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SOCIAL CHANGE

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## Social Change\*

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### Abstract

Social norms are influenced by the technological environment that a society faces. Behavioral modes reflect purposive decision making by individuals, given the environment they live in. Thus, as technology changes, so might social norms. There were big changes in social norms during the 20th century, especially in sexual mores. In 1900 only six percent of unwed women engaged in premarital sex. Now, three quarters do. It is argued here that this was the result of technological improvement in contraceptives, which lowered the cost of premarital sex. The evolution from an abstinent to a promiscuous society is studied using an equilibrium matching model.

**Keywords:** Social change; the sexual revolution; technological progress in contraceptives; bilateral search.

*JEL Classification Nos:* E1, J1, O3



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\*"Social Change" is the title of a classic book by the great sociologist William F. Ogburn. Updates are available at <http://www.econ.rochester.edu/Faculty/GreenwoodPapers/sc.pdf>

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Why is there so much social change today, and why was there so little in ancient times? The most probable answer, the result of quite extensive study, is mechanical invention and scientific discovery. There is no doubt that useful inventions and researches cause social changes. Steam and steel were major forces in developing our extensive urban life. Gunpowder influenced the decline of feudalism. The discovery of seed-planting destroyed the hunting cultures and brought a radically new form of social life. The automobile is helping to create the metropolitan community. Small inventions, likewise, have far-reaching effects. The coin-in-the-slot device changes the range and nature of salesmanship, radically affects different businesses, and creates unemployment. The effects of the invention of contraceptives on population and social institutions is so vast as to defy human estimation. It is obvious, then, that social changes are caused by inventions. William F. Ogburn (1936, pp. 1-2)

## 1 Introduction

What is culture? Define it simply as the attitudes and behavior that characterize a society. So, why and how does culture evolve? The idea here is that changes in culture are largely adaptations to improvements in a society's technological environment. As a society's production possibilities improve due to technological advance, it becomes in the self interest of some of its citizens to modify their behavior to take advantage of the new circumstances. The number may be small at first, and the first adaptors may seem to be heretics. But, if technological progress continues, more and more of its citizens will follow. Often attitudes lag behavior. The individuals participating in an activity may not condone it, as hypocritical as this may seem. What at first seems abnormal will eventually become conventional. Social change, then, is simply a shift in the fraction of society ascribing to a particular attitude or mode of behavior. There may be no better illustration of this phenomena than the change in sexual mores that occurred during the 20th century.

## 1.1 The change in sexual mores

In 1900 almost no unmarried teenage girl engaged in premarital sex; only a paltry 6 percent – see Figure 1.<sup>1</sup> By 2002 a large majority (roughly 75 percent) had experienced this. What caused this: the contraception revolution. Both the technology for contraception and education about its practice changed dramatically over the course of the last century. Along with a change in behavior came a change in attitude toward premarital sex. In 1968 only 15 percent of women had a permissive attitude toward premarital sex – Figure 2.<sup>2</sup> At the time, though, about 40 percent of 19 year-old women were experiencing it. The number with a permissive attitude had jumped to 45 percent by 1983. Another reflection of the change in sexual mores is the rise in the number of sexual partners that unmarried women have. For the women born between 1933 and 1942, the majority of those who engaged in premarital sex had only one partner by age 20, presumably their future husband – see Figure 3.<sup>3</sup> By the 1963-1972 cohort, the majority of these women had at least 2 partners. Notwithstanding the great improvement in contraception technology and education, the number of out-of-wedlock births to women rose from 3 percent in 1920 to 33 percent in 1999 – Figure 4.<sup>4</sup>

## 1.2 The Analysis

The rise in premarital sex will be analyzed within the context of an equilibrium matching model. The model has three salient features. First, when engaging in premarital sex individuals deliberate the costs and benefits from this risky activity. On this, Lundberg and

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<sup>1</sup> Sources: for 1900, 1924 and 1934, the numbers are computed from Kinsey *et al.* (1953, Table 83, p. 339); for 1958, 1961, 1965, 1971, 1976, 1979, and 1982, the data is derived from Hoffrett, Kahn and Baldwin (1987, Tables 2 and 3, pp. 48-49); for 1988 and 1995, see Abma and Sonenstein (2001, Table 1, p. 28); for 2002, the fraction of 19 year-old females with premarital sexual experience was received from Joyce Abma (Division of Vital Statistics, National Center for Health Statistics) via private correspondence. The data for 1900, 1924, and 1934 are for white females.

<sup>2</sup> Source: A reproduction of Figure 2 in Harding and Jencks (2003) using data kindly supplied by the authors.

<sup>3</sup> Source: Laudmann *et al.* (1994, Table 5.5, p. 198).

<sup>4</sup> Sources: For 1920 and 1930, see Cutright (1972, Table 1, p. 383), and for the data between 1940 and 1999, see Ventura and Bachrach (2000).

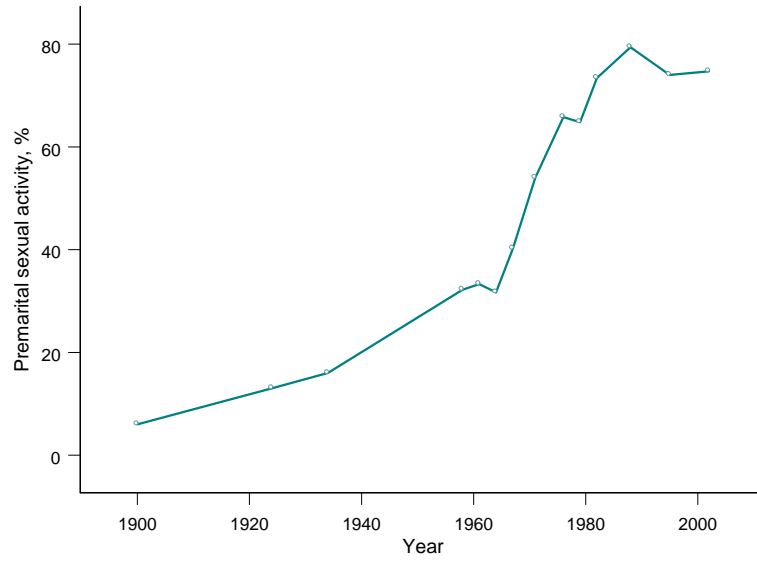


Figure 1: Percentage of 19 year-old females with premarital sexual experience.

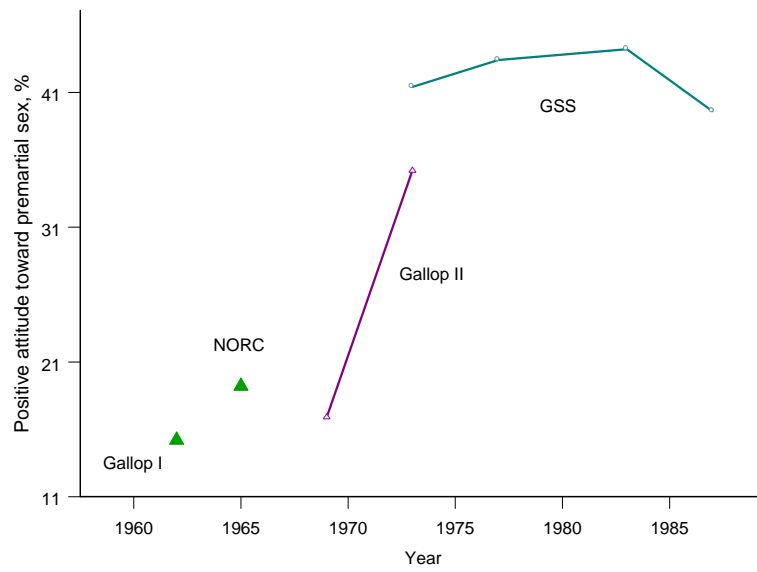


Figure 2: Percentage of females with a permissive attitude toward premarital sex.

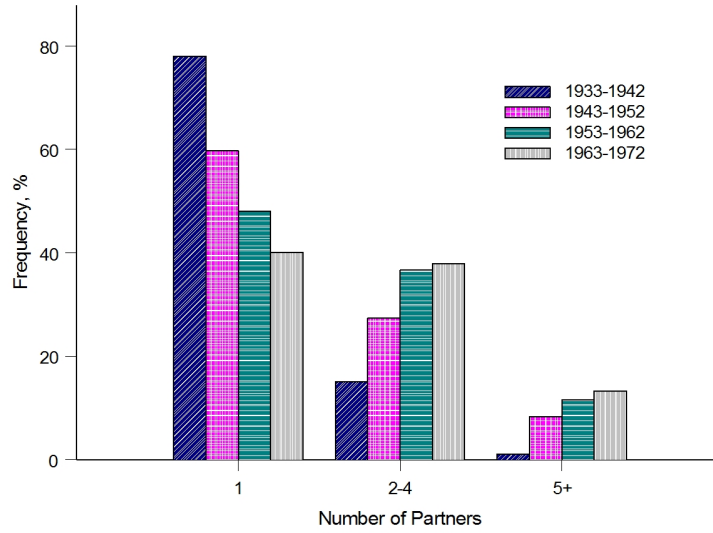


Figure 3: Number of partners by age 20 for women engaging in premarital sex, frequency distribution by birth cohort

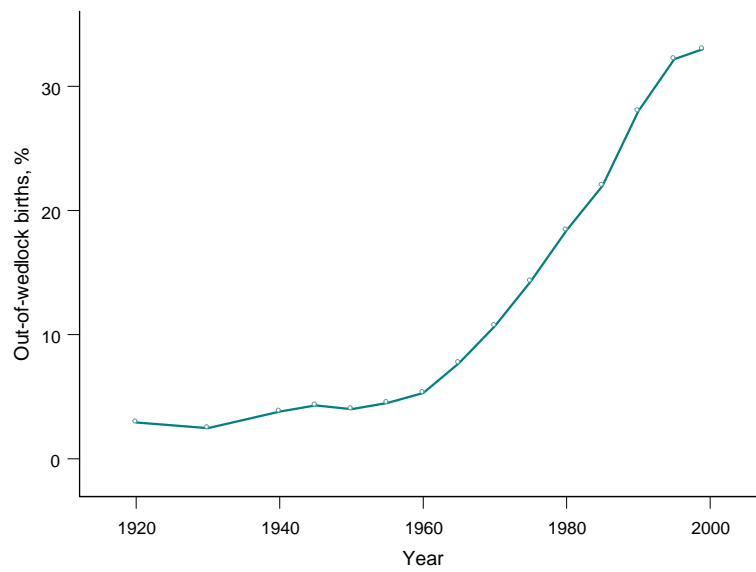


Figure 4: Out-of-wedlock births, percentage.

Plotnick (1995) find that white teenagers' sexual behavior systematically responds to economic incentives. In particular, they report that teenagers are more likely to get pregnant in states with restrictions on the sales, licensing and advertisement of contraceptives. Second, individuals differ in their tastes for sex. A person desires a mate who is similarly inclined so that they can enjoy the same lifestyle. This leads to a bilateral search structure, similar in some respects to the marriage model of Aiyagari, Greenwood, and Guner (2000). Third, given that people desire to find partners that share their views on sex, they will pick to circulate within social groups who subscribe to their beliefs. This is the most efficient way to find a suitable partner. This notion is not without precedence. For example, Burdett and Coles (1997) illustrate within the context of a marriage model how singles, when searching for mates, may voluntarily search only within groups that share their characteristics.<sup>5</sup>

There are other ways to approach social change. Cole, Mailath, and Postelwaite (1992) model the notion of social norms. Historically, societies have had conventions governing premarital sex, such as making it taboo. Individuals engaging in premarital sex may be outcast or shunned by other members of society. Given this fact most individuals may rationally choose to subscribe to the social norm and remain abstinent when young. Such an idea does not conflict with the current analysis. As a society's consumption possibilities change due to technological progress it may become increasingly impossible to sustain such a norm. There is some evidence that social norms may change slowly. Fernandez and Fogli (2005) examine, using 1970 Census data, the fertility and labor-force participation rates for American born women whose parents were immigrants. They find that the fertility and labor-force participation rates in the country of ancestry have significant explanatory power for these American women's fertility and work behavior. These ancestral effects reflect differences in attitudes or social norms about a women's role in society.

It is also possible to model social change via shifts in preferences over time. This would be in the spirit of Doepke and Zilibotti (2004) and Fernandez, Fogli, and Olivetti (2004).

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<sup>5</sup> An elementary discussion of the Burdett and Coles (1997) marriage model is contained in the survey paper on matching models by Rogerson, Shimer and Wright (2004).

For example, suppose parents influence the preferences of their offspring. Parents who were promiscuous when young might endow their offspring with less negative attitudes toward premarital sex than parents who were abstinent when young. Again, this is not at odds with the current analysis. Such a preference channel adds momentum to the technological one. Technological advance in contraception could operate to entice some youths to engage in premarital sex, who in turn will have offspring that will be even more predisposed toward it. The number of children in society who are inclined toward premarital sex will therefore increase magnifying the impact of the original, and also subsequent, technological progress.

## 2 Environment

Suppose that there are two social classes in society, one whose members are abstinent, the other whose members are promiscuous. Members in a social class circulate amongst themselves. Each class is a separate world, so to speak, but the members of a particular class are free to switch to the other class at any time. Social change will be measured by the shift in membership between the two classes.

Each member of society is indexed by the variable  $s \in \mathcal{S} = \{s_1, s_2, \dots, s_n\}$ , which represents their joy from sex. The value of  $s$  is known by an individual. Let  $s$  be distributed across individuals according to the density function  $S(s_j) = \sigma_j$ , with  $0 < \sigma_j < 1$ ,  $\sum_{j=1}^n \sigma_j = 1$ , and  $s_1 < s_2 < \dots < s_n$ . Suppose that time flows discretely. At the beginning of each period, a single member in a class will match with another unattached individual in the same class with probability  $\mu$ . The partner's type will be randomly determined in accordance with the type distribution prevailing at that time within the class. This couple must then make two intertwined decisions: whether or not to stay together for the period, and which social class to join. If they choose not to stay together, then they must wait until the next period for another opportunity to match. With probability  $1 - \mu$  a single agent fails to match with another single agent. These individuals just decide upon which social class to join. This will influence the type of mate that they might draw next period.

Similarly, at the beginning of each period, matches in each class from the previous period

break up with probability  $\delta$ . Couples in the surviving matches must also make two inextricably linked decision; to wit, whether or not to remain together and which social class to join. If they choose to break up then they must wait until the next period for another matching opportunity. Like single agents who fail to match, couples whose relationships break up exogenously just decide upon which social class to join.

Let a matched person in the abstinence class enjoy a level of momentary utility of  $u$ , and a single person realize a momentary utility level of  $v$ , with  $u > v$ . A matched person in the promiscuity class realizes a momentary utility level of  $u + s - \psi$ , where  $s$  is the joy from sex and  $\psi$  is the expected cost of sex say due to an out-of wedlock birth or a sexually transmitted disease. Note that  $\psi$  can't represent a stigma effect since this is really an attitude. Change in attitudes and behavior are what is being modelled here. An unmatched person in this class attains a utility of  $v$ . Individuals discount the next period's utility by the factor  $\beta$ . Assume that  $u$ ,  $v$ ,  $s$ , and  $\psi$  are specified in a way that guarantees that expected lifetime utility is always positive.

To complete the setup, some structure will be placed on the population. First, the size of the population will be normalized to one. Second, each period a fraction  $1 - \zeta$  of the population will move on to another phase of life, which will be interpreted as adulthood. This latter phase of life will be taken to be a continuation of their current life, but in a different location. These people are selected at random and are replenished by an equal flow of young unmatched individuals. So, assume that each single, and each couple, face a relocation probability of  $1 - \zeta$ .

