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Social Change

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Social Change

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ABSTRACT

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A society is characterized by the common attitudes and behavior of its members. Such behavior reflects 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 females 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.

JEL Classification: E1, J1, O3

Keywords: social change, sexual revolution, technological progress in contraceptives, bilateral search

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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://ideas.repec.org/p/eag/rereps/9.html

> 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 social change? Define it simply as shifts in the attitudes and behavior that characterize a society. So, why and how do societies evolve? The idea here is that social change is largely an adaptation 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. By 2002 a large majority (roughly 75 percent) had experienced this. What caused this: the contraception revolution.[1] 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. At the time, though, about 40 percent of 19 year-old females had experienced it. The number with a permissive attitude had jumped to 45 percent by 1983, a time when 73 percent of 19 year olds were sexually experienced. Another reflection of the change in sexual mores is the rise in the number of sexual partners that unmarried females 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. 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 females rose from 3 percent in 1920 to 33 percent in 1999 – Figure 4. Despite great public concern about teenage sexual behavior in recent years, there has not been any attempt to build formal models of it. The current work will attempt to fill this void.[2]

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, the availability

[1] The sources for the U.S. data displayed in the figures and tables are detailed in the Appendix, Section 13.5. Interestingly, the fraction of 18 to 19 year old women who are married is $\cap$ shaped over this period with the peak (31 percent) occurring in 1950. The fraction who are married in 1900 (21 percent) is about the same as the proportion married in 1970 (22 percent). It would seem hard to view the trend shown in Figure 1 as being caused by shifts in marital patterns.

[2] Restuccia and Urrutia (2004) show that pre-college education is critical for intergenerational transmission of inequality. Therefore, the lifecycle implications of teenage pregnancies can be high.

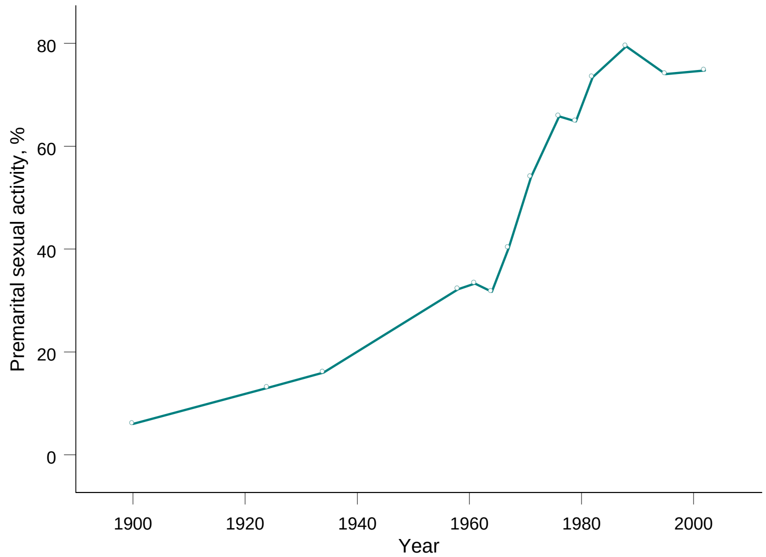

Figure 1: Percentage of 19 year-old females with premarital sexual experience

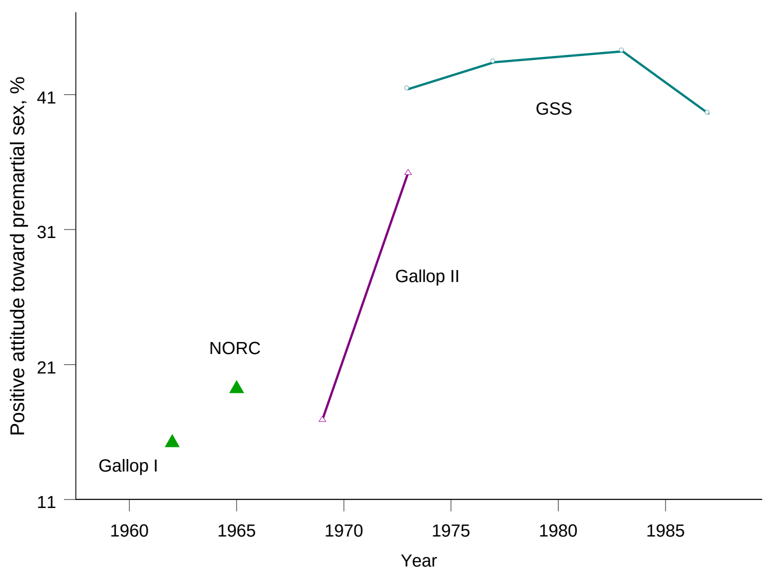

Figure 2: Percentage of females with a permissive attitude toward premarital sex

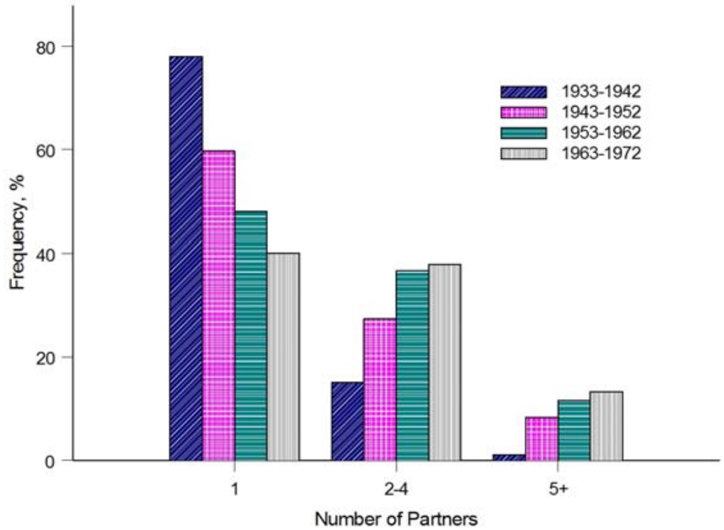

Figure 3: Number of partners by age 20 for women engaging in premarital sex, frequency distribution by birth cohort

Figure 4: Out-of-wedlock births, percentage

of contraceptives and abortion will lower the costs of premarital sex, while the presence of AIDS/HIV raise it. 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. The membership of social groups is therefore endogenous. Shifts in the sizes of the groups reflect social change.[3]

It is established theoretically that in the developed matching model's steady state the population sorts very neatly into two social groups. Those who want an abstinent relationship circulate exclusively among people who share the same ideal, while those who prefer a promiscuous one associate with others who desire the same thing. This does not have to happen outside of a steady state. It is also shown theoretically that the model is likely to display rapid transitional dynamics. This is desirable since sexual practice appears to have responded quite quickly to the availability of new and improved contraception. The model is solved numerically in order to assess its ability to explain the rise in premarital sex over the twentieth century. A key step in the simulation is the construction of a time series reflecting the cost of sex. This series is based upon the observed effectiveness and use of various types of contraception. The framework can replicate well the rapid rise in premarital sex that the last one hundred years witnessed. In particular, it is found that: (i) the reduction in the risk of pregnancy due to availability of new and improved contraceptions encouraged the rise of premarital sex; (ii) increased accessibility to abortion promoted premarital sex; (iii) the spread of AIDS/HIV dissuaded it. Last, it is shown how a simple modification of the framework captures the observed rise in the frequency of sex.

The search framework developed here has implications that would be harder to examine

[3] This notion is not without some precedence. For example, Burdett and Coles (1997) illustrate within the context of a marital search model how people may wed exclusively within their own social class (which is some range of types). Search is not directed within one's own social class, however. People look over the entire marriage market. An equilibrium may obtain where individuals choose to reject all potential mates below their own social class.

using other paradigms. First, the model is able to match both the fraction of teenagers having sex in a given period, as well as the proportion who have had sex by age 19. Likewise, the model can give predictions on the fraction of teenagers becoming pregnant each period, and the proportion who become pregnant by age 19. These two measures would be hard to disentangle in a static model. Yet, they might have different relevancies for public policies. The former could be indicative of the aggregate per-period costs of premarital sex, the latter a measure of the risk of premarital sex for a teenage girl. Second, the model can match the median duration of an adolescent relationship and the average number of partners for sexually active teenagers. In the data there is a huge dispersion across the number of sexual partners. The current prototype has difficulty matching this latter fact, but future versions might be able to do so. Modelling the average number of, and the dispersion in, sexual partners is likely to important for shedding light on the spread of sexually transmitted diseases such as AIDS/HIV. The adjustment of individual behavior to the risk of the infection, to prophylaxes that change the risk, and to the likelihood of having the disease based upon past behavior, could be important for understanding its transmission. Individuals could search for partners within certain risk pools, depending on their preferences for different types of sex. Future versions of the framework could be used to study this, something that would be difficult to do in a static framework.

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. Algan and Cahuc (2007) study differences in employment across OECD countries. They find a strong effect of improvements in household technology on prime-age female labor-force participation in all countries. But, the impact on employment for young and old family members, as well as the extent of the rise for prime-age females, interacts with culture factors. Algan and Cahuc (2007) capture culture by values reported in survey data. They argue that the survey questions on family values can be used to represent culture, as answers by people from a given region of Europe and those in the U.S. whose ancestors come from that same region of Europe are quite similar.

It is also possible to model social change via shifts in preferences over time. This would be in the spirit of Doepke and Zilibotti (2005) and Fernandez, Fogli, and Olivetti (2004). A child's preferences may be affected by parental investments, the approach that Doepke and Zilibotti (2005) take building upon earlier work by Becker and Mulligan (1997). Or, they be a function of one's parents' lifestyle, as in Fernandez, Fogli and Olivetti (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 $s \in \mathcal{S} = \{s_1, s_2, \cdots, s_n\}$, 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 $s_1 < s_2 < \cdots < s_n$. Suppose that time flows discretely. At the beginning of each period, an unattached member in a class will match with another single individual in the same class with probability μ. 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 $1 - \mu$ an unattached person fails to match with another single one. 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 δ. Couples in the surviving matches must also make two inextricably linked decisions; 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 w, with $u > w$. A matched person in the promiscuity class realizes a momentary utility level of $u + s - c$, where s is the joy from sex and c is the expected cost of sex say due to an out-of-wedlock birth or a sexually transmitted disease. Note that c 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 w. Individuals discount next period's utility by the factor β. Assume that u, w, s, and c are specified in a way that guarantees that expected lifetime utility is always positive. Assume that u, w, s, and c are finite, which ensures that expected lifetime utility is bounded. Additionally, suppose that they 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 facsimile 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. Let couples relocate together. So, assume that each single, and each couple, face a relocation probability of $1 - \zeta$.[4]

The idea is that over time the cost of premarital sex, c, 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 $\mathcal{A}$.

3 Decision Problems

Let $A(s, \widetilde{s})$ denote the expected lifetime utility for an individual of type s who is currently in an abstinent match with a partner of type $\widetilde{s}$. An individual does not experience any joy from sex while abstinent. 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, $\widetilde{s}$. Still, he cares indirectly about $\widetilde{s}$ 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 $P(s, \widetilde{s})$ will represent the expected lifetime utility for individual s who is currently in a promiscuous match with $\widetilde{s}$, and $Q(s)$

[4] Making an adult's world look like a teenager's one requires some additional assumptions. First, suppose that adults survive with probability $2\zeta - 1$. Second, assume that some new unmatched adults flow in from another source at rate $1 - \zeta$; i.e., there is a flow in of unmatched adults who somehow missed teenage life. These two assumptions ensure that an adult's world will have the same type distributions as the teenager's one. Third, when adults die assume that they realize a utility level of zero from then. Fourth, set the discount factor for an adult, $\widetilde{\beta}$, so that $\widetilde{\beta} = \beta/[2\zeta - 1]$. The last two assumptions guarantee that the adult's programming problem will be a copy of the teenager's one, even though the former faces death. These assumptions are made to ensure logical consistency, not realism.

