SOCIAL CHANGE: THE SEXUAL REVOLUTION[*]

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Abstract

In 1900 only six percent of unwed females engaged in premarital sex. Now, three quarters do. The sexual revolution is studied here using an equilibrium matching model, where the costs of premarital sex fall over time due to technological improvement in contraceptives. Individuals differ in their desire for sex. Given this, people tend to circulate in social groups where prospective partners share their views on premarital sex. To the extent that a society's customs and mores reflect the aggregation of decentralized decision making by its members, shifts in the economic environment may induce changes in what is perceived as culture.

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

JEL Classification Nos: E1, J1, O3

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

There may be no better illustration of social change than the sexual revolution that occurred during the 20th century. In 1900 almost no unmarried teenage girl engaged in premarital sex; only a paltry 6 percent – see Figure 1, left panel. By 2002 a large majority (roughly 75 percent) had experienced this. What caused this: the contraception revolution. (Sources for the U.S. data displayed in all figures and tables are detailed in the Appendix, Section 12.5.) Both the technology for contraception and education about its practice changed dramatically over the course of the last century. Another reflection of the change in sexual mores is the rise in the number of sexual partners that unmarried females have. For 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 1, right panel. 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 1, left panel. 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.
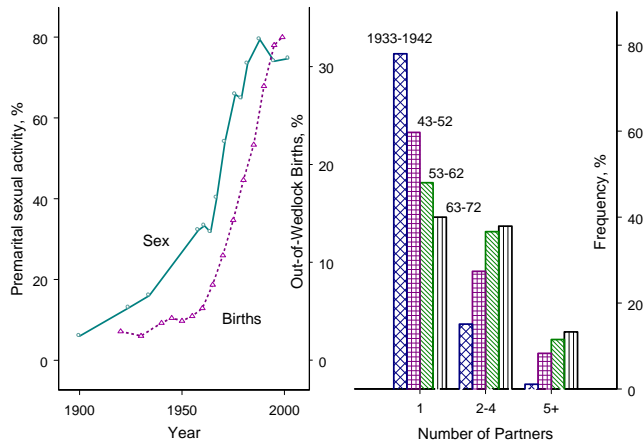
Figure 1: (i) Percentage of 19 year-old females with premarital sexual experience (left panel); (ii) Out-of-wedlock births, percentage (left panel); (iii) Number of partners by age 20 for women engaging in premarital sex, frequency distribution by birth cohort (right panel)

1.1   The Analysis

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

It is established theoretically that in the developed matching model's steady state the population sorts very neatly into two social groups.[1]   Those who want an abstinent relation-

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[1] 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

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ship 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 allows for efficient search, which would not transpire in the steady state of a standard search model. It 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. The model also does a reasonable job mimicing the rise in teenage pregnancies. That it can do so is not a forgone conclusion. On the one hand, an increase in the efficacy of contraception implies that there should be less pregnancies. On the other, it promotes more premarital sex. The end result depends on how these two factors interact.

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

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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.

able to do so. Modelling the average number of, and the dispersion in, sexual partners is likely to be 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.

The investigation is conducted within the context of a unisex framework. The model is used to address some stylized facts concerning female sexual behavior, such as the aforementioned rise in out-of-wedlock births. The costs of engaging in premarital sex are obviously different for males and females. An out–of-wedlock birth may severely affect a young girl's educational and job prospects as well as her opportunities for finding a future mate. Therefore, girls are likely to be less promiscuous than boys. Additionally, promiscuity may differ by family background, because girls from poorer families may feel that they have less to lose from an out-of-wedlock birth. These are important considerations, but incorporating them would introduce extra complications.[2]   The unisex abstraction conducted here really does little violence to the questions poised by Figure 1.

There is empirical work that connects differences in culture to differences in economic decision making. Guiliano (2007) finds that, in the wake of the sexual revolution, young Americans whose parents came from Southern Europe are now more likely to live at home compared with those from Northern Europe. She argues that family ties are stronger for Southerners and that a liberalization of sexual attitudes allowed young adults to remain in their parents' home while enjoying an active sexual life. Likewise, Fernández and Fogli (2009) examine fertility and labor-force participation rates for American born women whose parents were immigrants. They argue that ancestral differences in family culture have explanatory

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[2] A model with these features is presented in Fernández-Villaverde, Greenwood, and Guner (2009). Their analysis is in the spirit of Becker and Mulligan (1997) and Doepke and Zilibotti (2008). In particular, a child's preferences are affected by parental, and institutional, investments. The focus of the Fernández-Villaverde, Greenwood, and Guner (2009) is on the socialization of children by their parents and institutions such as the church. They illustrate how the inculcation of sexual mores is affected by the technological environment.

power for work and fertility behavior today. The current paper should not be read as saying that culture does not matter, but rather that some part of it may be endogenous.[3]

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 $j \in \mathcal{J} = \{j_1, j_2, \cdots, j_n\}$, which represents his or her joy from sex. The value of j is known by an individual. Let j be distributed across individuals according to the density function $J(j_i) = \phi_i$, with $0 < \phi_i < 1$, $\sum_{i=1}^n \phi_i = 1$, and $j_1 < j_2 < \cdots < j_n$. 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.

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[3] It may take some time for culture to respond to a new technological environment. Sometimes the change is sudden, other times it may be more gradual or smooth. For example, social behavior may be governed by norms–see the classic paper by Cole, Mailath, and Postelwaite (1992). Individuals who transgress the norm may be collectively outcast or shunned by other members of society. Given this fact most individuals may rationally choose to subscribe to the social norm. As the economic environment changes it may become increasingly impossible to sustain such a norm. Eventually, it collapses. Or, the process might be a gradual or smooth change in socialization practices in response to shifts in the environment, as is modeled in Fernández-Villaverde, Greenwood, and Guner (2009). Alternatively, Fernández, Fogli and Olivetti (2004) assume that childrens' preferences are a function of their parents' lifestyles (in a habit-formation way) which may change slowly over time. Another example of culture adapting to technological progress is contained in Doepke and Tertilt (forth.). 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.

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 level 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 $u + j - c$, where j is the joy from sex and c is the expected cost of it 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, j, and c are specified in a way that guarantees that expected lifetime utility is always positive. Assume that u, w, j, and c are finite, which ensures that expected lifetime utility is bounded.

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]

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[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. Alternatively, one could just simply assume that in adult life one obtains an expected lifetime utility of V, a constant. Since a teen shifts into adult life with an exogenous state-independent probability, ζ, this will not affect any choice that he makes. A teen's effective discount factor would be $\beta = \widehat{\beta}(1 - \zeta)$, where $\widehat{\beta}$ is his subjective discount factor. To get the

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, $\mathcal{P}$. 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 $A^m(j, \widetilde{j})$ denote the expected lifetime utility for an individual of type j who is currently in an abstinent match with a partner of type $\widetilde{j}$. An individual does not experience any joy from sex while abstinent. But, s/he could in the future. Thus, A^m should still be a function of j. Also, an individual's joy from sex does not depend directly upon his partner's type, $\widetilde{j}$. Still, he cares indirectly about $\widetilde{j}$ because this will delimit his future matching possibilities, as will be seen. Next, define $A^s(j)$ to be the expected lifetime utility for a single (or unmatched) agent in class $\mathcal{A}$. Turn now to the promiscuous class. Here $P^m(j, \widetilde{j})$ will represent the expected lifetime utility for individual j who is currently in a promiscuous match with $\widetilde{j}$, and $P^s(j)$ will proxy for the expected lifetime utility for a single agent in class $\mathcal{P}$. Finally, suppose that j and $\widetilde{j}$ meet. What will be the outcome of this meeting? Let $\mathbf{a}^m(j, \widetilde{j})$ be the equilibrium probability that an abstinent relationship will occur, $\mathbf{p}^m(j, \widetilde{j})$ denote the odds that a promiscuous one transpires, and $1 - \mathbf{a}^m(j, \widetilde{j}) - \mathbf{p}^m(j, \widetilde{j})$ give the chance that no match will ensue.

As will be seen, these equilibrium matching probabilities split the space of potential pairwise matches, $\mathcal{J} \times \mathcal{J}$, into four types of zones: viz, one where both parties desire an abstinent relationship so that $\mathbf{a}^m(j, \widetilde{j}) = 1$; another where both want a sexual one implying that $\mathbf{p}^m(j, \widetilde{j}) = 1$; a mixing region where one party prefers an abstinent relationship, the other side a sexual one, but both prefer some sort of relationship to none, so that $0 < \mathbf{a}^m(j, \widetilde{j}), \mathbf{p}^m(j, \widetilde{j}) < 1$; a zone where no relationship of any sort is possible and $\mathbf{a}^m(j, \widetilde{j}) = \mathbf{p}^m(j, \widetilde{j}) = 0$. An example of this is shown in Figure 2, which is detailed later on–in this figure both parties prefer some sort of relationship to none at all.

equilibrium discussed in the text just set $\widehat{\beta} = \beta/(1 - \zeta)$.

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

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

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\begin{aligned}
(1) \qquad A^m(j, \widetilde{j}) \;=\; & u + \beta(1-\delta)[\mathbf{a}^{m\prime}(j, \widetilde{j})A^{m\prime}(j, \widetilde{j}) + \mathbf{p}^{m\prime}(j, \widetilde{j})P^{m\prime}(j, \widetilde{j})] \\
& + \beta\{\delta + (1-\delta)[1 - \mathbf{a}^{m\prime}(j, \widetilde{j}) - \mathbf{p}^{m\prime}(j, \widetilde{j})]\} \max\{A^{s\prime}(j), P^{s\prime}(j)\},
\end{aligned}
$$

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 j can expect from tomorrow on. Note that his current match with $\widetilde{j}$ 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 $\mathbf{a}^{m\prime}(j, \widetilde{j})$ reports the *equilibrium* probability that an abstinent match between j and $\widetilde{j}$ will occur next period.[6]   Thus, the term $(1-\delta)\mathbf{a}^{m\prime}(j, \widetilde{j})A^{m\prime}(j, \widetilde{j})$ represents the component of expected lifetime utility from next period onward that is associated with the possibility of an abstinent match. Likewise, the part of expected lifetime utility linked to a promiscuous match is given by $(1-\delta)\mathbf{p}^{m\prime}(j, \widetilde{j})P^{m\prime}(j, \widetilde{j})$. 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 $(1-\delta)[1 - \mathbf{a}^{m\prime}(j, \widetilde{j}) - \mathbf{p}^{m\prime}(j, \widetilde{j})]$. When the match breaks up person j must decide whether to enjoy his single life in either the abstinent or promiscuous class. The term $\{\delta + (1-\delta)[1 - \mathbf{a}^{m\prime}(j, \widetilde{j}) - \mathbf{p}^{m\prime}(j, \widetilde{j})]\} \max\{A^{s\prime}(j), P^{s\prime}(j)\}$ gives the part of expected lifetime utility that is associated with single life next period. When single at that time person j will choose to join the social class ($\mathcal{A}$ or $\mathcal{P}$) that maximizes

