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Can technological change account for the sexual revolution?

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ABSTRACT

By reducing the risk of unwanted parenthood, better contraception reduces the cost of unmarried sex, increasing the value of single life. A simple one-period example suggests this could explain why marriage and birth rates have declined since 1970. We extend the analysis to allow for repeated matching over many periods, modelling the shotgun-marriage, contraception-method and abortion margins. We use US survey data on contraception, sexual activity and family dynamics to calibrate the model to the 1970s; we find that the effects of liberalizing access to contraception and abortion account for 60% of the behavioural shifts associated with the sexual revolution.

KEYWORDS

Two-Sided Search; Divorce; Family; Family Economics; Household Formation; Marriage; Marriage Rate; Premarital; Single Mother; Single Parent; Fertility.

JEL CLASSIFICATION

D10, E13, J12,J13,and O11.

EDITORIAL NOTE

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CAN TECHNOLOGICAL CHANGE ACCOUNT FOR THE SEXUAL REVOLUTION?

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1 INTRODUCTION

In the early 1970s, oral contraceptives were made legally available to unmarried women in the US. Although first approved for public use in 1960, and available to all married women since 1965, the pill was not available to unmarried women in all states until the Supreme Court decision *Eisenstadt v. Baird* in 1972. This technology was much more effective than other existing methods; according to Trussell et al. (1990) the pill reduced "typical-use" pregnancy rates of sexually-active women from 20% annually (condoms/IUD) to 5%. Empirical analysis by Goldin and Katz (2002) and Bailey (2006) has revealed that legal access to the pill had an immediate and profound impact on young women's marriage, fertility and labor-market outcomes.

In this light, it is somewhat paradoxical that unmarried birth rates are much higher now than they were in 1970. According to Ventura and Bachrach (2000), the birth rate to unmarried women in the 20-24 age range rose less than 4% per year in 1970 to nearly 8% in 1994. Together, the decline in marriage rates and the rise in marriage rates generated a share of births to unmarried women that reached 32.6% in 1994; by 2007, 40% of births were to unmarried women [1].

Among births between 1999 and 2002, 77% of those to married women were intended at conception, compared to only 35% of those to never-married. women.[2] This rise in unmarried birth rates from unintended conceptions is particularly problematic for a story in which improved contraception reduces the risk of unplanned parenthood.[3]

A similar trend is seen in the UK, where the unmarried share of births rose 1.6 percentage points in the decade preceding the 1974 NHS reorganization Act, which made all contraceptives available free of charge regardless of marital status. In the following decade, the share rose 8.3 points, 5 times faster. By 1995, the unmarried share of births in the UK stood at 33%, up from 5% in 1960. Most of the non-marital births currently are 'Sole registrations';

[1] For the 2007 figure, see NCHS Data Brief No. 18, May 2009, *Changing Patterns of Non-marital Childbearing in the United States. . .*

[2] NHS Reports No. 51, April 2012: *Fertility of Men and Women Aged 15 to 44 Years in the United States: National Survey of Family Growth, 2006-2010.*

[3] Trends in unmarried cohabitation , while significant, are far from being the whole story; before the 1990s the share of cohabitants among unmarried women in the U.S. was negligible. As late as 1995, only 10% of never-married women aged 18-44 had ever cohabited. Among women aged 20-24, the group most likely to cohabit, only 12% were currently cohabiting. Since then there has been tremendous growth in cohabitation, but even in 2008, only 28% of unmarried births were to cohabiting couples. With regards to parents the situation is even starker: according to GPO (2000) less than 2 percent of children lived with two cohabiting (i.e. non-married) biological parents in 1995. Statistics from Bramlett MD and Mosher WD. Cohabitation, Marriage, Divorce, and Remarriage in the United States. National Center for Health Statistics andVital Health Stat 23(22). 2002. See U.S. CENSUS BUREAU, Current Population Reports P20-563 Fertility of American Women: 2008.

i.e. no father is registered with the birth. These currently account for 30% of all UK births.[4]

In principle, if the elasticity of sexual activity is sufficiently high, then an increase in pregnancy rates can result from a reduced risk of pregnancy per sexually active woman. Abma and Sonenstein (2001) report that the fraction of females aged 15–19 years who have ever had sexual intercourse increased from 30% to 50% from 1971 to 1995. In this paper, we look at more direct evidence of sexual activity of unmarried women and find that, between the late 1960s and the mid 1990s, this nearly tripled. However we saw above that the pill reduced pregnancy rates by a factor of 4, so increased sexual activity alone is not enough to explain the doubling of unmarried birth rates.

Akerlof et al. (1996) (AYK) made the important empirical point that it was the sharp decline in the marriage rate of pregnant women, rather than an increase in the pregnancy rate, that contributed most to the rise in unmarried births in the 1970s. In our empirical section below, we decompose, into 9 different margins, the change in unmarried birth rates between the 1970s and the 1990s and extend the AYK finding: had the marriage rates of pregnant women remained constant, the birth rate to unmarried women would have *declined* 30%.

AYK develop a model of the decline of "shotgun weddings" in which a social norm requiring an unmarried couple to marry on pregnancy is undermined by the introduction of the pill and abortion. This theoretical aspect of the AYK argument would lead one to expect a dramatic decline in the fraction of marriages with a birth within 9 months of the wedding; the fraction has declined, as we show in this paper, but in a modest way, from 11% to 10% of marriages. Moreover virtually all of this decline is explained by composition effects: there is no decline for brides age 25 or younger; in fact the rate doubles for young women with previous children. This suggests that the decline in the marriage rate of pregnant women was driven by the decline in marriage rates more generally.

We propose a simple economic mechanism linking the decline of marriage to the advent of superior birth-control options (i.e. the pill and abortion). The premise is that people enjoy sex, but the prospect of unmarried motherhood would deter unmarried people from participating in the absence of birth control. The advent of better birth-control options reduces the gains from marriage by raising the sexual activity rates of unmarried people. This of course reduces the incentives to marry, whether pregnant or not, as unmarried mothers also benefit from improved birth control.

Can this mechanism generate realistic shifts in the rates of marriage and unmarried births? We first answer this question by developing a simple one-period model in which unmarried people must decide between searching for partners for casual sex or for marriage.

[4] ONS Statistical Bulletin: *Live births in England and Wales by characteristics of mother 2010.*

We find that as the effectiveness of birth control increases, both the unmarried birth rate and the share of births follow a hump shape. As the failure rate of birth control in our example decreases from 20% to 5%, the share of births to unmarried women rises from 10% to 35%, and marriage rates fall from 30% to 10%, echoing the patterns in the US data. To explain the empirical shifts, the economic conditions required are merely a relatively high surplus from unmarried sex and a large penalty for unmarried births.

The most obvious shortcoming of the one-period argument is that neither the value of marriage nor that of unmarried motherhood are modeled, but it is surely the difference between the two that constitutes the penalty for unmarried births. This raises an important question: if the argument is extended to a world with many periods, how well would this mechanism be able to match the changes in each of the contributing factors discussed above? It is not an easy question to answer, because it requires a model of the various margins required to produce an unmarried birth: sexual activity, contraception usage by method, abortion, and of course, marriage.

In Kennes and Knowles (2010), we developed a model in which unmarried birth rates and marriage rates were jointly determined in a directed-search equilibrium. The model allowed people to make their choices over many periods, and kept track of the number of children women accumulate over time. The current model builds on these features, which make it relatively straightforward to parameterize our model to annual data. The earlier paper however abstracted from the sexual-activity, contraception-method and abortion margins and thus could not explore the questions about the roles of shotgun marriage and birth control. These margins do not over-burden the theory with complexity, as it is separable into two components that can be solved separately; the optimal response of the fertility margins to incentives, and the generation of those incentives through equilibrium matching.

Marriages can arise from matchings in the sex market, but matching in the marriage market precludes pre-marital sex, so we can identify the rate of "shotgun" marriages with those marriages which produce children in the first period of the marriage. The choice between markets is critical for the analysis, as the low share of shotgun marriages in the data, combined with the low rate of sexual activity and the relatively high rates of marriage among pregnant women in the 1970s, suggests that only a small fraction of marriages in the 1970s arose from sexual matchings.

We parametrize a "benchmark" version of the model so that women's behavior in the model matches empirical targets drawn from the 1973 wave of the National Survey of Family Growth (NSFG). As is now standard in calibration of search models (cf Andolfatto (1996), Shimer (2005b)), these targets are comprised of transition rates, which in our case are comprised of the average rates of sexual activity, marriage, and births. We also include in the targets the rates of contraception and pregnancy among sexually active women and the rates of abortion and marriage among pregnant women. To construct these targets, we construct, from probit regression estimates, empirical age profiles that are purged of the effects of variables omitted from the model, such as education and cohabitation, and that condition on the number of previous children the women have. To set the effectiveness of different contraception methods we rely on the "typical-use" pregnancy rates reported by Trussell et al. (1990).

