potentially because male agents desire a larger number of partners and find themselves increasingly willing to ask partners who might be below their initial aspirations, and less desirable overall.

9. Implications for sexual behavior research, limitations, and future directions

Previous models of sexual partnership and sexual decision-making have focused almost exclusively on first marriage (see, for example, French & Kus, 2008; Simao & Todd, 2002), excluding the possibility of multiple sexual partnerships over time, either overlapping or one after the other. The only notable exception, Bearman, Moody, and Stovel's (2004) network model, is a static, rather than a dynamic model which focuses on high school students, whose preferences and patterns of sexual partnership cannot be easily extended to other contexts. Although Alam and his colleagues did allow for multiple partnerships for male agents, the specificity of their model to a Sub-Saharan African context similarly limited the generalizability of their conclusions. The model presented here expands on this work, and contributes to the literature a model that qualitatively matches a different set of empirical data, those describing sexual behavior rather than marriage.

The model results presented here suggest several interesting conclusions about sexual decision-making and patterns of sexual partnership. First, the model highlights certain individual preference parameters that substantially influence broader patterns of sexual behavior, including the desired number of sexual partners, the penalty for concurrency, and the courtship period. Second, because the preference parameters for male agents influence the behavior patterns for female agents, and vice versa, the model demonstrates the importance of interactions between agents, rather than just preferences, in determining behavior. Third, the effect of parameters such as the sex ratios, quality distribution of the agents, and norms around initiating dates emphasize the contextual nature of sexual decisions, and illustrate that using the same decision algorithms in different contexts yields different results.

The model is not without limitations. First, it considers only heterosexual partnerships, because we hypothesize the mechanisms and contexts of sexual decision-making and behavior to be qualitatively different for homosexual partnerships.

Second, the model is limited by current understanding of sexual decision-making: it simplifies many aspects of sexual partnership formation, and uses only estimates of other parameter values for which data are not available. A better understanding of the social processes underlying sexual partnership formation would likely result in improved model fit to empirical data. For example, variation in model output due to variation in values chosen for the desired number of partners for male and female agents, as well as courtship duration, suggest that more detailed descriptive population-level data about these preferences would help to refine the model to better fit specific contexts. In addition, interpretation of the effects of using the social network to find partners is complicated by the lack of empirical data about how these networks function. Although qualitative (as well as limited quantitative data used here) suggest that most individuals meet their sexual partners through their social network, the details of this process are not clear.

Similarly, details of the acceptance decision-making algorithm and the associated parameter values are likely to be important in some cases and not others. For example, in our model the effect of weighting in the algorithm that agents use to determine when to switch partners is a sensitive parameter. Previous implementations of multi-dimensional preferences, however, have not demonstrated improved comparisons with empirical data, suggesting that experimenting with alternative combinations of attributes or preferences for relationship characteristics (such as relationship duration) may be warranted, and a wide array of qualitative and quantitative data are available to inform this search (for example, Gilmore, DeLamater, & Wagstaff, 1996; Hitsch, et al., 2006). Specific data on the effect of preferences for monogamous partners over those with concurrent partnerships are also necessary, e.g., how much are individuals with concurrent partnerships punished? In addition, gathering further data about changing preferences and weighting mechanisms over the course of a relationship, or how an individual's requirements change depending on their current partnership status, would likely improve the implementation of this decision-making process in the model, and perhaps improve the fit of the model output with empirical data. A better understanding of how agents modify their strategies for partner search over time might also improve the fit of the model; agents in the model could modify their expectations (through changing their aspiration value) as well as their tolerance for concurrency, but did not adapt fundamentally different strategies based on success or failure.

In spite of the limitations of the model described in this paper, it extends previously validated work, most importantly by allowing multiple sequential and concurrent partnerships, while producing patterns of sexual behavior that are qualitatively similar to a wide range of empirical data. The reasonableness of both the mechanisms and the results suggest that this model is suitable for use in testing hypotheses about sexual partnership patterns and is a good starting place for further work on the processes that shape sexual decision making. For example, the model could be used to test hypotheses about the effects of interventions targeting sexual behavior, as well as to examine the potential effects of changing contextual variables that influence sexual decision-making. Future directions

include expanding the algorithm for partner switching to include additional attributes, examining the network structures generated by the model to determine whether they are similar to those documented in the Add Health data set and how observed network structures might facilitate or limit HIV transmission (Bearman, et al., 2004; Rothenberg & Muth, 2007), and implementing an HIV transmission process in the model.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Schematic of model implementation.