The idea is that over time the cost of premarital sex,  $\psi$ , declines due to technological progress in contraception and improvements in birth control education. As a consequence, people move out of the abstinence class,  $\mathcal{A}$ , into the promiscuity class,  $\mathcal{P}$ . The situation is portrayed in Figure 5, by the arrow moving left to right. As will be seen, there may also be some secondary movement from  $\mathcal{P}$  to  $\mathcal{A}$ . For example, some people may choose to live a promiscuous lifestyle rather than lose their partner. When one of these matches breaks up, one individual may move back to  $\mathcal{A}$ .

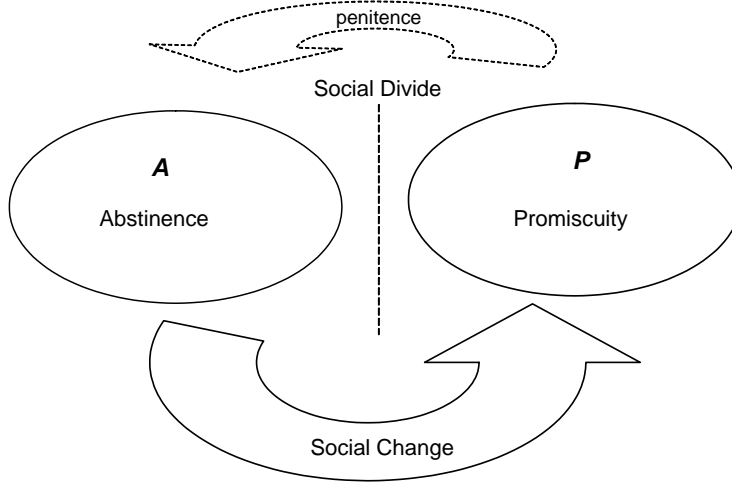


Figure 5: Social Change

### 3 Decision Problems

Let  $A(s, \tilde{s})$  denote the expected lifetime utility for an individual of type  $s$  who is currently in an abstinent match with a partner of type  $\tilde{s}$ . While abstinent an individual does not experience any joy from sex. But, s/he could in the future. Thus,  $A$  should still be a function of  $s$ . Also, an individual's joy from sex does not depend directly upon his partner's type,  $\tilde{s}$ . Still, he cares indirectly about his partner's type because this will delimit his future matching possibilities, as will be seen. Next, define  $B(s)$  to be the expected lifetime utility for an unmatched agent in class  $\mathcal{A}$ . Turn now to the promiscuous class. Here  $P(s, \tilde{s})$  will represent the expected lifetime utility for individual  $s$  who is currently in a promiscuous match with  $\tilde{s}$ , and  $Q(s)$  will proxy for the expected lifetime utility for an unmatched agent in class  $\mathcal{P}$ .

### 3.1 The Abstinence Class, $\mathcal{A}$

Suppose person  $s$  is matched with  $\tilde{s}$  in  $\mathcal{A}$ . The recursion defining the value of this match for  $s$ , or the function  $A(s, \tilde{s})$ , is given by

$$A(s, \tilde{s}) = u + \beta(1 - \delta)[X'(s, \tilde{s})A'(s, \tilde{s}) + Y'(s, \tilde{s})P'(s, \tilde{s})] \\ + \beta[\delta + (1 - \delta)Z'(s, \tilde{s})]\{L'(s)B'(s) + [1 - L'(s)]Q'(s)\}, \quad (1)$$

where in standard fashion a prime attached to a variable denotes its value next period. The first term on the righthand side is the momentary utility realized today from an abstinent match,  $u$ . The rest of the terms give the discounted value of the lifetime utility that  $s$  can expect from tomorrow on. Note that his current match with  $\tilde{s}$  will survive into next period with probability  $(1 - \delta)$ .<sup>6</sup> At this time the couple can decide to remain together in an abstinent relationship, switch to a promiscuous one, or break up. The function  $X'(s, \tilde{s})$  reports the *equilibrium* probability that an abstinent match between  $s$  and  $\tilde{s}$  will occur next period. Thus, the term  $(1 - \delta)X'(s, \tilde{s})A'(s, \tilde{s})$  represents the component of expected lifetime utility from next period on that is associated with the possibility of an abstinent match then. Likewise,  $Y'(s, \tilde{s})$  gives the probability of a promiscuous match for the pair arising at that time, so that  $(1 - \delta)Y'(s, \tilde{s})P'(s, \tilde{s})$  is the part of expected lifetime utility linked to a promiscuous match. Now a match may not occur next period because the pair breaks up, either exogenously or endogenously. A match breaks up exogenously with probability  $\delta$ , and endogenously with probability  $(1 - \delta)Z'(s, \tilde{s})$ , where  $Z'(s, \tilde{s}) \equiv 1 - X'(s, \tilde{s}) - Y'(s, \tilde{s})$ . When the match breaks up person  $s$  must decide whether to enjoy his single life in either the abstinent or promiscuous class. Let  $L'(s)$  be an indicator function taking the value one when  $s$  prefers to join the abstinence class next period, as opposed to the promiscuity class. Therefore,  $[\delta + (1 - \delta)Z'(s, \tilde{s})]\{L'(s)B'(s) + [1 - L'(s)]Q'(s)\}$  gives the part of expected lifetime utility that is associated with single life next period, which may occur in either  $\mathcal{A}$  or

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<sup>6</sup> Note that the pair,  $s$  and  $\tilde{s}$ , will move to a new location next period with probability  $1 - \zeta$ . But, by assumption  $s$ 's life will continue on in similar fashion there. Thus, there is no need to incorporate this survival probability into the recursion. As will be seen, it will enter into the laws of motion for the type distributions.

$\mathcal{P}$  depending on what is in  $s$ 's best interest at that time. The determination of the functions  $L$ ,  $X$ , and  $Y$  is discussed below. Last, note that time is implicitly a state variable in the above recursion, since the costs of premarital sex will be changing over time in a manner to be specified later.

Alternatively, consider the case where  $s$  is alone in  $\mathcal{A}$ . His expected lifetime utility is given by the function  $B(s)$ , which reads

$$B(s) = v + \beta\mu \sum_{j=1}^n v'_j [X'(s, \tilde{s}_j)A'(s, \tilde{s}_j) + Y'(s, \tilde{s}_j)P'(s, \tilde{s}_j)] \\ + \beta[(1 - \mu) + \mu \sum_{j=1}^n v'_j Z'(s, \tilde{s}_j)] \{L'(s)B'(s) + [1 - L'(s)]Q'(s)\}. \quad (2)$$

Note that  $s$ 's draw for a partner,  $\tilde{s}$ , next period will depend upon the type distribution for unmatched agents that will prevail in  $\mathcal{A}$  at that time. This type distribution is given by the  $v'_j$ 's, with  $0 \leq v'_j \leq 1$  and  $\sum_{j=1}^n v'_j = 1$ . Its determination is detailed later.

### 3.2 The Promiscuity Class, $\mathcal{P}$

When person  $s$  matches with  $\tilde{s}$  in the promiscuity class he will realize an expected lifetime utility level of

$$P(s, \tilde{s}) = u + s - \psi + \beta(1 - \delta)[X'(s, \tilde{s})A'(s, \tilde{s}) + Y'(s, \tilde{s})P'(s, \tilde{s})] \\ + \beta[\delta + (1 - \delta)Z'(s, \tilde{s})] \{L'(s)B'(s) + [1 - L'(s)]Q'(s)\}. \quad (3)$$

In the above problem the individual experiences a joy from sex, net of costs, in the amount  $s - \psi$ . Unmatched person  $s$  will attain

$$Q(s) = v + \beta\mu \sum_{j=1}^n \varpi'_j [X'(s, \tilde{s}_j)A'(s, \tilde{s}_j) + Y'(s, \tilde{s}_j)P'(s, \tilde{s}_j)] \\ + \beta[(1 - \mu) + \mu \sum_{j=1}^n \varpi'_j Z'(s, \tilde{s}_j)] \{L'(s)B'(s) + [1 - L'(s)]Q'(s)\}. \quad (4)$$

Note that  $s$ 's draw for a partner next period will depend upon the type distribution for unmatched agents that will prevail in  $\mathcal{P}$  at that time, or the  $\varpi'_j$ 's with  $0 \leq \varpi'_j \leq 1$  and  $\sum_{j=1}^n \varpi'_j = 1$ .

### 3.3 Social Class Membership Decision

Now, consider individual  $s$  who is matched with partner  $\tilde{s}$ . An abstinent match with  $\tilde{s}$  may be individual  $s$ 's first choice. Let the indicator  $H(s, \tilde{s})$  return a value of one if this is the case, and a value of zero otherwise. The indicator function  $H(\tilde{s}, s)$  is then given by

$$H(s, \tilde{s}) = \begin{cases} 1, & \text{if } A(s, \tilde{s}) > \max\{B(s), P(s, \tilde{s}), Q(s)\} \text{ (abstinent match is first choice),} \\ 0, & \text{otherwise.} \end{cases} \quad (5)$$

Observe that the analogous indicator function for person  $\tilde{s}$  will simply read  $H(\tilde{s}, s) = H^T(s, \tilde{s})$ , where the superscript  $T$  denotes the transpose of a matrix. Now, it may be the case that person  $s$  would prefer a promiscuous match with  $\tilde{s}$ , but this isn't feasible. Still,  $s$  may prefer to live with  $\tilde{s}$  in  $\mathcal{A}$ , relative to living alone in either  $\mathcal{A}$  or  $\mathcal{P}$ . Let the indicator function  $I(s, \tilde{s})$  return a value of one if  $s$  prefers a match with  $\tilde{s}$  in  $\mathcal{A}$ , relative to single life in either  $\mathcal{A}$  or  $\mathcal{P}$ , and a value of zero otherwise. Thus,  $I(s, \tilde{s})$  is given by

$$I(s, \tilde{s}) = \begin{cases} 1, & \text{if } A(s, \tilde{s}) > \max\{B(s), Q(s)\} \text{ (abstinent match preferred to single life),} \\ 0, & \text{otherwise.} \end{cases} \quad (6)$$

Person  $s$ 's preferences towards promiscuous matches can be analyzed in similar fashion. To this end, let the indicator function  $J(s, \tilde{s})$  return a value of one if  $s$  would prefer to live with  $\tilde{s}$  in  $\mathcal{P}$  over all other options, and a value of zero otherwise. This indicator function is defined by

$$J(s, \tilde{s}) = \begin{cases} 1, & \text{if } P(s, \tilde{s}) > \max\{A(s, \tilde{s}), B(s), Q(s)\} \text{ (promiscuous match is first choice),} \\ 0, & \text{otherwise.} \end{cases} \quad (7)$$

The situation where  $s$  prefers to live with  $\tilde{s}$  in  $\mathcal{P}$ , relative to living alone in either  $\mathcal{A}$  or  $\mathcal{P}$ , can be captured by the indicator function  $K(s, \tilde{s})$ :

$$K(s, \tilde{s}) = \begin{cases} 1, & \text{if } P(s, \tilde{s}) > \max\{B(s), Q(s)\} \text{ (promiscuous match preferred to single life),} \\ 0, & \text{otherwise.} \end{cases} \quad (8)$$

Consider an unmatched agent. S/he must choose between searching for a prospective mate in the abstinent or promiscuous class. Let  $L(s)$  will denote the decision rule for an unmatched individual. In particular,

$$L(s) = \begin{cases} 1, & \text{if } B(s) > Q(s), \text{ (single in } \mathcal{A} \text{ preferred to single in } \mathcal{P}), \\ 0, & \text{otherwise.} \end{cases} \quad (9)$$

Suppose that  $s$  and  $\tilde{s}$  have met, either through a new or pre-existing match. The probabilities of an abstinent or a promiscuous relationship,  $X(s, \tilde{s})$  and  $Y(s, \tilde{s})$ , occurring can be now constructed. In particular,

$$\begin{aligned} X(s, \tilde{s}) &= H(s, \tilde{s})H^T(s, \tilde{s}) + H(s, \tilde{s})K(s, \tilde{s})J^T(s, \tilde{s})I^T(s, \tilde{s})/2 \\ &\quad + H^T(s, \tilde{s})K^T(s, \tilde{s})J(s, \tilde{s})I(s, \tilde{s})/2 \\ &\quad + H(s, \tilde{s})[1 - K(s, \tilde{s})][1 - H^T(s, \tilde{s})]I^T(s, \tilde{s}) \\ &\quad + H^T(s, \tilde{s})[1 - K^T(s, \tilde{s})][1 - H(s, \tilde{s})]I(s, \tilde{s}), \end{aligned} \quad (10)$$

and

$$\begin{aligned} Y(s, \tilde{s}) &= J(s, \tilde{s})J^T(s, \tilde{s}) + H(s, \tilde{s})K(s, \tilde{s})J^T(s, \tilde{s})I^T(s, \tilde{s})/2 \\ &\quad + H^T(s, \tilde{s})K^T(s, \tilde{s})J(s, \tilde{s})I(s, \tilde{s})/2 \\ &\quad + [1 - J(s, \tilde{s})]K(s, \tilde{s})J^T(s, \tilde{s})[1 - I^T(s, \tilde{s})] \\ &\quad + [1 - J^T(s, \tilde{s})]K^T(s, \tilde{s})J(s, \tilde{s})[1 - I(s, \tilde{s})]. \end{aligned} \quad (11)$$

Now take the expression for  $X(s, \tilde{s})$ . It is not as formidable as it looks. The first term gives the situation where an abstinent match is both  $s$ 's and  $\tilde{s}$ 's first choice. When this occurs  $H(s, \tilde{s})H^T(s, \tilde{s}) = 1$ . The remaining terms enumerate situations where an abstinent match is not one person's first choice for a match, but they still prefer it to single life. Consider the second term. Suppose that person  $s$ 's first choice is an abstinent relationship, but she would be willing to accept a promiscuous one as opposed to being single. In this circumstance  $H(s, \tilde{s})K(s, \tilde{s}) = 1$ , and is zero otherwise. Additionally, suppose that her partner wants

a promiscuous match the most, but prefers an abstinent relationship to single life. Here,  $J^T(s, \tilde{s})I^T(s, \tilde{s}) = 1$ . How will the couple resolve this difference in tastes? Simply assume that they just flip a coin between the two alternatives. The odds of an abstinent match are then  $H(s, \tilde{s})K(s, \tilde{s})J^T(s, \tilde{s})I^T(s, \tilde{s})/2 = 1/2$ . This expression will return a value of zero in *any* other circumstance. The third term just reports the situation when the roles for  $s$  and  $\tilde{s}$  are reversed. The fourth term gives the situation where person  $s$  will refuse a promiscuous match. If  $s$ 's first choice is an abstinent match, and she'll refuse a promiscuous one, then  $H(s, \tilde{s})[1 - K(s, \tilde{s})] = 1$ . Likewise, when  $\tilde{s}$ 's best option is a promiscuous match, but he'll accept an abstinent one, then  $[1 - H^T(s, \tilde{s})]I^T(s, \tilde{s}) = 1$ . The odds of an abstinent match in this situation are given by  $H(s, \tilde{s})[1 - K(s, \tilde{s})][1 - H^T(s, \tilde{s})]I^T(s, \tilde{s}) = 1$ . Again, it is easy to deduce that this expression will be zero in any other situation. The roles between  $s$  and  $\tilde{s}$  are reversed in the fifth term. Note that by construction all of the terms in (10) are mutually exclusive and that  $X(s, \tilde{s}) \in \{0, 1/2, 1\}$ . Last the odds of no relationship are just simply given by

$$Z(s, \tilde{s}) \equiv 1 - X(s, \tilde{s}) - Y(s, \tilde{s}). \quad (12)$$

Observe that equations (1) to (12) jointly determine a solution for the value functions  $A(s, \tilde{s})$ ,  $B(s)$ ,  $P(s, \tilde{s})$ ,  $Q(s)$ , the decision rules  $H(s, \tilde{s})$ ,  $I(s, \tilde{s})$ ,  $\dots$ ,  $L(s)$ , and the matching functions,  $X(s, \tilde{s})$ ,  $Y(s, \tilde{s})$ , and  $Z(s, \tilde{s})$ , contingent upon the type distributions of unmatched agents in  $\mathcal{A}$  and  $\mathcal{P}$ , or the  $v_j$ 's and  $\varpi_j$ 's.