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[5] Note that the pair, j and $\widetilde{j}$, will move to a new location next period with probability $1 - \zeta$. But, by assumption j'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. It does 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). Aiyagari, Greenwood, and Guner (2000) develop a bilateral search model of marriage that is similar in some respects to the framework developed here.

expected lifetime utility so that he will realize the level of bliss given by $\max\{A^{s\prime}(j), P^{s\prime}(j)\}$. The determination of the functions $\mathbf{a}^m$ and $\mathbf{p}^m$ 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 j is alone in $\mathcal{A}$. His expected lifetime utility is given by the function $A^s(j)$, which reads

$$(2) \qquad A^s(j) = w + \beta\mu \sum_{i=1}^{n} a_i^{s\prime} [\mathbf{a}^{m\prime}(j, \widetilde{j}_i) A^{m\prime}(j, \widetilde{j}_i) + \mathbf{p}^{m\prime}(j, \widetilde{j}_i) P^{m\prime}(j, \widetilde{j}_i)]$$

$$+ \beta\{(1-\mu) + \mu \sum_{i=1}^{n} a_i^{s\prime} [1 - \mathbf{a}^{m\prime}(j, \widetilde{j}_i) - \mathbf{p}^{m\prime}(j, \widetilde{j}_i)]\} \max\{A^{s\prime}(j), P^{s\prime}(j)\}.$$

Note that j's draw for a partner, $\widetilde{j}$, 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 $a_i^{s\prime}$'s, with $0 \leq a_i^{s\prime} \leq 1$ and $\sum_{i=1}^{n} a_i^{s\prime} = 1$. This distribution is endogenously determined.

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

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

$$(3) \qquad P^m(j, \widetilde{j}) = u + j - c + \beta(1-\delta)[\mathbf{a}^{m\prime}(j, \widetilde{j}) A^{m\prime}(j, \widetilde{j}) + \mathbf{p}^{m\prime}(j, \widetilde{j}) P^{m\prime}(j, \widetilde{j})]$$

$$+ \beta\{\delta + (1-\delta)[1 - \mathbf{a}^{m\prime}(j, \widetilde{j}) - \mathbf{p}^{m\prime}(j, \widetilde{j})]\} \max\{A^{s\prime}(j), P^{s\prime}(j)\}.$$

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[7] Specifically, since the costs of premarital sex are assumed to be a function of time so will be the functions $A^m(j, \widetilde{j})$, $A^s(j)$, $P^m(j, \widetilde{j})$, $P^s(j)$, $\mathbf{a}^m(j, \widetilde{j})$, $\mathbf{p}^m(j, \widetilde{j})$, 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 4.

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

$$(4) \quad P^s(j) = w + \beta\mu \sum_{i=1}^{n} p_i^{s\prime}[\mathbf{a}^{m\prime}(j,\widetilde{j}_i)A^{m\prime}(j,\widetilde{j}_i) + \mathbf{p}^{m\prime}(j,\widetilde{j}_i)P^{m\prime}(j,\widetilde{j}_i)]$$

$$+ \beta\{(1-\mu) + \mu \sum_{i=1}^{n} p_i^{s\prime}[1 - \mathbf{a}^{m\prime}(j,\widetilde{j}_i) - \mathbf{p}^{m\prime}(j,\widetilde{j}_i)]\} \max\{A^{s\prime}(j), P^{s\prime}(j)\}.$$

Note that j'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 $p_i^{s\prime}$'s with $0 \le p_i^{s\prime} \le 1$ and $\sum_{i=1}^{n} p_i^{s\prime} = 1$. The value of searching in either $\mathcal{A}$ or $\mathcal{P}$ next period will depend upon the type distributions, $a^{s\prime}$ and $p^{s\prime}$, that exist in these classes then.

3.3   Social Class Membership Decision, Choosing $\mathcal{A}$ or $\mathcal{P}$

Now, consider individual j who is matched with partner $\widetilde{j}$. An abstinent match with $\widetilde{j}$ may be individual j's first choice. Let the indicator $\mathbf{1}^a(j,\widetilde{j})$ return a value of one if this is the case, and a value of zero otherwise. The indicator function $\mathbf{1}^a(\widetilde{j},j)$ is then given by

(5)
$$\mathbf{1}^a(j,\widetilde{j}) = \begin{cases} 1, & \text{if } A^m(j,\widetilde{j}) > \max\{P^m(j,\widetilde{j}), A^s(j), P^s(j)\} \text{ (abstinent match is first choice)}, \\ 0, & \text{otherwise.} \end{cases}$$

Observe that the analogous indicator function for person $\widetilde{j}$ will simply read $\mathbf{1}^a(\widetilde{j},j) = \mathbf{1}_T^a(j,\widetilde{j})$, where the subscript T denotes the transpose of a matrix. Now, it may be the case that person j would prefer a promiscuous match with $\widetilde{j}$, but this isn't feasible. Still, j may prefer to live with $\widetilde{j}$ in $\mathcal{A}$, relative to living alone in either $\mathcal{A}$ or $\mathcal{P}$. Let the indicator function $\mathbf{2}^{a,s}(j,\widetilde{j})$ return a value of one if j prefers a match with $\widetilde{j}$ in $\mathcal{A}$, relative to single life in either $\mathcal{A}$ or $\mathcal{P}$, and a value of zero otherwise. Thus, $\mathbf{2}^{a,s}(j,\widetilde{j})$ is given by

(6)
$$\mathbf{2}^{a,s}(j,\widetilde{j}) = \begin{cases} 1, & \text{if } A^m(j,\widetilde{j}) > \max\{A^s(j), P^s(j)\} \text{ (abstinent match preferred to single life)}, \\ 0, & \text{otherwise.} \end{cases}$$

Person j's preferences towards promiscuous matches can be analyzed in similar fashion. To this end, let the indicator function $\mathbf{1}^p(j,\widetilde{j})$ return a value of one if j would prefer to live

with $\widetilde{j}$ in $\mathcal{P}$ over all other options, and a value of zero otherwise. This indicator function is defined by

(7)
$$\mathbf{1}^p(j,\widetilde{j}) = \begin{cases} 1, & \text{if } P^m(j,\widetilde{j}) > \max\{A^m(j,\widetilde{j}), A^s(j), P^s(j)\} \text{ (promiscuous match is first choice)}, \\ 0, & \text{otherwise}. \end{cases}$$

The situation where j prefers to live with $\widetilde{j}$ in $\mathcal{P}$, relative to living alone in either $\mathcal{A}$ or $\mathcal{P}$, can be captured by the indicator function $\mathbf{2}^{p,s}(j,\widetilde{j})$:

(8)
$$\mathbf{2}^{p,s}(j,\widetilde{j}) = \begin{cases} 1, & \text{if } P^m(j,\widetilde{j}) > \max\{A^s(j), P^s(j)\} \text{ (promiscuous match preferred to single life)}, \\ 0, & \text{otherwise}. \end{cases}$$

Consider an unmatched agent. S/he must choose between searching for a prospective mate in the abstinent or promiscuous class. Let $\mathbf{1}_s^{a,p}(j)$ denote the decision rule for an unmatched individual. In particular,

(9)
$$\mathbf{1}_s^{a,p}(j) = \begin{cases} 1, & \text{if } A^s(j) > P^s(j), \text{ (single in } \mathcal{A} \text{ preferred to single in } \mathcal{P}\text{)}, \\ 0, & \text{otherwise}. \end{cases}$$

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

$$
\begin{aligned}
(10) \quad \mathbf{a}^m(j,\widetilde{j}) \;=\;& \mathbf{1}^a(j,\widetilde{j})\mathbf{1}_T^a(j,\widetilde{j}) + \mathbf{1}^a(j,\widetilde{j})\mathbf{2}^{p,s}(j,\widetilde{j})\mathbf{1}_T^p(j,\widetilde{j})\mathbf{2}_T^{a,s}(j,\widetilde{j})/2 \\
&+ \mathbf{1}_T^a(j,\widetilde{j})\mathbf{2}_T^{p,s}(j,\widetilde{j})\mathbf{1}^p(j,\widetilde{j})\mathbf{2}^{a,s}(j,\widetilde{j})/2 \\
&+ \mathbf{1}^a(j,\widetilde{j})[1 - \mathbf{2}^{p,s}(j,\widetilde{j})][1 - \mathbf{1}_T^a(j,\widetilde{j})]\mathbf{2}_T^{a,s}(j,\widetilde{j}) \\
&+ \mathbf{1}_T^a(j,\widetilde{j})[1 - \mathbf{2}_T^{p,s}(j,\widetilde{j})][1 - \mathbf{1}^a(j,\widetilde{j})]\mathbf{2}^{a,s}(j,\widetilde{j}),
\end{aligned}
$$

and

$$
\begin{aligned}
(11) \quad \mathbf{p}^m(j,\widetilde{j}) \;=\;& \mathbf{1}^p(j,\widetilde{j})\mathbf{1}_T^p(j,\widetilde{j}) + \mathbf{1}^a(j,\widetilde{j})\mathbf{2}^{p,s}(j,\widetilde{j})\mathbf{1}_T^p(j,\widetilde{j})\mathbf{2}_T^{a,s}(j,\widetilde{j})/2 \\
&+ \mathbf{1}_T^a(j,\widetilde{j})\mathbf{2}_T^{p,s}(j,\widetilde{j})\mathbf{1}^p(j,\widetilde{j})\mathbf{2}^{a,s}(j,\widetilde{j})/2 \\
&+ [1 - \mathbf{1}^p(j,\widetilde{j})]\mathbf{2}^{p,s}(j,\widetilde{j})\mathbf{1}_T^p(j,\widetilde{j})[1 - \mathbf{2}_T^{a,s}(j,\widetilde{j})] \\
&+ [1 - \mathbf{1}_T^p(j,\widetilde{j})]\mathbf{2}_T^{p,s}(j,\widetilde{j})\mathbf{1}^p(j,\widetilde{j})[1 - \mathbf{2}^{a,s}(j,\widetilde{j})].
\end{aligned}
$$