We begin with a very simple calibration; women can have at most one child, and only childless women can be active in the markets. If we rule out shotgun marriages and abortion, then we can replicate the result of the one-period model; the advent of the pill reduces marriage rates and drives up unmarried birth rates. When we re-calibrate the 1990s parameters for access to the pill to match usage rates in the 1990s, these effects are similar in size to their empirical analogs. The contraception hypothesis works therefore in a lifecycle context with endogenous birth probabilities and realistic marriage rates.

We then turn to the AYK hypothesis by allowing for shotgun marriages. Unlike AYK, we assume that couples can commit to marrying in the event of pregnancy. We extend the previous calibration for the 1970s so as to match the rate of marriages among pregnant unmarried women. We then carry out a re-calibration experiment analogous to the one above, reparameterizing the cost of contraception and the distribution of match-quality in the sex market, so as to match both the usage rates of the pill (by marital status) and the shotgun marriage rate in the 1995 NSFG. The result is that the marriage rate increases slightly and the sexual activity rate actually declines. This is because the declining value of the shotgun option reduces the value of unmarried sex far more than the impact of the pill can raise it. Our result confirms the problem with taking a simplistic view of AYK, who are forced instead to argue that many women are reluctantly driven into sex by competition for potential husbands.

The problem with generating higher unmarried birth rates from an increase in unmarried sexual activity turns out to be that the analysis so far has abstracted from the sexual activity of unmarried mothers. If these women are shut out of the matching markets, then an increase in the surplus from sex increases the incentive to avoid an unmarried birth. In fact, the data show that sexual activity rates among unmarried women in the 1973 NSFG were much higher for mothers (roughly 70% active, compared to 20% for non-mothers) ; indeed mothers accounted for 49% of the unmarried birth rate in the 1970s, despite their relative scarcity.

We therefore allow unmarried mothers to match in either market. Even when we restrict the model to match the sex, marriage and birth rates of single mothers, the model is now able to generate a significant increase in unmarried birth rates while the shotgun rate declines sharply. The reason is that single motherhood becomes more attractive relative to a shotgun marriage when mothers are allowed to match. All previous analysis of the sexual revolution, with the exception of Regalia and Ríos-Rull (1999), who abstract from sexual activity and birth control, excludes unmarried mothers from the analysis; we find this to be critical. We find that once we allow unmarried mothers to match and have more more children, the calibrated model implies that improved birth control can account for 60% of the sexual revolution: the decline of marriage, the rise in unmarried birth rates, and the decline of shotgun marriage.

Although AYK and Regalia and Ríos-Rull (1999) are the most relevant predecessors of our paper, there have been several other papers that focused on the role of contraception technology in the marital revolution. However, like AYK, these papers abstract from any consideration of the dynamics that arise from repeated fertility and marriage opportunities.Greenwood and Guner (2005) also relies on social norms to model the segregation of young singles into sexually promiscuous and abstinent groups in response to improvements in contraception technology. In Fernández-Villaverde et al. (2013), improved contraception causes the decline of the stigma asociated with unmarried births. Chiappori and Oreffice (2008) analyze marriage and bargaining in a frictionless matching model where women differ in their preferences for children; they show that improved birth-control only makes women better off if it is available to single women.

By including decisions that lead to irreversible outcomes (fertility), this paper, like Kennes and Knowles (2010), contribute to a recent literature on equilibrium search with investment decisions, such as Acemoglu and Shimer (1999) and Burdett and Coles (2001). However by considering the choice between search in the sex and the marriage markets, the current paper also contributes to a new literature on search with a choice between competing markets.

2 EMPIRICAL BACKGROUND

The goal of this section is to document the main empirical points made in the introduction and to provide targets for calibration. These empirical points include the decline of marriage rates, and the rise in unmarried women's sexual activity and the rate of births to unmarried women, as well as contraception methods. We will use several waves of the National Survey of Family growth to provide a statistical description of the changes between the 1970s and 1990s in terms of contraception and sexual activity of unmarried women, beginning with a highly aggregate approach, and then proceeding to decompose the changes over time by the number of children the women already have. Of course all of these changes have been described in other publications, but for our purposes, as this section demonstrates, it is important to measure the changes conditional on age and education, as the distribution of these variables changes both over time and by marital and parental histories. There are two reasons that we need bespoke statistics, rather than previously published results. First, our theoretical analysis excludes the effects of aging and of education, so we would like to analyze empirical analogs in which these effects have been removed. Second, in order to model the consequences of unmarried births, it would seem essential to consider the behavior of women after these births occur.

2.1 The NSFG samples for 1973 and 1995

In what follows analysis of the US population is often based on our computations from the National Survey of Family Growth (NSFG), a national survey of women aged 15-44. In each wave women are asked retrospective questions about contraception use and sexual activity. Complete birth and marital histories are collected as well.

We mainly rely on two waves, 1973 and 1995. It should be noted that single women are only included in the NSFG 1973 wave if they were previously married or are cohabiting with an own child. For some of the analysis in this section, we can repair this omission. We reweigh the survey by using the 1970 Census to account for these excluded women, grouping them into cells by age and education level, so that the proportions of these women in each cell match the 1970 census. The details of this procedure are in the appendix.[5] Obviously this will not allow us to construct representative samples for statistics that are not available in the census, but is useful for tracking variables such as education, marriages and births.

The means of our samples, by marital and parental status are reported in Table X. It is immediately apparent that important variables such as age, education and whether a woman was previously married vary widely across the four categories we report. We consider both education and aging outside the scope of this study, but as it is clearly an important correlate of the behavior that we analyze, we will follow a simple two-part strategy for most of our analysis. We focus the analysis on describing, as we did in the introduction, the aggregate changes that motivate the paper. However we also present the results of a probit analysis in which age, number of children, education, cohabitation and previous marriages are included as controls. The tables of estimates will be relegated to the appendix; the discussion will rely instead on age profiles in which the estimated effects of education etc have been removed. In this way we hope to show that the aggregate facts are not driven solely by changes in the

[5]We also show there that the distribution over single moms by age and education was stable between the 1970 census and the 1973 wave of the March CPS.

distribution of age, education, cohabitation or history of the different categories of women in the sample.

2.2 Birth Rates and the "decline" of Shotgun marriage.

Ventura shows that the fraction of births accounted for by births to unmarried mothers increased in the US from about 5% in 1940 to 35% by 1999. How seriously should we take this change? If it is just that couples who have decided to live together and raise children are less likely to formally marry? In Table 1 we show the change in the unmarried share of births to 1995 along with other measures of family decline: the fraction of children living with single mothers has increased 69% over the period [6], the fraction of mothers who are unmarried rose 127%, and the fraction of children living with both parents declined 24%[7].

Table 1 also suggests that the rise in the unmarried share is not just an artifact of declining marriage rates: the birth rate to unmarried women increased from 2.7% in 1970 to 4.6% in 1995. In Table 2 we decompose the change into the effect of rising birth rate and of rising population share of unmarried women. In the first two columns of the first three rows we show statistics from Ventura : the fraction of women married, the birth rate to married women, and the birth rate to unmarried. In rows 5 and 6 we show, for each year, the unmarried birth share; in row 5 the share implied by the statistics in the upper rows, and below the share reported by Ventura. There is some discrepancy, presumably to do with the original data sources being based on different samples, but the unmarried share in the two rows are similar. In the rightmost three columns we show the effect of holding constant two of the determining factors at the 1970 level and setting the third to the 1995 level. The message, as shown in Row 7, is that on its own the birth rate accounts for 22% of the rise in unmarried share of births; this is dwarfed however by the contribution of the married share which accounts for 45%. Alternatively we can ask how much smaller is the increase if hold constant only the variable of interest. The results are in Columns 6-8; holding the unmarried birth rate constant the increase in the share is 44% smaller, and holding the married fraction constant, 69% smaller. We conclude therefore that the birth rate plays an important role, even though the decline in marriage plays a larger one.

As Akerlof et al. point out, most of the increase in the unmarried birth share, at least to 1980, can be attributed to the decline of "shotgun" marriages; those that were realized after the conception of a child, as measured by the rate of marriages in which a baby is born less than 9 months later. In Table 3 we decompose the change in unmarried birth rates to assess the role of these shotgun marriages. The table uses mainly previously published statistics;

[6] *Living Arrangements of Children Under 18 Years Old: 1960 to Present.*

[7] Author's computations from Census 1970/2000

the sources are given in the table[8].