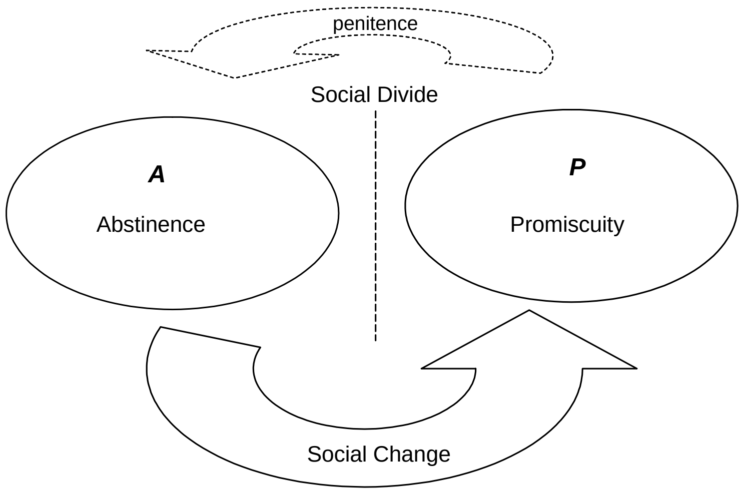

Figure 5: Social Change

will proxy for the expected lifetime utility for an unmatched agent in class $\mathcal{P}$. Finally, suppose that s and $\widetilde{s}$ meet. What will be the outcome of this meeting? Let $\mathbf{X}(s,\widetilde{s})$ be the equilibrium probability that an abstinent relationship will occur, $\mathbf{Y}(s,\widetilde{s})$ denote the odds that a promiscuous one transpires, and $\mathbf{Z}(s,\widetilde{s})$ give the chance that no match will ensue.

As will be seen, these equilibrium matching probabilities split the space of potential pairwise matches, $\mathcal{S}\times\mathcal{S}$, into four types of zones: viz, one where both parties desire an abstinent relationship so that $\mathbf{X}(s,\widetilde{s})=1$; another where both want a sexual one implying that $\mathbf{Y}(s,\widetilde{s})=1$; a mixing region where one party prefers an abstinent relationship, the other a sexual one, but both prefer some sort of relationship to none, so that $0<\mathbf{X}(s,\widetilde{s}),\mathbf{Y}(s,\widetilde{s})<1$; a zone where no relationship of any sort is possible and $\mathbf{Z}(s,\widetilde{s})=1$. An example of this is shown in Figure 7, which is detailed later on–here both parties prefer some sort of relationship to none at all.

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

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

$$\begin{aligned} A(s,\widetilde{s}) &= u+\beta(1-\delta)[\mathbf{X}'(s,\widetilde{s})A'(s,\widetilde{s})+\mathbf{Y}'(s,\widetilde{s})P'(s,\widetilde{s})] \\ &\quad +\beta[\delta+(1-\delta)\mathbf{Z}'(s,\widetilde{s})]\max\{B'(s),Q'(s)\}, \end{aligned} \tag{1}$$

where in standard fashion a prime attached to a variable or function 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 $\widetilde{s}$ will survive into next period with probability $(1-\delta)$.[5] At this time the couple can decide to remain together in an abstinent relationship, switch to a promiscuous one, or break up. Recall that the function $\mathbf{X}'(s,\widetilde{s})$ reports the *equilibrium* probability that an abstinent match between s and $\widetilde{s}$ will occur next period.[6] Thus, the term $(1-\delta)\mathbf{X}'(s,\widetilde{s})A'(s,\widetilde{s})$ represents the component of expected lifetime utility from next period on that is associated with the possibility of an abstinent match then. Likewise, the part of expected lifetime utility linked to a promiscuous match is given by $(1-\delta)\mathbf{Y}'(s,\widetilde{s})P'(s,\widetilde{s})$. Now a match may not occur next period because the pair breaks up, either exogenously or endogenously. A match breaks up exogenously with probability δ, and endogenously with probability $(1-\delta)\mathbf{Z}'(s,\widetilde{s})$, where $\mathbf{Z}'(s,\widetilde{s})\equiv 1-\mathbf{X}'(s,\widetilde{s})-\mathbf{Y}'(s,\widetilde{s})$. When the match breaks up person s must decide whether to enjoy his single life in either the abstinent or promiscuous class. The term $[\delta+(1-\delta)\mathbf{Z}'(s,\widetilde{s})]\max\{B'(s),Q'(s)\}$ gives the part of expected lifetime utility that is associated with single life next period. When single at that time person s will choose to join the social class ($\mathcal{A}$ or $\mathcal{P}$) that maximizes

[5] Note that the pair, s and $\widetilde{s}$, will move to a new location next period with probability $1-\zeta$. But, by assumption s's life will continue on in identical fashion there, since the new location is an exact copy of the old one. Thus, there is no need to incorporate this survival probability into the recursion. As will be seen, though, it will enter into the laws of motion for the type distributions.

[6] As will be seen, these probabilities must be determined in equilibrium as a function of one's partner's decisions. It is this factor that distinguishes a bilateral search from the standard one, as typified by the job-search models of Andolfatto and Gomme (1996), Hansen and Imrohoroglu (1992) and Jovanovic (1987).

expected lifetime utility so that he will realize the level of bliss given by $\max\{B'(s), Q'(s)\}$. The determination of the functions $\mathbf{X}$ and $\mathbf{Y}$ is discussed below. They will be predicated upon the preferences that each party in the match has toward a relationship, if they desire one at all. 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. Therefore, individuals will be rationally incorporating any changes in the cost of premarital sex into their decision making.[7]

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

$$\begin{aligned} B(s) = w + \beta\mu \sum_{j=1}^{n} \upsilon'_j [\mathbf{X}'(s, \widetilde{s}_j) A'(s, \widetilde{s}_j) + \mathbf{Y}'(s, \widetilde{s}_j) P'(s, \widetilde{s}_j)] \\ + \beta[(1-\mu) + \mu \sum_{j=1}^{n} \upsilon'_j \mathbf{Z}'(s, \widetilde{s}_j)] \max\{B'(s), Q'(s)\}. \end{aligned} \quad (2)$$

Note that s's draw for a partner, $\widetilde{s}$, 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 υ'_j's, with $0 \le \upsilon'_j \le 1$ and $\sum_{j=1}^{n} \upsilon'_j = 1$. Its determination is detailed later.

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

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

$$\begin{aligned} P(s, \widetilde{s}) &= u + s - c + \beta(1-\delta)[\mathbf{X}'(s, \widetilde{s}) A'(s, \widetilde{s}) + \mathbf{Y}'(s, \widetilde{s}) P'(s, \widetilde{s})] \\ &\quad + \beta[\delta + (1-\delta) \mathbf{Z}'(s, \widetilde{s})] \max\{B'(s), Q'(s)\}. \end{aligned} \quad (3)$$

[7] Specifically, since the costs of premarital sex are assumed to be a function of time so will be the functions $A(s, \widetilde{s})$, $B(s)$, $P(s, \widetilde{s})$, $Q(s)$, $\mathbf{X}(s, \widetilde{s})$, $\mathbf{Y}(s, \widetilde{s})$, etc. The dependence of these functions on time is connoted by the use of the prime symbol. A formal definition of the nonstationary rational expectations equilibrium that is being modelled is provided in Section 5.

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

$$Q(s) = w + \beta\mu \sum_{j=1}^{n} \varpi_j' [\mathbf{X}'(s, \widetilde{s}_j) A'(s, \widetilde{s}_j) + \mathbf{Y}'(s, \widetilde{s}_j) P'(s, \widetilde{s}_j)]$$
$$+ \beta[(1 - \mu) + \mu \sum_{j=1}^{n} \varpi_j' \mathbf{Z}'(s, \widetilde{s}_j)] \max\{B'(s), Q'(s)\}. \quad (4)$$

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

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

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

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

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

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

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

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

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

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

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

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

and

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

Take the expression for $\mathbf{X}(s,\widetilde{s})$. It is not as formidable as it looks. The first term gives the situation where an abstinent match is both s's and $\widetilde{s}$'s first choice. When this occurs $H(s,\widetilde{s})H^T(s,\widetilde{s}) = 1$. 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 $H(s,\widetilde{s})K(s,\widetilde{s}) = 1$, and is zero otherwise. Additionally, suppose that her partner wants a promiscuous match the most, but prefers an abstinent relationship to single life. Here, $J^T(s,\widetilde{s})I^T(s,\widetilde{s}) = 1$. 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 $H(s,\widetilde{s})K(s,\widetilde{s})J^T(s,\widetilde{s})I^T(s,\widetilde{s})/2 = 1/2$. 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 $\widetilde{s}$ are reversed. Therefore, when two people s and $\widetilde{s}$ have the above-mentioned difference in tastes, half of the time the match will be resolved in s's favor, while the other half it will be decided to $\widetilde{s}$'s benefit. (This is also true on average within a given match over time.)

At first sight, the mixing situation may seem strange in that certain pairs might have sex in some periods and not in others. Think about these types of relationships as having an intermediate level of sexual activity; they are less active than pairings with $\mathbf{Y}(s,\widetilde{s}) = 1$, and more active than ones with $\mathbf{X}(s,\widetilde{s}) = 1$. This could be important for modelling issues such as teenage pregnancy, or the incidences of diseases such as AIDS/HIV. In a more general model, one of the parties may want to make some sort of transfer to the other in order to attain what they desire. The transfer could be in terms of effort or gifts. One could think about these transfers as being undertaken via some sort of bargaining scheme, or as the outcome of a competitive equilibrium where they are explicitly priced. Here matches would be (more) efficient. In lieu of these possibilities, the above lottery scheme reconciles the differences in tastes about as best as can be done.

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 $H(s,\widetilde{s})[1-K(s,\widetilde{s})]=1$. Likewise, when $\widetilde{s}$'s best option is a promiscuous match, but he'll accept an abstinent one, then $[1-H^T(s,\widetilde{s})]I^T(s,\widetilde{s})=1$. The odds of an abstinent match in this situation are given by $H(s,\widetilde{s})[1-K(s,\widetilde{s})][1-H^T(s,\widetilde{s})]I^T(s,\widetilde{s})=1$. Again, it is easy to deduce that this expression will be zero in any other situation. The roles between s and $\widetilde{s}$ are reversed in the fifth term. Note that by construction all of the terms in (10) are mutually exclusive and that $\mathbf{X}(s,\widetilde{s})\in\{0,1/2,1\}$. Likewise, $\mathbf{Y}(s,\widetilde{s})\in\{0,1/2,1\}$. Last the odds of no relationship are just simply given by

$$\mathbf{Z}(s,\widetilde{s})\equiv 1-\mathbf{X}(s,\widetilde{s})-\mathbf{Y}(s,\widetilde{s}), \tag{12}$$

where $\mathbf{Z}(s,\widetilde{s})\in\{0,1\}$.