## 4 Laws of Motion for the Type Distributions

Computing a solution to the model involves calculating the time paths for the type distributions of unmatched agents in  $\mathcal{A}$  and  $\mathcal{P}$ . The solutions to the recursions (2) and (4) depend directly upon these distributions – the  $v_j$ 's and  $\varpi_j$ 's. Note these distributions will indirectly influence (1) and (3) as well. Hence, equilibrium social class memberships functions (9) to (12) will depend upon these distributions. And as will be seen, these distributions will be functions of these membership decisions. Thus, a fixed-point problem arises.

To this end, let  $M(s, \tilde{s})$  denote the *nonnormalized* distribution over matched pairs

in  $\mathcal{A}$  and  $U(s)$  denote the analogous (nonnormalized) distribution over singles. Therefore,  $\xi = \sum_{i=1}^n \sum_{j=1}^n M(s_i, \tilde{s}_j)$  gives the number of attached agents in  $\mathcal{A}$ , while similarly  $\lambda = \sum_{i=1}^n U(s_i)$  is the number of unattached ones. Thus,  $v_j = U(s_j)/\lambda$ . Likewise,  $N(s, \tilde{s})$  and  $V(s)$  will represent the distributions for matched and unmatched agents in  $\mathcal{P}$ . Therefore,  $\varpi_j = V(s_j)/\sum_{i=1}^n V(s_i)$ . Represent the number of unattached people in  $\mathcal{P}$  by  $\vartheta = \sum_{i=1}^n V(s_i)$ . The laws of motion for  $M(s, \tilde{s})$ ,  $U(s)$ ,  $N(s, \tilde{s})$  and  $V(s)$  are given by

$$\begin{aligned} M'(s, \tilde{s}) &= \zeta(1 - \delta)X(s, \tilde{s})M(s, \tilde{s}) + \zeta(1 - \delta)X(s, \tilde{s})N(s, \tilde{s}) \\ &\quad + \zeta\mu\lambda X(s, \tilde{s})U(s)U(\tilde{s})/\lambda^2 + \zeta\mu\vartheta X(s, \tilde{s})V(s)V(\tilde{s})/\vartheta^2, \end{aligned} \quad (13)$$

$$\begin{aligned} U'(s) &= \zeta(1 - \mu)L(s)U(s) + \zeta(1 - \mu)L(s)V(s) + (1 - \zeta)L(s)S(s) \\ &\quad + \zeta \sum_m \mu\lambda L(s)Z(s, \tilde{s}_m)U(s)U(\tilde{s}_m)/\lambda^2 \\ &\quad + \zeta \sum_m \mu\vartheta L(s)Z(s, \tilde{s}_m)V(s)V(\tilde{s}_m)/\vartheta^2 \\ &\quad + \zeta \sum_m L(s)[\delta + (1 - \delta)Z(s, \tilde{s}_m)]M(s, \tilde{s}_m) \\ &\quad + \zeta \sum_m L(s)[\delta + (1 - \delta)Z(s, \tilde{s}_m)]N(s, \tilde{s}_m), \end{aligned} \quad (14)$$

$$\begin{aligned} V'(s) &= \zeta(1 - \mu)[1 - L(s)]U(s) + \zeta(1 - \mu)[1 - L(s)]V(s) + (1 - \zeta)[1 - L(s)]S(s) \\ &\quad + \zeta \sum_m \mu\lambda[1 - L(s)]Z(s, \tilde{s}_m)U(s)U(\tilde{s}_m)/\lambda^2 \\ &\quad + \zeta \sum_m \mu\vartheta[1 - L(s)]Z(s, \tilde{s}_m)V(s)V(\tilde{s}_m)/\vartheta^2 \\ &\quad + \zeta \sum_m [1 - L(s)][\delta + (1 - \delta)Z(s, \tilde{s}_m)]M(s, \tilde{s}_m) \\ &\quad + \zeta \sum_m [1 - L(s)][\delta + (1 - \delta)Z(s, \tilde{s}_m)]N(s, \tilde{s}_m), \end{aligned} \quad (15)$$

and

$$\begin{aligned} N'(s, \tilde{s}) &= \zeta(1 - \delta)Y(s, \tilde{s})M(s, \tilde{s}) + \zeta(1 - \delta)Y(s, \tilde{s})N(s, \tilde{s}) \\ &\quad + \zeta\mu\lambda Y(s, \tilde{s})U(s)U(\tilde{s})/\lambda^2 + \zeta\mu\vartheta Y(s, \tilde{s})V(s)V(\tilde{s})/\vartheta^2. \end{aligned} \quad (16)$$

Take the law of motion for  $M$ , as given by (13). The first term represents those currently attached pairs in  $\mathcal{A}$  who choose to remain attached there next period. Specifically, there are  $\zeta(1 - \delta)M(s, \tilde{s})$  surviving matched pairs of type  $(s, \tilde{s})$ . Of these the fraction  $X(s, \tilde{s}) \in \{0, 1/2, 1\}$  agree to be matched in  $\mathcal{A}$ , as opposed to either matching in  $\mathcal{P}$  or each party going it alone. The second term in (13) calculates the number of currently matched pairs in  $\mathcal{P}$  who will enter into  $\mathcal{A}$  next period. Next, consider the today's pool of single agents in  $\mathcal{A}$ . From this pool there will be  $\zeta\mu\lambda U(s)U(\tilde{s})/\lambda^2$  matches of type  $(s, \tilde{s})$ . Out of these pairs the fraction  $X(s, \tilde{s})$  will agree to an abstinent match. This explains the third term. The fourth term calculates the number of abstinent matches tomorrow that arise from today's pool of singles in  $\mathcal{P}$ .

Next, examine (14), or the law of motion for  $U$ . The first term represents those who are currently unattached in  $\mathcal{A}$  and choose to remain there for next period [i.e.,  $L(s) = 1$ ]. Some people who are unattached in  $\mathcal{P}$  may choose to move to  $\mathcal{A}$ . The number of such people is given by the second term. The third term calculates the number of new unattached teenagers who search for a mate in the abstinent class next period. The remaining terms count the number of failed matches between person  $s$  and a prospective partner  $\tilde{s}$ , where  $s$  decides to search next period for a new mate in  $\mathcal{A}$  [implying  $L(s) = 1$ ]. Sometimes two singles,  $s$  and  $\tilde{s}$ , may meet in either  $\mathcal{A}$  or  $\mathcal{P}$  and one of the parties won't want to match – the fourth term for  $\mathcal{A}$  and the fifth for  $\mathcal{P}$ . Other times an existing abstinent match may breakup either exogenously or endogenously – the sixth term. The same could be true for promiscuous match – the seventh term. The other laws of motion can be explained in similar manner.

## 5 Equilibrium

It's time to specify more precisely what will constitute an equilibrium for the above economy.

**Definition** *For a given time path describing the costs of premarital sex,  $\{\psi_t\}_{t=1}^\infty$ , and some initial type distributions,  $M_1(s, \tilde{s})$ ,  $N_1(s, \tilde{s})$ ,  $U_1(s)$ , and  $V_1(s)$ , an equilibrium is represented by time paths for the value functions,  $\{A_t(s, \tilde{s})\}_{t=1}^\infty$ ,  $\{B_t(s)\}_{t=1}^\infty$ ,  $\{P_t(s, \tilde{s})\}_{t=1}^\infty$ , and  $\{Q_t(s)\}_{t=1}^\infty$ , the decision rules,  $\{H_t(s, \tilde{s})\}_{t=1}^\infty$ ,  $\{I_t(s, \tilde{s})\}_{t=1}^\infty$ ,  $\{J_t(s, \tilde{s})\}_{t=1}^\infty$ ,  $\{K_t(s, \tilde{s})\}_{t=1}^\infty$ , and  $\{L_t(s)\}_{t=1}^\infty$ ,*

the matching functions,  $\{X_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{Y_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Z_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and the type distributions,  $\{M_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{N_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{U_t(s)\}_{t=1}^{\infty}$ , and  $\{V_t(s)\}_{t=1}^{\infty}$ , such that:

1. The sequence of value functions,  $\{A_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{B_t(s)\}_{t=1}^{\infty}$ ,  $\{P_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Q_t(s)\}_{t=1}^{\infty}$ , solve the recursions (1) to (4), given the time paths for the social class decision rule for singles,  $\{L_t(s)\}_{t=1}^{\infty}$ , the matching functions for couples,  $\{X_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{Y_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Z_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and the type distributions for singles,  $\{U_t(s)\}_{t=1}^{\infty}$ , and  $\{V_t(s)\}_{t=1}^{\infty}$ .
2. The sequence of decisions rules and matching functions  $\{H_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{I_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{J_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{K_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{L_t(s)\}_{t=1}^{\infty}$ ,  $\{X_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{Y_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Z_t(s, \tilde{s})\}_{t=1}^{\infty}$ , satisfy (5) to (12), given the time paths for the value functions,  $\{A_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{B_t(s)\}_{t=1}^{\infty}$ ,  $\{P_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Q_t(s)\}_{t=1}^{\infty}$  and the type distributions for singles,  $\{U_t(s)\}_{t=1}^{\infty}$ , and  $\{V_t(s)\}_{t=1}^{\infty}$ . (Recall the superscript  $T$  denotes the transpose of a matrix.)
3. The sequence for the type distributions,  $\{M_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{N_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{U_t(s)\}_{t=1}^{\infty}$ , and  $\{V_t(s)\}_{t=1}^{\infty}$ , solve (13) to (16), given the social class decision rule for singles,  $\{L_t(s)\}_{t=1}^{\infty}$ , and the matching functions,  $\{X_t(s, \tilde{s})\}_{t=1}^{\infty}$ ,  $\{Y_t(s, \tilde{s})\}_{t=1}^{\infty}$ , and  $\{Z_t(s, \tilde{s})\}_{t=1}^{\infty}$ .

At a general level not much more can be said about the properties of the economy's equilibrium. Some insight into the model, however, can be gleaned by undertaking the following three tasks in turn. First, the solution to the model's steady state will be examined. Second, the transitional dynamics for the model will be fully characterized for the special case of a once-and-for-all change in  $\psi$ . Third, the solution to the above equilibrium will be computed numerically in order to speak to the issue at hand, the change in sexual mores – for the algorithm see the Appendix, Section 13.4. After all, the question of whether or not the above framework is capable of explaining the change in sexual mores is quantitative in nature.

## 6 Steady-State Analysis

Suppose that  $\psi$  is constant over time. What would a steady state for the above model look like? It seems reasonable to conjecture that those who enjoy sex, relatively speaking,

will circulate within the promiscuous class, and those who don't, won't. To pursue this conjecture, suppose that there exists some threshold type,  $s_c$ , such that  $\{s_1, \dots, s_c\} \in \mathcal{A}$  and  $\{s_{c+1}, \dots, s_n\} \in \mathcal{P}$ . In fact, one might suspect that  $s_c < \psi \leq s_{c+1}$ ; that is, those who have a joy for sex that is higher than its expected cost will be a member of  $\mathcal{P}$ , and those who don't will associate with people in  $\mathcal{A}$ . If this conjecture is true, then a partner's type in each class won't matter since the world is split into two noncommunicating social groups. That is, anyone in  $\mathcal{A}$  will be willing to accept an abstinent match with anybody else in  $\mathcal{A}$ , while all individuals in  $\mathcal{P}$  will take a promiscuous relationship with any other person in  $\mathcal{P}$ .

**Lemma 1** *There exists a steady-state equilibrium such that  $s_j \in \mathcal{A}$  for all  $s_j < \psi$ , and  $s_j \in \mathcal{P}$  for  $s_j \geq \psi$ .*

**Proof.** See the Appendix, Section 13.1. ■

Given the above lemma, there exists a steady state where there is a dividing line in the  $s$  distribution between the two classes given by  $\psi$ . Individuals with a  $s < \psi$  choose to live abstinent lives, and those with a  $s \geq \psi$  promiscuous ones. Hence, the (nonnormalized) type distributions in  $\mathcal{A}$  and  $\mathcal{P}$  will be given by  $\{\sigma_1, \dots, \sigma_c, 0, \dots, 0\}$  and  $\{0, \dots, 0, \sigma_{c+1}, \dots, \sigma_n\}$ , where  $c$  solves

$$s_c < \psi \leq s_{c+1}. \quad (17)$$

The number of people circulating in  $\mathcal{A}$  is  $\sum_{j=1}^c \sigma_j$ , so that the size of the population in  $\mathcal{P}$  is given by

$$\#\mathcal{P} = 1 - \sum_{j=1}^c \sigma_j. \quad (18)$$

In a steady state the fraction of people who are attached in either class  $\mathcal{A}$  or  $\mathcal{P}$  will be given by

$$\alpha = \frac{\zeta\mu}{1 - \zeta(1 - \delta) + \zeta\mu}, \quad (19)$$

so that the fraction who are unattached is

$$1 - \alpha = \frac{1 - \zeta(1 - \delta)}{1 - \zeta(1 - \delta) + \zeta\mu}.$$

Last, note that the size of the promiscuous class in a steady-state is a nonincreasing function of the cost of premarital sex, as the following lemma states.

**Lemma 2** *The steady-state number of people engaging in premarital sex (weakly) increases with a fall in the cost of premarital sex.*

**Proof.** As  $\psi$  decreases the  $c$  that solves (17) will fall, given that  $s_1 < s_2 < \dots < s_n$ . ■

## 7 Transitional Dynamics

### 7.1 The Impact of a Once-and-for-All Decline in $\psi$

As an aid toward gaining some understanding about how the transitional dynamics for the model work, consider the impact of a once-and-for-all decline in  $\psi$  from  $\bar{\psi}$  to  $\underline{\psi}$ . In particular, suppose that the economy is initially resting in a steady state associated with  $\psi = \bar{\psi}$ . In line with the analysis of Section 6, there will exist a  $c$  such that  $s_c < \bar{\psi} < s_{c+1}$ . The type distribution in  $\mathcal{A}$  will be given by  $\{\sigma_1, \dots, \sigma_c, 0, \dots, 0\}$ , and the one in  $\mathcal{P}$  by  $\{0, \dots, 0, \sigma_{c+1}, \dots, \sigma_n\}$ . In each class the fraction  $\alpha$ , as specified by (19), of the populace will be matched. Suppose that  $\psi$  suddenly drops to  $\underline{\psi}$ , and stays at that value forever after. Then, there will be new steady-state type distributions in  $\mathcal{A}$  and  $\mathcal{P}$  represented by  $\{\sigma_1, \dots, \sigma_d, 0, \dots, 0\}$  and  $\{0, \dots, 0, \sigma_{d+1}, \dots, \sigma_n\}$ , where  $s_d < \underline{\psi} < s_{d+1}$  – assume a large enough shift in  $\psi$  so that  $d < c$ .

Now, think about the following process of convergence between the two steady states, which will be verified later:

1. To begin with, take an attached  $(s, \tilde{s})$  pair in  $\mathcal{A}$  in the old steady state. If  $(s, \tilde{s}) \in \{s_{d+1}, \dots, s_c\} \times \{s_{d+1}, \dots, s_c\}$  they will move immediately to  $\mathcal{P}$ . Simply put, why should these individuals wait? There will be  $\alpha \sum_{j=d+1}^c \sum_{k=d+1}^c \sigma_j \tilde{\sigma}_k$  agents in this category, where  $\alpha$  is given by (19).
2. Likewise, consider unattached individuals in  $\mathcal{A}$ . If  $s \in \{s_{d+1}, \dots, s_c\}$  they too will immediately enter  $\mathcal{P}$ . Again, what would be the advantage to waiting? There are  $(1 - \alpha) \sum_{j=d+1}^c \sigma_j$  such agents. Note that this implies that the one-step-ahead unmatched type distributions in  $\mathcal{A}$  and  $\mathcal{P}$  will have the forms  $\{v'_1, \dots, v'_d, 0, \dots, 0\}$  and

$\{0, \dots, 0, \varpi'_{d+1}, \dots, \varpi'_n\}$ . By employing similar reasoning, it can be deduced that this latter feature will hold along all points of the transition path.