We suppose there are two contraceptive methods, with associated pregnancy rates π_1 and π_2 and usage rates p_1 and p_2, respectively. Empirically, we associate these with highly-effective methods such as the pill and the IUD, versus older, less effective methods such as the condom and the diaphragm. The pregnancy rate of sexually active non-contracepting women is π_0. Let the probability an unmarried woman is sterile be p_s and that a non-sterile woman is sexually active p_x. Let the probability a pregnant unmarried woman has an abortion be p_A and the probability that she marries instead by p_M. The unmarried birth rate π^B can therefore be written as

$$\pi^B = (1 - p_s)\, p_x \left[\pi_0 \left(1 - p_1 - p_2\right) + p_1\pi_1 + p_2\pi_2\right] \left(1 - p_A - p_M\right)$$

The bottom row of Table 3 consists of the unmarried birth rate, as computed from the statistics in the higher rows using the equation above. For the 1970s and 1990s columns the computed birth rates turn out to be close to the reported means. The remaining rates were computed while holding constant one of the variables from the equation. Thus in Column 3 we learn that holding the sexual activity rate constant would have caused a 40% decline, to 0.015, in the unmarried birth rate, despite the fall in the shotgun-marriage rate, because of the increased usage of more effective contraception. Holding the shotgun rate constant on the other hand would have resulted in a 22% decline. In terms of understanding the birth rates therefore it is the rise in unmarried sex that is the big player, not, contrary to AKYs findings for the 1980s, the shotgun rate.

Finally, it is important to assess how important the shotgun marriages are relative to marriages as a whole. For this exercise we draw on the NSFG samples for 1973 and 1995. According to the survey design, the sample of married women is representative of age 15-44 women in the U.S.. We count the marriages in which a child was born less than 9 months after the marriage; this is easily computed on the sample of married women who gave birth during the period of interest, using the variables for month of marriage and month of birth. We express this as a fraction of the number of women who married during the period of observation, excluding marriages that occurred less than 9 months before the interview date. The results are quite startling. First the fraction of marriages accounted for by shotgun marriages is about 18% in the 1970-73 period, but the decline is quite small; in the 1995 the rate is 14%. Second, when we divide the sample into old and young, and mothers versus non-mothers, we find that the shotgun share declines for only one cell: mothers older than

[8]For 1970 it was necessary to conjecture the rates of contraception usage and sexual activity for unmarried women; this was done on the basis of results from the NSFG, as described below. We also assume that the sterility rate in 1970 was the same as that measured in 1995.

age 25. Virtually all of the modest decline in the shotgun share of marriages is accounted for by the fact that brides are older now and more likely to have had a previous child. This suggests a relative stability of the role of the "shotgun norm" relative to marriage and single-birth trends, contrary to the AYK hypothesis.

This does not rule out shotgun marriages playing an important role in understanding the rise in the share of unmarried births, but the role of rising sexual activity plays a much stronger role in understanding birth rates, and and the decline of marriage is even more important than the rise in birth rates. The adoption of improved contraception has a strong, direct and contrary effect by reducing birth rates, so the other factors must sum up to a powerful force of change indeed.

2.3 Sexual activity and contraception

Because the 1973 NSFG is not representative of the US women in the age 18-44 range, we first consider the 1982 wave of the NSFG, where the sample is representative. Unfortunately, most of the sexual activity information in the 1982 wave only goes back three months. However women in the sample do report the age at which they first had sexual intercourse and also how many months elapsed from that date to their first marriage. This allows us to compute the fraction of women who first had sex while unmarried, by the age at which sexual intercourse first occurred. We classify sex as married sex if it occurred less than three months before the first marriage and unmarried sex otherwise. Because the NSFG sample is so large in 1982 (7969 women), we can split the sample into one-year age groups and report the fraction of women who had had unmarried sex by a given age.

Figure 1 reveals a rapid transition in sexual experience in the years 1967-1971; over the course of the entire sample, the fraction of women having had sex by age 18 nearly tripled, rising from 20% for women older than 33 years to about 55% for 19-year olds. The problem with this statistic is that it is not a direct measure of sexual activity rates, but if we think of the age at first intercourse as the onset of more or less continuous sexual activity, then this suggests a rapid rise in the sexual activity of unmarried younger women.

Comparing singles who are in the 1973 NSFG with the comparable population in the 1995 NSFG confirms that this increase in sexual *experience* is echoed by an increase in sexual *activity* of previously married women. In addition we can observe a sharp increase in the fraction of singles using highly effective ("safe") contraception methods, mainly the pill and the IUD. While the 1995 wave is designed to be representative of the US population as a whole, the 1973 wave excluded never-married women with no cohabiting own children.The sample design implies that we are limited to considering two classes of unmarried women in

1973: those who have been previously married and those with children.

In the 1973 survey we measure sexual activity from an interval-level variable that gives the number of months without sex in the interval. [9] To construct the sex activity measure, we compute the ratio of months without sex to the number of single, non-pregnant months in an interval; the sex variable equals 1 minus this ratio. Since this is a proportion, rather than an indicator, we then estimate our standard model by OLS.

For the 1995 survey, we have two sources of information; for each interval, we have the start/end dates for up to four periods of sexual inactivity per interval, and we also have a list of all male sexual partners over the last 5 years, along with the dates of the relationship. We measure inactivity as the sum of months in an inactive interval plus months not in recorded sexual relationship. This provides a lower bound on the number of months that an unmarried, non-pregnant woman is having sex.

In the sample-means table, it is clear that the sexual activity rate was on average much lower in the 1970s for unmarried women without children in the NSFG sample; 31% reported being sexually active in a given year, compared to 76% of unmarried women with children and 98% for married women. By 1995, 75% of unmarried women without children were sexually active in the past year, nearly 2.5 times the rate of the 1970s sample. If the women omitted from 1970's sample were less likely to be sexually active than the unmarried women in the sample then what we have here is a lower bound on the increase in sexual activity rates of these women. Of course the composition of this cell has also changed over time. They are older, 24 years instead of 21 on average, and more educated; 86% have finished high-school, compared to 67% in the 1970s and 54% attended college, compared to 29%. To see whether the apparent changes in sexual behavior go away after controlling for such variables, we now turn to a probit analysis of for sexual activity of unmarried women.

We estimate probit regressions by month for sexual activity (1995) and the use of contraception. The explanatory variables include indicators for whether the woman is cohabiting, whether she was previously married and whether she graduated from high school, attended college or attained a bachelor's degree.[10] The estimated coefficients, which are shown in Table AX in the appendix, are then used to construct predicted age profiles for each time period, holding constant education and other characteristics. In the left-hand panel of figure 3(a) we show the predicted age profiles for 1970-73 and 1990-95 for sexual activity of

[9] An interval can be of two types: "pregnancy" and "open"; the latter refers to the time elapsed since the last pregnancy if any. Pregnancy intervals are the time between the ending dates of each pregnancy.

[10] The 1973 wave does not record whether the respondent is attending school, nor her eventual attainment. Instead we know her years of schooling completed. We assume she is not attending if her age exceeds years of schooling by 6 years or more, while we use thresholds of 12 and 16 years as proxies for high-school graduation and attainment of a bachelors degree, respectively.

non-cohabiting, non-college women with no previous children or marriages. It is abundantly clear that there has been a radical shift in sexual activity of these women; the age profiles are quite flat and shift up from about 20% in 1970-73 to 80% in 1990-95. This picture of radical change in sexual behavior is entirely absent in the right-hand panel, which shows the sex profiles for single mothers. These women had high rates of sexual activity, around 80%, in both the 1970s and the 1990s.

We conduct a similar analysis for the use of contraception. We see in the sample-means table that contraception use increased dramatically for non-mothers. in 1969-72 only 16% of the unmarried non-mothers in the sample women were using the pill; by 1995 this had doubled to 32%. Even more than in the case of sexual activity, this is likely to be a lower bound on the increase, since the excluded women are likely to using the pill at a much lower rate; women who were previously married having had better access to the pill. A similar pattern holds for whether women were using contraception at all; in 1969-72, 49% of unmarried non-mothers were not using any reasonable method; this had fallen to 24% by 1990-95.

Again, Figure 4(b) shows the rise in contraception use for these women is robust to controlling for age and education. Indeed the change is even more dramatic; for women without children, the safe-method profiles shift up from 10% in 1973 to 40% in 1995 while the no-contraception profile, evaluated at age 25, shifts down from 60% to about 30%. For single mothers on the other hand, the changes are smaller, a rise from around 35% to 50%.[11]

2.4 Marriage and Birth Rates

The average marriage rates in Table 4 do not vary very much; 11% annually for non-mothers in 1969-72, falling to 8% in 1990-95, while for mothers the rates are 9% in the earlier period, falling to 8%. Birth rates decline modestly for married women (from 22% to 17%) and single mothers (from 8% to 6%), but the dramatic change is of course those of unmarried non-mothers, which more double, from 1.6% to 3.5% These are annual rates per single woman, and so the averages maybe misleading because the composition of the singles pool varies across the 4 samples of singles, as discussed earlier. In Figure 6 therefore we compare age profiles of marriage and birth rates for unmarried women.

They show marriage rates for non-mothers have declined sharply; at age 25, the predicted

[11]The profiles for pill use and not contracepting (not shown) yield a similar story. For single mothers, the fraction using the pill did increase, but only by about a third, from 30% to 40%, at age 25, while the fraction not using contraception declined slightly from about 35% to about 30%. An interesting difference between the two types of single women is that the role of other safe methods is more important for single mothers; this is due to the rise of female sterilization as a contraception method. Presumably this method is more appealing to women who already have children because they are less likely to want children in the future.

marriage rate for a woman without college education fell from 24.4% in the 1973 NSFG to 13% in the 1995 wave. However, if the woman already had a child, then the changes over time are much less pronounced: the marriage rate at this age declines from 12% to 11% and in fact for all higher ages is actually higher in the 1990s.