Observe that equations (1) to (12) jointly determine a solution for the value functions $A(s,\widetilde{s})$, $B(s)$, $P(s,\widetilde{s})$, $Q(s)$, the decision rules $H(s,\widetilde{s})$, $I(s,\widetilde{s})$, $\cdots$, $L(s)$, and the matching functions, $\mathbf{X}(s,\widetilde{s})$, $\mathbf{Y}(s,\widetilde{s})$, and $\mathbf{Z}(s,\widetilde{s})$, contingent upon the type distributions of unmatched agents in $\mathcal{A}$ and $\mathcal{P}$, or the υ_j's and ϖ_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 υ_j's and ϖ_j's. Note these distributions will indirectly influence (1) and (3) as well. Hence, the equilibrium social class membership 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 $M(s, \widetilde{s})$ denote the *non*normalized distribution over matched pairs in $\mathcal{A}$ and $U(s)$ denote the analogous (nonnormalized) distribution over singles. Therefore, $\xi = \sum_{i=1}^{n} \sum_{j=1}^{n} M(s_i, \widetilde{s}_j)$ 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, $\upsilon_j = U(s_j)/\lambda$. Likewise, $N(s, \widetilde{s})$ and $V(s)$ will represent the distributions for matched and unmatched agents in $\mathcal{P}$. Represent the number of unattached people in $\mathcal{P}$ by $\vartheta = \sum_{i=1}^{n} V(s_i)$. Therefore, $\varpi_j = V(s_j)/\vartheta$. The laws of motion for $M(s, \widetilde{s})$, $U(s)$, $N(s, \widetilde{s})$ and $V(s)$ are given by

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

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

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

and

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

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 $\zeta(1-\delta)M(s,\widetilde{s})$ surviving matched pairs of type $(s,\widetilde{s})$. Of these the fraction $\mathbf{X}(s,\widetilde{s}) \in \{0, 1/2, 1\}$ 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 $\zeta\mu\lambda U(s)U(\widetilde{s})/\lambda^2$ matches of type $(s,\widetilde{s})$. Out of these pairs the fraction $\mathbf{X}(s,\widetilde{s})$ 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., $L(s) = 1$ in line with (9)]. 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 $\widetilde{s}$, where s decides to search next period for a new mate in $\mathcal{A}$ [implying $L(s) = 1$]. Sometimes two singles, s and $\widetilde{s}$, 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,* $\{c_t\}_{t=1}^{\infty}$, *and some initial type distributions,* $M_1(s,\widetilde{s})$, $N_1(s,\widetilde{s})$, $U_1(s)$, *and* $V_1(s)$, *a nonstationary rational expectations equilibrium is represented by time paths for the value functions,*$\{A_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{B_t(s)\}_{t=1}^{\infty}$, $\{P_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{Q_t(s)\}_{t=1}^{\infty}$, *the decision rules,* $\{H_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{I_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{J_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{K_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{L_t(s)\}_{t=1}^{\infty}$, *the matching functions,* $\{\mathbf{X}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{\mathbf{Y}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{\mathbf{Z}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and the type distributions,* $\{M_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{N_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{U_t(s)\}_{t=1}^{\infty}$, *and* $\{V_t(s)\}_{t=1}^{\infty}$, *such that:*

1. *The sequence of value functions,* $\{A_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{B_t(s)\}_{t=1}^{\infty}$, $\{P_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *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,* $\{\mathbf{X}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{\mathbf{Y}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{\mathbf{Z}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and the type distributions for singles,* $\{U_t(s)\}_{t=1}^{\infty}$, *and* $\{U_t(s)\}_{t=1}^{\infty}$. *[Recall that* $\upsilon_{j,t} = U_t(s_j)/\lambda_t$ and $\varpi_{j,t} = V_t(s_j)/\vartheta_t$ with $\lambda_t = \sum_{i=1}^{n} U_t(s_i)$ and $\vartheta_t = \sum_{i=1}^{n} V_t(s_i)$.*]*

2. *The sequence of decisions rules and matching functions* $\{H_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{I_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{J_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{K_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{L_t(s)\}_{t=1}^{\infty}$, $\{\mathbf{X}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{\mathbf{Y}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{\mathbf{Z}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *satisfy (5) to (12), given the time paths for the value functions,* $\{A_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{B_t(s)\}_{t=1}^{\infty}$, $\{P_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *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,* $\{M_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{N_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{U_t(s)\}_{t=1}^{\infty}$, *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,* $\{\mathbf{X}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, $\{\mathbf{Y}_t(s,\widetilde{s})\}_{t=1}^{\infty}$, *and* $\{\mathbf{Z}_t(s,\widetilde{s})\}_{t=1}^{\infty}$.

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 c. 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 c 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_b, such that $\{s_1, \cdots, s_b\} \in \mathcal{A}$ and $\{s_{b+1}, \cdots, s_n\} \in \mathcal{P}$. In fact, one might suspect that $s_b < c < s_{b+1}$; 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 $\mathcal{A}$. (To simplify the analysis, without any real loss of generality, always suppose that c lies strictly between two s's.) 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 $s_j < c$, and $s_j \in \mathcal{P}$ for $s_j > c$.*

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 c. Individuals with a $s < c$ choose to live abstinent lives, and those with a $s > c$ promiscuous ones. Hence, the (nonnormalized) type distributions in $\mathcal{A}$ and $\mathcal{P}$ will be given by $\{\sigma_1, \cdots, \sigma_b, 0, \cdots, 0\}$ and $\{0, \cdots, 0, \sigma_{b+1}, \cdots, \sigma_n\}$, where b solves

$$s_b < c < s_{b+1}. \tag{17}$$

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

$$\#\mathcal{P} = 1 - \sum_{j=1}^{b} \sigma_j. \tag{18}$$

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

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

so that the fraction who are unattached is

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

Note that α does not depend upon the properties of the type distribution or on the shape of $S(s)$. This is also true for any other statistic describing the steady-state properties of matching *within* a class. 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 c decreases the b that solves (17) will fall, given that $s_1 < s_2 < \cdots < s_n$. The result then follows from (18). ■

7 Transitional Dynamics

7.1 The Impact of a Once-and-for-All Decline in c

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 c from $\bar{c}$ to $\underline{c}$. In particular, suppose that the economy is initially resting in a steady state associated with $c = \bar{c}$. In line with the analysis of Section 6, there will exist a b such that $s_b < \bar{c} < s_{b+1}$. The type distribution in $\mathcal{A}$ will be given by $\{\sigma_1, \cdots, \sigma_b, 0, \cdots, 0\}$, and the one in $\mathcal{P}$ by $\{0, \cdots, 0, \sigma_{b+1}, \cdots, \sigma_n\}$. In each class the fraction α, as specified by (19), of the populace will be matched. Suppose that c suddenly drops to $\underline{c}$, and stays at that value forever after. Then, there will be new steady-state type distributions in $\mathcal{A}$ and $\mathcal{P}$ represented by $\{\sigma_1, \cdots, \sigma_d, 0, \cdots, 0\}$ and $\{0, \cdots, 0, \sigma_{d+1}, \cdots, \sigma_n\}$, where $s_d < \underline{c} < s_{d+1}$ – assume a large enough shift in c so that $d < b$.

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 $(s, \widetilde{s})$ pair in $\mathcal{A}$ in the old steady state. If $(s, \widetilde{s}) \in \{s_{d+1}, \cdots, s_b\} \times \{s_{d+1}, \cdots, s_b\}$ they will move immediately to $\mathcal{P}$. Simply put, why should these individuals wait? There will be $\alpha \sum_{j=d+1}^{b} \sum_{k=d+1}^{b} \sigma_j \; \widetilde{\sigma}_k$ agents in this category, where α is given by (19). Since the adjustment here is immediate, this case is a force for rapid transitional dynamics.

2. Likewise, consider unattached individuals in $\mathcal{A}$. If $s \in \{s_{d+1}, \cdots, s_b\}$ they too will immediately enter $\mathcal{P}$. Again, what would be the advantage to waiting? There are $(1 - \alpha) \sum_{j=d+1}^{b} \sigma_j$ such agents. Thus, the model's transitional dynamics will be very fast on this account. Note that this implies that the one-step-ahead unmatched type distributions in $\mathcal{A}$ and $\mathcal{P}$ will have the forms $\{\upsilon'_1, \cdots, \upsilon'_d, 0, \cdots, 0\}$ and $\{0, \cdots, 0, \varpi'_{d+1}, \cdots, \varpi'_n\}$. 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 $s \in \{s_1, \cdots, s_d\}$ and $\widetilde{s} \in \{s_{d+1}, \cdots, s_b\}$, yet it remains optimal for $(s, \widetilde{s})$ to stay attached in $\mathcal{A}$. Here person $\widetilde{s}$'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 $[\mathbf{X}(s, \widetilde{s}) = 1/2]$, and those where she isn't $[\mathbf{X}(s, \widetilde{s}) = 1]$. There will be $\alpha \sum_{j=1}^{d} \sum_{k=d+1}^{b} \mathbf{X}(s_j, \widetilde{s}_k) \sigma_j \; \widetilde{\sigma}_k$ people in this situation. The survival rate for these matches is $\zeta(1 - \delta)$. The $\widetilde{s}$'s who are still around will switch to $\mathcal{P}$ after a breakup.

4. Likewise, there may be matches in the old steady state for which $s \in \{s_1, \cdots, s_d\}$ and $\widetilde{s} \in \{s_{d+1}, \cdots, s_b\}$ where it is optimal for $(s, \widetilde{s})$ to move to $\mathcal{P}$. Here individual s's unfavorable view of the net gain from sex with $\widetilde{s}$ is not bad enough to justify terminating her relationship with $\widetilde{s}$ and searching alone in $\mathcal{A}$. There will be $\alpha \sum_{j=1}^{d} \sum_{k=d+1}^{b} \mathbf{Y}(s_j, \widetilde{s}_k)\sigma_j \widetilde{\sigma}_k$ agents in this position. The survival rate for these matches is $\zeta(1-\delta)$. The surviving s's will enter $\mathcal{A}$ after a breakup.

5. Finally, there may be some matches $(s, \widetilde{s}) \in \{s_1, \cdots, s_d\} \times \{s_{d+1}, \cdots, s_b\}$ in the old steady state for which it is optimal for the couple to break up. Here, person s will search for a new mate in $\mathcal{A}$ while $\widetilde{s}$ will look in $\mathcal{P}$. There will be $\alpha \sum_{j=1}^{d} \sum_{k=d+1}^{b} \mathbf{Z}(s_j, \widetilde{s}_k)\sigma_j \widetilde{\sigma}_k$ agents in this case. Since the adjustment here is immediate, this case speaks for rapid transitional dynamics.

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 c, the (nonnormalized) type distribution in $\mathcal{A}$ immediately jumps from*

$$\{\sigma_1, \cdots, \sigma_b, 0, \cdots, 0\}$$

to

$$\{\sigma_1 - \alpha \textstyle\sum_{k=d+1}^{b} \mathbf{Y}(s_1, \widetilde{s}_k)\sigma_1\widetilde{\sigma}_k, \cdots, \sigma_d - \alpha \sum_{k=d+1}^{b} \mathbf{Y}(s_d, \widetilde{s}_k)\sigma_d\widetilde{\sigma}_k,$$
$$\alpha \textstyle\sum_{i=1}^{d} \mathbf{X}(s_i, \widetilde{s}_{d+1})\sigma_i\widetilde{\sigma}_{d+1}, \cdots, \alpha \sum_{i=1}^{d} \mathbf{X}(s_i, \widetilde{s}_b)\sigma_i\widetilde{\sigma}_b, 0, \cdots, 0\},$$

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

$$\{\sigma_1 - [\zeta(1-\delta)]^j \alpha \textstyle\sum_{k=d+1}^{b} \mathbf{Y}(s_1, \widetilde{s}_k)\sigma_1\widetilde{\sigma}_k, \cdots, \sigma_d - [\zeta(1-\delta)]^j \alpha \sum_{k=d+1}^{b} \mathbf{Y}(s_d, \widetilde{s}_k)\sigma_d\widetilde{\sigma}_k,$$
$$[\zeta(1-\delta)]^j \alpha \textstyle\sum_{i=1}^{d} \mathbf{X}(s_i, \widetilde{s}_{d+1})\sigma_i\widetilde{\sigma}_{d+1}, \cdots, [\zeta(1-\delta)]^j \alpha \sum_{i=1}^{d} \mathbf{X}(s_i, \widetilde{s}_b)\sigma_i\widetilde{\sigma}_b, 0, \cdots, 0\}. \quad (20)$$

Proof. See the Appendix, Section 13.2. ■

To summarize, following a once-and-for-all decline in c 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 $[\zeta(1-\delta)]^j\alpha\sum_{k=d+1}^{b}\mathbf{Y}(s_i,\widetilde{s}_k)\sigma_i\widetilde{\sigma}_k$ terms (for $i=1,\cdots,d$) in (20). Similarly, some matched individuals will remain in $\mathcal{A}$ because their partner refuses to have a promiscuous match. These high-$\widetilde{s}$ individuals will drift into $\mathcal{P}$ as their matches break up, so long as they survive. The $[\zeta(1-\delta)]^j\alpha\sum_{i=1}^{d}\mathbf{X}(s_i,\widetilde{s}_k)\sigma_i\widetilde{\sigma}_k$ terms (for $k=d+1,\cdots,b$) represent this situation.

It is readily apparent from (20) that the model will generate rapid transitional dynamics when δ is large or ζ is small; that is, when matches break up quickly or when teenage life is short. Last, there is a special case where the number of abstinent and promiscuous matches jump immediately to their new steady-state values. This is established in the corollary below. This happens when all the matches discussed in Points 3 and 4 involve mixing $[\mathbf{X}(s,\widetilde{s})=\mathbf{Y}(s,\widetilde{s})=1/2]$. Whether or not this will transpire depends upon parameter values, etc. This situation occurs in the simulation discussed in Section 10. Note that while at the aggregate level the number of people engaged in abstinent and promiscuous relationships is constant over time, at the micro level there is still movement between social classes that dampens out in line with (20). In this case, at the micro level the flows into and out of the two social classes balance each other exactly, as is made clear in the proof of the corollary.