3. There may be matches in the old steady state for which  $s \in \{s_1, \dots, s_d\}$  and  $\tilde{s} \in \{s_{d+1}, \dots, s_c\}$ , yet it remains optimal for  $(s, \tilde{s})$  to stay attached in  $\mathcal{A}$ . Here person  $\tilde{s}$ 's type is not high enough to warrant breaking up a relationship with  $s$  and searching by himself in  $\mathcal{P}$ . There are two types of situations here. Those where person  $s$  is willing to engage in a mixing relationship, and those where she isn't. There will be  $\alpha \sum_{j=1}^d \sum_{k=d+1}^c X(s_j, \tilde{s}_k) \sigma_j \tilde{\sigma}_k$  people in this situation. The survival rate for these matches is  $\zeta(1 - \delta)$ . The  $\tilde{s}$ 's who are still around will then enter  $\mathcal{P}$ .
4. Finally, there may be matches in the old steady state for which  $s \in \{s_1, \dots, s_d\}$  and  $\tilde{s} \in \{s_{d+1}, \dots, s_c\}$  where it is optimal for  $(s, \tilde{s})$  to move to  $\mathcal{P}$ . Here individual  $s$ 's unfavorable view of the net gain from sex with  $\tilde{s}$  is not bad enough to justify terminating her relationship with  $\tilde{s}$  and searching in  $\mathcal{A}$ . There will be  $\alpha \sum_{j=1}^d \sum_{k=d+1}^c Y(s_j, \tilde{s}_k) \sigma_j \tilde{\sigma}_k$  agents in this class. The survival rate for these matches is  $\zeta(1 - \delta)$ . The surviving  $s$ 's will then reenter  $\mathcal{A}$ .

The above line of reasoning suggests that the lemma below should hold – the above logic is verified during the course of the proof.

**Lemma 3** *Upon a once-and-for-all decrease in  $\psi$ , the (nonnormalized) type distribution in  $\mathcal{A}$  immediately jumps from*

$$\{\sigma_1, \dots, \sigma_c, 0, \dots, 0\}$$

to

$$\{\sigma_1 - \alpha \sum_{k=d+1}^c Y(s_1, \tilde{s}_k) \sigma_1 \tilde{\sigma}_k, \dots, \sigma_d - \alpha \sum_{k=d+1}^c Y(s_d, \tilde{s}_k) \sigma_d \tilde{\sigma}_k, \\ \alpha \sum_{i=1}^d X(s_i, \tilde{s}_{d+1}) \sigma_i \tilde{\sigma}_{d+1}, \dots, \alpha \sum_{i=1}^d X(s_i, \tilde{s}_c) \sigma_i \tilde{\sigma}_c, 0, \dots, 0\},$$

where  $d < c$ . The  $j$ -step-ahead type distribution in  $\mathcal{A}$  (for  $j \geq 1$ ) is given by

$$\{\sigma_1 - [\zeta(1 - \delta)]^j \alpha \sum_{k=d+1}^c Y(s_1, \tilde{s}_k) \sigma_1 \tilde{\sigma}_k, \dots, \sigma_d - [\zeta(1 - \delta)]^j \alpha \sum_{k=d+1}^c Y(s_d, \tilde{s}_k) \sigma_d \tilde{\sigma}_k, \\ [\zeta(1 - \delta)]^j \alpha \sum_{i=1}^d X(s_i, \tilde{s}_{d+1}) \sigma_i \tilde{\sigma}_{d+1}, \dots, [\zeta(1 - \delta)]^j \alpha \sum_{i=1}^d X(s_i, \tilde{s}_c) \sigma_i \tilde{\sigma}_c, 0, \dots, 0\}. \quad (20)$$

**Proof.** See the Appendix, Section 13.2. ■

To summarize, following a once-and-for-all decline in  $\psi$  some matched couples will immediately move from  $\mathcal{A}$  to  $\mathcal{P}$ . Sometimes one member might move somewhat reluctantly, in the sense that they would prefer a match in  $\mathcal{A}$  rather than  $\mathcal{P}$ . This ideal situation isn't on the table, because their partner prefers a relationship in  $\mathcal{P}$ . Over time these matches will break up exogenously and the (surviving) low- $s$  partner will return to  $\mathcal{A}$  – this explains the right-to-left arrow in Figure 5. These matches are captured by the  $[\zeta(1 - \delta)]^j \alpha \sum_{k=d+1}^c Y(s_i, \tilde{s}_k) \sigma_i \tilde{\sigma}_k$  terms (for  $i = 1, \dots, d$ ) in (20). Similarly, some matched individuals will remain in  $\mathcal{A}$  because their partner refuses to have a promiscuous match. These high- $\tilde{s}$  individuals will drift into  $\mathcal{P}$  as their matches break up, so long as they survive. The  $[\zeta(1 - \delta)]^j \alpha \sum_{i=1}^d X(s_i, \tilde{s}_k) \sigma_i \tilde{\sigma}_k$  terms (for  $k = d + 1, \dots, c$ ) represent this situation.

Return now to the issue under study, the rise in premarital sex over the last century. In order to analyze this issue something must be inputted into the simulation for the time path of costs that govern premarital sex,  $\{\psi_t\}_{t=1}^{\infty}$ . Turn to this subject now.

## 8 Technological Progress in Contraception

In 1900 engaging in premarital sex was a very risky business. Roughly 71 percent of women would have gotten pregnant. These odds had dropped to 28 percent by 2002. The reduction in the chance of pregnancy occurred for two reasons: technological improvement in contraceptives, and the dissemination of knowledge about contraception and reproduction.

### 8.1 A Brief History

Coitus interruptus has been practiced since ancient times, and is mentioned in the Bible.<sup>7</sup> This was the most important method of contraception historically. The condom has a long history. In the 18th century, Casanova reported using the "English riding coat." Handbills were circulated in England advertising condoms. One said [for a picture see Himes (1963, p. 198)]:

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<sup>7</sup> This history is compiled from Himes (1964), McLaren (1990), and Potts and Campbell (2002).

*To guard yourself from shame or fear,  
Votaries to Venus, haften here;  
None in my wares ever found a flaw,  
Self preservation's nature's law.*

Early condoms were used more to prevent venereal disease than pregnancy. They were expensive and uncomfortable. The diffusion of condoms was promoted by the vulcanization of rubber in 1843-1844. They were still expensive in 1850, selling for \$5 a dozen [McLaren (1990, p. 184)], which translates into \$34 a dozen relative to today's real wages. So, even when washed and reused, they were too expensive for the masses to use. Another major innovation was introduction of the latex condom in the 1930s, which dramatically reduced cost and increased quality. Other methods of birth control were also used, such as a variety of intrauterine devices. Casanova mentions using half of a lemon as a contraceptive device. This could have been quite effective since it acted as barrier-cum-spermicidal agent. In 1797, Bentham advocated the use of the sponge to keep down the size of the poor population. The rubber diaphragm entered service around 1890. It was expensive and had to be fit by a doctor. This limited its use to those who were relatively well off. The pill emblemizes modern contraception. In 1960 the Food and Drug Administration approved the use of it, which was a remarkable scientific achievement involving the synthesis of a hormone designed to fool the reproductive system.

The dissemination of knowledge about contraception and reproduction was also very important. Scientific knowledge about reproduction began to arise in the 19th century. Van Baer discovered mammalian ovum in 1827. Around the same time, the birth control movement in America started with the works of Robert Dale Owen and Dr. Charles Knowlton. Owen published the first book on birth control, *Moral Physiology*, in 1830. He suggested coitus interruptus as the best means of contraception. In 1833 Knowlton published *Fruits of Philosophy*, which ultimately had more influence. He advocated douching since there is "(n)o doubt a very small quantity of semen lodged anywhere within the vagina or within the vulva, may cause conception, if it should escape the influence of cold, or some chemical agent" – as quoted by Himes (1963, p. 228). He gave some rough prescriptions for douching

agents. Knowlton was prosecuted for obscenity. Scientific knowledge continued to progress, with Newport describing the fertility cycle of frogs in 1853. In 1873 a law was passed under the urging of Anthony Comstock banning the communication, via mail, of any information about contraception or abortion. The next year the U.S. Post Office seized 60,000 rubber articles and 3,000 boxes of pills.

The modern birth control movement started about 1914 when Margaret Sanger published a pamphlet, *Family Limitation*, for which she was prosecuted. It described the use of condoms, douching and suppositories. She became a tireless crusader for birth control clinics. She opened the first clinic in 1919. Nine days later the police came. The first continually effective birth control clinic was operational in 1923, according to Himes (1963). Sanger promoted the use of the diaphragm through the clinics. Human ovum were seen for the first time in 1930. An accurate tracking of the ovulation cycle was also attained in the 1930s, making the safe period method a little safer. At more than 70 years of age, Sanger persuaded a wealthy philanthropist in 1952 to donate \$116,000 toward the development of the pill.

## 8.2 The Effectiveness and Use of Contraception

The use of various methods of contraception during premarital intercourse with a first partner, and their efficacies are shown in Tables 1 and 2. The data for contraceptive use during first premarital intercourse starts in the early 1960s.<sup>8</sup> Between 1960 and 2002 the number of people not using any birth control fell by a remarkable 40 percentage points. Modern contraceptives are easy and effective to use, and information about this has now widely dis-

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<sup>8</sup> Sources for Table 1: for 1960-64, see Mosher and Bachrach (1987, Table 2, p. 87); for 1965-1988, the numbers are taken from Mosher and McNally (1991, Table 1, p. 110); for 1985-1995, the data is contained in Abma et al. (1997, Table 39, p. 49); for 1990-2002, the numbers are taken from Mosher et al. (2004). In Mosher et al. (2004), the percentage of users for each method counts the users of multiple methods. Thus, the sum across different methods is more than the total fraction who use any method. In Table 1, their percentage distribution across different methods was normalized to sum up to the total fraction who use any method. The "other" methods category includes the use of diaphragms, cervical caps, IUDs, vaginal spermicides (such as foams, jellies, creams and sponges), the rhythm method, and injections and implants which were introduced in 1990s.

seminated. The condom is the most popular method of birth control and its use has actually increased over time, notwithstanding the introduction of the birth control pill. Today more than half of people use condoms for premarital sexual relationships with their first partner.

In order to measure the decline in risk associated with premarital sex during the 20th century, an estimate must be made for both the use and effectiveness of contraception in 1900. Take the use of contraception in 1900, first. Set use in 1900 to the values observed in 1960-1964 period – Table 1. Clearly, this is a conservative assumption since use has been increasing steadily over time. The pill was not yet introduced in 1900. So, for 1900 allocate the small percentage of women in the pill cell into the "other" category.<sup>9</sup>

TABLE 1: CONTRACEPTION USE AT FIRST PREMARITAL INTERCOURSE, PERCENT

<i>Method</i>	1900	60-64	65-69	70-74	75-79	80-82	83-88	85-89	90-94	95-98	99-02
none	61.4	61.4	54.2	55.6	53.5	46.9	34.6	36.1	29.7	27.2	21.2
pill	-	4.2	8.6	12.1	12.8	14.2	12.1	19.7	14.1	15.3	16.0
condom	21.9	21.9	24.0	21.0	22.0	26.7	41.8	36.4	49.9	49.8	51.2
withdrawal	7.3	7.3	9.5	7.3	7.5	8.4	8.9	5.6	3.5	4.9	7.3
other	9.7	5.3	3.7	4.0	4.2	3.8	2.6	2.2	2.8	2.8	4.3

Turn now to the effectiveness of contraception in 1900. A number for effectiveness in 1900 is constructed as follows: First, Kopp (1934) reports a 45 percent failure rate for condoms and a 59.2 percent failure rate for withdrawal. His numbers are based on pre-clinical use by married couples who sought advice from the Birth Control Clinical Research Bureau in New York City between 1925 and 1929. Although it seems quite high, a 45 percent failure rate for condoms is quite close to other estimates from the same period.<sup>10</sup> Why was the

<sup>9</sup> The results are almost identical if instead for 1900 the 4.2 percent of women in the pill category are distributed among the no-use, condom, withdrawal and other categories according to these methods' relative shares in the 1960-64 period.

<sup>10</sup> Tone (2001) cites two scientific studies before the Food and Drug Administration started inspecting condoms in the late 1930s. One of these studies from 1924 reports a 50 percent failure rate, while a later one from 1934-35 reports a 41 percent failure rate.

failure rate for withdrawal so high then as well? The main reason was that partial withdrawal was considered as effective as complete withdrawal, and despite better scientific evidence this practice did not change quickly — see Brodie (1994). Second, the other methods that people used around 1920 were not much more effective, either. Kopp (1934) reports the following failure rates: douche, 70.6 percent; jelly or suppository, 46.6; lactation, 56.6; pessary 28.1; sponge, 50, and safe period, 59.7. Hence, it is safe to presume that the failure rate for other methods at the time was no more than 50 percent. Finally, following Hatcher *et al.* (1976) assume that using no method, and simply taking your chances, had about a 85 percent failure rate.

Since the 1960s evidence on the effectiveness of different contraceptives, for both their ideal and typical-use, is quite systematic. First, based on several studies from the early 1960s, Tietze (1970) reports a 10 to 20 percent failure rate for condoms. According to Hatcher *et al.* (1976, 1980, 1984, 1988, 1998, and 2004), the failure rates for condoms were pretty constant at 15 to 20 percent during the 1970s and early 1980s, and then declined to about 11 percent in the mid 1980s. Somewhat mysteriously, they rose slightly in the 1990s.<sup>11</sup> Hence, the condom's failure rate has fallen from 45 to 14.5 percent, a decline of about 200 percent, both due to technological improvement and increased knowledge about its appropriate use.

Second, as can be seen in Table 2, the pill is the most effective method of contraception. It was introduced in the 1960s. Its initial failure rates were about 5 to 10 percent. They declined to 3.35 percent by 1989, again due to both technological improvement and better education about its use.<sup>12</sup> Again, the failure rate rose slightly during the 1990s. Third,

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<sup>11</sup> Hatcher *et al.* (1976, 1980) report a 15 to 20 percent failure rate of condoms for typical users. Given the 10 to 20 percent failure rates given by Tietze (1970), it is safe to set a 17.5 percent failure rate in Table 2 for the 1960-1982 period. Hatcher *et al.* (1984, 1988) present 10, and 12 percent failure rates, respectively. Accordingly, an average value of 11 percent is selected for the 1983-1989 period. Finally, Hatcher *et al.* (1998 and 2004) list 14 and 15 percent failure rates. For the 1990-2002 period the average value of 14.5 percent is used.