The predicted birth rate for non-mothers at age 25 rose more than the average: from 2% to 5.5%, an increase of roughly 170% of the initial rate. The response of single mothers is more muted and of the opposite sign: birth rates fell from 17% to 11%, a decline of about 55%. Note that the contrast in unmarried birth rate responses of mothers and non-mothers is exactly what one would expect under our hypothesis if sexual activity rates for women with children was already very high before they had improved access to more effective birth control.

For married women, we also report in the appendix (Figure A2) the profiles for birth rates, as in Kennes and Knowles (2010). We see that married birth rates are strikingly uniform between periods and whether there is a previous child, declining in all cases from around 25% when the wife is in her early 20s. Of course in families with two children the birth rates are much lower, about 11% in both years.[12]

It is perhaps worth stressing that the method of this section controls for shifts in both cohabitation and education, as well as for the shift in age differences between women with and without children, features of the data that are apparent from Table 1. Overall the marital transition appears to be reflecting changes in behavior of women without children; the relative stability of single-mother behavior is a challenge for models of fertility and marriage that was first identified in Kennes and Knowles (2010).

3 EXAMPLE

Before proceeding to the main model, we present an example to illustrate the mechanism by which contraception technology influences birth rates for unmarried women. The example also shows how the payoff probabilities for men and women depend on the participation rates in the sex market, which in turn are going to depend on the opportunity costs for each sex, most obviously the benefit of pursuing more stable relationships that lead to marriage.

[12]The stability of marital fertility is consistent with the fact that that married birth rates declined slightly over the period, from 9% to 8% annually, according to Ventura and Bachrach (2000), because of the rising education levels of women; more educated women have lower birth rates, but in this paper, we abstract from variation in education levels.

3.1 The matching model

The economy lasts one period and is comprised of 2 continua, each of unit mass, of identical singles of each sex, M, W. There are two markets for matches between agents of the opposite sex; the sex market and the marriage market. Men pay a deterministic participation cost $\gamma > 0$ to join either market, while women pay an iid stochastic cost ξ_F , with CDF $F(\xi_F)$, to enter the sex market.

The timing of decisions in the example is as in Figure 6, except that in the example there is only one period. At the start of the period, markets open and women learn how much it would cost to enter the sex market. Having chosen a market, men and women then learn whether they are matched. Those who are matched in the sex market have sex, which entails a risk of having a child outside of marriage.

Each market operates according to the urn-ball mechanism: the men in each market are allocated randomly to the women. Let the number of agents of sex s in each market n be N_s^n . Define the "queue length" or "market-tightness" as $\phi_n \equiv N_M^n / N_W^n$.

The surplus from matching is parametric: it is equal to S^m should the match occur in the marriage market, and S^x should it occur in the sex market. The allocation of the surplus is determined by a second-price auction mechanism: women auction the match to the men: for women who have one suitor, the entire surplus is awarded to the husband, while those women with more suitors get the surplus. The urn-ball mechanism implies that the probability a woman has z suitors is given by $\omega_z(\phi_n) = \frac{(1+z)\exp(-\phi)}{z!}$. A woman has no suitors with probability $\omega_0(\phi) = e^{-\phi}$, is matched with probability $1 - \omega_0(\phi) = 1 - e^{-\phi}$, and has more than suitor with probability $1 - \omega_0(\phi) - \omega_1(\phi) = 1 - (1 + \phi)e^{-\phi}$.

In the sex market, a matched couple has sex and creates the surplus S^x. The man is awarded the surplus with probability$p^x(\phi_x) \equiv \omega_0(\phi_x)$, conditional on participation, while the probability that it is awarded to a woman, conditional on participation, will be designated $q^x(\phi_x) \equiv [1 - \omega_0(\phi_x) - \omega_1(\phi_x)]$. In the marriage market, a matched couple is allowed to marry with probability π_z. Therefore a man is awarded the surplus with probability$p^m(\phi_m) \equiv \omega_0(\phi_n)\pi_z$, conditional on participation, while for a woman, the probability is $q^m(\phi_m) \equiv [1 - \omega_0(\phi_m) - \omega_1(\phi_m)]\pi_z$.

3.1.1 Optimality Conditions

If each market is active, then the indifference condition below must hold for men:

$$p^m(\phi_m) S^m = p^x(\phi_x) S^x \tag{1}$$

Assuming that men are in excess supply implies that men who prefer not to participate in the sex market will be indifferent between participating or not in any active market:

$$\begin{aligned} p(\phi_m) S^m - \gamma &= 0 \quad (2) \\ p^x(\phi_x) S^x - \gamma &= 0 \quad (3) \end{aligned}$$

The indifference condition for women is

$$q(\phi_x) S^x - \xi_F = q(\phi_m) S^m \quad (4)$$

.

3.1.2 Equilibrium

A matching equilibrium consists of two queues $\{\phi_m^*, \phi_x^*\}$, and a sex-participation threshold ξ_F^* such that the economy satisfies the above optimality conditions and a resource constraint. The resource constraint is that the demand for women equals the supply, which can be written as $N_W^x + N_W^m \leq 1$.

Using these conditions, it is easy to show that, so long as men are in excess supply, the queue and the mass in the sex market will increase together in response to an increase in S^x or a decline in S^m. Using (2)

$$p(\phi_m) = \frac{\gamma}{S^m}$$

. Similarly, using (3) we have:

$$p(\phi_x) = \frac{\gamma}{S^x}$$

. Using the definitions of the surplus probabilities, we can solve for the queue length in the each market:

$$\begin{aligned} \phi_m^* &= \log \frac{\pi_z S^m}{\gamma} \quad (5) \\ \phi_x^* &= \log \frac{S^x}{\gamma} \quad (6) \end{aligned}$$

. Now using (4) :

$$\xi_F^* = q(\phi_x^*) S^x - q(\phi_m^*) S^m \quad (7)$$

, which implies a unique value for ξ_F^* , so the mass of women in the sex market is $F(\xi_F^*)$, and that of men $F(\xi_F^*)\phi_x^*$.

Combining all three expressions gives:

$$\xi_F^* = q\left(\log\frac{S^x}{\gamma}\right)S^x - q\left(\log\frac{\pi_z S^m}{\gamma}\right)S^m$$

The function q is strictly increasing: as the surplus from sex increases the participation rate of women in the sex market will increase, and the marriage rate will decline.

3.2 Birth Control

So far we have ignored the determination of the surplus S^x. We now put some structure on this by assuming that the birth of a child to an unmarried woman entails a benefit ΔV that may be positive or negative. We let the probability of a birth, conditional on unmarried sex, be π_s^B and the utility from sex be u^x; the surplus is $S^x(\Delta V) \equiv u^x + \pi_s^B \Delta V$. We set $\Delta V < 0$; this means we can interpret π^B as the failure rate of the birth control technology. Therefore a decline in π_s^B would make women more likely to participate in the sex market.

First note that since we are assuming only matched women have sex and therefore can give birth, the observed birth rate to unmarried women in the model is:

$$c_s(\phi_m^*, \phi_x^*, \xi_F^*) = \frac{F(\xi_F^*)(1-\omega_0(\phi_x^*))\pi_s^B}{F(\xi_F^*) + (1-F(\xi_F^*))\omega_0(\phi_m^*)} \tag{8}$$

. Let π_m^B be the conditional birth rate to married women. We can think of the difference between the two conditional rates as reflecting birth-control responses to different incentives to avoid births; this will be developed more explicitly in the full model.

The share of births accounted for by single women is

$$\frac{F(\xi_F^*)(1-\omega_0(\phi_x^*))\pi_s^B}{(1-F(\xi_F^*))(1-\omega_0(\phi_m^*))\pi_m^B} \tag{9}$$

. Obviously if the equilibrium objects $(\phi_m^*, \phi_x^*, \xi_F^*)$ were all held constant, both the unconditional birth rate and the share of unmarried women would be increasing in π_s^B. In equilibrium however, the response of ξ_F^*, as given by (7), makes it difficult to determine from expressions (8) and (9) whether the share will rise or fall with an increase in π_s^B. We now turn therefore to a numerical evaluation of expressions (8) and (9), using the equilibrium conditions (5),(6) and (7), to determine $(\phi_m^*, \phi_x^*, \xi_F^*)$.

3.3 Unmarried births and the decline of Marriage

In Figure 7 we show some numerical results for this example, all plotted against the birth-control failure rate π_s^B , which is set to range from 0.01 to 0.2, so as to include the range from the averages for the Pill (0.05) to the average for condoms (0.15) and diaphgrams (0.20) . The parameter values of the model, shown in Table 6, were selected in order to generate a range of variation similar to the annual rates observed in the US data for the 1970s and 1990s, as summarized in Tables 2 and 3.