Corollary 1 *Suppose that for all matched pairs $(s,\widetilde{s})$ with $s<\underline{c}$ and $\widetilde{s}>\underline{c}$ it is optimal to mix; i.e., assume that $\mathbf{X}(s,\widetilde{s})=\mathbf{Y}(s,\widetilde{s})=1/2$ for all $s<\underline{c}$ and $\widetilde{s}>\underline{c}$. Then, $\#\mathcal{A}_t=\sum_{i=1}^{d}\sigma_i$ and $\#\mathcal{P}_t=\sum_{i=d+1}^{n}\sigma_i$ for all t.*

Proof. Take all matched pairs of a particular type $(s,\widetilde{s})$ with $s<\underline{c}$ and $\widetilde{s}>\underline{c}$. By the mixing condition, half of the matches will be in $\mathcal{A}_t$, the other half in $\mathcal{P}_t$. Now, every period δ of the surviving matches will breakup in each set. Individuals of type s will go to $\mathcal{A}_{t+1}$ while those of type $\widetilde{s}$ will move to $\mathcal{P}_{t+1}$. Since for every breakup in $\mathcal{A}_t$ there is one in $\mathcal{P}_t$, the number of individuals in $\mathcal{A}$ and $\mathcal{P}$ will not change over time. ■

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 governs premarital sex, $\{c_t\}_{t=1}^{\infty}$. 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 females would have gotten pregnant (had they engaged in sex for a year at normal frequencies). 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.[8] 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)]:

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.

[8] This history is compiled from Himes (1964), McLaren (1990), and Potts and Campbell (2002).

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 emblematizes 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 ovulaton 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. Between 1960 and 2002 the number of people not using any birth control fell by a remarkable 40 percentage points. The increased use of contraception may derive from two factors. First, technological improvement has made them both effective and easy to use. As more and more teenagers engage in sex on this account, one would see an increase in their use. Second, the diffusion of contraceptives may be slow, as with any new product. The birth control movement has made information about contraceptives widely available (in a manner similar to advertising for other products) and access to them easy. This has greatly sped up their diffusion. How much is an open question, for which it would be difficult to provide a quantitative answer. 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. According to Darroch and Singh (1999), the rise of condom users played a significant role in the decline of pregnancies among the teenagers during the 1990s. The increase in the use of condoms was influenced by the expansion of formal reproductive health education during the period. On this, Ku, Sonenstein and Pleck (1992) show that sex education about AIDS, birth control, and resisting sexual activity is associated with more consistent condom use. Furthermore, Lindberg, Ku and Sonenstein (2000) report that formal sex education on these topics expanded significantly during the 1990s.

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 females in the pill cell into the "other" category.

Table 1: Contraception use At First Premarital Intercourse, percent

Method	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.[9] Why was the 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,

[9] 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.

1980, 1984, 1988, 1998, and 2004) assume that using no method, and simply taking your chances, had an 85 percent failure rate.

Since the 1960s evidence on the effectiveness of different contraceptives, for both their ideal and typical use, is quite systematic. From that time on failure rates have been measured as the percentage of women who become pregnant during the first year of use. By contrast, the statistics from earlier studies, such as Kopp (1934), are based on married women who used birth control clinics. 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. 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. Again, the failure rate rose slightly during the 1990s. Third, even the effectiveness of withdrawal has increased over time; this shows the importance of education. 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.

TABLE 2: EFFECTIVENESS OF CONTRACEPTION (ANNUAL FAILURE RATES), PERCENT

Method	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 conservative estimates for 1900, this riskiness has fallen by more than 125 percent, from about 71 percent in 1900 to 28 percent in 2002. Now, the series shown in Figure 6 has an important endogenous component in it, specifically the choice of contraceptive used.

Why individuals would choose to use one method over another is not modelled in the analysis. Doing so could be difficult, and the benefit questionable. The same issue also arises for the conventionally measured aggregate total factor productivity series used by macroeconomists, although it is not as transparent and perhaps is less problematic. This series effectively constructs total factor productivity across plants using a Divisia index. Of course the technology used by any particular plant is an endogenous variable, and there is a large variance in the technological practice adopted across plants. The important thing to note is that the data used for constructing the risk of pregnancy reported in Figure 6 are conditioned upon an individual having sex. Hence, the data used are not directly affected by the decision to have sex or not, which is the margin under study. That is, the series plotted shows the average failure rate over time conditioned upon a person deciding to engage in

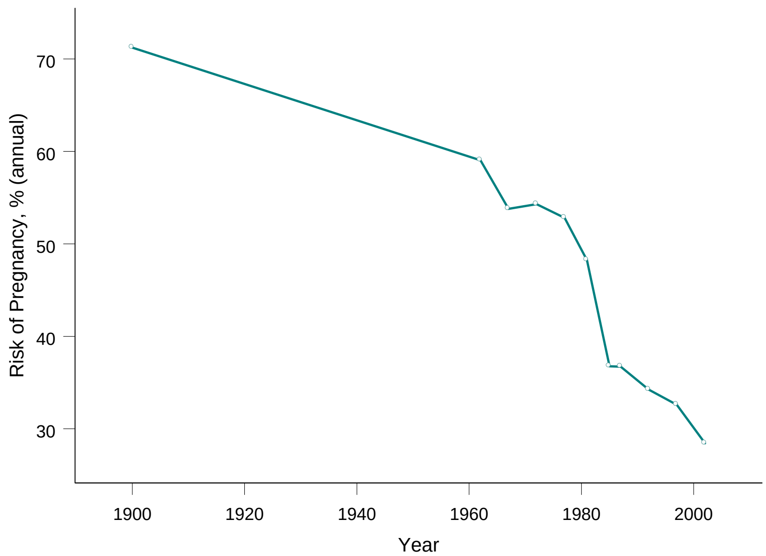

Figure 6: Technological improvement in the effectiveness and use of contraceptives

premarital sex.[10]

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

[10] Take the expected cost of sex, when adopting a particular contraceptive j, to be given by the sum of the failure rate, c_j, and the cost of using the contraceptive, m_j. This will keep the linear structure adopted in the text. Let $c_j = C_j(\theta, z, e)$ be method j's failure rate for a type-θ teenager and, analogously, $m_j = M_j(\theta, z, e)$ represent the cost of using contraceptive j. Here θ might represent factors such as carefulness, impatience, parental influence, etc. Both the failure rates and costs for contraceptives are taken to be functions of the levels of technology, z, and sex education, e. For instance, the efficacies of the withdrawal and rhythm methods were improved solely via education. The cost of obtaining contraceptives was reduced by the birth control movement. The contraceptive chosen by a type-θ teenager will be $j^* = J^*(\theta, z, e) = \arg\min_{j=1,\cdots,n}\{C_j(\theta, z, e) + M_j(\theta, z, e)\}$. The average failure rate will be given by $c = C(z, e) = \int C_{J^*(\theta,z,e)}(\theta)dF(\theta)$, where F is the distribution over type. Note that θ has been assumed to be independent of a teenager's preference for sex, s. The average cost of a contraceptive will be given by $m = M(z, e) = \int M_{J^*(\theta,z,e)}(\theta, z, e)dF(\theta)$. Think about the latter as being netted out from the joy of sex, s. The analysis here factors out the idiosyncratic factors associated with the efficacy and cost of contraceptives, and focuses on the failure rate for a representative teenager, so to speak.

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, $\overline{s}$, and standard deviation, ς_s. Given this, there are 8 parameters to pick: μ, δ, ζ, β, u, w, $\overline{s}$, and ς_s. This is done in the following manner:[11]

1. *Matching parameters*, μ, δ and ζ. In 2002 roughly 34.4 percent of teenagers between the ages of 15 and 19 had coitus within the last 3 months.[12] 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.[13] Now, construct a simple Markov chain to match these two facts. Let teenagers match with probably μ and breakup with probability δ. 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 $\delta = 0.231$. This high destruction rate speaks for relatively fast transitional dynamics, in light of Lemma 3. Next, choose a value for μ so that the statistical mechanics of the (μ, δ)-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 π_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

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

[12] This number is taken from Abma *et al.* (2004, Table 4, p. 19).

[13] 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.

are given by

$$\begin{bmatrix} \pi_j \\ 1-\pi_j \end{bmatrix} = \begin{bmatrix} 1-\delta & \mu \\ \delta & 1-\mu \end{bmatrix}^j \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \text{ for } j = 1, \cdots, 20. \tag{21}$$

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 μ 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 population 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*, $\overline{s}$ and ς_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 one, set $c = c_{1900} = 0.2676$, which is the quarterly failure rate for 1900. The second steady state matches the year 2002. Here, pick $c = c_{2002} = 0.0802$.[14] Last, the mean and standard deviation, $\overline{s}$ and ς_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 $\chi \equiv 1 - (1-\mu)(1-\zeta)/[1-(1-\mu)\zeta]$. 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 $\overline{s} = 0.1432$ and $\varsigma_s = 0.0833$. Note that Lemma 1 implies that in a steady state the number of people in $\mathcal{A}$ and $\mathcal{P}$ depends *solely* on the cost of sex, c, and the shape of the $S(s)$ distribution, as governed here by $\overline{s}$ and ς_s. Therefore, for given values of c, μ and ζ, the above procedure solves the two steady-state equations determining the number of people engaged in premarital sex for the two unknowns $\overline{s}$ and ς_s. Given the setup of the model, there does not seem to be another so-natural criteria for choosing $\overline{s}$ and ς_s. Especially because statistics describing the properties of matching within a class, such as the average number of partners for a sexually active person, do not depend upon

[14] 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 $\widehat{c}$, then take the quarterly probability, c, to be given by $c = 1 - (1-\widehat{c})^{(1/4)}$.

the shape of the $S(s)$ distribution, as was mentioned in Section 6.

3. *Taste parameters*, β, u, and w. Given that a period is one quarter, set $\beta = 0.99$. In the simulation the values chosen for u and w don't matter very much. In fact, theoretically they don't affect the steady state at all, as Lemma 1 makes clear. In light of this, simply set $u - w = 1$ and let $w = |\min\{s_1, 0\}| + c_{1900}$. The latter restriction ensures that lifetime utility is always positive.[15]

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 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 calculation 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 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 teenagers engaging in premarital sex resemble the pattern observed in the U.S. data? That is the question.

[15] This restriction is not needed for the theory and does not impact on the numerical results. It is imposed because the programming language used has some very fast built-in commands that can be employed when the matrices in the analysis are positive.

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 $\widetilde{s}$ pairs, or the types for the potential match (where 1 is the lowest index for type, and 300 the highest). The varying heights on the vertical axis 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 $[\mathbf{X}(s,\widetilde{s}) = \mathbf{Y}(s,\widetilde{s}) = 1/2]$. Here s would prefer an abstinent match and $\widetilde{s}$ 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 $\widetilde{s}$ reversed. These matches were discussed in Points 3 and 4 of Section 7.1. Hence, they won't occur in steady state since, since all $s < c$ will be in $\mathcal{A}$ and all $s > c$ will be in $\mathcal{P}$. Since only mixing situations occur when couples have differing views on the desirability of sex, the corollary to Lemma 3 suggests that the model's transitional dynamics will be rapid. Now, move to the large area in the corner at the back of the figure. This block gives the $(s,\widetilde{s})$ 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 c, δ and μ. Promiscuity is more costly the higher is c. A match becomes more valuable, relative to searching, as μ and δ fall. When μ is low it is hard to find a mate, and when δ is small the benefits from a relationship are enduring. Therefore, when both μ and δ are low an agent is reluctant to decline a potential partner.