Take the expression for $\mathbf{a}^m(j,\tilde{j})$. It is not as formidable as it looks. The first term gives the situation where an abstinent match is both j's and $\tilde{j}$'s first choice. When this occurs $\mathbf{1}^a(j,\tilde{j})\mathbf{1}_T^a(j,\tilde{j}) = 1$. 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 j'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 $\mathbf{1}^a(j,\tilde{j})\mathbf{2}^{p,s}(j,\tilde{j}) = 1$, and is zero otherwise. Additionally, suppose that her partner wants a promiscuous match the most, but prefers an abstinent relationship to single life. Here, $\mathbf{1}_T^p(j,\tilde{j})\mathbf{2}_T^{a,s}(j,\tilde{j}) = 1$. 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 $\mathbf{1}^a(j,\tilde{j})\mathbf{2}^{p,s}(j,\tilde{j})\mathbf{1}_T^p(j,\tilde{j})\mathbf{2}_T^{a,s}(j,\tilde{j})/2 = 1/2$. This expression will return a value of zero in *any* other circumstance. The third term just reports the situation when the roles for j and $\tilde{j}$ are reversed. Therefore, when two people j and $\tilde{j}$ have the above-mentioned difference in tastes, half of the time the match will be resolved in j's favor, while the other half it will be decided to $\tilde{j}$'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 $\mathbf{p}^m(j,\tilde{j}) = 1$, and more active than ones with $\mathbf{a}^m(j,\tilde{j}) = 1$. 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 specifies the case where person j will refuse a promiscuous match. If j's first choice is an abstinent match, and she'll refuse a promiscuous one, then $\mathbf{1}^a(j,\tilde{j})[1 - \mathbf{2}^{p,s}(j,\tilde{j})] = 1$. Likewise, when $\tilde{j}$'s best option is a promiscuous match, but he'll accept

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an abstinent one, then $[1 - \mathbf{1}_T^a(j,\widetilde{j})]\mathbf{2}_T^{a,s}(j,\widetilde{j}) = 1$. The odds of an abstinent match in this situation are given by $\mathbf{1}^a(j,\widetilde{j})[1 - \mathbf{2}^{p,s}(j,\widetilde{j})][1 - \mathbf{1}_T^a(j,\widetilde{j})]\mathbf{2}_T^{a,s}(j,\widetilde{j}) = 1$. Again, it is easy to deduce that this expression will be zero in any other situation. The roles between j and $\widetilde{j}$ are reversed in the fifth term. Note that by construction all of the terms in (10) are mutually exclusive and that $\mathbf{a}^m(j,\widetilde{j}) \in \{0, 1/2, 1\}$. Likewise, $\mathbf{p}^m(j,\widetilde{j}) \in \{0, 1/2, 1\}$. Last the odds of no relationship are just simply given by $1 - \mathbf{a}^m(j,\widetilde{j}) - \mathbf{p}^m(j,\widetilde{j}) \in \{0, 1\}$.

Observe that equations (1) to (11) jointly determine a solution for the value functions $A^m(j,\widetilde{j})$, $A^s(j)$, $P^m(j,\widetilde{j})$, $P^s(j)$, the decision rules $\mathbf{1}^a(j,\widetilde{j})$, $\mathbf{2}^{a,s}(j,\widetilde{j})$, $\cdots$, $\mathbf{1}_s^{a,p}(j)$, and the matching functions, $\mathbf{a}^m(j,\widetilde{j})$ and $\mathbf{p}^m(j,\widetilde{j})$, contingent upon the type distributions of unmatched agents in $\mathcal{A}$ and $\mathcal{P}$, or the a_i^s's and p_i^s's.

4   Equilibrium

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 a_i^s's and p_i^s's. Note these distributions will indirectly influence (1) and (3) as well. Hence, the equilibrium social class membership functions (9) to (11) will depend upon these distributions. In turn, the evolution of these distributions will be functions of these membership decisions, $\mathbf{a}^m$, $\mathbf{a}^p$, and $\mathbf{1}_s^{a,p}$. Let $M^a(j,\widetilde{j})$ denote the *non*normalized distribution over matched pairs in $\mathcal{A}$, and $S^a(j)$ denote the analogous (nonnormalized) distribution over singles. Likewise, $M^p(j,\widetilde{j})$ and $S^p(j)$ will represent the distributions for matched and unmatched agents in $\mathcal{P}$. Note that $a_i^s = S^a(j_i)/\Sigma_k S^a(j_k)$ and $p_i^s = S^p(j_i)/\Sigma_k S^p(j_k)$. Write the law of motion for these distributions as

(12) $(M^{a\prime}, S^{a\prime}, M^{p\prime}, S^{p\prime}) = \mathcal{L}(M^a, S^a, M^p, S^p, \mathbf{a}^m, \mathbf{a}^p, \mathbf{1}_s^{a,p})$.

The operator $\mathcal{L}$ is fully specified in the Appendix, Section 12.2. Thus, computing an equilibrium for the model involves solving a fixed-point problem.

Definition *For a given time path describing the costs of premarital sex, $\{c_t\}_{t=1}^{\infty}$, and some initial type distributions, $M_1^a(j,\widetilde{j})$, $M_1^p(j,\widetilde{j})$, $S_1^a(j)$, and $S_1^p(j)$, a nonstationary rational expectations equilibrium is represented by time paths for the value functions, $\{A_t^m(j,\widetilde{j})\}_{t=1}^{\infty}$, $\{A_t^s(j)\}_{t=1}^{\infty}$, $\{P_t^m(j,\widetilde{j})\}_{t=1}^{\infty}$, and $\{P_t^s(j)\}_{t=1}^{\infty}$, the decision rules, $\{\mathbf{1}_t^a(j,\widetilde{j})\}_{t=1}^{\infty}$, $\{\mathbf{2}_t^{a,s}(j,\widetilde{j})\}_{t=1}^{\infty}$,*

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$\{\mathbf{1}_t^p(j,\widetilde{j})\}_{t=1}^\infty$, $\{\mathbf{2}_t^{p,s}(j,\widetilde{j})\}_{t=1}^\infty$, and $\{\mathbf{1}_{s,t}^{a,p}(j)\}_{t=1}^\infty$, the matching functions for couples, $\{\mathbf{a}_t^m(j,\widetilde{j})\}_{t=1}^\infty$ and $\{\mathbf{p}_t^m(j,\widetilde{j})\}_{t=1}^\infty$, and the type distributions, $\{M_t^a(j,\widetilde{j})\}_{t=1}^\infty$, $\{M_t^p(j,\widetilde{j})\}_{t=1}^\infty$, $\{S_t^a(j)\}_{t=1}^\infty$, and $\{S_t^p(j)\}_{t=1}^\infty$, such that:

1. The sequence of value functions, $\{A_t^m(j,\widetilde{j})\}_{t=1}^\infty$, $\{A_t^s(j)\}_{t=1}^\infty$, $\{P_t^m(j,\widetilde{j})\}_{t=1}^\infty$, and $\{P_t^s(j)\}_{t=1}^\infty$, solve the recursions (1) to (4), given the time paths for the matching functions for couples, $\{\mathbf{a}_t^m(j,\widetilde{j})\}_{t=1}^\infty$ and $\{\mathbf{p}_t^m(j,\widetilde{j})\}_{t=1}^\infty$, and the type distributions for singles, $\{S_t^a(j)\}_{t=1}^\infty$, and $\{S_t^p(j)\}_{t=1}^\infty$. [Recall that $a_{i,t}^s = S_t^a(j_i)/\Sigma_k S_t^a(j_k)$ and $p_{i,t}^s = S_t^p(j_i)/\Sigma_k S_t^p(j_k)$.]

2. The sequence of decisions rules and matching functions $\{\mathbf{1}_t^a(j,\widetilde{j})\}_{t=1}^\infty$, $\{\mathbf{2}_t^{a,s}(j,\widetilde{j})\}_{t=1}^\infty$, $\{\mathbf{1}_t^p(j,\widetilde{j})\}_{t=1}^\infty$, $\{\mathbf{2}_t^{p,s}(j,\widetilde{j})\}_{t=1}^\infty$, $\{\mathbf{1}_{s,t}^{a,p}(j)\}_{t=1}^\infty$, $\{\mathbf{a}_t^m(j,\widetilde{j})\}_{t=1}^\infty$, and $\{\mathbf{p}_t^m(j,\widetilde{j})\}_{t=1}^\infty$, satisfy (5) to (11), given the time paths for the value functions, $\{A_t^m(j,\widetilde{j})\}_{t=1}^\infty$, $\{A_t^s(j)\}_{t=1}^\infty$, $\{P_t^m(j,\widetilde{j})\}_{t=1}^\infty$, and $\{P_t^s(j)\}_{t=1}^\infty$ and the type distributions for singles, $\{S_t^a(j)\}_{t=1}^\infty$, and $\{S_t^p(j)\}_{t=1}^\infty$. (Recall the subscript T denotes the transpose of a matrix.)

3. The sequence for the type distributions, $\{M_t^a(j,\widetilde{j})\}_{t=1}^\infty$, $\{M_t^p(j,\widetilde{j})\}_{t=1}^\infty$, $\{S_t^a(j)\}_{t=1}^\infty$, and $\{S_t^p(j)\}_{t=1}^\infty$, solve (12), given the social class decision rule for singles, $\{\mathbf{1}_{s,t}^{a,p}(j)\}_{t=1}^\infty$, and the matching functions, $\{\mathbf{a}_t^m(j,\widetilde{j})\}_{t=1}^\infty$ and $\{\mathbf{p}_t^m(j,\widetilde{j})\}_{t=1}^\infty$.

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 12.4. After all, the question of whether or not the above framework is capable of explaining the change in sexual mores is quantitative in nature.