Panel (a) shows the unmarried share of births, which follows a hump shape, declining from 45% to zero, and increasing only in the neighborhood of $\pi_s^B = 0$. Doubling the standard deviation of the sex cost distribution, from 0.5 to 1.0 results in a less-responsive series, but the share still declines below 10% for a failure rate of 20%, which is roughly the average for condoms and diaphgrams. Panel (b) shows that this pattern is similar to that of the unmarried birth rate.

The unmarried birth rate, shown in Panel(b), follows a similar hump-shaped pattern, declining from from 4% to zero, or in the case of the high-variance series, to 7.5%. Panel (c) shows a rapid decline in the female rate of unmarried sexual-activity , from 60% to zero; this is clearly the force driving the paradoxical decline of unmarried births. The marriage rate, also shown in Panel (c), increases from about 10% to 30%. Panel (d) shows that the aggregate birth rate is essentially stationary over the range in which contraception effectiveness increases the unmarried share of births.

The key features of the parameterization that generate declining participation rates in unmarried sex are a large value of the enjoyment of sex ($u^x = 8$), relative to the marital surplus ($S^m = 5$), and an offsetting strong distaste for unmarried births ($\Delta V = -20$). [13]

We conclude from this example that improved birth control can indeed account for the main facts that motivate this paper: the rise in the unmarried share of births and the decline of marriage. The model was also successful in explaining the rise of the unmarried birth rate;

[13]The other parameter values are : male participation cost $\gamma = 1$ and log sex-cost distribution $N(1.0, 0.5)$. The married birth rate is set to $\pi_m^B = 0.2$ to approximate the birth rate of married women without children in the 1960s. In order to reduce marriage rates to the empirical target, we set the matching friction $p_z = 0.5$.

the magnitude ranged from .01 to 0.04, similar to the empirical averages in Table 1.

It is not clear how plausible is the value of $|\Delta V|$ required for the story to work. In a dynamic setting, the effect of an unmarried birth on continuation values is determined by marriage probabilities which is likely to depend, through equilibrium considerations, on the fertility behavior of both married and unmarried women. In Kennes and Knowles (2010), we argued that the strong negative association in the 1970s between marriage rates and unmarried motherhood generated incentives that may have been strong enough to explain the lower rates of unmarried fertility that were then prevalent. This suggests using observed marriage rates for single mothers to restrict the value of ΔV in a dynamic model of marriage.

Another crude simplification in the example was that unmarried sex precludes marriage, but in real life there is no reason to believe this is the case. [14]The example also abstracts from the possibility of abortion, and from the choice of birth-control methods. In the model developed below, we deal with all of these concerns.

4 THE MODEL

The population of agents consists of infinitely-lived adults, with a continuum of each sex denoted by $\{M, F\}$ and mass N_M and N_F. Women are of sex F and may produce up to $K > 0$ children. There are three types of households; single males, single females, and married couples. "Marriage" is defined as a match that lasts more than one period. Married adults live together as husband and wife with all the children ever born to the female spouse. Let k be the number of kids a woman has, and, in a married-couple household, let $k_m \leq k$ be the number of the husband's biological (own) kids.

Agents can be either matched with men or unmatched. Each period, matched women are assumed to have sex. Married women are matched by definition, while singles participate in either of two matching markets: the "sex market", and the marriage market. [15] Marriage can ensue from matches in either market, but only in the sex market is pre-marital sex possible. When matches are formed in the sex market, sexual activity will occur regardless of whether marriage ensues. Women with $k = K$ are not permitted to participate in either market. The timing of participation decisions is as in Figure 6.

Life is divided into two discrete phases; active, and inactive. Children are born to active women who are matched with men and have fewer than K previous children, at rates that

[14]Note that our fourth motivating fact, the decline of "shotgun marriage", was identified by Akerlof et al. (1996) as the main "cause" of rising unmarried births; this margin though is entirely absent in the example.

[15]The term market as used here is an abstraction that is not intended to imply payments for sex or marriage partners. The idea, in the spirit of Gary Becker's work on marriage, is that the equilibrium allocations depend on the demand and supply of partners.

are determined endogenously each period. During the active phase, unmarried agents can match either for casual sex or to form marriages. Households exit permanently from active status, i.e. "become sterile" with probability δ each period. They are replaced by an equal inflow of active unmatched agents, consisting of equal numbers of men and child-less women. The population of singles therefore consists of new entrants and older agents who were single last period.

4.1 Preferences

Utility within matched couples is perfectly transferable. Each period, each household type generates an exogenous utility flow. These are designated u_{SM}, $u_{SF}(k)$ and $u_M(k, k_m)$, for, respectively, single males, single women and married-couples. Sex between unmarried couples generates additional utility u^x.

The critical assumption is that children generate more utility within a marriage than without:

$$u_{SF}(k+1) - u_{SF}(k) < u_M(k+1, k_m - 1) - u_M(k, k_m)$$

. Parents get less utility from step children than from their own children, so that an additional child within a marriage raises the father's utility more than a pre-existing child would. To avoid additional complexity, we assume that children outside the household do not enter the parent's utility function.

Newly matched couples learn the value of their match quality, a one-period utility shock. The stochastic process for match quality ϵ is assumed to be iid across matches, with cdf $\Phi(\cdot)$ if the couple has met in the marriage market , and cdf $\Phi^x(\cdot)$ if the couple has met in the sex market.

We also assume that single men must pay a utility cost $\gamma > 0$ to participate in either market; while participation in the marriage market is costless for women, they face an iid cost ξ_F of participating in the sex market.

4.2 Birth Control

The first step in developing a theory of birth control is to reconcile two canonical facts: 1) most sexually-active married women are actively contracepting, even those without children, and 2) most births to married women are not the unwanted result of accidental pregnancies. Clearly having children is in general desired, and yet delaying fertility is equally important. We postulate that the timing of children is very important; women contracept because most of the time it is optimal to delay fertility. Rather than model explicitly the optimal timing of births, we add an element of uncertainty over the "wantedness" of children. This takes the form of a one-time iid utility shock κ that accompanies the birth of a child. Let the PDF of κ be $g(\kappa)$ and the CDF be $G(\kappa)$. The total gain from having a child consists therefore of a deterministic portion, which we label $\Delta V(k, k_m)$ and a stochastic portion κ that is realized at the time of the contraception decision.

We assume that in the absence of contraception, women who are sexually active will become pregnant at rate $\hat{\pi} \in [0, 1]$. Those couples who want to reduce the probability of pregnancy can choose between two costly contraception methods, (θ_1, α_1) and (θ_2, α_2). Users of method i become pregnant at rate $\alpha_i\hat{\pi}$ and incur utility cost θ_i. We assume that $\theta_1 > \theta_2$. once a woman is pregnant, the couple can choose an abortion to terminate the pregnancy. We assume that, at the time of the contraception decision, women are aware that abortion will involve a iid utility cost θ_A , but that the realized value of that cost is only revealed at pregnancy.

In the appendix, we derive the optimal birth-control behavior by working backwards from the case of a couple where the woman is pregnant, given a realized abortion cost θ_A and a realized child-utility shock κ. The result is a set of reduced-form "frontiers" that give the optimal behavior as a function of ΔV. For instance the probability of birth is given by the fertility frontier $\pi^F(\Delta V)$, and the expected costs associated with sex, including the contraception and abortion costs associated with the optimal strategy, as well as the expected impact on the continuation value is given by $\Theta_{nk}(\Delta V)$, where $n \in \{m, s\}$ indicates the marital status and k the number of children the woman already has. These two objects are all we need to know about birth control to solve the matching model, although other frontiers, corresponding to the contraception and abortion choices, will be useful for calibration purposes.

The resulting frontiers are shown in Figure 7, for the case where abortion is available with probability 0.8 and where unmarried couples only have access to the pill (labeled as CC2) with 50% probability.

Since pregnancy involves couples, and we are assuming efficient outcomes, the actual form of ΔV depends on the consequences for the couple. This is determined by the equilibrium of the matching model.

4.3 Marriage

The marriage decisions can be summarized by the match-quality thresholds. Let the threshold for a newly matched couple in the marriage market be $\epsilon^m(k, t)$. As in the example, the probability that matched couples who wish to marry are indeed allowed to marry is π_z.

With probability $[1 - \Phi(\epsilon^m(k,t))]\,\pi_z$ the couple ends up marrying. If they do not marry, the members of the couple spend the remainder of the period as single agents. We show the timing of decisions for married couples in Figure 8(a).

The probability that a newly matched couple in the sex market ends up marrying is a bit more complicated because in the sex market the decision can be conditioned on whether the woman becomes pregnant. We show the timing of decisions for unmarried couples in Figure 8(b). The match quality ϵ is drawn from a distribution with CDF Φ^x. A matched couple learns the realization of ϵ *before* the contraception decision. There are two relevant thresholds $\{\epsilon^0(k,t), \epsilon^1(k,t)\}$. A couple with $\epsilon > \epsilon^0(k,t)$ will commit to marry regardless of whether the woman becomes pregnant. However if $\epsilon^1(k,t) < \epsilon < \epsilon^0(k,t)$ then the couple will commit to marry only if the woman becomes pregnant. The precise expressions for these thresholds are derived in the appendix.