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

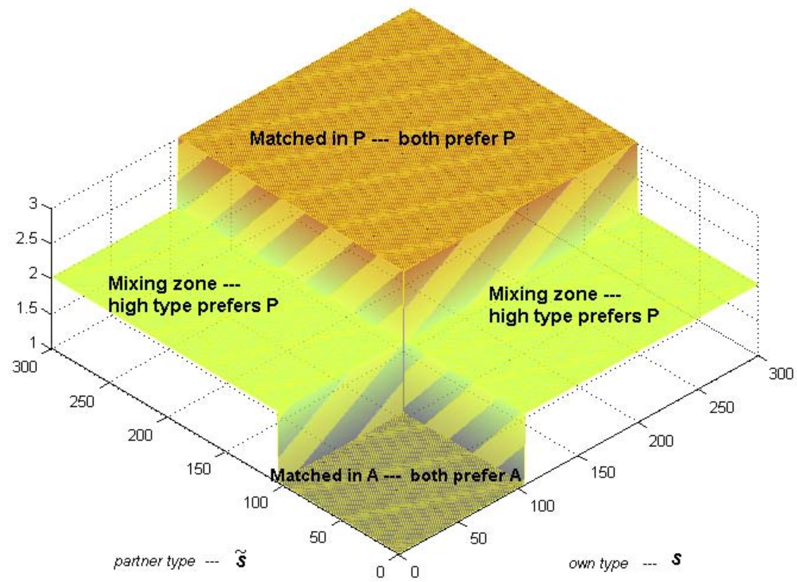

Figure 7: Matching set, final steady state

in data. This is characteristic of technological adoption, here contraceptives.[16] 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.[17] 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

[16] Some economic factors that underlie the S-shaped diffusion patterns associated with the adoption of new technologies are studied in Andolfatto and MacDonald (1998), Jovanovic and MacDonald (1994), Manuelli and Seshadri (2004), and Mukoyama (2006).

[17] Note that the model reacts very quickly in response to the inputted technology series. This was suggested by the corollary to Lemma 3, as was discussed in Section 10.1. It is also due to the very smooth nature of inputted technology series which exhibits little change on a period by period basis. As a result of this, simply using the model's steady-state condition would also do a reasonable job in predicting the rise in premarital sex. The same is true of the neoclassical growth model. The steady-state condition setting the marginal production of capital to a constant interest rate plus depreciation predicts almost *perfectly* the time path for postwar GDP (per hour), after inputting in a series for total factor productivity – for the details, see http://www.econ.rochester.edu/Faculty/GreenwoodPapers/ncgm.pdf. This works because total factor productivity moves in a smooth, predictable manner over time. Hence, the need for the model's dynamics are minimized. (Furthermore, the standard implementation of the neoclassical growth also exhibits rapid dynamics.) Notwithstanding this, very few would suggest throwing out the workhorse of macroeconomics for a simple condition setting the marginal product of capital equal to a constant rental rate.

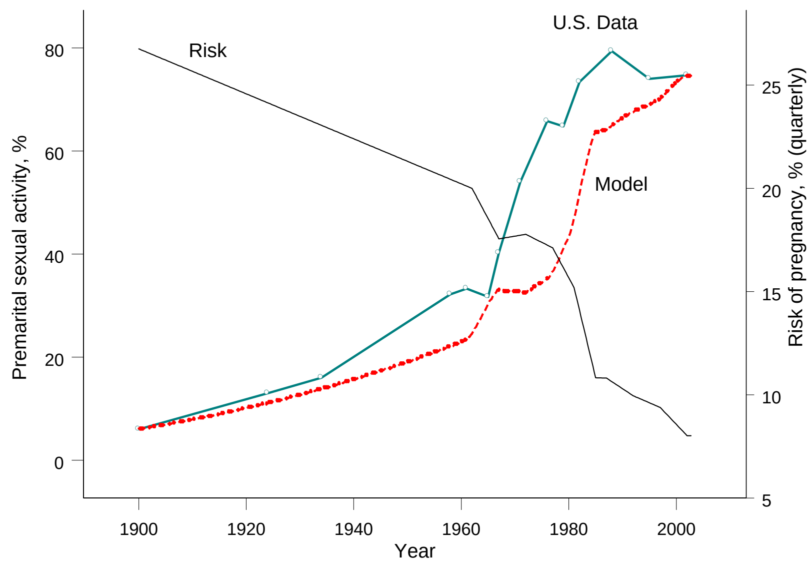

Figure 8: Rise in premarital sex, U.S. data and model

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 period. Figure 9 shows the percentage of girls who become pregnant, both in the data and the model. The total number of pregnancies in the data is calculated in two ways as the sum of births, abortions and miscarriages for unmarried females between ages 15 and 19–the exact details are provided in the Appendix. Pregnancies for the model economy are calculated as follows: Let m_t denote the fraction of females who are having sex in period t and let c_t be the quarterly risk. It is reasonable to assume that if a girl is pregnant in a given period, she can not get pregnant again during the following two model periods (six months). These girls can still have sex as long as they are matched, but are not counted as a part of the risk pool for the pregnancy calculations. Then, an adjusted value, m_t^a, for the

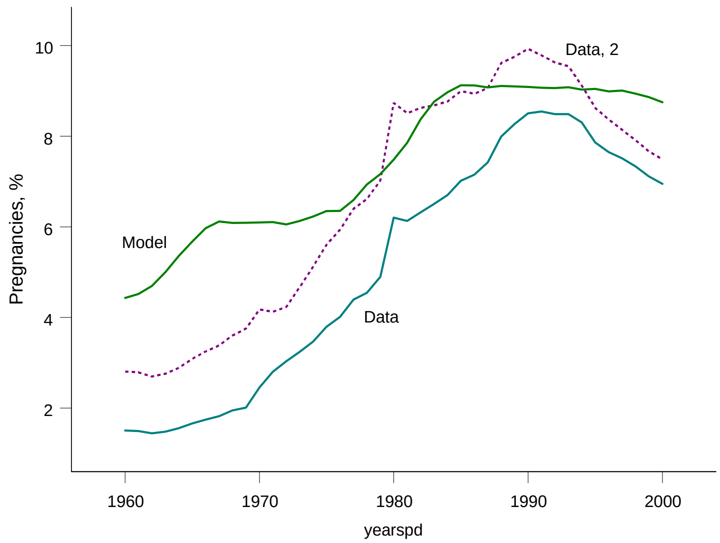

Figure 9: Increase in teenage pregnancies, U.S. data and model

fraction of women having sex at time t who are at risk for pregnancy can be calculated as

$$m_t^a = m_t - m_{t-1}p_{t-1}(1-\delta) - m_{t-2}p_{t-2}(1-\delta)(1-\delta) - m_{t-2}p_{t-2}\delta\mu.$$

The yearly pregnancy numbers in Figure 9 are constructed simply as $m_t^a[(1-(1-c_t)^4]$. The model performs well in generating the right level of pregnancies. In particular, it predicts a rise and decline in the number of pregnancies, the same pattern that is observed in the data.

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.[18] Search now is less efficient. Individuals who are inclined toward abstinence may now meet

[18] As before, let $A(s,\widetilde{s})$ and $P(s,\widetilde{s})$ denote the value of abstinent and promiscuous relationships, and $\mathbf{X}(s,\widetilde{s}) \in \{0, 1/2, 1\}$ and $Y(s,\widetilde{s}) \in \{0, 1/2, 1\}$ denote the probabilities that such relationships will occur, conditional upon a meeting between s and $\widetilde{s}$. Again, $Z(s,\widetilde{s}) = 1 - \mathbf{X}(s,\widetilde{s}) - \mathbf{Y}(s,\widetilde{s})$. Additionally, let $Q(s)$ denote the value of s searching in the lone pool of unattached people, with ϖ_j representing the odds of

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 would now become permanently classified as experienced in U.S. vital statistics – 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, $\overline{s}$ and ς_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

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meeting a type-j person. The value function when s is in an abstinent relationship with $\widetilde{s}$, or $A(s,\widetilde{s})$, will read

$$\begin{aligned} A(s,\widetilde{s}) &= u + \beta(1-\delta)[\mathbf{X}'(s,\widetilde{s})A'(s,\widetilde{s}) + \mathbf{Y}'(s,\widetilde{s})P'(s,\widetilde{s})] \\ &\quad + \beta[\delta + (1-\delta)\mathbf{Z}'(s,\widetilde{s})Q'(s)]. \end{aligned}$$

Likewise, the value of search, when s is unattached, is given by

$$\begin{aligned} Q(s) &= w + \beta\mu[\mathbf{X}'(s,\widetilde{s})A'(s,\widetilde{s}) + \mathbf{Y}'(s,\widetilde{s})P'(s,\widetilde{s})] \\ &\quad + \beta[(1-\mu) + \mu \textstyle\sum_j \varpi_j \mathbf{Z}'(s,\widetilde{s}_j)]Q'(s). \end{aligned}$$

The rest of the setting can be constructed by making similar changes.

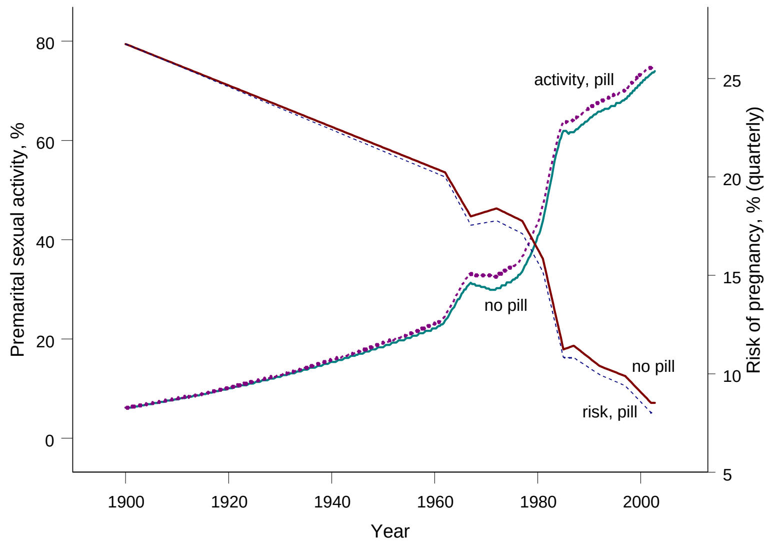

Figure 10: The power of the pill

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, and once this number is allocated to other methods the overall effects are small. Thus, its introduction did not affect the risk of pregnancy much. A similar experiment can be conducted for condoms, with much the same result. Thus, no one particular contraceptive is responsible for the sexual revolution, since there were readily available reasonable alternatives.

10.3 Cross-Sectional Implications on the Number of Partners

Relationships are governed in the model's steady state by a Markov chain structure. Recall that the probability of a meeting, μ, and the odds of a breakup, δ, are chosen so that the Markov chain (21) generates the fraction of teenage age life spent in a relationship and the observed median duration for one that are observed in the U.S. data. The Markov chain matching technology also yields predictions on the number of partners that a promiscuous person will have between the ages of 15 and 19, or across 20 model 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

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

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 μ of single agents with $j-1$ partners will find matches and thus have j partners next period. In similar fashion,

$$u_{t+1}^j = (1-\mu)u_t^j + \delta m_t^j. \tag{23}$$

An upper bound on the maximum number of partners after T periods of matching is $N = T/2+1$. Thus, equations (22) and (23) define a Markov chain over $\{m_t^0, u_t^0, \cdots, m_t^N, u_t^N\}$. This Markov chain can be simulated for T periods starting from the initial distribution $\{0, 1, \cdots, 0, 0\}$. 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.[19]

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 Markov chain does as Table 3 shows. 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.

[19] Note that Markov chain used in the model is slightly different from the one fit to the U.S. data. In the real world teenage life lasts a fixed number of years, here taken to be the 5 years between 15 and 19, inclusive. In the model they exit teenage life each period with probability $1-\zeta$. Recall that ζ is set so that teenage life expectancy is 5 years. This does not lead to significant difference in the two Markov chains' predictions on the number of partners.