5   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, j_b, such that $\{j_1, \cdots , j_b\} \in \mathcal{A}$ and $\{j_{b+1}, \cdots , j_n\} \in \mathcal{P}$. In fact, one might suspect that $j_b < c < j_{b+1}$; 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 j'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 *(Separate Worlds) There exists a steady-state equilibrium such that $j_i \in \mathcal{A}$ for all $j_i < c$, and $j_i \in \mathcal{P}$ for $j_i > c$.*

Proof. See the Appendix, Section 12.1.1. ∎

Given the above lemma, there exists a steady state where there is a dividing line in the j distribution between the two classes given by c. Individuals with a $j < c$ choose to live abstinent lives, and those with a $j > c$ promiscuous ones. The steady state of a standard search model would not exhibit this type of efficient matching. Hence, the (nonnormalized) type distributions in $\mathcal{A}$ and $\mathcal{P}$ will be given by $\{\phi_1, \cdots , \phi_b, 0, \cdots , 0\}$ and $\{0, \cdots , 0, \phi_{b+1}, \cdots , \phi_n\}$, respectively, where b solves

(13)
$$j_b < c < j_{b+1}.$$

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

(14)
$$\#\mathcal{P} = 1 - \sum_{i=1}^{b} \phi_i.$$

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

(15)
$$\alpha = \frac{\zeta\mu}{1 - \zeta(1 - \delta) + \zeta\mu},$$

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 $J(j)$. 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 *(Sexual Revolution) 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 (13) will fall, given that $j_1 < j_2 < \cdots < j_n$. The result then follows from (14). ∎

6 Transitional Dynamics

6.1 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 5, there will exist a b such that $j_b < \bar{c} < j_{b+1}$. The type distribution in $\mathcal{A}$ will be given by $\{\phi_1, \cdots, \phi_b, 0, \cdots, 0\}$, and the one in $\mathcal{P}$ by $\{0, \cdots, 0, \phi_{b+1}, \cdots, \phi_n\}$. In each class a fraction α, as specified by (15), 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 $\{\phi_1, \cdots, \phi_d, 0, \cdots, 0\}$ and $\{0, \cdots, 0, \phi_{d+1}, \cdots, \phi_n\}$, where $j_d < \underline{c} < j_{d+1}$ – 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 $(j, \widetilde{j})$ pair in $\mathcal{A}$ in the old steady state. If $(j, \widetilde{j}) \in \{j_{d+1}, \cdots, j_b\} \times \{j_{d+1}, \cdots, j_b\}$ they will move immediately to $\mathcal{P}$. Simply put, why should these individuals wait? There will be $\alpha \sum_{i=d+1}^{b} \sum_{k=d+1}^{b} \phi_i \, \widetilde{\phi}_k$ agents in this category, where α is given by (15). Since the adjustment here is immediate, this case is a force for rapid transitional dynamics.

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2. Likewise, consider unattached individuals in $\mathcal{A}$. If $j \in \{j_{d+1}, \cdots, j_b\}$ they too will immediately enter $\mathcal{P}$. Again, what would be the advantage to waiting? There are $(1 - \alpha) \sum_{i=d+1}^{b} \phi_i$ 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 $\{a_1^{s\prime}, \cdots, a_d^{s\prime}, 0, \cdots, 0\}$ and $\{0, \cdots, 0, p_{d+1}^{s\prime}, \cdots, p_n^{s\prime}\}$. 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 $j \in \{j_1, \cdots, j_d\}$ and $\widetilde{j} \in \{j_{d+1}, \cdots, j_b\}$, yet it remains optimal for $(j, \widetilde{j})$ to stay attached in $\mathcal{A}$. Here person $\widetilde{j}$'s type is not high enough to warrant breaking up a relationship with j and searching by himself in $\mathcal{P}$. There are two types of situations here. Those where person j is willing to engage in a mixing relationship $[\mathbf{a}^m(j, \widetilde{j}) = 1/2]$, and those where she isn't $[\mathbf{a}^m(j, \widetilde{j}) = 1]$. There will be $\alpha \sum_{i=1}^{d} \sum_{k=d+1}^{b} \mathbf{a}^m(j_i, \widetilde{j}_k) \phi_i \ \widetilde{\phi}_k$ people in this situation. The survival rate for these matches is $\zeta(1 - \delta)$. The $\widetilde{j}$'s who are still around will switch to $\mathcal{P}$ after a breakup.

4. Analogously, there may be matches in the old steady state for which $j \in \{j_1, \cdots, j_d\}$ and $\widetilde{j} \in \{j_{d+1}, \cdots, j_b\}$ where it is optimal for $(j, \widetilde{j})$ to move to $\mathcal{P}$. Here individual j's unfavorable view of the net gain from sex with $\widetilde{j}$ is not bad enough to justify terminating her relationship with $\widetilde{j}$ and searching alone in $\mathcal{A}$. There will be $\alpha \sum_{i=1}^{d} \sum_{k=d+1}^{b} \mathbf{p}^m(j_i, \widetilde{j}_k) \phi_i \ \widetilde{\phi}_k$ agents in this position. The survival rate for these matches is $\zeta(1 - \delta)$. The surviving j's will enter $\mathcal{A}$ after a breakup.

5. Finally, there may be some matches $(j, \widetilde{j}) \in \{j_1, \cdots, j_d\} \times \{j_{d+1}, \cdots, j_b\}$ in the old steady state for which it is optimal for the couple to break up. Here, person j will search for a new mate in $\mathcal{A}$ while $\widetilde{j}$ will look in $\mathcal{P}$. There will be $\alpha \sum_{i=1}^{d} \sum_{k=d+1}^{b} [1 - \mathbf{a}^m(j_i, \widetilde{j}_k) - \mathbf{p}^m(j_i, \widetilde{j}_k)] \phi_i \ \widetilde{\phi}_k$ 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 *(Rapid Transitional Dynamics) Upon a once-and-for-all decrease in c, the (non-normalized) type distribution in $\mathcal{A}$ immediately jumps from*

$$\{\phi_1, \cdots, \phi_b, 0, \cdots, 0\}$$

to

$$\{\phi_1 - \alpha \sum_{k=d+1}^{b} \mathbf{p}^m(j_1, \widetilde{j_k})\phi_1\widetilde{\phi_k}, \cdots, \phi_d - \alpha \sum_{k=d+1}^{b} \mathbf{p}^m(j_d, \widetilde{j_k})\phi_d\widetilde{\phi_k},$$
$$\alpha \sum_{h=1}^{d} \mathbf{a}^m(j_h, \widetilde{j_{d+1}})\phi_h\widetilde{\phi_{d+1}}, \cdots, \alpha \sum_{h=1}^{d} \mathbf{a}^m(j_h, \widetilde{j_b})\phi_h\widetilde{\phi_b}, 0, \cdots, 0\},$$

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

$$(16) \{\phi_1 - [\zeta(1-\delta)]^i\alpha \sum_{k=d+1}^{b} \mathbf{p}^m(j_1, \widetilde{j_k})\phi_1\widetilde{\phi_k}, \cdots, \phi_d - [\zeta(1-\delta)]^i\alpha \sum_{k=d+1}^{b} \mathbf{p}^m(j_d, \widetilde{j_k})\phi_d\widetilde{\phi_k},$$
$$[\zeta(1-\delta)]^i\alpha \sum_{h=1}^{d} \mathbf{a}^m(j_h, \widetilde{j_{d+1}})\phi_h\widetilde{\phi_{d+1}}, \cdots, [\zeta(1-\delta)]^i\alpha \sum_{h=1}^{d} \mathbf{a}^m(j_h, \widetilde{j_b})\phi_h\widetilde{\phi_b}, 0, \cdots, 0\}.$$

Proof. See the Appendix, Section 12.1.2. ∎

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-j partner will return to $\mathcal{A}$. These matches are captured by the $[\zeta(1-\delta)]^i\alpha \sum_{k=d+1}^{b} \mathbf{p}^m(j_h, \widetilde{j_k})\phi_h\widetilde{\phi_k}$ terms (for $h = 1, \cdots, d$) in (16). Similarly, some matched individuals will remain in $\mathcal{A}$ because their partner refuses to have a promiscuous match. These high-$\widetilde{j}$ individuals will drift into $\mathcal{P}$ as their matches break up, so long as they survive. The $[\zeta(1-\delta)]^i\alpha \sum_{h=1}^{d} \mathbf{a}^m(j_h, \widetilde{j_k})\phi_h\widetilde{\phi_k}$ terms (for $k = d+1, \cdots, b$) represent this situation.

It is readily apparent from (16) 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 $[\mathbf{a}^m(j, \widetilde{j}) = \mathbf{p}^m(j, \widetilde{j}) = 1/2]$. Whether or not this will transpire depends upon parameter values, etc. This situation occurs in the simulation discussed in Section 9. 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 (16). 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 *(Instantaneous Aggregate Dynamics) Suppose that for all matched pairs* $(j, \widetilde{j})$ *with* $j < \underline{c}$ *and* $\widetilde{j} > \underline{c}$ *it is optimal to mix; i.e., assume that* $\mathbf{a}^m(j, \widetilde{j}) = \mathbf{p}^m(j, \widetilde{j}) = 1/2$ *for all* $j < \underline{c}$ *and* $\widetilde{j} > \underline{c}$. *Then,* $\#\mathcal{A}_t = \sum_{h=1}^{d} \phi_h$ *and* $\#\mathcal{P}_t = \sum_{h=d+1}^{n} \phi_h$ *for all* t.

Proof. Take all matched pairs of a particular type $(j, \widetilde{j})$ with $j < \underline{c}$ and $\widetilde{j} > \underline{c}$. 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 j will go to $\mathcal{A}_{t+1}$ while those of type $\widetilde{j}$ 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.

7   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.

7.1   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)]:

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

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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 the introduction of the latex condom in the 1930s, which dramatically reduced cost and increased quality. Other methods of birth control were also used, such as a variety of intrauterine devices. Casanova mentions using half of a lemon as a contraceptive device. This could have been quite effective since it acted as barrier-cum-spermicidal agent. In 1797 Bentham advocated the use of the sponge to keep down the size of the poor population. The rubber diaphragm entered service around 1890. It was expensive and had to be fit by a doctor. This limited its use to those who were relatively well off. The pill 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.

7.2   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 the fraction of non-users 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. Himes (1963) provides information on the fraction of married females who use different methods in 1930s. Assume that the selection pattern for contraception by young female users during their first premarital intercourse was similar to the pattern selected by married women. If one also assumes that the selection pattern in 1900 was the same as the one displayed in the 1930s (again a conservative assumption), contraceptive use at first premarital intercourse can be constructed for 1900.[9]

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[9] The results are almost identical if instead the 1900 values are set to the ones observed in 1960-1964 for teenage female users. Since the pill was not yet introduced in 1900, for these calculations 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	9.42	21.9	24.0	21.0	22.0	26.7	41.8	36.4	49.9	49.8	51.2
withdrawal	11.19	7.3	9.5	7.3	7.5	8.4	8.9	5.6	3.5	4.9	7.3
other	17.99	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.[10] 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, 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,

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[10] 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.

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 (continuously compounded) decline of about 113 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 (by the line marked 'Data') in the right panel of Figure 3, which presents the riskiness of premarital sex. Even when using conservative estimates for 1900, this riskiness has fallen by (a continuously compounded) 94 percent, from about 72 percent in 1900 to 28 percent in 2002. Now, the series shown in Figure 3 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 3 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 premarital sex.