<sup>12</sup> Hatcher *et al.* (1976, 1980) give 5 to 10 percent and 10 percent failure rates for the typical use of the pill. Therefore, set the failure rate at about 7.5 percent for the 1960 to 1982 period. Hatcher *et al.* (1984, 1988) present much lower failure rates of 2 and 4.7 percent. Accordingly, set the effectiveness for the 1983-1989 period to the average value of 3.35 percent. Finally, for the 1990-2002 period use the 3 percent failure rate reported by Hatcher *et al.* (1998) and Kelly (2001) and the 8 percent failure rate given by Hatcher *et al.*

even the effectiveness of withdrawal has increased over time; this shows the importance of education.<sup>13</sup> Finally, during this period the effectiveness of other methods improved as well. New and much more effective methods, such as injections and implants, were introduced in the 1990s.<sup>14</sup>

TABLE 2: EFFECTIVENESS OF CONTRACEPTION, PERCENT

<i>Method</i>	1900	60-64	65-69	70-74	75-79	80-82	83-88	85-89	90-94	95-98	99-02
none	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
pill		7.5	7.5	7.5	7.5	7.5	3.4	3.4	5.5	5.5	5.5
condom	45.0	17.5	17.5	17.5	17.5	17.5	11.0	11.0	14.5	14.5	14.5
withdrawal	59.2	22.5	22.5	22.5	22.5	22.5	20.5	20.5	20.5	23.0	23.0
other	50.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0	10.0	10.0	10.0

So what is the upshot of this analysis? By combining the information on the effectiveness and use of contraceptives contained in Tables 1 and 2, one can get a measure of the extent of technological innovation in birth control. To do this, for each year take an average over the effectiveness of each method of birth control listed in Table 2. When doing this weight each practice by its yearly frequency of use, shown in Table 1. The upshot of this calculation is illustrated in Figure 6, which presents the riskiness of premarital sex. Even when using (2004).

<sup>13</sup> The numbers are again based on the estimates of Hatcher et al. (1976, 1980) who give 20 to 25 percent failure rates. The numbers for 1983-95 are based on Hatcher et al. (1984, 1989), who report 23 and 18 percent failure rates, while those for the 1995-2002 period derive from Hatcher et al (1998 and 2004) who present 19 and 27 percent failure rates.

<sup>14</sup> Given the small number of people using other methods the results are not very sensitive to the assumption made regarding their effectiveness. A simple assumption is made here that the failure rate for all other methods between 1960 and 1988 was about 20 percent, and then declined to 10 percent. According to Hatcher et al. (1976, 1980, 1984, 1988, 1998, and 2004) the failure rate of the IUD was about 6 to 10 percent in 1976, declined to about 5 percent in the 1980s, and finally reached 3 percent by 2004. The failure rate for the diaphragm was about 20 to 25 percent in 1976, and remained pretty much constant until recently. It had a 16 percent failure rate in 2004. The same is also true for many vaginal spermicides (foams, jellies, sponges, etc.) that had about 20 to 30 percent failure rates during this entire period. Injections and implants, two very effective contraceptives, were introduced in the 1990s — see FDA (1997).

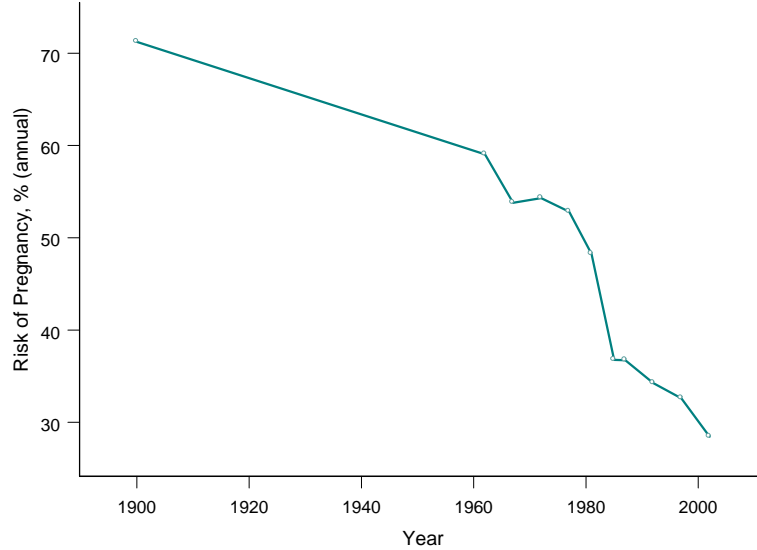


Figure 6: Technological improvement in the effectiveness and use of contraceptives

conservative estimates for 1900, this riskiness has fallen by more than 125 percent, from about 71 percent in 1900 to 28 percent in 2002.

## 9 Calibration

Prior to simulating the model, values must be assigned to the various parameters governing tastes, the matching technology, and the type distribution. Toward this end set up the type distribution,  $S(s)$ , so that it approximates a truncated normal, where the truncation points are 2.5 standard deviations on either side of the mean. An evenly spaced grid of 300 points is used for  $\mathcal{S}$ . Hence,  $S(s)$  will be governed by two parameters, namely its mean,  $\bar{s}$ , and standard deviation,  $\varsigma_s$ . Given this, there are 8 parameters to pick:  $\mu$ ,  $\delta$ ,  $\zeta$ ,  $\beta$ ,  $u$ ,  $v$ ,  $\bar{s}$ , and  $\varsigma_s$ . This is done in the following manner:<sup>15</sup>

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<sup>15</sup> The model is an infinite horizon framework. The real world is made up of finitely-lived overlapping generations. Every year a new generation of young people enters into the dating world for the first time, while members of older cohorts exit due to marriage. This mismatch between the data and the model

1. *Matching parameters,  $\mu$ ,  $\delta$  and  $\zeta$ .* In 2002 roughly 34.4 percent of teenagers between the ages of 15 and 19 had coitus within the last 3 months.<sup>16</sup> Adolescent relationships are pretty short. On average a teen’s first sexual relationship lasts for almost 6 months. The median duration of an adolescent relationship is about 13 months.<sup>17</sup> Now, construct a simple Markov chain to match these two facts. Let teenagers match with probably  $\mu$  and breakup with probability  $\delta$ . Given the short duration of teenage relationships, take the model period to be a quarter. This implies that there will be 20 periods of teenage life between the ages of 15 and 19, inclusive. The mean duration of a relationship is given by  $1/\delta$ . Thus, let  $1/\delta = 13/3$  so that  $\delta = 0.231$ . Next, choose a value for  $\mu$  so that the statistical mechanics of the  $(\mu, \delta)$ -matching technology imply that on average a teenager will be sexually active 34.4 percent of time between ages 15 and 19. Assume that a teenager starts off unmatched at the end of his/her 14th year. Let  $\pi_j$  represent the odds of a teenager being matched  $j$  periods down the road. Thus,  $1 - \pi_j$  is the probability of being unmatched then. These odds are given by

$$\begin{bmatrix} \pi_j \\ 1 - \pi_j \end{bmatrix} = \begin{bmatrix} 1 - \delta & \mu \\ \delta & 1 - \mu \end{bmatrix}^j \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \text{ for } j = 1, \dots, 20.$$

The fraction of a promiscuous teenager’s life spent in a sexually active relationship is then  $\sum_{j=1}^{20} \pi_j/20$ . Therefore, pick  $\mu$  so that  $0.75 \times \sum_{j=1}^{20} \pi_j/20 = 0.344$ , where it will be assumed that 75 percent of the 2002 populaton is sexually active – see below. This results in  $\mu = 0.222$ . Last, a twenty-period teenage life dictates setting  $\zeta = 1 - 1/20$ .

2. *Type distribution parameters,  $\bar{s}$  and  $\zeta_s$ .* Now, in 1900 only 6 percent of unmarried teenage girls engaged in premarital sex. This had risen to 75 percent by 2002. The model is solved for two steady states. The first one mimics the year 1900. For this

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appears to be second order, as the results in Section 10 will show.

<sup>16</sup> This number is taken from Abma *et al.* (2004, Table 4, p. 19).

<sup>17</sup> Sources: Ryan, Manlove, and Franzetta (2003) and Udry and Bearman (1998). According to Udry and Bearman (1998), the median duration is about 10 months when the respondent is a male and about 13 months when the respondent is a female. The latter is taken here, although the results are very similar if instead a duration of 10 months is targeted.

one, set  $\psi = \psi_{1900} = 0.2676$ . The second steady state matches the year 2002. Here, pick  $\psi = \psi_{2002} = 0.0802$ .<sup>18</sup> Last, the mean and standard deviation,  $\bar{s}$  and  $\zeta_s$ , are specified so that in the first steady state 6 percent of people engage in premarital sex, while in the second 75 percent do. Note that for the model, the probability of a person finding a mate in their teenage years is given by  $\chi \equiv (1 - \mu)(1 - \zeta)/[1 - (1 - \mu)\zeta]$ . Hence, equations (17) and (18) should be solved while setting  $\chi \times \#\mathcal{P}_{1900} = 0.06$  and  $\chi \times \#\mathcal{P}_{2002} = 0.75$ . The result is  $\bar{s} = 0.1432$  and  $\zeta_s = 0.0833$ .

3. *Taste parameters,  $\beta$ ,  $u$ , and  $v$ .* Given that a period is one quarter, set  $\beta = 0.99$ . In the simulation the values chosen for  $u$  and  $v$  don't matter very much. In fact, theoretically they don't affect the steady state at all. In light of this, simply set  $u - v = 1$  and let  $v = s_1 - \psi_{1900}$ . The latter restriction ensures that lifetime utility is always positive.

The model is now ready to be simulated.

## 10 Social Change: The Computational Experiment

Go back in time to 1900. Premarital sex is dangerous, since a young woman runs a 71 percent of risk of pregnancy. Given this, the vast majority of youth chose to live abstinent lifestyles. Sex is a taboo subject. All of this is about to change due to technological progress in contraception. Over time the risk of pregnancy declines. This changes the cost and benefit calculations of engaging in premarital sex. Slowly more and more people engage in it so that by 2002 a substantial majority of teens are experiencing it. Can the model capture this pattern of social change?

To answer this question, start the model economy off in a steady state resembling the situation in 1900. Then, subject it to the time path of technological progress for contraception that is observed in the data from 1900 to 2002, as calculated in Section 8.2. When

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<sup>18</sup> According to the calculations in Section 8.2, the risk of pregnancy was 0.7122 per year in 1900 and 0.2843 per year in 2002. If the probability of pregnancy over a year is  $\hat{\psi}$ , then take the quarterly probability,  $\psi$ , to be given by  $\psi = 1 - (1 - \hat{\psi})^{(1/4)}$ .

doing this assume for simplicity that there is no technological advance in contraception after 2002. Given this the economy will eventually converge to a situation resembling 2002, given Point 2 in Section 9. Now, calculate the resulting time path for the type distributions in the abstinent and promiscuous classes for the model economy. Does the resulting time path for people engaging in premarital sex resemble the pattern observed in the U.S. data? That is the question.

## 10.1 2002 Steady State

To glean some insight into the model's mechanics, focus for a moment on the matching set that obtains in the final steady state. This is portrayed in Figure 7. The horizontal axes simply plot  $s$  and  $\tilde{s}$  pairs, or the types for the potential match (where 1 is the lowest index for type, and 300 the highest). The vertical axis reports a value of zero when a match doesn't occur, and a non-zero value when one will. The varying heights denote different matching situations. For instance, the trough in the center reflects the situation where both types' first choice is an abstinent match. The adjacent block on the left reports a mixing situation. Here  $s$  would prefer an abstinent match and  $\tilde{s}$  a promiscuous one. Half of the matches in this zone will be abstinent, and the other half promiscuous. The other adjacent block on the right reflects the same situation with the positions of  $s$  and  $\tilde{s}$  reversed. These matches were discussed in Point 3 of Section 7.1. Hence, they won't occur in steady state since, since all  $s < \psi$  will be in  $\mathcal{A}$  and all  $s > \psi$  will be in  $\mathcal{P}$ . Now, move to the large area in the corner at the back of the figure. This block gives the  $(s, \tilde{s})$  combinations where a promiscuous match is the first choice of both individuals. Note that according to Figure 7, no agent rejects a match; i.e., the blocks exhaust the type space. This result is sensitive to the values of  $\psi$ ,  $\delta$  and  $\mu$ . Promiscuity is more costly the higher is  $\psi$ . A match becomes more valuable, relative to searching, as  $\mu$  and  $\delta$  fall. When  $\mu$  is low it is hard to find a mate, and when  $\delta$  is small the benefits from a relationship are enduring. Therefore, when both  $\mu$  and  $\delta$  are low an agent is reluctant to decline a potential partner.

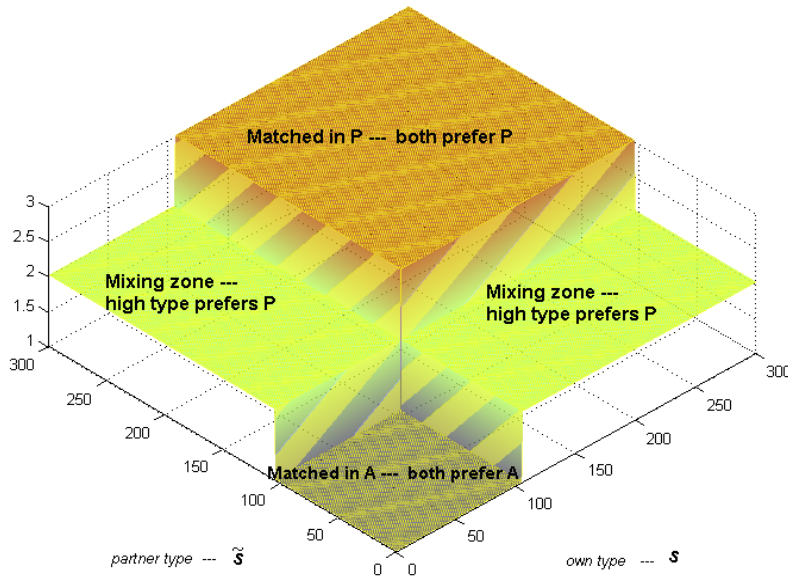


Figure 7: Matching set, final steady state

## 10.2 Transitional Dynamics

Now, turn to the transitional dynamics. The model has little trouble replicating the rise in premarital sex over the last century, as can be seen from Figure 8. Note that the model gives a *S*-shaped diffusion pattern for the increase in premarital sex, a pattern also visible in data. This is characteristic of technological adoption, here contraceptives. Observe that the sharpest rate of increase in premarital sex, for both the model and the data, occurs when the drop in the risk of pregnancy is most precipitous (i.e., after 1960). Premarital sex rises faster in the data than in the model, however. This could be due to missing factors, such as the legalization of abortion. Note that in the U.S. there is a downturn in the rate of premarital sex after 1987, perhaps due to the fear of AIDS. The benchmark model can't mimic this. The impact that abortion and HIV/AIDS had on premarital sex will be analyzed in Section 10.4. Still, it's surprising how far the analysis can go without such considerations.