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
Markov chain	0.1343	0.7205	0.1451	0.0001

How to model such variety in sexual experience is an interesting issue. One might think that modelling unfaithfulness (that is simultaneous relationships by a person) is important here. The fraction of teenagers with multiple partners, however, seems to be quite low. Abma and Sonenstein (2001), using the 1995 National Survey of Family Growth (NSFG), report that only 17.5% of teenage girls and 12.8% of teenage boys had more than one partner in the last three months. But, some of these would just be a change in partners. Hence, the fraction of teenagers with multiple *simultaneous* partners within a three months period must be even smaller. In a similar vein, Sonenstein, Pleck, and Ku (1991, p. 164) also report that "(v)ery few of the sexually active respondents in the NSAM appear to have been involved in simultaneous sexual relationships. Seventy-nine percent of sexually active young men reported having had no multiple sexual relationships in any of the last 12 months." They also report that between the 1979 and 1988 waves of NSAM, the number of partners declined while the level of sexual activity was increasing. Their analysis uses a different data set, the National Survey of Adolescent Males (NSAM). Finally, in an extensive report on teenage sexual behavior, the Alan Guttmacher Institute (1994, p. 24) reports that '(b)ecause of concerns about STDs, especially HIV, health officials and medical professionals advise sexually active individuals to have only one partner – that is, to be in a mutually monogamous relationship. Unmarried people, young and old alike, often translate this advise into "serial monogamy."'

How can more dispersion in partners be obtained? Cutting the period length can help, because the length of a period limits the number of partners one can have during your teenage years. Indeed, some limited experimentation shows that cutting period length from a quarter to a month allows the model to match the dispersion in the data better.[20] It is still hard to get a substantial number of girls with a large number of partners (7+), though. One way of doing this may be to allow for heterogeneity in types. That is, perhaps one could let a small number of individuals have higher values for μ and δ than others. This could proxy for the fact that some people like variety in mates. This is the type of extension that the next generation of models may be able to entertain.

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. About 56 percent of pregnancies were terminated in 1979. One of the 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 ϕ_a represent the cost of an abortion, ϕ_b denote the cost of an out-of-wedlock birth, and ϕ_h be the cost of contracting HIV. Let π be the odds of becoming pregnant for a girl engaging in premarital sex. Some fraction α of these girls will terminate their pregnancies, while the fraction $1 - \alpha$ will bear the child. Likewise, specify η to be the probability of contracting HIV in a sexual relationship. Given

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[20] With a shorter period length the model does a better job in predicting the first three cells of Table 3. In particular, the number of girls with just one partner now looks much better. As period length shrinks the model becomes much more computationally demanding, both in terms of memory and speed. Additionally, calibrating the model and matching it up with the data is now more of a concern. In particular, one must think carefully about how to map the high frequency observations from the model with the low frequency observations from the U.S. data. For example, a smaller number of teenagers will have sex in a month than in a quarter, and less will have sex in quarter than in a year. So, issues about time aggregation for the model and in the U.S. data are important.

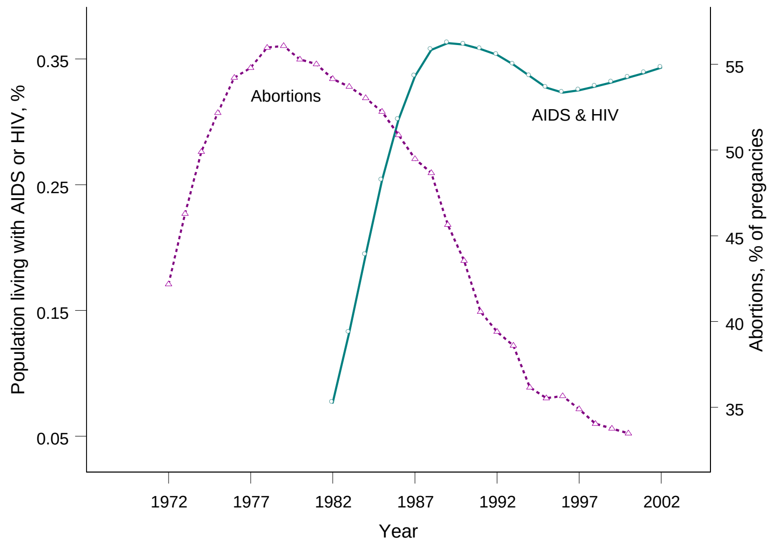

Figure 11: The prevalence of abortion and HIV

this notation, the expected cost of premarital sex, c, can therefore be written as

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

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

The parameters ϕ_a and ϕ_h will be picked to so that the model does the best possible job in explaining the trend toward premarital sex. The numbers α, π, and η are all taken from the data. The probability of becoming pregnant, π, is given by the failure rates calculated above. The time series for the fraction of pregnancies terminated in an abortion, α, is presented in Figure 11. Last, the probability of contacting 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 against becoming infected with HIV. 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 for ϕ_h.

Table 4: Effectiveness of contraception against HIV

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

The empirical procedure picks $\phi_a = 0.4602$ and $\phi_h = 1,704.6$. 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 1972 due to the legalization of abortion. As a consequence, the number of young females 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. In particular, note the downward dip in sexual activity that occurs in the model as the risk of sex rises in the mid 1980s–in contrast, the benchmark model displays a monotonic rise.

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

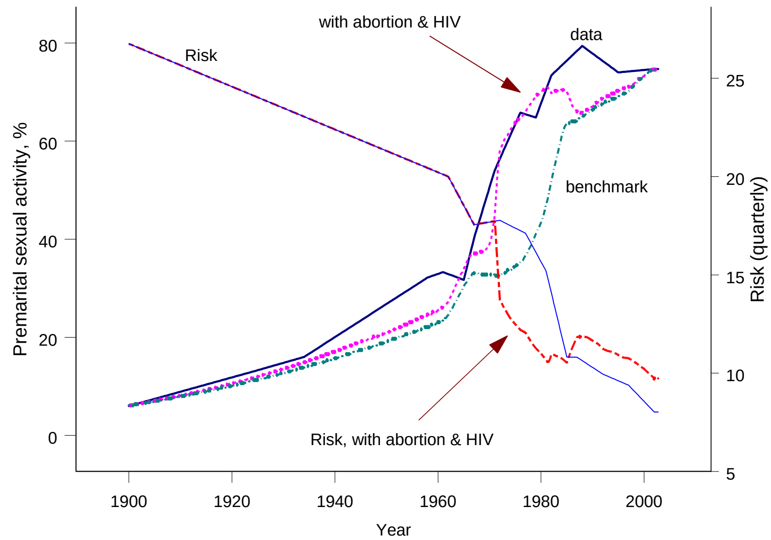

Figure 12: The model's fit with abortion and HIV

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.[21]

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. 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.[22] 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.

[21] Unfortunately, the study does not report the frequency of premarital intercourse by birth cohorts.

[22] 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.

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	

11.2 A Framework for Studying Frequency

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

$$\ln\{\widetilde{s}\exp(\chi f^{\iota}/\iota - \chi/\iota)\} = \ln\widetilde{s} + \chi f^{\iota}/\iota - \chi/\iota, \text{ with } \iota < 0 \text{ and } \chi > 0, \tag{24}$$

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

$$\widetilde{c} = 1 - p^{f}, \tag{25}$$

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

$$\frac{d\widetilde{c}}{df} = -\left(\ln p\right)p^{f} > 0 \text{ and } \frac{d^{2}\widetilde{c}}{(df)^{2}} = -\left(\ln p\right)^{2}p^{f} < 0,$$

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:

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

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

$$\chi f^{\iota-1} = -(\ln p)p^f, \tag{26}$$

and

$$(\iota-1)\chi f^{\iota-2} + (\ln p)^2 p^f < 0. \tag{27}$$

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 $-\ln p \lesseqqgtr 1/f$.*

Proof. Differentiating the efficiency condition (26) 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 (27) implies that the denominator of the above expression is negative. Next see that $-p^{f-1} - (\ln p)fp^{f-1} \lesseqqgtr 0$ as $-\ln p \lesseqqgtr 1/f$. ■

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 (24) the marginal benefit from sex does not depend on the person's type $\widetilde{s}$. This abstraction is unrealistic, yet its simplicity is a big virtue. It allows the framework for 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 exits values for ι and χ such that the efficiency condition (26) returns the observed frequencies of sex in 1900 and 2002, given the observed probabilities of safe sex in these years. To this end, note from (25) that the probability of a safe sexual encounter is given by $p_t = (1-\widetilde{c}_t)^{1/f_t}$, 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 (26) that

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

This equation can be used to pin down a value for ι, 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 χ can also be backed out from (26). 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 (26) will return $f = 7.92$ when $p = 0.9614$, and $f = 12.71$ when $p = 0.9934$. The second-order condition (27) also holds when evaluated at the 1900 and 2002 values. Thus, a maximum obtains notwithstanding the concave cost function.[23] 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 $\ln \widetilde{s} = s \in \mathcal{S} = \{s_1, s_2, \cdots, s_n\}$ and $c = -\chi f^{\iota}/\iota + \chi/\iota + \widetilde{c}$. 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 $\overline{s} = -11.3337$ and $\varsigma_s = 0.1125$.

[23] 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.

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.

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 benefit 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.

The analysis does *not* say that there is no role for culture. For instance, between 1900 and 2000 there was a 12 percentage point increase in the number of teenagers engaging in premarital sex without the use of contraceptives, with an associated rise in out-of-wedlock births. Perhaps this speaks to change in culture. Or, it may be telling of changing economic circumstance. In seventeenth century England it was not economically feasible for a young women to raise a child out of wedlock. Pregnancies were secretly aborted. Babies were abandoned or killed. The Church frowned on such practices. Bastardy was also a great financial burden for a Parish. For both of these reasons, the Church treated out-of-wedlock births harshly. According to Stone (1977, p. 634), "Bastardy cases tended to be treated severely, although sentences varied from place to place and justice to justice. In 1601 the Lancashire Quarter sessions condemned the father and mother of an illegitimate child to be publicly whipped and then sat in the stocks still naked from the waist upwards, with a placard on there heads reading 'These persons are punished for fornication.'" Given the draconian measures used to control out-of-wedlock births, it is not surprising that sex was a taboo subject. Wilkinson (1973) argues that in primitive societies many social norms regulating sexual practice and child bearing were really mechanisms designed to ensure that population size remained within an economy's food supply. In modern times it is easy to regulate fertility using contraceptives, and economically feasible for a woman to have an out-of-wedlock birth. Thus, the necessity for such harsh punishment is no longer needed.[24] [25]

The (likely) increase in homosexuality is almost certainly driven by a change in attitudes. Even here, however, findings reported in Rosenfeld and Kim (2005) suggest that higher living standards, which have allowed young adults to leave the home earlier and thereby develop more independent lifestyles, have facilitated the rise in homosexuality. This is in the spirit of Ogburn and Nimkoff (1955), who argued that changes in contraceptive technology, together with urbanization that allows more anonymity, led to changes in sexual mores.

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.[26] 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

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[24] On this, Lee (1975) argues that rising wages played a key role in the rise in premarital pregnancies in Bavaria between 1750 and 1850. The wage index for agricultural servants (where most of the premarital pregnancies occurred) rose 6 or 7 times over the period 1654 to 1869 (see his Table 7).

[25] Another example of culture adapting to technological progress is contained in Doepke and Tertilt (2007). They argue that women's liberation in the 19th century was the result of rising returns to human capital formation for females. In extending rights to women, men faced a trade-off between losing power with their own wives but emancipating other men's wives, such as their own daughters. This trade off resolves in favor of extending rights for all women when the returns to human capital are high enough.

[26] This fact is taken from Greenwood and Guner (2004), and is analyzed from a different perspective there.