8 Calibration

Prior to simulating the model, values must be assigned to the various parameters governing tastes, the matching technology, and the type distribution. Towards this end, set up the type distribution, $J(j)$, 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 $\mathcal{J}$. Hence, $J(j)$ will be governed by two parameters, namely its mean, $\overline{j}$, and standard deviation, ς_j. Given this, there are 8 parameters to pick: μ, δ, ζ, β, u, w, $\overline{j}$,

and ς_j. 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] 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_i represent the odds of a teenager being matched i periods down the road. Thus, $1 - \pi_i$ is the probability of being unmatched then. These odds are given by

$$(17) \qquad \begin{bmatrix} \pi_i \\ 1 - \pi_i \end{bmatrix} = \begin{bmatrix} 1 - \delta & \mu \\ \delta & 1 - \mu \end{bmatrix}^i \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \text{ for } i = 1, \cdots, 20.$$

The fraction of a promiscuous teenager's life spent in a sexually active relationship is then $\sum_{i=1}^{20} \pi_i / 20$. Therefore, pick μ so that $0.75 \times \sum_{i=1}^{20} \pi_i / 20 = 0.344$, where it will

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[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 9 will show.

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

[13] Sources: Ryan, Manlove, and Kerry (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.

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*, $\bar{j}$ and ς_j. 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 $c = c_{1900} = 0.2729$, 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, $\bar{j}$ and ς_j, 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 (13) and (14) should be solved while setting $\chi \times \#\mathcal{P}_{1900} = 0.06$ and $\chi \times \#\mathcal{P}_{2002} = 0.75$. The result is $\bar{j} = 0.1450$ and $\varsigma_j = 0.0857$. 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 $J(j)$ distribution, as governed here by $\bar{j}$ and ς_j. 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 $\bar{j}$ and ς_j. Given the setup of the model, there does not seem to be another so-natural criteria for choosing $\bar{j}$ and ς_j. 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 the shape of the $J(j)$ distribution, as was mentioned in Section 5.

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 $w = |\min\{j_1, 0\}| + c_{1900}$. The latter restriction

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[14] According to the calculations in Section 7.2, the risk of pregnancy was 0.7205 per year in 1900 and 0.2843 per year in 2002. If the probability of pregnancy over a year is $\hat{c}$, then take the quarterly probability, c, to be given by $c = 1 - (1 - \hat{c})^{(1/4)}$.

ensures that lifetime utility is always positive.[15]

The model is now ready to be simulated.

9 Social Change: The Computational Experiment

Go back in time to 1900. Premarital sex is dangerous, since a young woman runs a 72 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 premarital sex 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 7.2. 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 8. 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.

9.1 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 2. The horizontal axes simply plot j and $\widetilde{j}$ pairs, or the types for the potential match (where 1 is the lowest index

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[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.

for type, and 300 the highest). The varying heights on the vertical axis denote different matching situations. For instance, the trough in the front reflects the situation where both types' first choice is an abstinent match. The adjacent block on the left reports a mixing situation $[\mathbf{a}^m(j,\widetilde{j}) = \mathbf{p}^m(j,\widetilde{j}) = 1/2]$. Here j would prefer an abstinent match and $\widetilde{j}$ 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 j and $\widetilde{j}$ reversed. These matches were discussed in Points 3 and 4 of Section 6.1. Hence, they won't occur in steady state, since all $j < c$ will be in $\mathcal{A}$ and all $j > c$ will be in $\mathcal{P}$. Since in the figure 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. This turns out to be true. Now, move to the large area in the corner at the back of the figure. This block gives the $(j,\widetilde{j})$ combinations where a promiscuous match is the first choice of both individuals. Note that according to Figure 2, 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.

9.2   Transitional Dynamics

Now, turn to the transitional dynamics. As can be seen from the left panel of Figure 3, the model (marked 'Baseline') has little trouble replicating the rapid rise in premarital sex over the last century. Indeed, Lemma 3 suggests the number of people engaging in premarital sex will response quickly to declines in the cost of sex. Furthermore, given the matching patterns exhibited in Figure 2, the corollary hints that reaction could be instantaneous. Note that the model gives a S-shaped diffusion pattern for the increase in premarital sex, a pattern also visible in data. This is characteristic of technological adoption, here contraceptives.[16]
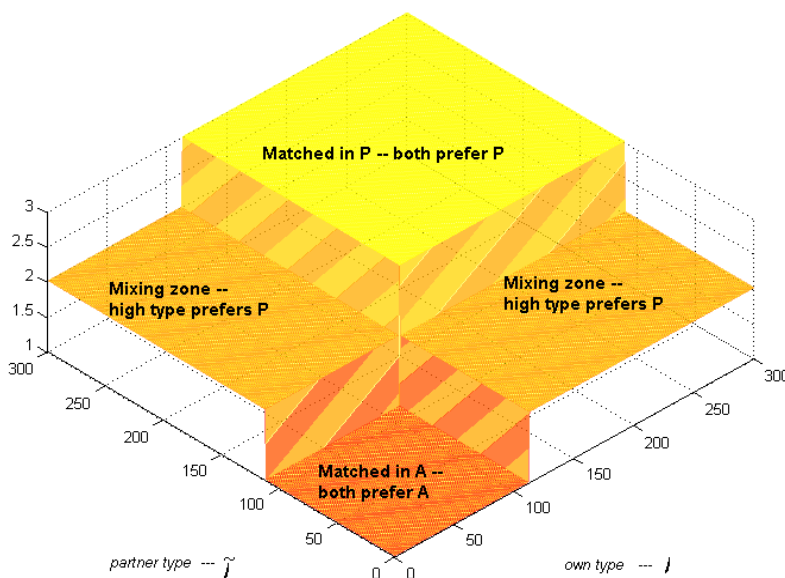
Figure 2: Matching set, final steady state

Observe that the sharpest rate of increase in premarital sex, for both the model and the data, occurs when the drop in the risk of pregnancy is most precipitous (i.e., after 1960). Premarital sex rises faster in the data than in the model, however. This could be due to missing factors, such as the legalization of abortion, introduced in the next section. Still, it's surprising how far the analysis can go without such considerations.

9.3   Abortion

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 the right panel of Figure 4 illustrates. About 56 percent of pregnancies were terminated in 1979. One of the effects

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[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).
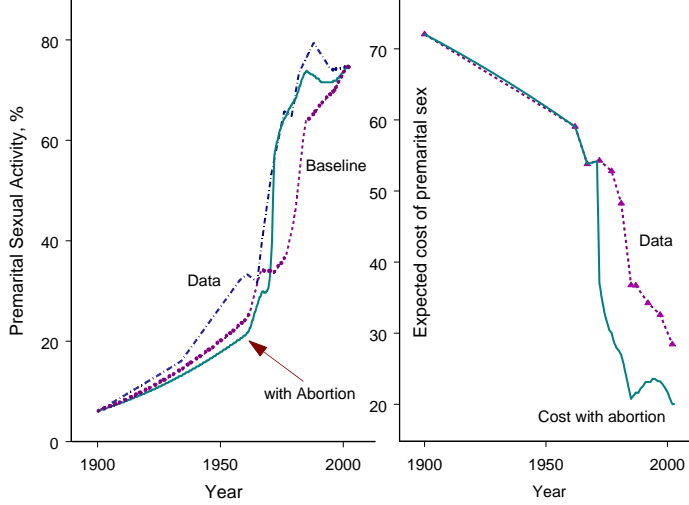
Figure 3: (i) Rise in premarital sex, U.S. data and the model with and without abortion (left panel). (ii) Expected cost of premarital sex (right panel). The line marked 'Data' plots the expected risk of pregnancy (annualized, %) given the effectiveness and use of contraception. The other line shows the expected cost of premarital sex given the availability of abortion.

of the legalization of abortion was undoubtedly to reduce the cost of premarital sex.

The effects of the liberalization of abortion laws will now be incorporated into the analysis. To this end, let ψ_a represent the cost of an abortion and ψ_b denote the cost of an out-of-wedlock birth. The odds of becoming pregnant for a girl engaging in premarital sex are represented by π. Some fraction ξ of these girls will terminate their pregnancies, while the fraction $1 - \xi$ will bear the child. Given this notation, the expected cost of premarital sex, c, can therefore be written as

$$c = \psi_a \xi \pi + \psi_b (1 - \xi) \pi.$$

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

The parameter ψ_a will be picked so that the model does the best possible job in explaining the trend toward premarital sex. The numbers ξ and π are 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, ξ, is presented in Figure

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4, right panel. The empirical procedure picks $\psi_a = 0.0853$, so an abortion is much less costly than an out-of-wedlock birth. Figure 3, left panel, shows the fit. The procedure now picks $\bar{j} = 0.1278$ and $\varsigma_j = 0.0972$. As can be seen, the model does much better once abortion is allowed for. Observe that the risk associated with premarital sex declines rapidly after 1973 due to the legalization of abortion. As a consequence, the number of young females experiencing premarital sex increases more rapidly than in the baseline model. As the number of abortions decline after its peak in 1980, the trend toward premarital sex is dampened vis à vis the baseline 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 baseline model displays a monotonic rise.[17]

Finally, between 1900 and 1970 the number of teenage girls who had experienced premarital sex rose from 6 to 51 percent. The 1973 Roe v. Wade decision cannot explain any of this rise. The model (fitted with abortion) predicts that 34 percent of girls would have engaged in premarital sex in 1970. In 1990 about 72 percent of 19-year-old girls had experienced premarital sex. The model fitted with abortion can be used to make a prediction about this. It forecasts that 66 percent of teenage girls would have had premarital sex when abortion is freely available, versus 51 percent when it isn't ($\xi = 0$). Therefore, abortion explains roughly 23 percent of the predicted value of premarital sex for 1990, or 25 percent of the predicted rise.