Figure 2.
Average behavior over 50 model runs.

Figure 3.
Average behavior over a single sample run.

Figure 4.
Differences in distribution of partners in the past 12 months.

Figure 5.
Differences in distribution of number of lifetime partners.

Table 1.

Key characteristics of existing models of partner selection

	Todd and Simao	French and Kus	Alam, Meyer and Norling	Bearman, Moody, and Stovel	Knittel et al
Context	General/ Conceptual	General/Conceptual	Sekhukhune district, Limpopo, South Africa	A high school in a midsized, Midwestern town	Young adults, United States
Mate Quality Measure	Single value	Vector of attributes	Single value with endorsements	Grade in school, smoking status, popularity, and attractiveness	Single Value
Aspiration	Single value	Weighted vector of attributes	Single value	Matched values	Single Value
Partner Solicitation	Male-ask-female	Male-ask-female Female-ask-male Both-ask	Male-ask-female	Not applicable	Both-ask
Parameters establishing willingness to change partners	Meeting rate and remaining courtship time	Temperature	Increasing aspiration with partnership duration	Not applicable	Partnership switch weighted by relationship duration
Concurrent Partnerships	No	No	Men only	Yes	Yes
Network Architecture	No	No	Yes	Yes	Yes
Migration	No	No	Yes	No	No

Table 2.

Agent-level Characteristics

Characteristic	Variable Name	Description
Gender	gender	Male/Female
Quality	baseQuality	Representation of the value of the agent in a sexual relationship
Aspiration	aspirationLevel	Level of quality the agent seeks in a partner
ID	id	ID number
Courtship Duration	courtShipDuration	Minimum duration of dating before engaging in a sexual relationship
Waiting Threshold	waitingThreshold	How long the agent will wait to have a partner before decreasing the aspiration level
Maximum number of partners	maxPartners	How many partners an agent is able to have at one time

Table 3.**Run-time Settable Model Parameters**

Parameter	Variable Name	Description
Number of Time steps	stopT	Number of steps the model runs before stopping
Number of Agents	NumNodes	Number of agents in the simulation
Sex Ratio	sexRatio	Proportion of men in the initial population, ranges from 0–1
Maximum Degree	maxDegree	Maximum number of social connections for each agent
Probability of Edge Removal	removeProb	Probability that a given edge will be removed
R_0	Rsub0	Proportion of possible pairs chosen to make random meetings
R_1	Rsub1	Multiplier to determine the number of nodes chosen to make neighbor meetings
Aspiration Level Mean	meanAspiration	Mean for the normal distribution of aspiration levels assigned to the agents
Aspiration Level SD	sdAspiration	Standard deviation for the distribution of aspiration levels assigned to the agents
Quality Level Mean	meanQuality	Mean for the distribution of quality values assigned to the agents
Quality Level SD	sdQuality	Standard deviation for the distribution of quality values assigned to the agents
Ask Method	Ask	Switch: if “men,” only men propose relationships; if “women,” only women propose relationships; if “both,” all agents propose relationships
Probability of Random Meeting	probRandomPartner	Probability that at a given time step an agent will meet a potential partner randomly (rather than through the friendship network)
Courtship Duration Mean	meanDuration	Mean for the distribution of minimum courtship time before engaging in a sexual partnership
Courtship Duration SD	sdDuration	Standard deviation for the distribution of minimum courtship times
Minimum Waiting Time	minWaiting	Minimum time without a partner before an agent decreases his/her aspiration level
Maximum Waiting Time	maxWaiting	Maximum time without a partner before an agent decreases his/her aspiration level
Maximum Number Dating Mean	meanNumberDating	Mean for the distribution of the maximum number of potential partners an agent can remember and date at one time
Maximum Number Dating SD	sdNumberDating	Standard deviation for the distribution of the maximum number of potential partners an agent can remember and date at one time
Maximum Number of Partners Alpha - Male	alphaM	Shape parameter for the gamma distribution of maximum number of partners for the male agents
Maximum Number of Partners Lambda - Male	lambdaM	Scale parameter for the gamma distribution of maximum number of partners for the male agents
Maximum Number of Partners Alpha - Female	alphaF	Shape parameter for the gamma distribution of maximum number of partners for the female agents
Maximum Number of Partners Lambda - Female	lambdaF	Scale parameter for the gamma distribution of maximum number of partners for the female agents
Network On	networkOn	Switch: if true, agents meet potential partners through the friendship network; if false, agents meet potential partners randomly
Weighted Partner Switch	weightedSwitch	Switch: if true, agents weight partner comparisons by relationship duration; if false, agents compare raw quality measures
Probability of recognizing true concurrency	probRecognizeConcurrentTrue	Probability that an agent will correctly identify a partner with other concurrent partners
Probability of falsely identifying concurrency	probRecognizeConcurrentFalse	Probability that an agent will identify a truly monogamous partner as having other concurrent partners