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.[27] [28]

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 $P(s,\widetilde{s}) - A(s,\widetilde{s}) = s - c$. Clearly, $P(s,\widetilde{s}) - A(s,\widetilde{s}) \gtreqless 0$ as $s \gtreqless c$. Thus, there is no gain for a matched couple $(s,\widetilde{s})$ $\in \mathcal{P}$ or another one $(s,\widetilde{s}) \in \mathcal{A}$ 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) $H(s,\widetilde{s}) = I(s,\widetilde{s}) = L(s) = 1$ and $J(s,\widetilde{s}) = 0$ for all $s,\widetilde{s} \in \mathcal{A}$,
(ii) $H(s,\widetilde{s}) = L(s) = 0$ and $J(s,\widetilde{s}) = K(s,\widetilde{s}) = 1$ for all $s,\widetilde{s} \in \mathcal{P}$.
Now, (i) and (ii) imply that $\mathbf{X}(s,\widetilde{s}) = 1$ and $\mathbf{Y}(s,\widetilde{s}) = 0$ for $(s,\widetilde{s}) \in \mathcal{A}$, and $\mathbf{X}(s,\widetilde{s}) = 0$ and $\mathbf{Y}(s,\widetilde{s}) = 1$ for $(s,\widetilde{s}) \in \mathcal{P}$. Additionally, (i) and (ii) imply that $Q(s) < B(s)$ for $s \in \mathcal{A}$ and $Q(s) > B(s)$ 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 the 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 $\upsilon_j = 0$ for all $j > b$ and $\varpi_j = 0$ for all $j < b$. Using this observation, subtract (2) from (4) *in steady*

[27] Interestingly, Choo and Siow (2006) estimate, using an non-transferable utility model of the U.S. marriage market, that the gains for marriage accruing to young adults fell sharply between 1971 and 1981.

[28] The introduction of infant formula is another example of a small invention having a large impact on household activity. Albanesi and Olivetti (2006) argue that this promoted labor-force participation by married women. It could also impact on marriage and divorce.

state to get

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

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

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

[Note that $P(s,\widetilde{s}_j)>A(s,\widetilde{s}_j)$ for s and that $0\le\mathbf{X}(s,\widetilde{s}_j)+\mathbf{Y}(s,\widetilde{s}_j)\le 1$.] Now, clearly this equation cannot be satisfied for $Q(s)-B(s)<0$. Hence, $Q(s)-B(s)>0$. 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 $Q(s)-B(s)\gtreqless 0$ as $s\gtreqless c$. Thus, the lefthand side supports the conjectured solution for $L(s)$.]

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

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

and

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

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

$$A^{*}(s)=\frac{[1-\beta(1-\mu)]u+\beta\delta w}{\Delta}, \tag{28}$$

and

$$B^*(s) = \frac{[1-\beta(1-\delta)]w + \beta\mu u}{\Delta}, \tag{29}$$

where $\Delta \equiv (1-\beta)\left[1-\beta(1-\mu-\delta)\right] > 0$. 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 $u > w$. Therefore, $H(s, \widetilde{s}) = I(s, \widetilde{s}) = 1$ and $J(s, \widetilde{s}) = 0$ for $(s, \widetilde{s}) \in \mathcal{A}$.

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

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

and

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

The solutions to these two equations are given by

$$P^*(s) = \frac{(u+s-c)[1-\beta(1-\mu)] + w\beta\delta}{\Delta}, \tag{30}$$

and

$$Q^*(s) = \frac{[1-\beta(1-\delta)]w + \beta\mu(u+s-c)}{\Delta}. \tag{31}$$

It is easy to see that

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

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

13.2 Lemma 3

Proof. The proof proceeds using the guess-and-verify strategy. To this end, suppose that the value functions $A(s, \widetilde{s})$, $B(s)$, $P(s, \widetilde{s})$, and $Q(s)$ immediately jump to their new steady-state values upon the once-and-all decline in c. Now, consider a pair in the situation described by Point 1 in Section 7.1. The payoffs for matched individuals with $s, \widetilde{s} \in \{s_{d+1}, \cdots, s_n\}$ will be given by (30) and (31). Note that when this match breaks up person s will not have to worry about subsequently matching in $\mathcal{P}$ with a $\widetilde{s} \in \{s_1, \cdots, s_d\}$, 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 $\{s_1, \cdots, s_d\}$. Next, focus upon those individuals in the situation outlined by Point 2. Their payoffs will again be described by (30) and (31). Again, if they switch to $\mathcal{P}$ they will not have to worry about matching next period with a $\widetilde{s} \in \{s_1, \cdots, s_d\}$. So, from their viewpoint, these agents will be immediately moving into the new steady-state situation in $\mathcal{P}$. (The optimality of the steady state from an individual's perspective is detailed in the proof of Lemma 1.)

Now, move to Point 3. Let $s \in \{s_1, \cdots, s_d\}$ and $\widetilde{s} \in \{s_{d+1}, \cdots, s_b\}$. For it to be optimal for s to be matched with $\widetilde{s}$ in this situation in $\mathcal{A}$ it must transpire that $A(s, \widetilde{s}) > \max\{B(s), Q(s)\}$ and $P(s, \widetilde{s}) < \max\{A(s, \widetilde{s}), B(s), Q(s)\}$. First, by subtracting (1) from (3) it can be see that $P(s, \widetilde{s}) - A(s, \widetilde{s}) = s - c \gtreqless 0$ as $s \gtreqless c$. Therefore, s's first choice is a match in $\mathcal{A}$, while $\widetilde{s}$'s would be one in $\mathcal{P}$. Now, there are two cases to consider for s. Either she is in a mixing situation with $\widetilde{s}$ [implying $K(s, \widetilde{s}) = 1$] or she is refusing a promiscuous match all together [$K(s, \widetilde{s}) = 0$]. 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 $L(s, \widetilde{s}) = 1$, $\mathbf{X}(s, \widetilde{s}) = 1$, $\mathbf{Y}(s, \widetilde{s}) = 0$. Using this on the righthand sides of (1) and (2) and solving for $A(s, \widetilde{s})$ and $B(s)$ results in

$$A(s, \widetilde{s}) = A^*(s), \qquad \text{[for } s \leq s_d < s_{d+1} \leq \widetilde{s} \text{ and } \mathbf{X}(s, \widetilde{s}) = 1]$$

and

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

where $A^*(s)$ and $B^*(s)$ are specified by (28) and (29). Imposing this conjecture on (4) leads to

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

Thus, s will remain happy with her lot in $\mathcal{A}$, so there is no need to change her strategy today, taking as given $\widetilde{s}$'s strategy.

Next, consider the mixing situation for s. Here, the solution for $A(s,\widetilde{s})$ reads

$$A(s,\widetilde{s}) = \frac{u + \beta(1-\delta)(s-\underline{c})/2 + \beta\delta B^*(s)}{1-\beta(1-\delta)} < A^*(s) \text{ [for } s \le s_d < \widetilde{s} \text{ and } \mathbf{X}(s,\widetilde{s}) = 1/2].$$

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

Now, move to person $\widetilde{s}$. For $\widetilde{s}$ to be matched with s it must happen that $A(\widetilde{s},s) > \max\{B(\widetilde{s}), Q(\widetilde{s})\}$. Person $\widetilde{s}$ may find himself in one of two situations: either a mixing situation or one where s will refuse a promiscuous match. In the former $K(s,\widetilde{s}) = 1$, while in the latter $K(s,\widetilde{s}) = 0$. Take the latter case and suppose that the steady-state solution holds true at some point in time. Here, then $\mathbf{X}(s,\widetilde{s}) = 1$ and $\mathbf{Y}(s,\widetilde{s}) = 0$. It is then easy to deduce that $A(\widetilde{s},s)$ and $B(\widetilde{s})$ are given by

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

and

$$\begin{aligned} B(\widetilde{s}) &= w + \beta\mu \sum_{i=1}^{d} \upsilon_i [\mathbf{X}(\widetilde{s},s_i) A(\widetilde{s},s_i) + \mathbf{Y}(\widetilde{s},s_i) P(\widetilde{s},s_i)] \\ &\quad + \beta(1-\mu) Q^*(\widetilde{s}) \\ &< Q^*(\widetilde{s}) < P^*(\widetilde{s}) \quad (\text{for } s_{d+1} \le \widetilde{s}). \end{aligned}$$

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

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

As can be seen, mixing will yield $\widetilde{s}$ a higher level of utility than a purely abstinent match when $\widetilde{s} > c$. Mixing cannot occur for any $\widetilde{s} > s_r$ where $r = \arg\max_j\{j : A(\widetilde{s}_j, s) > Q^*(\widetilde{s}_j)\}$. Individual $\widetilde{s}$ will have no incentive to deviate from the conjectured strategy when this is true.

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 (22) and (23) set up a Markov chain as follows:

$$\begin{bmatrix} m^0_{t+1} \\ u^0_{t+1} \\ m^1_{t+1} \\ u^1_{t+1} \\ \vdots \\ \mu^{N-1}_{t+1} \\ m^N_{t+1} \\ u^N_{t+1} \end{bmatrix} = \begin{bmatrix} (1-\delta) & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \delta & (1-\mu) & 0 & 0 & & 0 & 0 & 0 \\ 0 & \mu & (1-\delta) & 0 & & 0 & 0 & 0 \\ 0 & 0 & \delta & (1-\mu) & & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & & & \vdots & \vdots \\ & & & & \cdots & 1-\mu & & \\ 0 & 0 & 0 & 0 & & \mu & (1-\delta) & 0 \\ 0 & 0 & 0 & 0 & \cdots & & \delta & (1-\mu) \end{bmatrix} \begin{bmatrix} m^0_t \\ u^0_t \\ m^1_t \\ u^1_t \\ \vdots \\ \mu^{N-1}_t \\ m^N_t \\ u^N_t \end{bmatrix},$$

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 $\{c_t\}_{t=1}^{T}$ sequence so that the first $4 \times (2002 - 1900)$ values match the time series properties observed for the effectiveness of contraception in the U.S. data. Set the last $T - 4 \times (2002 - 1900)$ 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 $\{H_t^{j+1}\}_{t=1}^{T-1}$,$\{I_t^{j+1}\}_{t=1}^{T-1}$, $\{J_t^{j+1}\}_{t=1}^{T-1}$,$\{K_t^{j+1}\}_{t=1}^{T-1}$, $\{L_t^{j+1}\}_{t=1}^{T-1}$, $\{\mathbf{X}_t^{j+1}\}_{t=1}^{T-1}$,$\{\mathbf{Y}_t^{j+1}\}_{t=1}^{T-1}$, and $\{\mathbf{Z}_t^{j+1}\}_{t=1}^{T-1}$. 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 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.

13.5 Data Sources

- Figure 1 – premarital sex: 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 obtained via private correspondence with Joyce Abma (Division of Vital Statistics, National Center for Health Statistics). The data for 1900, 1924, and 1934 are for white females.

- Figure 2 – attitudes by women toward premarital sex: The data are displayed in Figure 2 in Harding and Jencks (2003) and was kindly supplied by the authors.

- Figure 3 – number of partners: Laudmann *et al.* (1994, Table 5.5, p. 198).

- Figure 4 – out-of-wedlock births: For 1920 and 1930, see Cutright (1972, Table 1, p. 383), and for the data between 1940 and 1999, see Ventura and Bachrach (2000).

- Table 1 — contraception use at first premarital intercourse: For the years 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 are contained in Abma et al. (1997, Table 39, p. 49); for 1990-2002, the numbers are taken Mosher et al. (2004, Table 3, page 16). These papers use different waves of the National Survey of Family Growth (NSFG). The multiple users were not reported until the 1995 NSFG. 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 is 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. The results are almost identical if instead for 1900 the 4.2 percent of females 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 (as opposed to just being placed in the other category).

- Table 2 — failure rates for condoms, the pill, withdrawal, and other methods: For all contraceptives, failure rates are measured in terms of the percentage of women who become pregnant during the first year of use. First, for the period prior to 1960, see the discussion in Section 8.2. Second, for the period 1960 to 2002 the sources are more varied. 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. 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 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 average 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.* (2004). The numbers for withdrawal 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. Finally, 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 9 — teenage pregnancies: Henshaw (2004 Table 1, p. 1) reports the number of births, abortions, and miscarriages (the latter calculated as 20 percent of births plus 10 percent of abortions) for *all* teenager girls for the 1972-2000 period. To calculate the number of pregnancies for *unmarried* teenager girls, 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 (number of abortions to all teenagers)×(out-of-wedlock births to teenagers)/(births to all teenagers). Last, the number 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 (abortions + miscarriages)/(out-of-wedlock births) ratio took the same value as it did in 1972.

- Table 3 – number of partners: 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.

- Figure 11 – abortion and HIV: The sources for the abortion numbers presented in this figure are discussed in the data sources for Figure 9 above. 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 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.

- Table 4 – effectiveness of contraception against HIV: See the discussion in Section 10.4.

- Table 5 – frequency of sex: Abma *et al.* (2004, Table 6, p. 21) provide numbers for the frequency of sex for females aged 15-19 for the year 2002. Table 5 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.