9.3.1 Pregnancies

The model generates a prediction on how many teenage girls will get pregnant each period. Figure 4, left panel, 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 as the sum of births, abortions and miscarriages for unmarried females between ages 15 and 19–the exact

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[17] The cost structure can be further modified to include the cost associated with HIV/AIDS

$$c = \psi_a \xi \pi + \psi_b (1 - \xi) \pi + \psi_h \eta,$$

where ψ_h is the cost of contracting HIV and η is the probability of contracting HIV in a sexual relationship. This extension did not significantly improve the model's performance.
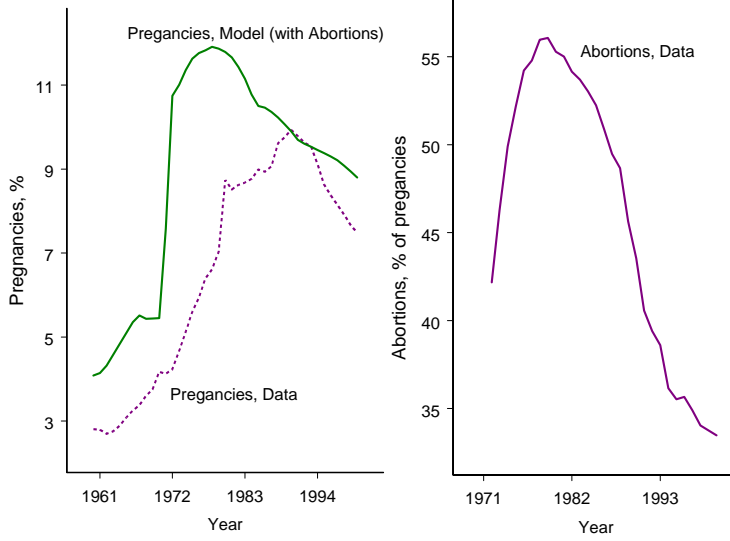
Figure 4: (i) Increase in teenage pregnancies, U.S. data and model (left panel); (ii) The prevalence of abortion in the U.S. (right panel)

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 expected cost of premarital sex. Assume that if a girl is pregnant in a given period, she cannot get pregnant again (whether or not the pregnancy was terminated through an abortion) 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 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 4 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.

9.3.2 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.[18] The upshot of the experiment is shown in Figure 5. As can be seen, the invention of the birth control pill contributed very little to the rise in premarital sex among teenagers. For example, in 2002 it accounted for 1 percentage points out of the 75 percent of girls who had experienced sex by age 19. The reason is simple. The pill is not used by a large number of teenage girls, 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 pretty much the same result. Thus, no particular contraceptive is responsible for the sexual revolution, since there were readily available reasonable alternatives.

9.3.3 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 (17) generates the fraction of teenage 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^i denote the number of matched agents with i sexual encounters by time t and

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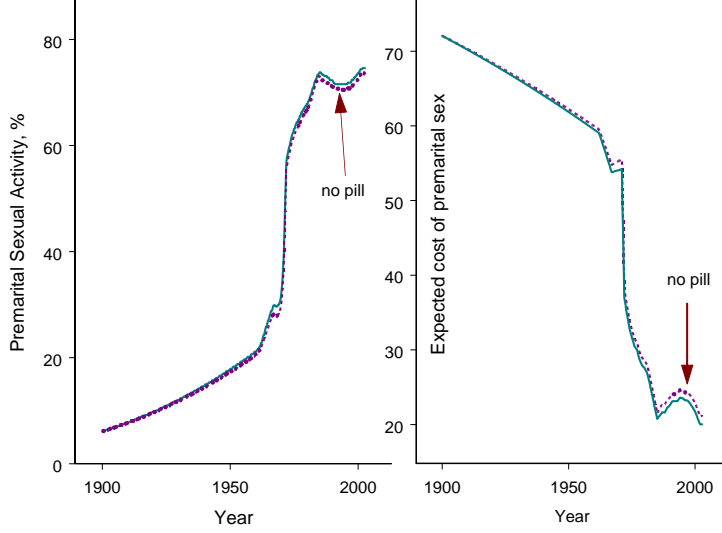[18] Keep $\bar{j} = 0.1278$ and $\varsigma_j = 0.0972$.

Figure 5: The power of the pill

u_t^i represent the number of unmatched agents with i sexual encounters. Then, the number of matched individuals with i sexual encounters in period $t+1$ is given by

$$(18) \qquad m_{t+1}^i = (1 - \delta)m_t^i + \mu u_t^{i-1}.$$

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

$$(19) \qquad u_{t+1}^i = (1 - \mu)u_t^i + \delta m_t^i.$$

An upper bound on the maximum number of partners after T periods of matching is $N = T/2 + 1$. Thus, equations (18) and (19) 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

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over T periods – see the Appendix, Section 12.3, 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.

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 percent of teenage girls and 12.8 percent 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

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[19] Note that the 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.

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   The Frequency of Sex: A Proposed Extension

10.1   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).

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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.

They report a mean frequency of sex for "active" females between the ages of 16 and 19 of 0.5 times per week, or 7.92 times per quarter – Kinsey *et al.* (1953, Table 76, p. 334). This classic study is based on female histories collected over the 1938 to 1950 period. Since the sample consists of women/girls between ages 2 and 71+, the data on premarital sexual experience provides information for the earlier periods as well. So, presuppose that the frequency of sex for teenagers with premarital sexual experience was 7.92 times per quarter in 1900.[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.

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	

---

[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.

10.2 A Framework for Studying Frequency

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

$$(20) \qquad \ln\{\widetilde{j}\exp(\chi f^{\iota}/\iota - \chi/\iota)\} = \ln\widetilde{j} + \chi f^{\iota}/\iota - \chi/\iota, \text{ with } \iota < 0 \text{ and } \chi > 0,$$

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

$$(21) \qquad\qquad\qquad\qquad \widetilde{c} = 1 - p^{f},$$

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

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

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

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

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

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

$$(22) \qquad\qquad\qquad\qquad \chi f^{\iota-1} = -(\ln p)p^{f},$$

and

$$(23) \qquad\qquad\qquad (\iota - 1)\chi f^{\iota-2} + (\ln p)^{2}p^{f} < 0.$$

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 (22) yields

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

The second-order condition (23) implies that the denominator of the above expression is negative. Next see that $-p^{f-1} - (\ln p) f p^{f-1} \lesseqqgtr 0$ 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 (20) the marginal benefit from sex does not depend on the person's type $\widetilde{j}$. 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 (22) 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 (21) 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 $p_{1900} = (1 - 0.2729)^{1/7.92} = 0.9606$. Likewise, in 2002 the odds of not becoming pregnant were $p_{2002} = (1 - 0.0543)^{1/12.71} = 0.9956$. 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 (22) that

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

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

$$\iota = \ln\left[\frac{(\ln p_{2002})(p_{2002})^{f_{2002}}}{(\ln p_{1900})(p_{1900})^{f_{1900}}}\right] / \ln\left(\frac{f_{2002}}{f_{1900}}\right) + 1 = -3.13.$$

Finally, a value for χ can also be backed out from (22). In particular, set

$$\chi = \frac{(-\ln p_{1900})(p_{1900})^{\iota}}{(f_{1900})^{\iota-1}} = 149.39.$$

To summarize given $\iota = -3.13$ and $\chi = 149.39$, the above procedure implies that the first-order condition (22) will return $f = 7.92$ when $p = 0.9606$, and $f = 12.71$ when $p = 0.9956$. The second-order condition (23) 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 $\ln \widetilde{j} = j \in \mathcal{J} = \{j_1, j_2, \cdots, j_n\}$ 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 8, Point 2, results in $\overline{j} = -47.6261$ and $\varsigma_j = 0.1226$.

11   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 (an aggregation of individual behavior) slowly evolves too.

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[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.

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 the expected cost of premarital sex, due technological improvement in contraceptives and their increased availability. 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.

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.[24] This is due to delays in first marriages and remarriages, and a rise in divorce. Historically, the institution of marriage was a mechanism to have safe sex, among other things. As sex became safer, the need for marriage declined on this account. According to Becker (1991, p. 326):

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

An interesting avenue for future research might be to investigate the implications of the contraceptive revolution for marriage and divorce.[25] [26]

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[24] This fact is taken from Greenwood and Guner (2009), and is analyzed from a different perspective there.

[25] 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.

[26] The introduction of infant formula is another example of a small invention having a large impact on household activity. Albanesi and Olivetti (2009) argue that this promoted labor-force participation by married women (in addition to advances in pediatric and obstetric medicine). It could also impact on marriage and divorce.

12 Appendix

12.1 Lemmas

12.1.1 Lemma 1

Proof. Conjecture a solution for the decision rules and value functions in steady state. Specifically, assume that:

(i) $\mathbf{1}^a(j,\widetilde{j}) = \mathbf{2}^{a,s}(j,\widetilde{j}) = \mathbf{1}_s^{a,p}(j) = 1$ and $\mathbf{1}^p(j,\widetilde{j}) = 0$ for all $j,\widetilde{j} \in \mathcal{A}$,

(ii) $\mathbf{1}^a(j,\widetilde{j}) = \mathbf{1}_s^{a,p}(j) = 0$ and $\mathbf{1}^p(j,\widetilde{j}) = \mathbf{2}^{p,s}(j,\widetilde{j}) = 1$ for all $j,\widetilde{j} \in \mathcal{P}$,

(iii) $A^m(j,\widetilde{j}) = A^{m*}(j)$, where $A^{m*}(j)$ is a function, for all $j,\widetilde{j} \in \mathcal{A}$,

(iv) $P^m(j,\widetilde{j}) = P^{m*}(j)$, where $P^{m*}(j)$ is a function, for all $j,\widetilde{j} \in \mathcal{P}$.

This conjectured solution will now be verified.

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 $P^m(j,\widetilde{j}) - A^m(j,\widetilde{j}) = j - c$. Clearly, $P^m(j,\widetilde{j}) - A^m(j,\widetilde{j}) \gtreqqless 0$ as $j \gtreqqless c$. Thus, there is no gain for a matched couple $(j,\widetilde{j})$ $\in \mathcal{P}$ or another one $(j,\widetilde{j}) \in \mathcal{A}$ to switch from their respective social classes.

Now, (i) and (ii) imply that $\mathbf{a}^m(j,\widetilde{j}) = 1$ and $\mathbf{p}^m(j,\widetilde{j}) = 0$ for $(j,\widetilde{j}) \in \mathcal{A}$, and $\mathbf{a}^m(j,\widetilde{j}) = 0$ and $\mathbf{p}^m(j,\widetilde{j}) = 1$ for $(j,\widetilde{j}) \in \mathcal{P}$. Given (i), (ii), and (iii) when $(j,\widetilde{j}) \in \mathcal{A}$ equations (1) and (2) can be represented by

$$A^{m*}(j) = u + \beta(1-\delta)A^{m*}(j) + \beta\delta A^s(j),$$

and

$$A^{s*}(j) = w + \beta\mu A^{m*}(j) + \beta(1-\mu)A^s(j).$$

Clearly, when $(j,\widetilde{j}) \in \mathcal{A}$ then $A^m(j,\widetilde{j})$ is no longer a function of $\widetilde{j}$. This occurs because $\widetilde{j}$ will always desire to remain matched with j and vice versa. Direct calculation reveals that

(24)
$$A^{m*}(j) = \frac{[1 - \beta(1-\mu)]u + \beta\delta w}{\Delta},$$

and

(25)
$$A^{s*}(j) = \frac{[1 - \beta(1-\delta)]w + \beta\mu u}{\Delta},$$

where $\Delta \equiv (1-\beta)\,[1-\beta(1-\mu-\delta)] > 0$. Thus, point (iii) has been shown. For future reference, let an asterisk attached to a function signify its closed-form solution in a steady state, defined only over the equilibrium set of agents that live in the relevant social class. Observe that $A^{m*}(j) > A^{s*}(j)$, as was conjectured, because $u > w$.