The model generates a prediction on how many teenage girls will get pregnant each

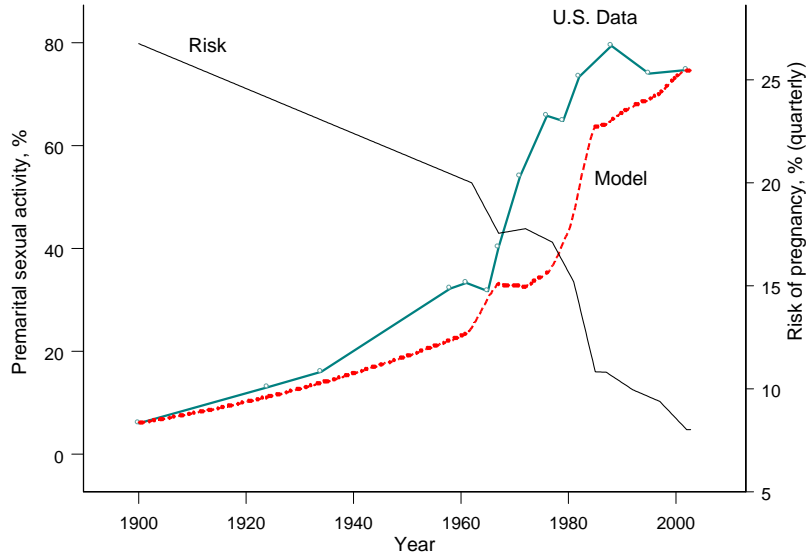


Figure 8: Rise in premarital sex, U.S. data and model

period. Figure 9 shows the percentage of girls who will get pregnant, both in the data and the model. The total number of pregnancies in the data is calculated as the sum of births, abortions and miscarriages for unmarried women between ages 15 and 19.<sup>19</sup> The model

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<sup>19</sup> Henshaw (2004 Table 1, p. 1) reports the number of births, abortions, and miscarriages (the latter calculated as 20% of births plus 10% of abortions) for *all* teenagers for the 1972-2000 period. To calculate the number of pregnancies for *unmarried* teenagers, the number births and abortions for unmarried teenagers are needed. The number of abortions, however, is only available for *all* teenagers, and just for the post-1972 period. Hence, certain assumptions are made to generate a pregnancy series for unmarried teenagers. In Figure 9 two such series for the 1960-2000 period are plotted. The first series, the lower estimate, is calculated in the following manner. Tietze (1983, Table 2, p. 33) reports an abortions-to-births ratio for all women for the years 1963-1972. Assuming that this ratio declined at the same rate for teenagers as it did for all women, one can extend the Henshaw (2004) abortion numbers back to 1963. Suppose there were no abortions between 1960 and 1963. Then, the total number of pregnancies to unmarried teenagers can be calculated as the number of births plus abortions plus miscarriages. Here the number of births is taken from Ventura and Bachrach (2000, Table 2, p. 18) and Ventura, Mathews and Hamilton (2001, Table 1, p. 10). The number of abortions to unmarried teenagers is calculated as the  $(\text{number teenagers}) \times (\text{out-of-wedlock births to teenagers}) / (\text{total births to teenagers})$ . Last, the numbers of miscarriages is computed as 20 percent of births plus 10 percent of abortions. The second series makes a much simpler calculation. For the 1972-2000 period it sums births to unmarried teenagers, all abortions to teenagers, and miscarriages (calculated as 20 percent of births plus 10 percent of abortions). For the 1960-1971 period it estimates the total number pregnancies by simply assuming that the  $(\text{abortions} + \text{miscarriages}) / (\text{out-of-wedlock births})$  ratio took the same value as it did in 1972.

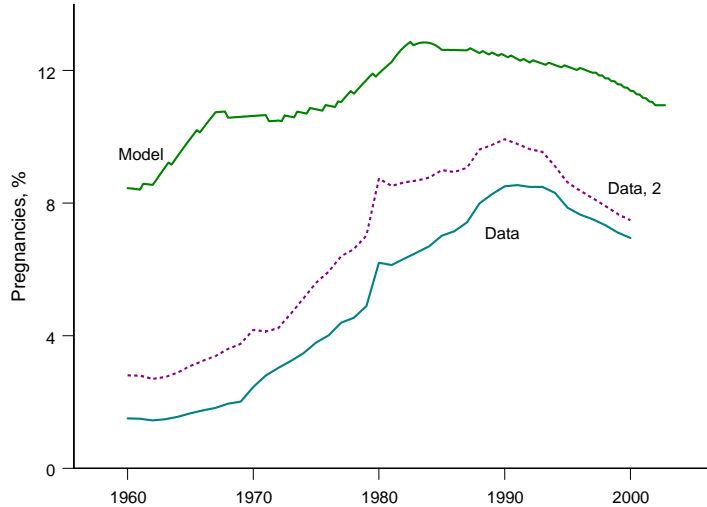


Figure 9: Increase in teenage pregnancies, U.S. data and model

predicts a rise and decline in the number of pregnancies, the same pattern as is observed in the data. Quantitatively speaking, the model overpredicts the number of pregnancies. Now, note that the number of pregnancies should be the product of the percentage of females practicing premarital sex multiplied by the failure rate. For the year 2002 at any point in time about 35 percent of females were having premarital sex. The quarterly failure was 8 percent. So, about  $11.2 = 4 \times 0.08 \times 35$  percent of girls should have become pregnant in that year. Yet, only 7 percent actually did. Thus, there seems to be a mismatch in the underlying data concepts. Perhaps the reported failure rate are too high, or the number of pregnancies recorded too low.

### 10.2.1 The Standard Search Model

It's interesting to compare the framework developed with a more standard search model. Visualize the world where all unattached people must search for a mate in a single class. Search now is more inefficient. Individuals who are inclined toward abstinence may now meet who those who are predisposed toward promiscuity, or vice versa. At the benchmark

parameter values this leads to too much promiscuity. Take an individual whose tastes favor abstinence. At some time in her teenage life she may draw a partner with a propensity toward promiscuity. Rather than lose this person she may consent to a sexual relationship. This female now becomes permanently classified as experienced - some things in life can't be reversed. At the benchmark parameter values about 25 percent of people are sexually experienced in the initial steady state, as opposed to 6 percent in 1900. One might think that the type distribution can be recalibrated to overcome this along the lines of Point 2 in Section 9. Surprisingly, there does not seem to exist values for the two type distribution parameters,  $\bar{s}$  and  $\zeta_s$ , that allow both the 1900 and 2002 targets to be hit.

### **10.2.2 The Power of the Pill**

The rise in premarital sex is often associated with the invention of the birth control pill. The model can be used to assess this claim. In particular, one can run the counterfactual experiment where no pill is invented. The first step in the experiment is to calculate the risk of premarital sex without the pill. This is easy to do using the information provided in Tables 1 and 2. Specifically, allocate birth control pill users across the other method of contraceptions, including withdrawal, according to their frequency of use. After having done this, construct a new series for the risk of pregnancy in the same manner as before. Rerun the simulations using this new series. The upshot of the experiment is shown in Figure 10. As can be seen, the invention of the birth control pill contributed very little to the rise in premarital sex among teenagers. For example, in 2002 it accounted for 1 percentage points out of the 75 percent of girls who had experienced sex by age 19. The reason is simple. The pill is not used by a large number of teenage girls, the vast majority use condoms. Thus, its introduction did not affect the risk of pregnancy much.

### **10.3 Cross-Sectional Implications on the Number of Partners**

The Markov chain matching technology generates predictions on the number of partners that a promiscuous person will have between the ages of 15 and 19, or across 20 model

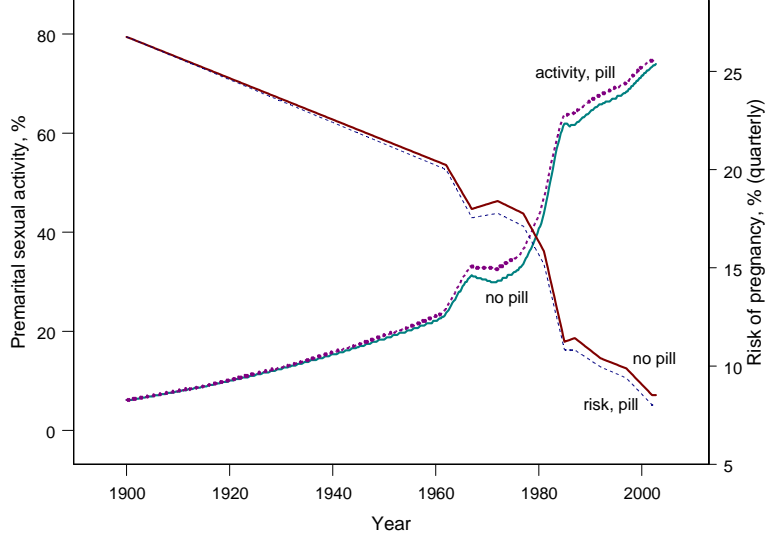


Figure 10: The power of the pill

periods. In order to calculate the total number of partners per promiscuous agent over 20 model periods, let  $m_t^j$  denote the number of matched agents with  $j$  sexual encounters by time  $t$  and  $u_t^j$  represent the number of unmatched agents with  $j$  sexual encounters. Then, the number of matched individuals with  $j$  sexual encounters in period  $t + 1$  is given by

$$m_{t+1}^j = (1 - \delta)m_t^j + \mu u_t^{j-1}. \quad (21)$$

In this equation, the fraction  $(1 - \delta)$  of matched promiscuous people with  $j$  lifetime partners in period  $t$  will remain in their current relationship next period so that these individuals will still have  $j$  partners then, while the proportion  $\mu$  of single agents with  $j - 1$  partners will find matches and thus have  $j$  partners next period. In similar fashion,

$$u_{t+1}^j = (1 - \mu)u_t^j + \delta m_t^j. \quad (22)$$

An upper bound on the maximum number of partners after  $T$  periods of matching is  $N = T/2 + 1$ . Thus, equations (21) and (22) define a Markov chain over  $\{m_t^0, u_t^0, \dots, m_t^N, u_t^N\}$ . This Markov chain can be simulated for  $T$  periods starting from the initial distribution

$\{0, 1, \dots, 0, 0\}$ . It can be used to calculate the mean number of total partners per individual over  $T$  periods – see the Appendix, Section 13.3, for more detail.

In 2002 a sexually active teenage girl had 3.0 partners by age 19. The Markov chain’s prediction is 2.5. While the means are close, the data exhibits far more cross-sectional variation than the model does as Table 3 shows.<sup>20</sup> As can be seen, in the data far more girls have just one partner than predicted by the Markov chain for matching. At the same time, a much larger number of girls have more than 7 partners in the data than is forecasted by the Markov chain. How to model such heterogeneity is an interesting issue? A simple way may be to have a higher destruction rate,  $\delta$ , for matches for some individuals as opposed to others. This could proxy for the fact that some people more easily tire of their partner than do others. Should these individuals search in their own high turn-over social classes? This is the type of question that the next generation of models may be able to answer.

TABLE 3: NUMBER OF PARTNERS				
(Active females by age 19, fraction)				
# of Partners	1	2 to 3	4 to 6	7+
Data	0.390	0.306	0.171	0.133
Model	0.1343	0.7205	0.1451	0.0001

## 10.4 Abortion and HIV

In 1973 the Supreme Court struck down a Texas law that criminalized abortion except when the life of the mother was in jeopardy. The ruling effectively provided free access to abortion in the United States. The number of abortions immediately rose, as Figure 11 illustrates.<sup>21</sup> About 56 percent of pregnancies were terminated in 1979. One of the

<sup>20</sup> The source is Abma *et al.* (2004, Table 13, p. 26). When calculating the mean number of partners from this data a value of 8 is assigned for the 7+ category.

<sup>21</sup> The sources for the abortion numbers presented in this figure are discussed in footnote 10. The total population living with HIV/AIDS for the 1978-2000 period is taken from Holtgrave (2003). For the years 2001 and 2002 the numbers come from the Centers for Disease Control and Prevention (2002). Numbers on the fraction of teenagers with HIV/AIDS might be more appropriate. Calculating this would require

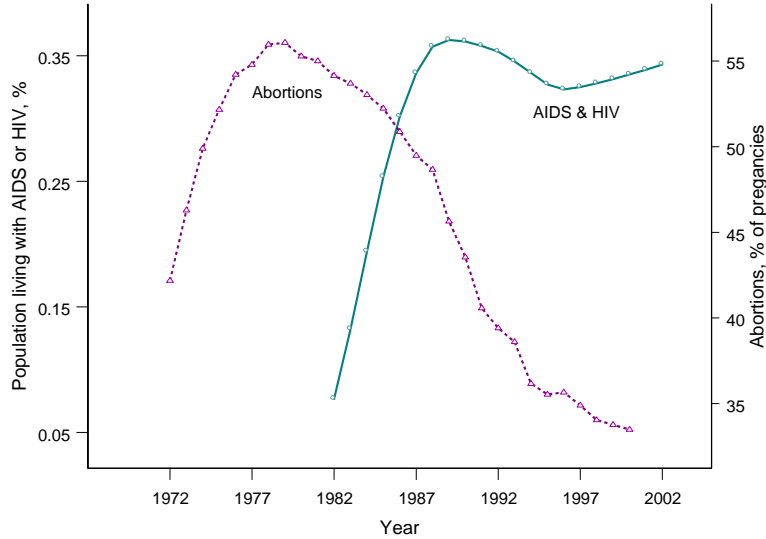


Figure 11: The prevalence of abortion and HIV

effects of the legalization of abortion was undoubtedly to reduce the cost of premarital sex. In 1982 the word AIDS was used for the first time. Since that time AIDS and HIV have spread through the population. Due to an aggressive public health campaign, the fraction of the population with AIDS and HIV appears to have now stabilized. The presence of HIV, however, has undoubtedly made sexual activity more risky.

The effects of the liberalization of abortion laws and the discovery of HIV will now be incorporated into the analysis. To this end, let  $\phi_a$  represent the cost of an abortion,  $\phi_b$  denote the cost of an out-of-wedlock birth, and  $\phi_h$  be the cost of contracting HIV. Let  $\pi$  be the odds of becoming pregnant for a girl engaging in premarital sex. Some fraction  $\alpha$  of these girls will terminate their pregnancies, while the fraction  $1 - \alpha$  will bear the child. Likewise, specify  $\eta$  to be the probability of contracting HIV in a sexual relationship. Given

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making a lot of assumptions, though, since HIV/ AIDS statistics are not readily available by narrow age groups, except for recent years. The results were not much different when a series for teenagers living with HIV/AIDS was constructed.

this notation, the expected cost of premarital sex,  $\psi$ , can therefore be written as

$$\psi = \phi_a \alpha \pi + \phi_b (1 - \alpha) \pi + \phi_h \eta.$$

Without loss of generality, normalize  $\phi_b = 1$ .

The parameters  $\phi_a$  and  $\phi_h$  will be picked to so that the model does the best possible job in explaining the trend toward premarital sex. The numbers  $\alpha$ ,  $\pi$ , and  $\eta$  are all taken from the data. The probability of becoming pregnant,  $\pi$ , is given by the failure rates calculated above. The time series for the fraction of pregnancies terminated in an abortion,  $\alpha$ , is presented in Figure 11. Last, the probability of contracting HIV depends on: (i) the probability of having sex with an infected person; (ii) whether or not a condom is used in sex; (iii) the transmission rate for unprotected sex, or when a condom fails. The odds of meeting an HIV infected person are given in Figure 11. Condoms are taken to have a 13 percent failure rate – Davis and Weller (1999). Again, Table 1 gives the usage of condoms. All other methods of contraception are assumed to have a 100 percent failure rate. Table 4 gives the effectiveness of contraception, after weighting each method by its use, against HIV. Estimates of the transmission rate are quite varied. Davis and Weller (1999) report a 6.8/100 transmission rate for males to females and one of 5.9/100 from females to males. A value of 1/1000 is given in Pinkerton and Ambramson (1997). An intermediate rate of 1/100 is used here. Note that since this rate is a constant any error here will simply be absorbed in the estimate of  $\phi_h$ .

TABLE 4: EFFECTIVENESS OF CONTRACEPTION AGAINST HIV

	80-82	83-88	85-89	90-94	95-98	99-02
Failure Rate (%)	76.77	63.63	68.33	56.55	56.66	55.46

The empirical procedure picks  $\phi_a = 0.4602$  and  $\phi_h = 1704.6$ . Therefore, an abortion is less costly than an out-of-wedlock birth, while contracting HIV is much more costly. Figure 12 shows the fit. As can be seen, the model does much better once abortion and HIV are allowed for. Observe that the risk associated with premarital sex declines rapidly after

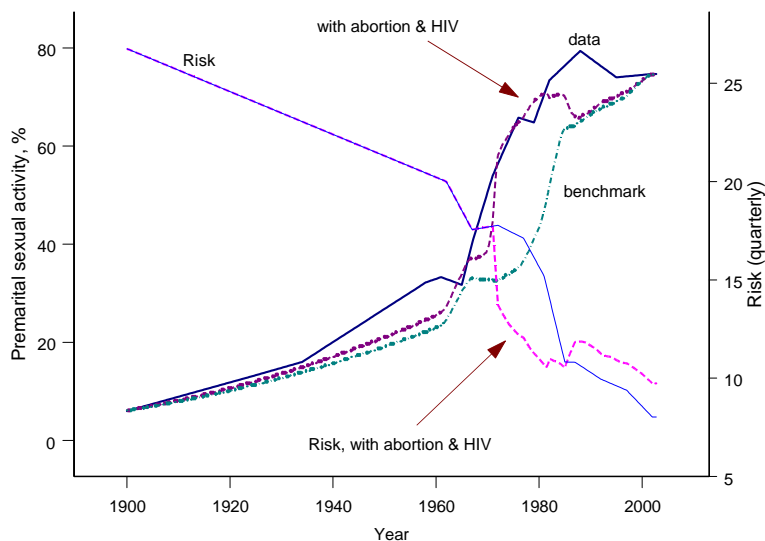


Figure 12: The model’s fit with abortion and HIV

1972 due to the legalization of abortion. As a consequence, the number of young women experiencing premarital sex increases more rapidly than in the benchmark model. The risk of premarital sex rises after 1982 due to HIV. This operates to dampen the trend toward premarital sex vis à vis the benchmark model.