Parameter	Variable Name	Description
Concurrency penalty	concurrentPenalty	Fractional adjustment to partner quality applied when concurrency is identified (either true or false)

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Table 4.

Parameter effects on number of lifetime partners.

Increase in parameter value increases number of partners	Increase in parameter value decreases number of partners
Sex Ratio (female only)	Sex Ratio (male only)
Ask Method (men < both < women) (male only)	Female Lambda (female only)
Mean Number of Dates	Friendship Network (true > false)
Probability Punish True Concurrence	Skewed Quality Distribution
Probability Punish False Concurrence	Male/Female Quality Distribution (equal > unequal)
Weighted Switch (false < true)	Courtship Duration
Concurrence Penalty	Male Alpha (female only)
Female Alpha	
Male Lambda	

Table 5.

Parameter effects on number of partners in the past 12 months.

Increase in parameter value increases number of partners	Increase in parameter value decreases number of partners
Sex Ratio (female only)	Sex Ratio (male only)
Male and Female Alphas	Probability Punish True Concurrency (male only)
Courtship Duration	
Friendship Network	
Mean Number of Dates (female only)	

Table 6.

Parameter effects on rate of concurrency.

Increase in parameter value increases rate of concurrency	Increase in parameter value decreases rate of concurrency
Courtship Duration (male only)	Sex Ratio (male only)
Male and Female Alphas	Mean Number of Dates (female only)
Friendship Network (true > false)	Male and Female Lambdas
Skewed Quality Distribution (male only)	Probability Punish True Concurrency (male only)
Weighted Switch	Probability Punish False Concurrency (female only)
	Concurrency Penalty
	Male/Female Difference in Quality Distribution (equal > unequal)

Table 7.

Parameter effects on quality correlation between partners.

Increase in parameter value increases partner quality correlation	Increase in parameter value decreases partner quality correlation
Mean Number of Dates	Ask Method (men > both > women)
Skewed Quality Distribution (skewed > unskewed)	Male/Female Difference in Quality Distribution (equal > unequal)

Table 8.