References

Abma, Joyce C.; Mosher, William D.; Peterson, Linda S.; and Piccinino, Linda J. *Fertility, Family Planning, and Women's Health: New Data from the 1995 National Survey of Family Growth.* Vital and Health Statistics, Series 23, no. 19. Hyattsville, Maryland: National Center for Health Statistics, 1997.

Abma, Joyce C.; Martinez, G. M.; Mosher, William D.; Dawson, B. S. *Teenagers in the United States: Sexual Activity, Contraceptive use, and Childbearing, 2002.* Vital and Health Statistics, Series 23, no. 24. Hyattsville, Maryland: National Center for Health Statistics, 2004.

Abma, Joyce C., and Sonenstein, Freya L. *Sexual Activity and Contraceptive Practices Among Teenagers in the United States, 1988 and 1995.* Vital and Health Statistics. Series 23, no. 21. Hyattsville, Maryland: National Center for Health Statistics, 2001.

Albanesi, Stefania and Olivetti, Claudia. "Gender Roles and Technological Progress." Mimeo, Boston University, 2006.

Algan, Yann and Cahuc, Pierre. "The Roots of Low European Employment: Family Culture?" *NBER International Seminar on Macroeconomics 2005* (edited by Jeffery A. Frankel and Christopher A. Pissarides), MIT Press, 2007: 65-109.

The Alan Guttmacher Institute. *Sex and America's Teenagers.* New York, NY: The Alan Guttmacher Institute, 1994.

Aiyagari, S. Rao; Greenwood, Jeremy; and Guner, Nezih. "On the State of the Union." *Journal of Political Economy* 108, 2 (April 2000): 213-244.

Andolfatto, David and Gomme, Paul. "Unemployment Insurance and Labor-market Activity in Canada." *Carnegie-Rochester Conference Series on Public Policy*, 44 (June 1996): 47-82.

Andolfatto, David and MacDonald, Glenn M. "Technology Diffusion and Aggregate Dynamics." *Review of Economic Dynamics* 1, 2 (April 1998): 338-370.

Becker, Gary S. *A Treatise on the Family.* Cambridge, MA: Harvard University Press, 1991.

Becker, Gary S. and Mulligan, Casey B. "The Endogenous Determination of Time Preference," *The Quarterly Journal of Economics*, 113, 3 (August 1997): 729-758.

Brodie, Janet F. *Contraception and Abortion in Nineteenth-Century America*. Ithaca, NY: Cornell University Press, 1994.

Burdett, Kenneth and Coles, Melyvn G. "Marriage and Class." *The Quarterly Journal of Economics*, 112, 1 (February 1997), 141-168.

Center for Disease Control and Prevention. *HIV/AIDS Surveillance Report*, Vol.14, 2002.

Choo, Eugene and Siow, Aloysius. "Who Marries Whom and Why." *Journal of Political Economy*, 114, 1 (February 2006): 175-201.

Cole, Harold L.; Mailath, George J. and Postelwaite, Andrew. "Social Norms, Savings Behavior, and Growth." *Journal of Political Economy*, 100, 6 (December 1992): 1092-1125.

Cutright, Philips. "Illegitimacy in the United States: 1920-1968." In *Demographic and Social Aspects of Population Growth*, Vol. 1, edited by Charles F. Robert and Robert Parke. U.S. Commission on Population Growth and the American Future. Washington, D.C.: Government Printing Office, 1972.

Darroch, Jacqueline E., and Singh, Susheela. "Why is Teenage Pregnancy Declining? The Roles of Abstinence, Sexual Activity and Contraceptive Use." The Alan Guttmacher Institute, Occasional Report No. 1, 1999.

Davis, Karen R., and Weller, Susan C. "The Effectiveness of Condoms in Reducing Heterosexual Transmission of HIV." *Family Planning Perspectives*, 31, 6 (November/December 1999): 272-279.

Doepke, Matthias and Zilibotti, Fabrizio. "Social Class and the Spirit of Capitalism." *Journal of the European Economic Association*, 3, 2-3 (April/May 2005): 516-524.

Doepke, Matthias and Tertilt, Michele. "Women's Liberation: What Was in It for Men?" Mimeo, Department of Economics, Stanford University, 2007.

Fernandez, Raquel; Fogli, Alessandra; and Olivetti, Claudia. "Mothers and Sons: Preference Formation and Female Labor Dynamics." *The Quarterly Journal of Economics*, 119, 1 (November 2004): 1249-1299.

Food and Drug Administration (FDA). *Birth Control, Guide 1997*. Available at http://www.fda.gov/fdac/features/1997/babyguide2.pdf.

Greenwood, Jeremy and Guner, Nezih. "Marriage and Divorce since World War II: Analyzing the Role of Technological Progress on the Formation of Households." Working Paper 10772, National Bureau of Economic Research, Cambridge, MA, 2004.

Hansen, Gary D. and Imrohoroglu, Ayse. "The Role of Unemployment Insurance in an Economy with Liquidity Constraints and Moral Hazard." *Journal of Political Economy*, 100, 1 (February 1992): 118–142.

Hatcher, Robert A. *et al. Contraceptive Technology.* New York, NY: Irvington Publishers, 1976, 1980, 1984, and 1988; Ardent Media, Inc., 1998 and 2004.

Harding, David J., and Jencks, Christopher. "Changing Attitudes Toward Premarital Sex: Cohort, Period, and Aging Effects." *Public Opinion Quarterly* 67, 2 (Summer 2003): 211–226.

Henshaw, Stanley K. *U.S. Teenage Pregnancy Statistics with Comparative Statistics for Women Aged 20-24*. New York, NY: The Alan Guttmacher Institute, 2004.

Himes, Norman E. *Medical History of Contraception.* New York, NY: Gamut Press, Inc., 1963.

Hoffreth, Sandra L.; Kahn, Joan R.; and Baldwin, Wendy. "Premarital Sexual Activity Among U.S. Teenage Women Over the past Three Decades." *Family Planning Perspectives* 19, 2 (March/April 1987): 46-53.

Holtgrave, David R. "Estimation of Annual HIV Transmission Rates in United States, 1978-2000." *Journal of Acquired Immune Deficiency Syndrome,* 35, 1 (January 2004): 89-92.

Jovanovic, Boyan. "Work, Rest, and Search: Unemployment, Turnover, and the Cycle." *Journal of Labor Economics*, 5, 2 (April 1987): 131-148.

Jovanovic, Boyan and MacDonald, Glenn M. "Competitive Diffusion." *Journal of Political Economy*, 102, 1 (February 1994): 24-52.

Kelly, Gary F. *Sexuality Today*: *The Human Perspective.* New York, NY: McGraw-Hill, 2001.

Kinsey, Alfred C.; Pomeroy, Wardell B.; Martin, Clyde E.; and Gebhard, Paul H. *Sexual Behavior in the Human Female*. Philadelphia, PA: W. B. Saunders Company, 1953.

Kopp, Marie E. *Birth Control in Practice: Analysis of Ten Thousand Case Histories of the Birth Control Clinical Research Bureau.* New York, NY: Robert M. Bride and Company, 1934.

Ku, Leighton C.; Sonenstein, Freya L.; and Pleck, Joseph H. "The Association of AIDS Education and Sex Education with Sexual Behavior and Condom Use Among Teenage Men." *Family Planning Perspectives*, 24 ,3 (May/June 1992): 100-106.

Laudmann, Edward O.; Gagnon, John H.; Michael, Robert T.; and Michaels, Stuart. *The Social Organization of Sexuality.* Chicago, IL: The University of Chicago Press, 1994.

Lee, W. Robert. "Bastardy and the Socioeconomic Structure of South Germany," *Journal of Interdisciplinary History*, 7, 3 (Winter 1977): 403-425.

Lindberg, Laura D.; Ku, Leighton; and Sonenstein, Freya. "Adolescents' Reports of Reproductive Health Education, 1988 and 1995." *Family Planning Perspectives*, 32, 5 (September/October): 220-226.

Manuelli, Rodolfo and Seshadri, Ananth. "Frictionless Technology Diffusion: The Case of Tractors." Mimeo, Department of Economics, University of Wisconsin, 2004.

McLaren, Angus. *A History of Contraception: From Antiquity to the Present Day.* Cambridge: Basil Blackwell Inc., 1990.

Mosher, William D. *et al. Use of Contraception and Use of Family Planning Services in the United States: 1982-2002.* Advance Data from Vital and Health Statistics, no. 350. Hyattsville, Maryland: National Center for Health Statistics, 2004.

Mosher, William D. and Bachrach, Christine A. "First Premarital Contraceptive Use: United States, 1960-82." *Studies in Family Planning* 18, 2 (March/April 1987): 83-95.

Mosher, William D., and McNally, James W. "Contraceptive Use at First Premarital Intercourse: United States, 1965-1988." *Family Planning Perspectives* 23, 3 (May/June 1991): 108-116.

Mukoyama, Toshihiko. "Rosenberg's 'Learning by Using' and Technology Diffusion." *Journal of Economic Behavior and Organization* 61, 1 (September 2006): 123-144.

Ogburn, William F. *Social Change, With Respect to Culture and Original Nature.* New York, NY: The Viking Press, Inc., 1924.

Ogburn, William F. "Technology and Governmental Change." *Journal of Business of the University of Chicago*, IX, 1, (January 1936): 1-13.

Ogburn, William F. and Nimkoff, Meyer F. *Technology and the Changing Family.* Boston: Houghton Mifflin Company, 1955.

Pinkerton, Stephen D., and Ambramson, Paul R. "Effectiveness of Condoms in Preventing HIV Transmission." *Social Science and Medicine*, 44, 9 (May 1997): 1303-1312.

Potts, Malcolm and Campbell, Martha. "History of Contraception." School of Public Health, University of California at Berkeley, http://big.berkeley.edu/ifplp.history.pdf, 2002.

Restuccia, Diego and Urrutia, Carlos. "Intergenerational Persistence of Earnings: The Role of Early and College Education." *American Economic Review*, 94, 5 (December 2004): 1354-1378.

Rosenfeld, Michael J. and Kim, Byung-Soo. "The Independence of Young Adults and the Rise of Interracial and Same-Sex Unions." *American Sociological Review*, 70, 4 (August, 2005): 541–562.

Ryan, Suzanne; Manlove, Jennifer; and Kerry Franzetta. "The First Time: Characteristics of Teens' First Sexual Relationships." Child Trends Research Brief. Washington, D.C.: Child Trends, 2003.

Sonenstein, Freya L.; Pleck, Joseph H.; and Ku, Leighton, C. "Levels of Sexual Activity Among Adolescent Males in the United States." *Family Planning Perspective*, 23, 4 (July-August 1991): 162-167.

Stone, Lawrence. *The Family, Sex and Marriage in England 1500-1800.* London: Weidenfeld and Nicolson, 1977.

Tietze, Christopher. *Induced Abortions, A World Review, 1983.* A Population Council Fact Book. New York, NY: The Population Council, 1983.

Tone, Andrea. *Devices and Desires: History of Contraceptives in America.* New York, NY: Hill and Wang, 2001.

Udry, J. Richard, and Bearman, Peter S. "New Methods for New Research on Adolescent Sexual Behavior." In *New Perspectives on Adolescent Risk Behavior*, edited by Richard Jessor. Cambridge, U.K.: Cambridge University Press, 1998.

Ventura, Stephanie J., and Bachrach, Christine A. *Nonmarital Childbearing in the United States, 1940–99.* National Vital Statistics Reports, Vol. 48, no 16. Hyattsville, Maryland: National Center for Health Statistics, 2000.

Ventura, Stephanie J.; Mathews, T. J.; and Hamilton, Brady E. *Births to Teenagers in the United States, 1940-2000.* National Vital Statistics Reports, Vol. 49, no 10. Hyattsville, Maryland: National Center for Health Statistics, 2001.

Wilkinson, Richard G. *Poverty and Progress: An ecological model of economic development*. London: Methun and Co Ltd, 1973.

Zelnik, Melvin; Kantner, John F.; and Ford, Kathleen. *Sex and Pregnancy in Adolescence.* Beverly Hills, CA: SAGE Publications, 1981.