## 11 The Frequency of Sex: A Proposed Extension

### 11.1 Facts

As contraceptive technology became more effective, and its use more widespread, one might expect that the frequency of premarital sex within a promiscuous relationship should rise also. This is the case. The earliest source on the frequency of sex is Kinsey *et al.* (1953). They report a mean frequency of sex for “active” females between the ages of 16 and 19 of 0.5 times per week, or 7.92 times per quarter – Kinsey *et al.* (1953, Table 76, p. 334). This classic study is based on female histories collected over the 1938 to 1950 period. Since the sample consists of women/girls between ages 2 and 71+, the data on premarital sexual

experience provides information for the earlier periods as well. So, presuppose that the frequency of sex for teenagers with premarital sexual experience was 7.92 times per quarter in 1900.<sup>22</sup>

Now, move forward to recent times. Abma *et al.* (2004, Table 6, p. 21) report frequency for females aged 15-19 for the year 2002. Table 5 shows some statistics based on their findings.<sup>23</sup> As can be seen, the mean monthly frequency for girls with premarital sexual experience was 3.18 times, which translates into a quarterly frequency of 12.71.<sup>24</sup> Therefore, the frequency of sex between practicing partners rose by a factor of 1.6 over the last century. It is also interesting to note the wide dispersion in the frequency of sex, about which little will be said here.

TABLE 5: MONTHLY FREQUENCY OF SEX	
(Active females, ages 15 to 19)	
# of times	distribution
0	0.3890
1	0.0945
2 to 3 (= 2.5)	0.1604
4 to 7 (= 5.5)	0.1495
8+ (= 9)	0.2066
Mean = 3.177	

<sup>22</sup> Unfortunately, the study does not report the frequency of premarital intercourse by birth cohorts.

<sup>23</sup> The Abma *et al.* (2004) numbers apply to all girls. Table 4 converts their numbers so that they apply to sexually experienced girls. Specifically, Abma *et al.* (2004) report that only 45.5 percent of girls had experienced sex. So, their numbers for the non-zero frequencies are scaled up by  $1/0.455$ . The number for the zero frequency in Table 5 is then simply taken to be one minus the sum over the non-zero frequencies. The numbers in parenthesis in Table 5 present the data points used to tabulate the mean.

<sup>24</sup> Zelnick, Kanter and Ford (1981, Table 3.7, p. 86) report a mean frequencies of 2.9 and 2.6 for 1971 and 1976. These lie between the Kinsey *et al.* (1953) and Abma *et al.* (2004) numbers, as would be expected.

## 11.2 A Model of Frequency

To model the above facts, change the term in the utility function involving sex to

$$\ln\{\tilde{s}\exp(\chi f^\iota/\iota - \chi/\iota)\} = \ln \tilde{s} + \chi f^\iota/\iota - \chi/\iota, \text{ with } \iota < 0 \text{ and } \chi > 0, \quad (23)$$

where  $f$  represents the frequency of sex and  $\tilde{s}$  now denotes the joy from it. Let the cost of sex be given by

$$\tilde{\psi} = 1 - p^f, \quad (24)$$

where  $p$  is the odds of having a safe sexual encounter. Observe that  $1 - p^f$  is the probability of becoming pregnant, given the frequency of sex  $f$ . The cost function is increasing and *concave* in  $f$ , since

$$\frac{d\tilde{\psi}}{df} = -(\ln p)p^f > 0 \text{ and } \frac{d^2\tilde{\psi}}{(df)^2} = -(\ln p)^2 p^f < 0,$$

where the signs of the above expressions follow from the fact that  $0 \leq p \leq 1$ . Therefore, while the chances of getting pregnant increase with the frequency of sex, they do so at a diminishing rate.

Cast an individual's decision regarding the frequency of sex as follows:

$$\max_f \{\ln \tilde{s} + \chi f^\iota/\iota - \chi/\iota - 1 + p^f\}.$$

The first- and second- order conditions for this problem are

$$\chi f^{\iota-1} = -(\ln p)p^f, \quad (25)$$

and

$$(\iota - 1)\chi f^{\iota-2} + (\ln p)^2(p^f) < 0. \quad (26)$$

The first-order condition simply sets the marginal benefit from coitus,  $\chi f^{\iota-1}$ , equal to its marginal cost,  $-(\ln p)p^f$ . One might expect the frequency of sex will rise with an improvement in the effectiveness of contraceptives, or a fall in  $p$ . Strictly speaking this need not be the case since the marginal cost of sex is not necessarily decreasing in  $p$ .

**Lemma 4** *The frequency of sex,  $f$ , increases or decreases with the effectiveness of contraception,  $p$ , depending on whether  $-\ln p \stackrel{\leq}{\geq} 1/f$ .*

**Proof.** Differentiating the efficiency condition (25) yields

$$\frac{df}{dp} = \frac{-p^{f-1} - (\ln p)fp^{f-1}}{(\iota - 1)\chi f^{\iota-2} + (\ln p)^2(p^f)}.$$

The second-order condition (26) implies that the denominator of the above expression is negative. Next see that  $-p^{f-1} - (\ln p)fp^{f-1} \stackrel{\leq}{\geq} 0$  as  $-\ln p \stackrel{\leq}{\geq} 1/f$ . ■

Now, for empirically relevant values of  $p$  and  $f$  it will transpire that  $df/dp > 0$ , as will be clear from the discussion below.

Given the form of (23) the marginal benefit from sex does not depend on the person's type  $\tilde{s}$ . This abstraction is unrealistic, yet its simplicity is a big virtue. It allows the model of the frequency of sex to be tacked on to the existing apparatus in a very simple manner, as will be discussed. If type and frequency are allowed to interact then each partner to a match would have to bargain over frequency, at least if their types differed.

Is the above framework consistent with the observed increase in the frequency of sex? The answer is yes. The question really amounts to asking whether or not there exists values for  $\iota$  and  $\chi$  such that the efficiency condition (25) will return the observed frequencies of sex in 1900 and 2002, given the observed probabilities of safe sex in these years. To this end, note from (24) that the probability of a safe sexual encounter is given by  $p_t = (1 - \tilde{\psi}_t)^{1/f_t}$ , where the subscript  $t$  refers to the time period for a variable. Recall that the quarterly failure rate of contraception in 1900 was 0.27 and the observed frequency of sex 7.92. Hence, the probability of a safe sexual encounter in 1900 is given by  $p_{1900} = (1 - 0.2676)^{1/7.92} = 0.9614$ . Likewise, in 2002 the odds of not becoming pregnant were  $p_{2002} = (1 - 0.0802)^{1/12.71} = 0.9934$ . Interestingly, while a single sexual encounter in 2002 looks very safe, having sex  $4 \times 12.71 = 51$  times over the course of the year results in a 28.5 percent chance of pregnancy.

Next, it follows from (25) that

$$\left(\frac{f_{2002}}{f_{1900}}\right)^{\iota-1} = \frac{(\ln p_{2002})(p_{2002})^{f_{2002}}}{(\ln p_{1900})(p_{1900})^{f_{1900}}}.$$

This equation can be used to pin down a value for  $\iota$ , given observations for  $f_{1900}$ ,  $f_{2002}$ ,  $p_{1900}$ , and  $p_{2002}$ . Specifically,

$$\iota = \ln \left[ \frac{(\ln p_{2002})(p_{2002})^{f_{2002}}}{(\ln p_{1900})(p_{1900})^{f_{1900}}} \right] / \ln \left( \frac{f_{2002}}{f_{1900}} \right) + 1 = -2.30.$$

Finally, a value for  $\chi$  can also be backed out from (25). In particular, set

$$\chi = \frac{(-\ln p_{1900})(p_{1900})^\iota}{(f_{1900})^{\iota-1}} = 26.5.$$

To summarize given  $\iota = -2.30$  and  $\chi = 26.5$ , the above procedure implies that the first-order condition (25) will return  $f = 7.92$  when  $p = 0.9614$ , and  $f = 12.71$  when  $p = 0.9934$ . The second-order condition (26) also holds when evaluated at the 1900 and 2002 values. Thus, a maximum obtains notwithstanding the concave cost function.<sup>25</sup> With regard to Lemma 2, observe that once the framework has been calibrated to match the observed (fairly small) values for  $f$  it must transpire that  $df/dp > 0$ , since  $\ln p \simeq 0$ .

Last, to tack the above framework onto the earlier model simply let  $\ln \tilde{s} = s \in \mathcal{S} = \{s_1, s_2, \dots, s_n\}$  and  $\psi = -\chi f^\iota / \iota + \chi / \iota + \tilde{\psi}$ . Hence, the cost of sex in Section 2 must now incorporate into it the utility derived from the optimal frequency of sex. Transforming the type distribution in this way and following the procedure mentioned in Section 9, Point 2, results in  $\bar{s} = -11.3337$  and  $\zeta_s = 0.1125$ .

## 12 Conclusions

What causes social change? The idea here is that a large part of social change is a reaction to technological progress in the economy. Technological progress affects society's consumption and production possibilities. It therefore changes individuals' incentives to abide by social customs and mores. As people gradually change their behavior to take advantage of emerging opportunities, custom slowly evolves too.

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<sup>25</sup> Also, note that  $\chi f^\iota / \iota - \chi / \iota - (1-p)^f > 0$  for both 1900 and 2002 so that an individual is obtaining positive utility from the frequency of sex. This consideration is important for deciding which matches to accept or reject, or which social class to join.

This notion is applied here to the rocket-like rise in premarital sex that occurred over the last century. Now, a majority of youth engage in premarital sex. One hundred years ago almost none did. This is traced here to the dramatic decline in risk of pregnancy, due technological improvement in contraceptives. This is modeled within the context of an equilibrium matching model. The model has two key ingredients. First, individuals weigh the cost and benefits of coitus when engaging in premarital sexual activity. Second, they associate with individuals who share their own proclivities. Such a model mimics well the observed rise in premarital sexual activity, given the observed decline in the risk of sex.

Improvement in contraceptive technology may also partially explain the decline in the fraction of life spent married for a female from 0.88 in 1950 to 0.60 in 1995.<sup>26</sup> This is due to delays in first marriages and remarriages, and a rise in divorce. Historically, the institution of marriage was a mechanism to have safe sex, among other things. As sex became safer, the need for marriage declined on this account. According to Becker (1991, p. 326):

Since the best way to learn about someone else is by being together, intensive search is more effective when unwed couples spend considerable time together, perhaps including trial marriages. Yet when contraceptives are crude and unreliable, trial marriages and other premarital contact greatly raise the risk of pregnancy. The significant increase during this century in the frequency of trial marriages and other premarital contact has been in part a rational response to major improvements in contraceptive techniques, and is not decisive evidence that young people now value sexual experiences more than they did in the past.

An interesting avenue for future research might be to investigate the implications of the contraceptive revolution for marriage and divorce.

## 13 Appendix

### 13.1 Lemma 1

**Proof.** To begin with, establish that there is no incentive for a matched couple in  $\mathcal{A}$  to switch to  $\mathcal{P}$ , or vice versa. To this end, subtract (1) from (3) to obtain  $P(s, \tilde{s}) - A(s, \tilde{s}) = s - \psi$ .

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<sup>26</sup> This fact is taken from Greenwood and Guner (2004), and is analyzed from a different perspective there.

Clearly,  $P(s, \tilde{s}) - A(s, \tilde{s}) \geq 0$  as  $s \geq \psi$ . Thus, there is no gain for a matched couple  $(s, \tilde{s}) \in \mathcal{P}$  or another one  $(s, \tilde{s}) \in \mathcal{A}$  to switch from their respective social classes.

What about unmatched people? Conjecture a solution for the decision rules in steady state. Specifically, assume that:

(i)  $H(s, \tilde{s}) = I(s, \tilde{s}) = L(s) = 1$  and  $J(s, \tilde{s}) = 0$  for all  $s, \tilde{s} \in \mathcal{A}$ ,

(ii)  $H(s, \tilde{s}) = L(s) = 0$  and  $J(s, \tilde{s}) = K(s, \tilde{s}) = 1$  for all  $s, \tilde{s} \in \mathcal{P}$ .

Now, (i) and (ii) imply that  $X(s, \tilde{s}) = 1$  and  $Y(s, \tilde{s}) = 0$  for  $(s, \tilde{s}) \in \mathcal{A}$ , and  $X(s, \tilde{s}) = 0$  and  $Y(s, \tilde{s}) = 1$  for  $(s, \tilde{s}) \in \mathcal{P}$ . Additionally, (i) implies that  $Q(s) < B(s)$  for  $s, \tilde{s} \in \mathcal{A}$  and  $Q(s) \geq B(s)$  for  $s \in \mathcal{P}$ . This conjectured solution will now be verified. For a given set of decisions rules, the recursions (1) to (4) define a contraction mapping. So, imagine a fixed point for the value functions predicated upon conjectured set of decisions rules. If the resulting value functions imply the hypothesized decision rules then an equilibrium with the specified properties has been found. First, note that in the conjectured steady state  $v_j = 0$  for all  $j > c$  and  $\varpi_j = 0$  for all  $j < c$ . Using this observation, subtract (2) from (4) *in steady state* to get

$$\begin{aligned}
Q(s) - B(s) &= \beta\mu \sum_{j=c+1}^n \varpi_j [X(s, \tilde{s}_j)A(s, \tilde{s}_j) + Y(s, \tilde{s}_j)P(s, \tilde{s}_j)] \\
&\quad - \beta\mu \sum_{j=0}^c v_j [X(s, \tilde{s}_j)A(s, \tilde{s}_j) + Y(s, \tilde{s}_j)P(s, \tilde{s}_j)] \\
&\quad + \beta[(1 - \mu) + \mu \sum_{j=c+1}^n \varpi_j Z(s, \tilde{s}_j)] \{L(s)B(s) + [1 - L(s)]Q(s)\} \\
&\quad - \beta[(1 - \mu) + \mu \sum_{j=0}^c v_j Z(s, \tilde{s}_j)] \{L(s)B(s) + [1 - L(s)]Q(s)\}.
\end{aligned}$$

For  $s \in \mathcal{P}$  (which implies  $s \geq \psi$ ) it is easy to see that

$$\begin{aligned}
Q(s) - B(s) &= \beta\mu P(s, \tilde{s}_j) - \beta\mu \sum_{j=0}^c v_j [X(s, \tilde{s}_j)A(s, \tilde{s}_j) + Y(s, \tilde{s}_j)P(s, \tilde{s}_j)] \\
&\quad + \beta(1 - \mu)Q(s) - \beta[(1 - \mu) + \mu \sum_{j=0}^c v_j Z(s, \tilde{s}_j)]B(s) \\
&\geq \beta(1 - \mu)[Q(s) - B(s)] > 0.
\end{aligned}$$

[Note that  $P(s, \tilde{s}_j) \geq A(s, \tilde{s}_j)$  for  $s$  and that  $0 \leq X(s, \tilde{s}_j) + Y(s, \tilde{s}_j) \leq 1$ .] Now, clearly this equation cannot be satisfied for  $Q(s) - B(s) < 0$ . Hence,  $Q(s) - B(s) \geq 0$ . Thus, no unmatched  $s \in \mathcal{P}$  would want to switch. A similar argument can be made for  $s \in \mathcal{A}$ . The hypothesized solution for  $L(s)$  has now been verified. [That is, assuming that (i) and (ii) hold on the righthand side implies that on the lefthand side  $Q(s) - B(s) \geq 0$  as  $s \geq \psi$ . Thus, the lefthand side supports the conjectured solution for  $L(s)$ .]