4.4 Frictional assignment

The matching markets are similar in spirit to those of the directed-search literature, such as Shi (2002) and Shimer (2005a). Each market consists of $K+1$ submarkets, one for each $k \in \{0, 1...K\}$. All unmarried women with k children who decide to participate in a given market are assigned to submarket k of the market in question. Unmarried people can also choose not to participate in either market. The number of single-female households with k children is denoted by $N_F(k,t)$. Of these women, a mass $N_F^x(k,t)$ choose to enter sub-market k of the sex market, while the mass $N_F^m(k,t)$ choose to enter sub-market k of the marriage market.

Men choose both which market and which submarket to enter. $N_M^m(k,t)$ denotes the number of men who enter sub-market k of the marriage market, while $N_M^x(k,t)$ denotes the mass of those who enter sub-market k of the sex market.

Each period there is random assignment of men to women within each of the sub-markets. Let $\phi_k^j(t) \equiv N_M^j(k,t)/N_F^j(k,t)$ denote the queue-length for sub-market (j,k). Each single woman is assigned a random integer number of suitors $z \in \mathbb{N}$ with probability $\omega_z^k = \omega_z(\phi_k)$. This probability equals $\omega_0(\phi_k) = e^{-\phi_k}$ for $z = 0$, and $\phi_k e^{-\phi_k}$ for $z = 1$. A man assigned to a woman with z suitors will match with probability $1/z$. On average the male matching rate is equal to the number of matches $1 - \omega_0(\phi_k)$ divided by the number of men per woman ϕ^k.

As in the example, women auction the match to the highest bidder. In the sex market, the probability that a man receives the surplus is therefore $p_M^x(\phi_k) \equiv \omega_0(\phi_k^x)$, the probability that he was the only bidder. Similarly, the probability that a woman matches is given by $[1 - \omega_0(\phi_k^x)]$, the probability that she has at least one suitor, and the probability that she gets the surplus is $p_F^x(\phi_k^x) \equiv [1-\omega_0(\phi_k^x)-\omega_1(\phi_k^x)]\,\pi_z$.

In the marriage market the surplus is only awarded if the marriage occurs. The probability that a man receives the surplus is therefore $p_M^m(\phi_k,t) \equiv \omega_0(\phi_k^m(t))\,(1-\Phi(\epsilon^m(k,t)))\,\pi_z$. The probability that a woman marries is given by $\pi_F^m(k,t) \equiv [1-\omega_0(\phi_k^m(t))]\,(1-\Phi(\epsilon^m(k,t)))\,\pi_z$, and the probability that she gets the surplus is $p_F^m(\phi_k^m) \equiv [1-\omega_0(\phi_k^m)-\omega_1(\phi_k^m)]\,(1-\Phi(\epsilon^m(k,t)))\,\pi_z$.

4.5 Expected payoffs

It is convenient to divide the period into the stage before and the stage after the matching decisions. We use the superscript E to refer to the expectations as of the start of the period ("ex ante") and R to refer to the expectations as of the close of the matching markets, but before fertility is realized. Let the effective discount rate be denoted $\beta \equiv \tilde{\beta}(1-\delta)$.

4.5.1 Marriages

Let $Y^E(k,k_m,t)$ denote the expected value, on entering the period at time t, of a marriage consisting of a woman with k kids of her own, of which k_m are fathered with her current husband.

Define

$$\Delta V_m(k,k_m,t) \equiv \Delta u_M(k,k_m) + \beta \Delta Y^E(k,k_m,t+1) \tag{10}$$

where for any function $g(k)$, $\Delta g(k) \equiv g(k+1)-g(k)$ represents the effect of having one more child. For instance $\Delta u_M(k,k_m) \equiv u_M(k+1,k_M+1)-u_M(k,k_M)$. This represents the deterministic component of the incentive to have children.

We can write the marriage value in terms of the flows we have just defined as: .

$$Y^E(k,k_m,t) = u(k,k_m,t) + \beta Y^E(k,k_m,t+1) - \Theta_m(\Delta V(k,k_m,t)) \tag{11}$$

.

4.5.2 Singles

Singles, except for women with $k=K$, can enter either the marriage or sex markets, or stay out of both markets .

Let the expected values on entering sub-market (k,j), for men and women respectively, be denoted $V_{SM}^E(k,j,t)$ and $V_{SF}^E(k,j,t)$. Now we can define the values of single people on entering the period:

$$\begin{aligned} W_{SF}^{E}\left(k,t\right) \equiv & E\max\left(V_{SF}^{E}\left(k,x,t\right),V_{SM}^{E}\left(k,j,t\right)\right) && (12)\\ W_{SM}^{E}\left(t\right) = & E\max_{k}\left\{\max\left(V_{SM}^{E}\left(k,x,t\right)-\zeta_{M},V_{SM}^{E}\left(k,j,t\right)-\gamma\right)\right\} && (13)\end{aligned}$$

The continuation values for unmatched people, regardless of whether they entered the markets, are $V_{SM}^{R}\left(t\right)$ and $V_{SF}^{R}\left(k,t\right)$ for men and women, respectively.

We can write the continuation value for single men as:

$$V_{SM}^{R}\left(t\right)=u_{SM}+\beta W_{SM}^{E}\left(t\right) \tag{14}$$

, while for a woman with k children,

$$V_{SF}^{R}\left(k,t\right)=u_{SF}\left(k\right)+\beta W_{SF}^{E}\left(k,t\right) \tag{15}$$

.

Value of Entering the Sex Market We derive in the appendix an equation for the child-birth incentive $\Delta V_{s}\left(k,t\right)$ of a newly-matched couple in the sex market. The surplus of a match in the sex market is:

$$S_{x}\left(k\right)\equiv u_{S}^{x}-\int_{\epsilon}\Theta_{s}\left(\Delta V_{s}\left(k,t,\epsilon\right)\right)d\Phi\left(\epsilon\right) \tag{16}$$

. The derivation of this expression, along with the definition of $\Delta V_{s}\left(k,t,\epsilon\right)$ is presented in the Appendix, where the optimal marriage plan is solved for. Note that the value of any marriages ensuing from the match are included in $\Delta V_{s}\left(k,t,\epsilon\right)$.

. The (*ex ante*) expected value of a woman entering the sex market is:

$$V_{SF}^{E}\left(k,x,t\right)\equiv V_{SF}^{R}\left(k,t\right)+p_{F}^{x}\left(\phi_{k}^{x}\left(t\right)\right)S_{x}\left(k,t\right) \tag{17}$$

, whereas for a man the (ex ante) expected value is:

$$V_{SM}^{E}\left(k,x,t\right)\equiv V_{SM}^{R}\left(k,t\right)+p_{M}^{x}\left(\phi_{k},t\right)S_{x}\left(k,t\right) \tag{18}$$

.

Value of Entering the Marriage Market A couple matched in the marriage market will want to marry if and only if:

$$\epsilon_{t}>\epsilon^{m}\left(k,t\right)\equiv-\left[u_{m}\left(k,0\right)+\beta Y^{E}\left(k,0,t\right)-V_{SF}^{R}\left(k,t\right)-V_{SM}^{R}\left(t\right)\right]$$

. The expected surplus from a marriage where the bride has k children is:

$$S_m(k,t) \equiv u_m(k,0) + \beta Y^E(k,0,t) + E(\epsilon|\epsilon > \epsilon^m(k,t)) - \left[V_{SF}^R(k,t) + V_{SM}^R(t)\right] \tag{19}$$

. Given that a man has probability $p_M^m(\phi_k^m(t))$ of getting the marital surplus, the *ex ante* net value of a man's prospects in marriage market k is given by

$$V_{SM}^E(k,m,t) = V_{SM}^R(t) + p_M^m(\phi_k^m(t))\, S_m(k,0,t) \tag{20}$$

. Similarly for single women with k children, the *ex ante* net value of entering the marriage market is:

$$V_{SF}^E(k,t) = V_{SF}^R(k,t) + p_F^m(\phi_k^m(t))\, S_m(k,0,t) \tag{21}$$

.

4.6 Solving the Asset equations

Consider women at time t with k children who are either single, or married without any joint children. Suppose that we already know the queue lengths $\phi_k^x(t), \phi_k^m(t)$, and the value functions $Y^E(k,0,t+1), Y^E(k+1,1,t+1), W_{SF}^E(k,t+1)$ for the next period.

We solve for the current values by iteration on the following procedure. First, guess the values $Y^E(k,0,t)$ and $W_{SF}^E(k,t)$. This gives us values for the fertility incentives $\Delta V_s(k,t)$ and $\Delta V_m(k,k_m,t)$. Equations (16) and (19) then allow us to compute the surplus functions $S_m(k,0,t), S_x(k,t)$, using equations (14) and (15) to substitute for $V_{SM}^R(t)$ and $V_{SF}^R(k,t)$. This in turn allows us to compute $Y^E(k,k_m,t)$ from equation (**??**).