Final parameterization of the model and type of parameter sources

Parameter	Final Value	Type of Source
Number of Time steps	260	Theoretical
Number of Agents	250	Theoretical
Sex Ratio	0.5	Empirical/Theoretical
Maximum Degree	10	Calibration
Probability of Edge Removal	0.005	Alam et al
R_0	0.2	Alam et al and Calibration
R_1	2	Alam et al and Calibration
Aspiration Level Mean	50	Alam et al
Aspiration Level SD	25	Alam et al
Quality Level Mean	50	Alam et al
Quality Level SD	25	Alam et al
Ask Method	both	Empirical/Theoretical
Probability of Random Meeting	0.2	Empirical
Courtship Duration Mean	10	Empirical and Calibration
Courtship Duration SD	2	Empirical and Calibration
Minimum Waiting Time	5	Calibration
Maximum Waiting Time	10	Calibration
Maximum Number Dating Mean	10	Calibration
Maximum Number Dating SD	5	Calibration
Maximum Number of Partners Alpha - Male	20	Empirical and Calibration
Maximum Number of Partners Lambda - Male	1	Empirical and Calibration
Maximum Number of Partners Alpha - Female	2	Empirical and Calibration
Maximum Number of Partners Lambda - Female	1	Empirical and Calibration
Network On	true	Empirical
Weighted Switch	true	Empirical and Calibration
Probability of recognizing true concurrency	0.3	Empirical and Calibration
Probability of falsely identifying concurrency	0.15	Empirical and Calibration
Concurrency penalty	0.6	Calibration
Quality Distribution	normal	Theoretical
Equal Male/Female Quality Distributions	true	Theoretical
Tolerance Change	true	Theoretical

Table 9.

Number of sexual partners over the past 12 months, the past 5 years, and since age 18 reported in the National Health and Social Life Survey (1992) compared with model output.

Social Characteristics	Number of Partners (%)						N
<i>Partners in the past 12 months</i>	<i>0</i>	<i>1</i>	<i>2–4</i>	<i>5+</i>	<i>-</i>	<i>-</i>	
Men (all ages)	9.9	66.7	18.3	5.1	-	-	1,407
Women (all ages)	13.6	74.7	10.0	1.7	-	-	1,748
Age 18–24 (men and women combined)	10.8	57.0	23.7	8.6	-	-	502
Age 25–29 (men and women combined)	5.5	72.0	16.8	5.7	-	-	457
Model Output (Male Agents)	43.9	22.3	24.1	9.6	-	-	125
Model Output (Female Agents)	15.6	41.7	39.4	3.3	-	-	125
<i>Partners in the past 5 years</i>	<i>0</i>	<i>1</i>	<i>2–4</i>	<i>5–10</i>	<i>11–20</i>	<i>21+</i>	
Men (all ages)	7.1	45.7	27.7	12.0	4.2	3.3	1,330
Women (all ages)	8.7	59.4	24.3	5.9	1.4	0.4	1,669
Age 18–24 (men and women combined)	11.8	21.5	38.1	18.4	6.0	4.1	483
Age 25–29 (men and women combined)	4.4	38.0	36.6	11.5	6.5	3.0	434
<i>Partners since age 18</i>	<i>0</i>	<i>1</i>	<i>2–4</i>	<i>5–10</i>	<i>11–20</i>	<i>21+</i>	
Men (all ages)	3.4	19.5	20.9	23.3	16.3	16.6	1,394
Women (all ages)	2.5	31.5	36.4	20.4	6.0	3.2	1,732
Age 18–24 (men and women combined)	7.8	32.1	34.1	15.4	7.8	2.8	499
Age 25–29 (men and women combined)	2.2	25.3	31.3	22.2	9.9	9.0	454
<i>Lifetime Partners</i>							
Model Output (Male Agents)	15.0	10.9	29.1	33.7	10.3	1.1	125
Model Output (Female Agents)	10.9	14.9	33.3	27.7	12.0	1.1	125

Table 10.

Number of sexual partners over the past 12 months and over the lifetime reported in the National Survey of Family Growth (2002) compared to model output.