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

$$P^{m*}(j) = u + j - c + \beta(1-\delta)P^{m*}(j) + \beta\delta P^s(j),$$

and

$$P^s(j) = w + \beta\mu P^{m*}(j) + \beta(1-\mu)P^s(j).$$

The solutions to these two equations are given by

(26)
$$P^{m*}(j) = \frac{(u+j-c)[1-\beta(1-\mu)] + w\beta\delta}{\Delta},$$

and

(27)
$$P^{s*}(j) = \frac{[1-\beta(1-\delta)]w + \beta\mu(u+j-c)}{\Delta}.$$

It is easy to see that

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

Thus, $P^{m*}(j) > P^{s*}(j)$ when $u+j-c > w$, which will hold for all $j > c$. Therefore, point (iv) has been established.

Conditions (i) to (iv) imply that $P^s(j) < A^s(j)$ for $j \in \mathcal{A}$ and $P^s(j) > A^s(j)$ for $j \in \mathcal{P}$. First, note that in the conjectured steady state $a_i^s = 0$ for all $i > b$ and $p_i^s = 0$ for all $i < b$. Using this observation, subtract (2) from (4) *in steady state* to get

$$
\begin{aligned}
P^s(j) - A^s(j) \;=\; & \beta\mu \sum_{i=b+1}^{n} p_i^s [\mathbf{a}^m(j,\widetilde{j}_i)A^m(j,\widetilde{j}_i) + \mathbf{p}^m(j,\widetilde{j}_i)P^m(j,\widetilde{j}_i)] \\
& -\beta\mu \sum_{i=1}^{b} a_i^s [\mathbf{a}^m(j,\widetilde{j}_i)A^m(j,\widetilde{j}_i) + \mathbf{p}^m(j,\widetilde{j}_i)P^m(j,\widetilde{j}_i)] \\
& +\beta\{(1-\mu) + \mu \sum_{i=b+1}^{n} p_i^s[1 - \mathbf{a}^m(j,\widetilde{j}_i) - \mathbf{p}^m(j,\widetilde{j}_i)]\}\{\mathbf{1}_s^{a,p}(j)A^s(j) + [1 - \mathbf{1}_s^{a,p}(j)]P^s(j)\} \\
& -\beta\{(1-\mu) + \mu \sum_{i=1}^{b} a_i^s[1 - \mathbf{a}^m(j,\widetilde{j}_i) - \mathbf{p}^m(j,\widetilde{j}_i)]\}\{\mathbf{1}_s^{a,p}(j)A^s(j) + [1 - \mathbf{1}_s^{a,p}(j)]P^s(j)\}.
\end{aligned}
$$

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

$$
\begin{aligned}
P^s(j) - A^s(j) &= \beta\mu\sum_{i=b+1}^{n} p_i^s P^m(j,\widetilde{j_i}) - \beta\mu\sum_{i=1}^{b} a_i^s[\mathbf{a}^m(j,\widetilde{j_i})A^m(j,\widetilde{j_i}) + \mathbf{p}^m(j,\widetilde{j_i})P^m(j,\widetilde{j_i})] \\
&\quad + \beta(1-\mu)P^s(j) - \beta\{(1-\mu) + \mu\sum_{i=0}^{b} a_i^s[1 - \mathbf{a}^m(j,\widetilde{j_i}) - \mathbf{p}^m(j,\widetilde{j_i})]\}P^s(j) \\
&> \beta\mu P^{m*}(j) - \beta\mu\sum_{i=1}^{b} a_i^s[\mathbf{a}^m(j,\widetilde{j_i}) + \mathbf{p}^m(j,\widetilde{j_i})]P^m(j,\widetilde{j_i}) \\
&\quad - \beta\mu\sum_{i=1}^{b} a_i^s[1 - \mathbf{a}^m(j,\widetilde{j_i}) - \mathbf{p}^m(j,\widetilde{j_i})]P^m(j,\widetilde{j_i}) \\
&= \beta\mu P^{m*}(j) - \beta\mu\sum_{i=1}^{b} a_i^s P^m(j,\widetilde{j_i}) > 0
\end{aligned}
$$

The first inequality relies on the facts that $P^m(j,\widetilde{j_i}) > A^m(j,\widetilde{j_i})$ and $P^m(j,\widetilde{j_i}) > P^s(j)$ for $j \in \mathcal{P}$. The latter fact is intuitive. Surely, a promiscuous type would prefer to have sex now and search for another partner later as opposed to searching now and having sex later. It is straightforward to establish. The last inequality employs the fact that $P^{m*}(j) > P^m(j,\widetilde{j_i})$ for $\widetilde{j_i} \in \mathcal{A}$. Again this is appealing. A promiscuous type should prefer a partner whose type also lies in $\mathcal{P}$. This, too, is not difficult to prove. Thus, no unmatched $j \in \mathcal{P}$ would want to switch. A similar argument can be made for $j \in \mathcal{A}$.

It is easy to deduce that the above facts established about the value functions support the conjectured decision rules in (i) and (ii). ∎

12.1.2 Lemma 3

Proof. The proof proceeds using the guess-and-verify strategy. To this end, suppose that the value functions $A^m(j,\widetilde{j})$, $A^s(j)$, $P^m(j,\widetilde{j})$, and $P^s(j)$ 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 6.1. The relevant payoffs for j when matched with $\widetilde{j}$, for $j,\widetilde{j} \in \{j_{d+1}, \cdots, j_n\}$, will be given by (26) and (27). Note that when this match breaks up person j will not have to worry about subsequently matching in $\mathcal{P}$ with a $\widetilde{j} \in \{j_1, \cdots, j_d\}$, 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 $\{j_1, \cdots, j_d\}$. Next, focus upon those individuals in the situation outlined by Point 2. Their payoffs will again be described by (26) and (27). Again, if they switch to $\mathcal{P}$ they will not have to worry about matching next period with a $\widetilde{j} \in \{j_1, \cdots, j_d\}$. 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 $j \in \{j_1, \cdots, j_d\}$ and $\widetilde{j} \in \{j_{d+1}, \cdots, j_b\}$. For it to be optimal for j to be matched with $\widetilde{j}$ in this situation in $\mathcal{A}$ it must transpire that $A^m(j, \widetilde{j}) > \max\{A^s(j), P^s(j)\}$ and $P^m(j, \widetilde{j}) < \max\{A^m(j, \widetilde{j}), A^s(j), P^s(j)\}$. First, by subtracting (1) from (3) it can be seen that $P^m(j, \widetilde{j}) - A^m(j, \widetilde{j}) = j - c \gtreqless 0$ as $j \gtreqless c$. Therefore, j's first choice is a match in $\mathcal{A}$, while $\widetilde{j}$'s would be one in $\mathcal{P}$. Now, there are two cases to consider for j. Either she is in a mixing situation with $\widetilde{j}$ [implying $\mathbf{2}^{p,s}(j, \widetilde{j}) = 1$] or she is refusing a promiscuous match all together [$\mathbf{2}^{p,s}(j, \widetilde{j}) = 0$]. Take the latter situation first. The conjecture is that today's value functions will immediately jump to their steady-state values and remain there. This would imply that $\mathbf{1}_s^{a,p}(j, \widetilde{j}) = 1$, $\mathbf{a}^m(j, \widetilde{j}) = 1$, $\mathbf{p}^m(j, \widetilde{j}) = 0$. Using this on the righthand sides of (1) and (2) and solving for $A^m(j, \widetilde{j})$ and $A^s(j)$ results in

$$A^m(j, \widetilde{j}) = A^{m*}(j), \qquad \text{[for } j \leq j_d < j_{d+1} \leq \widetilde{j} \text{ and } \mathbf{a}^m(j, \widetilde{j}) = 1]$$

and

$$A^s(j) = A^{s*}(j), \ \text{(for } j \leq j_d),$$

where $A^{m*}(j)$ and $A^{s*}(j)$ are specified by (24) and (25). Imposing this conjecture on (4) leads to

$$\begin{aligned} P^s(j) &= w + \beta\mu \sum_{k=d+1}^{n} p_k^s[\mathbf{a}^m(j, \widetilde{j}_k)A^m(j, \widetilde{j}_k) + \mathbf{p}^m(j, \widetilde{j}_k)P^m(j, \widetilde{j}_k)] \\ &\quad + \beta(1-\mu)A^{s*}(j) \\ &< A^{s*}(j) < A^{m*}(j) \quad \text{(for } j \leq j_d < j_{d+1} \leq \widetilde{j}). \end{aligned}$$

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

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

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

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

Now, move to person $\widetilde{j}$. For $\widetilde{j}$ to be matched with j it must happen that $A^m(\widetilde{j},j) > \max\{A^s(\widetilde{j}), P^s(\widetilde{j})\}$. Person $\widetilde{j}$ may find himself in one of two situations: either a mixing situation or one where j will refuse a promiscuous match. In the former $\mathbf{2}^{p,s}(j,\widetilde{j}) = 1$, while in the latter $\mathbf{2}^{p,s}(j,\widetilde{j}) = 0$. Take the latter case and suppose that the steady-state solution holds true at some point in time. Here, $\mathbf{a}^m(j,\widetilde{j}) = 1$ and $\mathbf{p}^m(j,\widetilde{j}) = 0$. It is then easy to deduce that $A^m(\widetilde{j},j)$ and $A^s(\widetilde{j})$ are given by

$$
\begin{aligned}
A^m(\widetilde{j},j) &= u + \beta(1-\delta)A^m(\widetilde{j},j) + \beta\delta P^{s*}(\widetilde{j}) \\
&= \frac{u + \beta\delta P^{s*}(\widetilde{j})}{1-\beta(1-\delta)} > A^{m*}(\widetilde{j}) \text{ [for } j \le j_d < j_{d+1} \le \widetilde{j} \text{ and } \mathbf{a}^m(j,\widetilde{j}) = 1],
\end{aligned}
$$

and

$$
\begin{aligned}
A^s(\widetilde{j}) &= w + \beta\mu\sum_{h=1}^{d} a_h^s[\mathbf{a}^m(\widetilde{j},j_h)A^m(\widetilde{j},j_h) + \mathbf{p}^m(\widetilde{j},j_h)P^m(\widetilde{j},j_h)] \\
&\quad + \beta(1-\mu)P^{s*}(\widetilde{j}) \\
&< P^{s*}(\widetilde{j}) < P^{m*}(\widetilde{j}) \quad \text{(for } j_{d+1} \le \widetilde{j}).
\end{aligned}
$$