Now we use equations (17) and (12) to solve for $W_{SF}^E(k,t)$. This step provides us with new values for the guess, so we can repeat the procedure until the values of $Y^E(k,0,t)$ and $W_{SF}^E(k,t)$ converge. Note that, due to recursivity of the model, we are solving sequentially (one value of k at a time), so in this loop we are solving for only two unknowns rather than a system of size $2(K+1)$.

4.7 Market-Clearing

Suppose the surplus is greater in the sex market than in the marriage market. Given the assumption that the cost support extends from zero to ∞, then there will be some men who strictly prefer the sex market to the marriage market. Let the threshold be ξ^*, so that only men with $\xi < \xi^*$ participate in the sex market.

Let $\mathcal{M} \subseteq \{0,...K-1\}$ be the set of active marriage markets of type k. Consider an unmarried woman i with k children; if $k \in \mathcal{M}$, then she is indifferent between the two markets; this defines the sex-cost threshold $\xi_F^*(k,t)$:

$$p_F^m(\phi_k^m(t))\,S(k,0,t) = p_F^x(\phi_k^x(t))\,S_x(k,t) - \xi_F^*(k,t) \tag{22}$$

. For any k where both sub-markets operate, men must be indifferent:

$$V_{SM}^E(k,x,t) - \gamma = V_{SM}^E(k,m,t) - \gamma = V_{SM}^R(t) \tag{23}$$

, which in turn implies

$$p_M^m(\phi_k^m(t))\,S(k,0,t) = p_F^x(\phi_k^x(t))\,S_x(k,t) \tag{24}$$

. Since men also have the option of sitting out of all markets, the participation constraint must be satisfied:

$$V_{SM}^R(t) \geq V_{SM}^A \tag{25}$$

, where the autarky value equals the discounted flow of utility of single males: $V_{SM}^A = u_{SM}/(1-\beta)$.

There is also a resource constraint for each market, which we can express in terms of demand and supply of single men. This constraint is

$$\sum_{k<K}\left[N_M^x(k,t) + N_M^m(k,t)\right] \leq N_M(t) \tag{26}$$

using the definition of queue length, we can write this as:

$$\sum_{k\in\{0,..K-1\}} \phi_k^x N_F^x(k,t) + \sum_{M(t)} \phi_k^m N_F^m(k,t) \leq N_M(t) \tag{27}$$

4.7.1 Distributions

Let the mass of married couples currently in state (k,k_m) be $M(k,k_m,t)$ and let the mass of single women in state k be $N_F(k,t)$. In the appendix we show, followingKennes and Knowles (2010), that the distribution of single women follows a linear law of motion of the form:

$$N_F(k,t+1) = a_{k1}(t)\,N_F(k,t) + a_{k,k_m}(t)\,M(k,k_m,t) + d_1(k,t) \tag{28}$$

, where $a_{k1}(t)$ represents the probability that single women of k children undergo no transitions, $a_{k,k_m}(t)$ represents the probability that a woman in a married couple has no births, and $d_1(k,t)$ the relevant terms for women with $k-1$ children.

Similarly, we can represent the law of motion for married women as

$$M(k,k_m,t+1) = c_1(k,k_m,t)\, N_F(k,t) + c_2(k,k_m,t)\, M(k,k_m,t) + d_2(k,t) \tag{29}$$

, where $c_1(k,k_m,t)$, $d_1(k,t)$ and $c_2(k,k_m,t)$ are coefficients that depend on the marital/fertility decisions.

4.8 Stationary Equilibrium

A stationary equilibrium of the matching model with free entry consists of the following objects: a list of decision rules for sex $\{\xi_F^*(k)\}_{k=0}^{k=K-1}$, fertility and birth-control cost frontiers $\left\{\pi_{nk}^F(\Delta V), \Theta_{nk}(\Delta V)\right\}_{k=0}^{K-1}$, $n \in \{s,m\}$, marriage $\{\varepsilon^m(k), \varepsilon^0(k), \varepsilon^1(k)\}_{k=0}^{K-1}$, rules $\{N_M^m(k), N_M^x(k)\}_{k=0}^{K-1}$ and $\{N_F^m(k), N_F^x(k)\}_{k=0}^{K-1}$ for assigning singles to markets , and laws of motion $\left\{T_S(k), \{T_M(k,k_m,q)\}_{k_m=0}^{k}\right\}_{k=0}^{K}$ for the distributions. These objects must satisfy the following conditions:

1. Optimality. For every $k < K$:

   (a) the decision rules for participation in unmarried sex are optimal: for each k, a woman with realization $\xi_F = \xi_F^*(k)$ is indifferent between her two submarkets.

   (b) the frontiers $\pi_{nk}^F(\Delta V), \Theta_{nk}(\Delta V)$ for fertility and birth-control costs are generated by optimal decision rules for contraception and abortion, given ΔV

   (c) newly-matched couples at the thresholds $\{\varepsilon^m(k), \varepsilon^0(k), \varepsilon^1(k)\}$ are indifferent between marriage and finishing the period as unmatched singles.

2. Market-clearing:

   (a) the assignment rules imply queue lengths such that men are indifferent across all active submarkets

   (b) free entry: men are not made strictly better off by participating in any market

3. Aggregation:

   (a) The laws of motion of the distributions of agents over states aggregate the individual decisions; i.e. they solve equations (28) and (29).

   (b) Stationarity: The distributions are the fixed points of their laws of motion.

4.9 Solving the Model

The model is solved for the stationary equilibrium by iteration. Taking $\{\phi_k^m, \phi_k^x\}$ as given, we can solve the asset equations for each level of k separately by backwards induction from $k = K$. Given the complete system of decision rules, we then solve for steady-state distributions, starting from $k = 0$. This yields new values of $\{\phi^m, \phi^x\}$, inferred from the market-clearing conditions. We then repeat the procedure using the new values until they converge. We assume that men are in excess supply, so condition (27) will not bind. Therefore condition (25) binds in equilibrium. Since all marriage markets yield men the same value *ex ante*, men will be indifferent between either market and sitting out. The reservation value V_{SM}^R therefore equals the autarky value.[16]

The first step, given a guess on $\{\phi^m, \phi^x\}$, is to find the surplus vectors $\left\{S^x\left(k\right), \{S^m\left(k,0,q\right)\}_{q=1}^{N_q}\right\}_{k=0}^{K}$. This requires that we know the value functions, which are given by the asset equations. Due to the directed-search nature of the model, the decision rules in the markets for women with k children depend on the rest of the economy only through the values of the market-clearing vectors $\{\phi_h^m, \phi_h^x\}_{h=k+1}^{K-1}$, which determine the value functions associated with having additional children.

To solve the asset equations for a given level of k, we first iterate on the vector of values of women without husband's children, $\left[V_{SF}^R\left(k\right), \{Y\left(q\right)\}\right]$. Given our guess on the values vector, it is easy to solve for the optimal fertility rules for the given level of k. Once we have the policy rules $E\pi_k^{SF}$ and $\left\{\pi^D\left(k, k_m, q\right), E\pi_{k,k_m}^{MF}\left(q\right)\right\}_{q=1}^{n_q}$, we can write the asset equations relevant to the marriage market for women with k children as a square linear system of dimension $(N_q + 1)$; the equations for $k' < k$ are irrelevant, and those for $k' > k$ are independent of k and so appear only in the constant term. Solving this system produces the next guess for the values vector, so we iterate on this procedure until we find a fixed point. The solution to this system allows us to solve in a similar way the smaller system of equations for the values of households in which husbands children are present; we nee this to solve the asset equations for households without husband's children and $k-1$ children. The details of these linear equations systems are in the appendix.

[16] Suppose instead that single men strictly prefer participation in marriage markets: $V_{SM}^E > V_{SM}^R$. Another way to think of this is that there is excess demand for husbands; the supply constraint (27) binds. In that case there is some reservation value $V_{SM}^R > V_{SM}^A$ that will generate a vector of queue lengths $\{\phi_k^x, \phi_k^m\}$ such that equation (27) holds with equality.

5 CALIBRATION

Since our goal is to explore the impact of contraception on sexual behavior, we now consider specifications of the model such that the model's predictions for marriage, sexual activity and birth rates approximate the analogous statistics in US data. As in the empirical and example sections above, we begin with a very simple analysis, taking advantage of the fact that our model nests more simplified views of the problem. We first calibrate a minimal version of the model, and then explore the impact of improved unmarried birth control in that context. We then proceed by adding in one margin at a time, along with the corresponding statistical targets.

A specification of the model consists of functional forms and parameters. The parameters can be divided into three sets; "fixed" parameters, whose values can be pinned down directly from empirical observations or convention, "normalized" parameters, those that will be held fixed at arbitrary values, and "free" parameters, whose values will be set so as to minimize the distance between the targets and the relevant model statistics.

For each candidate parameterization, we simulate a cohort of 10,000 women from age 18 to age 44 using the decision rules and stochastic processes implied by the benchmark model and compute the relevant moments from the simulated population. We then set the score equal to the average deviation between the moments of the model and the targets, and update the choice of parameters, repeating the process until the numerical solver finds a minimum of the score, as measured by a Euclidean metric..