Social Characteristics	Number of Partners (%)[*]										N
<i>Partners in the past 12 months</i>	<i>0</i>	<i>1</i>	<i>2</i>	<i>3+</i>	-	-	-	-	-	-	
Men 18–19	30.5	36.5	16.2	15.4	-	-	-	-	-	-	4,460
Men 20–24	15.6	49.3	12.7	19.3	-	-	-	-	-	-	9,883
Men 25–29	11.4	67.1	6.6	12.5	-	-	-	-	-	-	9,226
Women 18–19	24.8	42.9	13.6	16.8	-	-	-	-	-	-	4,015
Women 20–24	13.4	60.9	12.6	11.5	-	-	-	-	-	-	9,840
Women 25–29	6.9	75.9	9.4	5.7	-	-	-	-	-	-	9,249
Model Output (Male Agents)	43.9	22.3	11.3	22.4	-	-	-	-	-	-	125
Model Output (Female Agents)	15.6	41.7	23.9	18.8	-	-	-	-	-	-	125
<i>Lifetime partners</i>	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6–9</i>	<i>10–19</i>	<i>20+</i>		
Men 15–19	54.0	15.5	6.7	6.9	3.9	3.4	5.3	3.1	1.1		10,208
Men 20–24	12.6	14.8	11.5	10.4	8.4	8.5	14.8	10.1	8.9		9,883
Men 25–29	4.2	12.5	8.0	8.0	9.0	6.7	21.6	14.9	15.1		9,226
Model Output (Male Agents)^{**}	15.0	10.9	11.0	9.3	8.8	7.7	26.0	10.3	1.1		125
	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6–9</i>	<i>10+</i>	-		
Women 15–19	53.2	18.2	6.9	7.4	4.1	2.4	5.2	2.6	-		9,834
Women 20–24	13.3	23.3	13.4	11.0	7.3	7.5	13.1	11.0	-		9,840
Women 25–29	3.4	23.0	13.1	10.4	7.9	8.2	15.0	19.1	-		9,249
Model Output (Female Agents)^{**}	10.9	14.9	13.7	11.1	8.5	7.0	20.7	13.1	-		125

* Percentages do not add to 100% if there are individuals who did not respond to this question.

** Highest categories for model output are 6–10, 11–20, and 21+ for male agents, and 6–10, and 10+ for female agents.

Table 11.

Number of sexual partners over the past 12 months and over the lifetime reported in the National Longitudinal Survey of Adolescent Health.

Social Characteristics	Number of Partners (%)									N
<i>Partners in the past 12 months</i>	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5+</i>	<i>-</i>	<i>-</i>	<i>-</i>	
Men 18–26	22.1	41.9	14.7	7.8	3.5	10.0	-	-	-	5092
Women 18–26	19.1	55.4	12.5	5.4	2.0	5.5	-	-	-	5736
Model Output (Male Agents)	43.9	22.3	11.3	7.8	5.0	9.6	-	-	-	125
Model Output (Female Agents)	15.6	41.7	23.9	11.1	4.4	3.3	-	-	-	125
<i>Lifetime partners</i>	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6–10</i>	<i>11–20</i>	<i>21+</i>	
Women 18–26	12.8	18.6	11.6	10.8	8.2	8.5	17.0	7.3	5.2	5092
Men 18–26	14.3	16.7	11.7	8.9	6.8	7.5	16.4	9.3	8.5	5736
Model Output (Male Agents)	15.0	10.9	11.0	9.3	8.8	7.7	26.0	10.3	1.1	125
Model Output (Female Agents)	10.9	14.9	13.7	11.1	8.5	7.0	20.7	12.0	1.1	125

Table 12.

Rates of concurrency as reported in the National Survey of Family Growth and National Longitudinal Survey of Adolescent Health compared to model output.

	Respondents reporting concurrent partnerships % (SD)
<i>National Survey of Family Growth (1995)</i> Concurrent partnership in the past 4 years	
All women	12%
Women 18–24	23%
Women 25–29	15%
<i>National Survey of Family Growth (2002)</i> Concurrent partnership in the past year	
All men	11%
Men with at least 1 sexual partner in the past year	12.5%
<i>National Longitudinal Survey of Adolescent Health (2001–2002)</i> Concurrent partnerships ever	
Women 18–26	29%
Men 18–26	24%
<i>Model Output</i> Concurrent partnerships in the past 5 years	
Women	43% (4.6)
Men	41% (4.5)

Table 13.

Reported correlation between partners based on selected attributes compared to model output.

	Marriage	Dating	Model Output
<i>Attribute</i>			
Education	0.64	0.13	
Income	0.13	0.15	
Height	0.31–0.63	0.16	
Weight/BMI	0.08–0.32	0.13	
Looks	0.34–0.54	0.33	
“Quality”			0.16 (0.11)