Next, given (i) and (ii), when  $(s, \tilde{s}) \in \mathcal{A}$  equations (1) and (2) can be represented by

$$A(s, \tilde{s}) = u + \beta(1 - \delta)A(s, \tilde{s}) + \beta\delta B(s),$$

and

$$B(s) = v + \beta\mu A(s, \tilde{s}) + \beta(1 - \mu)B(s).$$

Clearly, when  $(s, \tilde{s}) \in \mathcal{A}$  then  $A(s, \tilde{s})$  is no longer a function of  $\tilde{s}$ . Direct calculation reveals that

$$A^*(s) = \frac{[1 - \beta(1 - \mu)]u + \beta\delta v}{\Delta}, \quad (27)$$

and

$$B^*(s) = \frac{[1 - \beta(1 - \delta)]v + \beta\mu u}{\Delta}, \quad (28)$$

where  $\Delta \equiv (1 - \beta)[1 - \beta(1 - \mu - \delta)] > 0$ . For future reference, let an asterisk attached to a function denote its closed-form solution that obtains in steady state, defined only over the equilibrium set of agents that live in the relevant social class. Observe that  $A^*(s) > B^*(s)$ , as was conjectured, because  $u > v$ . Therefore,  $H(s, \tilde{s}) = I(s, \tilde{s}) = 1$  and  $J(s, \tilde{s}) = 0$  for  $(s, \tilde{s}) \in \mathcal{A}$ .

Likewise, for  $(s, \tilde{s}) \in \mathcal{P}$  note that equations (3) and (4) can then be rewritten as

$$P(s, \tilde{s}) = u + s - \psi + \beta(1 - \delta)P(s, \tilde{s}) + \beta\delta Q(s),$$

and

$$Q(s) = v + \beta\mu P(s, \tilde{s}) + \beta(1 - \mu)Q(s).$$

The solutions to these two equations are given by

$$P^*(s) = \frac{(u + s - \psi)[1 - \beta(1 - \mu)] + v\beta\delta}{\Delta}, \quad (29)$$

and

$$Q^*(s) = \frac{[1 - \beta(1 - \delta)]v + \beta\mu(u + s - \psi)}{\Delta}. \quad (30)$$

It is easy to see that

$$P^*(s) - Q^*(s) = \frac{(u + s - \psi - v)(1 - \beta)}{\Delta}.$$

Thus,  $P^*(s) > Q^*(s)$  when  $u + s - \psi > v$ , which will hold for all  $s > \psi$ . Consequently, for  $(s, \tilde{s}) \in \mathcal{P}$  it transpires that  $H(s, \tilde{s}) = 0$  and  $J(s, \tilde{s}) = K(s, \tilde{s}) = 1$ . It has now been shown that (i)  $H(s, \tilde{s}) = I(s, \tilde{s}) = L(s) = 1$  and  $J(s, \tilde{s}) = 0$  for all  $(s, \tilde{s}) \in \mathcal{A}$ , and (ii) that  $H(s, \tilde{s}) = L(s) = 0$  and  $J(s, \tilde{s}) = K(s, \tilde{s}) = 1$  for all  $s, \tilde{s} \in \mathcal{P}$ . ■

## 13.2 Lemma 3

**Proof.** The proof proceeds using the guess-and-verify strategy. To this end, suppose that the value functions  $A(s, \tilde{s})$ ,  $B(s)$ ,  $P(s, \tilde{s})$ , and  $Q(s)$  immediately jump to their new steady-state values upon the once-and-all decline in  $\psi$ . Now, consider a pair in the situation described by Point 1 in Section 7.1. The payoffs for matched individuals with  $s, \tilde{s} \in \{s_{d+1}, \dots, s_n\}$  will be given by (29) and (30). Note that when this match breaks up an individual will not have to worry about subsequently matching in  $\mathcal{P}$  with a  $\tilde{s} \in \{s_1, \dots, s_d\}$ , given Point 2. Thus, from their own limited perspective, these agents will be immediately jumping into the new steady state since they will never have to mix with a type in the set  $\{s_1, \dots, s_d\}$ . Next, focus upon those individuals in the situation outlined by Point 2. Their payoffs will again be described by (29) and (30). Again, if they switch to  $\mathcal{P}$  they will not have to worry about matching next period with a  $\tilde{s} \in \{s_1, \dots, s_d\}$ . So, from their viewpoint, these agents will be immediately moving into the new steady-state situation in  $\mathcal{P}$ .

Now, move to Point 3. Let  $s \in \{s_1, \dots, s_d\}$  and  $\tilde{s} \in \{s_{d+1}, \dots, s_c\}$ . For it to be optimal for  $s$  to be matched with  $\tilde{s}$  in this situation in  $\mathcal{A}$  it must transpire that  $A(s, \tilde{s}) > \max\{B(s), Q(s)\}$  and  $P(s, \tilde{s}) < \max\{A(s, \tilde{s}), B(s), Q(s)\}$ . First, by subtracting (1) from (3) it can be seen that  $P(s, \tilde{s}) - A(s, \tilde{s}) = s - \psi \geq 0$  as  $s \geq \psi$ . Therefore,  $s$ 's first choice is a match in  $\mathcal{A}$ , while  $\tilde{s}$ 's would be one in  $\mathcal{P}$ . Now, there are two cases to consider for  $s$ . Either

she is in a mixing situation with  $\tilde{s}$  [implying  $K(s, \tilde{s}) = 1$ ] or she is refusing a promiscuous match all together [ $K(s, \tilde{s}) = 0$ ]. Take the latter situation first. The conjecture is that today's value functions will immediately jump to their steady values and remain there. This would imply that  $L(s, \tilde{s}) = 1$ ,  $X(s, \tilde{s}) = 1$ ,  $Y(s, \tilde{s}) = 0$ . Using this on the righthand sides of (1) and (2) and solving for  $A(s, \tilde{s})$  and  $B(s)$  results in

$$A(s, \tilde{s}) = A^*(s), \quad [\text{for } s < s_d \leq \tilde{s} \text{ and } X(s, \tilde{s}) = 1]$$

and

$$B(s) = B^*(s), \quad (\text{for } s < s_d),$$

where  $A^*(s)$  and  $B^*(s)$  are specified by (27) and (28). Imposing this conjecture on (4) leads to

$$\begin{aligned} Q(s) &= v + \beta\mu \sum_{k=d+1}^n \varpi_k [X(s, \tilde{s}_k)A(s, \tilde{s}_k) + Y(s, \tilde{s}_k)P(s, \tilde{s}_k)] \\ &\quad + \beta(1 - \mu)B^*(s) \\ &< B^*(s) < A^*(s) \quad (\text{for } s < s_d \leq \tilde{s}). \end{aligned}$$

Thus,  $s$  will remain happy with her lot in  $\mathcal{A}$ , so there is no need to change her strategy today, taking as given  $\tilde{s}$ 's strategy. Consider the mixing situation for  $s$ . Here, the solution for  $A(s, \tilde{s})$  reads

$$A(s, \tilde{s}) = \frac{u + \beta(1 - \delta)(s - \psi)/2 + \beta\delta B^*(\tilde{s})}{1 - \beta(1 - \delta)} < A^*(s) \quad [\text{for } s < s_d \leq \tilde{s} \text{ and } X(s, \tilde{s}) = 1/2].$$

For  $s$  to agree to a mixing situation it must transpire that  $A(s, \tilde{s}) \geq B^*(s)$ . Thus, mixing cannot occur for any  $s < s_p$  where  $p = \arg \max_j \{j : A(s_j, \tilde{s}) \leq B^*(s_j)\}$ . Providing that  $s \geq s_p$ , there will be no incentive for  $s$  to switch strategies.

Now, move to person  $\tilde{s}$ . For  $\tilde{s}$  to be matched with  $s$  it must happen that  $A(\tilde{s}, s) > \max\{B(\tilde{s}), Q(\tilde{s})\}$ . Person  $\tilde{s}$  may find himself in one of two situations: either a mixing situation or one where  $s$  will refuse a promiscuous match. In the former  $K(s, \tilde{s}) = 1$ , while in the latter  $K(s, \tilde{s}) = 0$ . Take the latter case and suppose that the steady-state solution

holds true at some point in time. Here, then  $X(s, \tilde{s}) = 1$  and  $Y(s, \tilde{s}) = 0$ . It is then easy to deduce that  $A(\tilde{s}, s)$  and  $B(\tilde{s})$  are given by

$$\begin{aligned} A(\tilde{s}, s) &= u + \beta(1 - \delta)A(\tilde{s}, s) + \beta\delta Q^*(\tilde{s}) \\ &= \frac{u + \beta\delta Q^*(\tilde{s})}{1 - \beta(1 - \delta)} > A^*(\tilde{s}) \text{ [for } s < s_d \leq \tilde{s} \text{ and } X(s, \tilde{s}) = 1], \end{aligned}$$

and

$$\begin{aligned} B(\tilde{s}) &= v + \beta\mu \sum_{i=1}^d v_i [X(\tilde{s}, s_i)A(\tilde{s}, s_i) + Y(\tilde{s}, s_i)P(\tilde{s}, s_i)] \\ &\quad + \beta(1 - \mu)Q^*(\tilde{s}) \\ &\leq Q^*(\tilde{s}) < P^*(\tilde{s}) \text{ (for } s_d \leq \tilde{s}). \end{aligned}$$

[Note that  $P(\tilde{s}, s_i) > A(\tilde{s}, s_i)$  for  $\tilde{s}$  and  $0 \leq X(\tilde{s}, s_i) + Y(\tilde{s}, s_i) \leq 1$ .] Now, an abstinent match cannot occur for any  $\tilde{s} \geq s_q$  where  $q = \arg \max_j \{j : A(\tilde{s}_j, s) \geq Q^*(\tilde{s}_j)\}$ . Provided that this is true, there is no incentive for  $\tilde{s}$  to shift from the conjectured strategy. Similarly, it is straightforward to calculate that when there is mixing

$$A(\tilde{s}, s) = \frac{u + \beta(1 - \delta)(\tilde{s} - \psi)/2 + \beta\delta Q^*(\tilde{s})}{1 - \beta(1 - \delta)} > A^*(\tilde{s}) \text{ [for } s < s_d \leq \tilde{s} \text{ and } X(s, \tilde{s}) = 1/2].$$

As can be seen, mixing will yield  $\tilde{s}$  a higher level of utility than a purely abstinent match. This can only occur, though, when  $s_p \leq s \leq s_d$  – since  $s$  must also agree to mixing.

The situation described in Point 4 can be analyzed in a similar manner. The reader is spared the details. ■

### 13.3 Markov Chain for the Number of Partners

Using (21) and (22) set up a Markov chain as follows:

$$\begin{bmatrix} m_{t+1}^0 \\ u_{t+1}^0 \\ m_{t+1}^1 \\ u_{t+1}^1 \\ \vdots \\ \mu_{t+1}^{N-1} \\ m_{t+1}^N \\ u_{t+1}^N \end{bmatrix} = \begin{bmatrix} (1-\delta) & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \delta & (1-\mu) & 0 & 0 & & 0 & 0 & 0 \\ 0 & \mu & (1-\delta) & 0 & & 0 & 0 & 0 \\ 0 & 0 & \delta & (1-\mu) & & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots & \\ & & & & \cdots & 1-\mu & & \\ 0 & 0 & 0 & 0 & & \mu & (1-\delta) & 0 \\ 0 & 0 & 0 & 0 & \cdots & & \delta & (1-\mu) \end{bmatrix} \begin{bmatrix} m_t^0 \\ u_t^0 \\ m_t^1 \\ u_t^1 \\ \vdots \\ \mu_t^{N-1} \\ m_t^N \\ u_t^N \end{bmatrix},$$

which can be represent more compactly by

$$p_{t+1} = Pp_t.$$

Note that

$$p_{t+1} = P^{t+1}p_0,$$

where

$$p_{t+1} = \begin{bmatrix} p_{t+1,1} \\ p_{t+1,2} \\ p_{t+1,3} \\ \vdots \\ p_{t+1,2N+2} \end{bmatrix} \text{ and } p_0 = \begin{bmatrix} p_{0,1} \\ p_{0,2} \\ p_{0,3} \\ \vdots \\ p_{0,2N+2} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix}.$$

Hence, the mean number of sexual encounters for the experienced is

$$\frac{\sum_{j=1}^{N+2-1} (p_{N,2j+1} + p_{N,2j+2})j}{\sum_{j=2}^{N+2} p_{N,j}}.$$

### 13.4 Algorithm

The algorithm computes a transition path between two steady states. Pick a time horizon  $T$  sufficiently large so that the economy will have converged to the final steady state by

this time. Set the period  $T$  value functions and type distributions to their final steady-state values. Likewise, fix the period-1 type distributions at their values in the initial state. Finally, pick the  $\{\psi_t\}_{t=1}^T$  sequence so that the first  $4(2002 - 1900)$  values match the time series properties observed for the effectiveness of contraception in the U.S. data. Set the last  $T - 4(2002 - 1900)$  values equal to the number observed for 2002, which amounts to assuming that there is no technological progress in contraception after this year.

1. Enter iteration  $j + 1$  with a guess from the previous iteration for the time path of  $M, N, U$  and  $V$ , denoted by  $\{M_t^j\}_{t=2}^{T-1}, \{N_t^j\}_{t=2}^{T-1}, \{U_t^j\}_{t=2}^{T-1}$  and  $\{V_t^j\}_{t=2}^{T-1}$ .
2. Solve the recursions (1) to (4) using this guess. Retrieve the time path for the policy functions associated with these recursions represented by  $\{H_t^{j+1}\}_{t=1}^{T-1}, \{I_t^{j+1}\}_{t=1}^{T-1}, \{J_t^{j+1}\}_{t=1}^{T-1}, \{K_t^{j+1}\}_{t=1}^{T-1}, \{L_t^{j+1}\}_{t=1}^{T-1}, \{X_t^{j+1}\}_{t=1}^{T-1}, \{Y_t^{j+1}\}_{t=1}^{T-1}$ , and  $\{Z_t^{j+1}\}_{t=1}^{T-1}$ . These are specified by (5) to (12).
3. Calculate new time paths for  $M, N, U$  and  $V$ , or  $\{M_t^{j+1}\}_{t=2}^{T-1}, \{N_t^{j+1}\}_{t=2}^{T-1}, \{U_t^{j+1}\}_{t=2}^{T-1}$  and  $\{V_t^{j+1}\}_{t=2}^{T-1}$ , using the laws of motion (13) to (16).
4. Check for convergence.
  - (a) If  $\text{norm}(\{M_t^{j+1}, N_t^{j+1}, U_t^{j+1}, V_t^{j+1}\}_{t=2}^{T-1} - \{M_t^j, N_t^j, U_t^j, V_t^j\}_{t=2}^{T-1}) < \varepsilon$  then stop, since a solution has been found.
  - (b) If not, then repeat Step 1 using  $\{M_t^{j+1}\}_{t=2}^{T-1}, \{N_t^{j+1}\}_{t=2}^{T-1}, \{U_t^{j+1}\}_{t=2}^{T-1}$  and  $\{V_t^{j+1}\}_{t=2}^{T-1}$  for the new guess.

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