[Note that $P^m(\widetilde{j},j_h) > A^m(\widetilde{j},j_h)$ for $\widetilde{j}$ and $0 \le \mathbf{a}^m(\widetilde{j},j_h) + \mathbf{p}^m(\widetilde{j},j_h) \le 1$.] Now, an abstinent match cannot occur for any $\widetilde{j} > j_q$ where $q = \arg\max_{i}\{i : A^m(\widetilde{j}_i,j) > P^{s*}(\widetilde{j}_i)\}$. When this is true, there is no incentive for $\widetilde{j}$ to shift from the conjectured strategy. Similarly, it is straightforward to calculate that when there is mixing

$$A^m(\widetilde{j},j) = \frac{u + \beta(1-\delta)(\widetilde{j}-\underline{c})/2 + \beta\delta P^{s*}(\widetilde{j})}{1-\beta(1-\delta)} > A^{m*}(\widetilde{j}) \text{ [for } j \le j_d < j_{d+1} \le \widetilde{j} \text{ and } \mathbf{a}^m(j,\widetilde{j}) = 1/2].$$

As can be seen, mixing will yield $\widetilde{j}$ a higher level of utility than a purely abstinent match when $\widetilde{j} > c$. Mixing cannot occur for any $\widetilde{j} > j_r$ where $r = \arg\max_{i}\{i : A^m(\widetilde{j}_i,j) > P^{s*}(\widetilde{j}_i)\}$.

Individual $\widetilde{j}$ will have no incentive to deviate from the conjectured strategy when this is true.

The situations described in Points 4 and 5 can be similarly analyzed. The reader is spared the details. ∎

12.2 Laws of Motion for the Type Distributions

Recall that the distributions M^a, S^a, M^p and S^p are nonnormalized. Let $\iota \equiv \sum_{h=1}^{n} \sum_{i=1}^{n} M^a(j_h, \widetilde{j}_i)$ represent the number of attached agents in $\mathcal{A}$, while similarly $\lambda \equiv \sum_{h=1}^{n} S^a(j_h)$ is the number of unattached ones. Likewise, the number of unattached people in $\mathcal{P}$ reads $\vartheta \equiv \sum_{h=1}^{n} S^p(j_h)$. The laws of motion for $M^a(j, \widetilde{j})$, $S^a(j)$, $M^p(j, \widetilde{j})$ and $S^p(j)$, which define the operator (12), are given by

$$
(28) \qquad M^{a\prime}(j,\widetilde{j}) = \zeta(1-\delta)\mathbf{a}^m(j,\widetilde{j})M^a(j,\widetilde{j}) + \zeta(1-\delta)\mathbf{a}^m(j,\widetilde{j})M^p(j,\widetilde{j})
$$
$$
+ \zeta\mu\lambda\mathbf{a}^m(j,\widetilde{j})S^a(j)S^a(\widetilde{j})/\lambda^2 + \zeta\mu\vartheta\mathbf{a}^m(j,\widetilde{j})S^p(j)S^p(\widetilde{j})/\vartheta^2,
$$

$$
(29) \qquad S^{a\prime}(j) = \zeta(1-\mu)\mathbf{1}_s^{a,p}(j)S^a(j) + \zeta(1-\mu)\mathbf{1}_s^{a,p}(j)S^p(j) + (1-\zeta)\mathbf{1}_s^{a,p}(j)J(j)
$$
$$
+ \zeta\sum_m \mu\lambda\mathbf{1}_s^{a,p}(j)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]S^a(j)S^a(\widetilde{j}_m)/\lambda^2
$$
$$
+ \zeta\sum_m \mu\vartheta\mathbf{1}_s^{a,p}(j)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]S^p(j)S^p(\widetilde{j}_m)/\vartheta^2
$$
$$
+ \zeta\sum_m \mathbf{1}_s^{a,p}(j)\{\delta+(1-\delta)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]\}M^a(j,\widetilde{j}_m)
$$
$$
+ \zeta\sum_m \mathbf{1}_s^{a,p}(j)\{\delta+(1-\delta)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]\}M^p(j,\widetilde{j}_m),
$$

(30)

$$S^{p\prime}(j) = \zeta(1-\mu)[1-\mathbf{1}_s^{a,p}(j)]S^a(j) + \zeta(1-\mu)[1-\mathbf{1}_s^{a,p}(j)]S^p(j) + (1-\zeta)[1-\mathbf{1}_s^{a,p}(j)]J(j)$$

$$+ \zeta\sum_m \mu\lambda[1-\mathbf{1}_s^{a,p}(j)][1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]S^a(j)S^a(\widetilde{j}_m)/\lambda^2$$

$$+ \zeta\sum_m \mu\vartheta[1-\mathbf{1}_s^{a,p}(j)][1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]S^p(j)S^p(\widetilde{j}_m)/\vartheta^2$$

$$+ \zeta\sum_m [1-\mathbf{1}_s^{a,p}(j)]\{\delta + (1-\delta)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]\}M^a(j,\widetilde{j}_m)$$

$$+ \zeta\sum_m [1-\mathbf{1}_s^{a,p}(j)]\{\delta + (1-\delta)[1-\mathbf{a}^m(j,\widetilde{j}_m)-\mathbf{p}^m(j,\widetilde{j}_m)]\}M^p(j,\widetilde{j}_m),$$

and

(31)
$$M^{p\prime}(j,\widetilde{j}) = \zeta(1-\delta)\mathbf{p}^m(j,\widetilde{j})M^a(j,\widetilde{j}) + \zeta(1-\delta)\mathbf{p}^m(j,\widetilde{j})M^p(j,\widetilde{j})$$
$$+\zeta\mu\lambda\mathbf{p}^m(j,\widetilde{j})S^a(j)S^a(\widetilde{j})/\lambda^2 + \zeta\mu\vartheta\mathbf{p}^m(j,\widetilde{j})S^p(j)S^p(\widetilde{j})/\vartheta^2.$$

Take the law of motion for M^a, as given by (28). The first term represents those currently attached pairs in $\mathcal{A}$ who choose to remain attached there next period. Specifically, there are $\zeta(1-\delta)M^a(j,\widetilde{j})$ surviving matched pairs of type $(j,\widetilde{j})$. Of these the fraction $\mathbf{a}^m(j,\widetilde{j}) \in \{0, 1/2, 1\}$ 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 (28) 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 $\zeta\mu\lambda S^a(j)S^a(\widetilde{j})/\lambda^2$ matches of type $(j,\widetilde{j})$. Out of these pairs the fraction $\mathbf{a}^m(j,\widetilde{j})$ 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 (29), or the law of motion for S^a. The first term represents those who are currently unattached in $\mathcal{A}$ and choose to remain there for next period [i.e., $\mathbf{1}_s^{a,p}(j) = 1$ 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. Recall that j is distributed according to the density $J(j)$. The remaining terms count the number of

failed matches between person j and a prospective partner $\widetilde{j}$, where j decides to search next period for a new mate in $\mathcal{A}$ [implying $\mathbf{1}_s^{a,p}(j) = 1$]. Sometimes two singles, j and $\widetilde{j}$, 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.

12.3 Markov Chain for the Number of Partners

Using (18) and (19) set up a Markov chain as follows:

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

which can be represent more compactly by

$$
p_{t+1} = P p_t.
$$

Note that

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

where

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

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

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

12.4   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 $i + 1$ with a guess from the previous iteration for the time path of M^a, M^p, S^a and S^p, denoted by $\{M_t^{a,i}\}_{t=2}^{T-1}, \{M_t^{p,i}\}_{t=2}^{T-1}, \{S_t^{a,i}\}_{t=2}^{T-1}$ and $\{S_t^{p,i}\}_{t=2}^{T-1}$.

2. Solve the recursions (1) to (4) using this guess. Retrieve the time path for the policy functions associated with these recursions represented by $\{\mathbf{1}_t^{a,i+1}\}_{t=1}^{T-1}, \{\mathbf{2}_t^{a,s,i+1}\}_{t=1}^{T-1}$, $\{\mathbf{1}_t^{p,i+1}\}_{t=1}^{T-1}, \{\mathbf{2}_t^{p,s,i+1}\}_{t=1}^{T-1}, \{\mathbf{1}_{s,t}^{a,p,i+1}\}_{t=1}^{T-1}, \{\mathbf{a}_t^{m,i+1}\}_{t=1}^{T-1}$, and $\{\mathbf{p}_t^{m,i+1}\}_{t=1}^{T-1}$. These are specified by (5) to (11).

3. Calculate new time paths for M^a, M^p, S^a and S^p, or $\{M_t^{a,i+1}\}_{t=2}^{T-1}, \{M_t^{p,i+1}\}_{t=2}^{T-1}$, $\{S_t^{a,i+1}\}_{t=2}^{T-1}$ and $\{S_t^{p,i+1}\}_{t=2}^{T-1}$, using the laws of motion (28) to (31).

4. Check for convergence.

   (a) If norm$(\{M_t^{a,i+1}, M_t^{p,i+1}, S_t^{a,i+1}, S_t^{p,i+1}\}_{t=2}^{T-1} - \{M_t^{a,i}, M_t^{p,i}, S_t^{a,i}, S_t^{p,i}\}_{t=2}^{T-1}) < \varepsilon$ then stop, since a solution has been found.

   (b) If not, then repeat Step 1 using $\{M_t^{a,i+1}\}_{t=2}^{T-1}, \{M_t^{p,i+1}\}_{t=2}^{T-1}, \{S_t^{a,i+1}\}_{t=2}^{T-1}$ and $\{S_t^{p,i+1}\}_{t=2}^{T-1}$ for the new guess.

12.5 Data Sources

- Figure 1

  - left panel, 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 Hoffreth, 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. Left panel – 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). Right panel–number of partners: Laudmann *et al.* (1994, Table 5.5, p. 198).

  - left panel, 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).

  - right panel, number of partners: Laudmann *et al.* (1994, Table 5.5, p. 198).

- Table 1, contraception use at first premarital intercourse: For 1900, see Himes (1963, Table V, p. 345); 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.

- 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 7.2. 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 4,

    - left panel, 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, 15 to 19 years old, 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. The series reported in the paper is based on a simple 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.

    - right panel, abortion: The sources for the abortion numbers presented in this figure are discussed in the data sources for left panel. The ratio of abortions to pregnancies is calculated as the total number of abortions as reported by Henshaw (2004) divided by the total number of pregnancies.

- 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.

- 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.

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