We take as targets the mean behavior conditional on the number of children. We choose our targets from the 1973 National Survey of Family Growth (NSFG). In order not to confound the effects of changes in the distributions of single women over education and cohabitation, whether over time or by number of children, we use as targets the predicted means for a given age-interval from the age profiles we derived in the empirical section above. [17]

5.1 Model Specification

5.1.1 Functional Forms

The distribution Γ of the female cost of participation in the sex market is assumed to be log normal; the log of ξ_F is normally distributed with mean and standard deviation (μ_ξ, σ_ξ). The

[17] Although the NSFG is larger and more complete in the 1995 wave (for instance, unmarried non-mothers are not excluded from the sample), we use statistics from the earlier wave because it is more informative about singles behavior with access to the pill limited by law, whereas in the 1995 wave selection into pill use on unobservables would more of an issue.

distribution of the child-utility shock κ is assumed to be normal with parameters $(\mu_\kappa, \sigma_\kappa)$. The abortion cost has a log-normal distribution with parameters (μ_A, σ_A). The match quality distribution is normal with mean and standard deviation $(\mu_\epsilon^m, \sigma_\epsilon)$ for married couples and singles who meet in the marriage market. When matching occurs in the sex market, the mean of the match quality distribution is $\mu_\epsilon^x < \mu_\epsilon^m$.

The utility flows generated by different household types are parameterized as linear functions of the number of children. Thus married households without children receive utility flow α_m single households without children receive utility flow α_s. The first child increases utility by α_W^0, for single households, and by $\alpha_W^0 + \alpha_M^0$ if married. The arrival of additional children increases utility of single households by α_W^1 and that of married , if the child arrives inside the marriage, by $\alpha_W^1 + \alpha_M^1$. The marginal effect of an additional child born previous to the marriage is $\alpha_W^1 + \alpha_M^2$.

$$
\begin{aligned}
U_M(k, k_M) &= \alpha_M^0 + \alpha_M^1 k_M + \alpha_M^2, (k_M - k) + \alpha_M^3 (k_M - k)^2 \\
U_F(k, k_M) &= \alpha_W^0 + \alpha_W^1 k
\end{aligned}
$$

5.1.2 Fixed Parameters

As in Kennes and Knowles (2010), the probability δ of exiting the active state is set so as to replicate the average number of years a woman spends in the reproductive state, which we take to be 20.45 fecund years per woman, so we set $\delta = 0.05$. We set $\beta = 0.96$, the standard value for the discount factor at annual frequencies in the macroeconomics literature.

The natural fertility rate $\hat{\pi}_k$, is assumed to be a declining function of the number of children, $\hat{\pi}_k = f_0/(1 + kf_1)$. This reflects the decline with age observed in the literature, such as Trussell and Wilson (1985), who infer from a population of married women in England from the 16th to the 19th centuries, a natural (non-contracepting) birth rate of roughly 80% annually for sexually active women under age 25. We therefore set $f_0 = 0.8$, and choose $f_1 = 0.29$ to match the rate of decline of annualized pregnancy rates, by number of existing children, of non-contracepting, sexually active married women in the 1995 NSFG.[18]

The effects of contracepting on the pregnancy rate are set to $\alpha_1 = 0.2$ (inferior technology) to match the average for condoms and diaphgrams, the two most effect methods available in 1970 apart from the pill, and $\alpha_2 = 0.08$ which is the average annual pregnancy rate for sexually active women on the pill in the 1990s.

We limit the availability of the pill and of abortion in the 1970s by setting the probabilities $\tau_p^s = 0.25$ for singles and $\tau_A = 0.2$ for all. Married women are assumed to have easier access

[18]The pregnancy-rate of non-contracepting married women rate declines in the NSFG from 0.38 at k=0 to 0.15 at k=5.

to the pill, so we set $\tau_p^m = 0.75$. This is admittedly arbitrary; it seems plausible that access to contraception and abortion was less than perfect in the 1990s, and much less so in 1970. [19]

the problem is explaining why married women in the 1970s and unmarried women in the 1990s often use other contraception methods. In the model this can be explained by differences in the incentives to avoid pregnancy, due to different realizations of the child utility shock κ , or by imperfect access to the pill.

5.1.3 Normalized Parameters

The male participation cost is normalized to $\gamma = 1$, the sex-cost mean μ_ξ to zero, the utility α_0^m of married life without children and the women's utility α_W^0 from a first child to zero, the mean of match quality μ_ϵ^m for married couples to zero, and the standard deviation σ_A of the abortion cost to one.

5.1.4 Free Parameters

When $K = 1$, the calibration will determine values for the following free parameters: utility of single life α_s standard deviation of match quality σ_ξ , the child-utility shock parameters $(\mu_\kappa, \sigma_\kappa)$, and u^x the direct utility generated by having sex. In addition, when these margins are active, the contraception and abortion costs $(\theta_1, \theta_2, \mu_A)$, and the mean μ_ϵ^x of the match-quality distribution that governs shotgun marriages. Finally, when $K > 1$, the calibration will also determine values for the the taste parameters that govern the flow of utility from additional children $(\alpha_M^1, \alpha_M^2, \alpha_W^1)$.

5.2 Targets

Relative to previous models, the contribution of the method used here is that we can calibrate to annual transition rates, such as marriages, and births, as well as rates of sexual activity and contraception usage. Our model is not expected to do particularly well as a theory of the lifecycle in terms of the shape of the age profiles, as we have no aging within the population of active people[20]. The targets are based on the age profiles, as computed in the empirical section. For the purpose of understanding marriages and births, the important part of the

[19] The results of a recent (July 2010) poll by Planned Parenthood suggests that one in three women voters—including 55 percent of young women—have struggled to afford prescription birth control. http://www.plannedparenthood.org/about-us/newsroom/press-releases/survey-nearly-three-four-voters-america-support-fully-covering-prescription-birth-control-33863.htm

[20] Knowles and Vandenbroucke (2013) do fit age profiles, using an otherwise simpler version of KK2010, by allowing for stochastic transitions between age groups.

profiles are the mid 20's, so we take as targets the mean annual transition rates over ages 21-28.

Not all targets are derived from the estimated age profiles. In the case of abortion, there are widely-acknowledged issues with under-reporting in the NSFG surveys, so we target the aggregate ratio of abortions to pregnancies, as documented by Akerlof et al. (1996) for 1965-70, and Ventura (2009) for the 1990s.

6 RESULTS

6.1 Specification 1: the simplest model

Our simplest specification of the model assumes away abortion and shotgun marriages. We also assume, for now, that in the 1970s only the less-effective contraception method is available. We set $K = 1$, so that only women with no children are active. This model extends the example model by allowing for an infinite lifetime, and endogenous choice of contraception by both single and married couples. The surplus values from matching in each market are now jointly determined and people have many opportunities to match. The free parameters in this case are $\{\alpha, \mu_\kappa, \sigma_\kappa, u^x\}$.

We calibrate the model to four moments for women in the 1973 NSFG who are high-school graduates aged 18-28, without children: the marriage rate (0.26), the birth rate to married couples (0.3) , the birth rate to singles (0.03), and the contraception usage rate if married (0.5). This results in Model 1, as shown in Table 8(a) ; the parameter values are shown in Table 7, column 1. The negative value for α_m^0 indicates a gain of 0.4 for married couples with children; the gain for unmarried women, set to $\alpha_w^0 = 0$, is not shown. The utility effect of being single is -0.51; however as the gain from sex is relatively large, 12.9, this does not imply an unconditional preference for married life. The importance of timing of children is indicated by a large absolute value of the mean, $\mu_\kappa = 9.9$, for the child-preference shock.[21] When comparing parameter values, it is useful to bear in mind that some parameters, such as κ, u^x, are one-time shocks, while others, such as $\alpha_m^0, \alpha_w^0, \alpha_m^2$ are recurring.

We then take the calibrated model and introduce the more effective contraception method, CC2, calibrating the cost θ_2 and the singles-access probability μ_2 to match the 1990s Pill-usage rates of married (0.38) and singles (0.37). In the resulting parameter set, the Pill costs 3 times as much as the less-effective technology, and unmarried have only a 40% of of obtaining the pill when they need it. Despite this, the main result is that, as in the one-period example, introducing the contraceptive pill drives down the marriage rate and raises

[21]The distribution has mean -μ_κ.

the unmarried birth rate, generating values close to the empirical means for the 1990s. This is remarkable, because the example result was driven by an exogenously high impact of children on the value of being an unmarried woman; now not only is this (partly) endogenous, but we have just shown it to be consistent with realistic marriage and birth rates.

Of course it should be noted that the initial condition is more of an analog to the 1950s than the 1970s, since we are not allowing married women to use the pill in the benchmark calibration. We will revisit this below.

6.2 Specification 2: shotgun marriages

We now repeat the procedure used for specification 1, with an additional margin; marriages can arise from matchings in the sex market. We add one free parameter to the mix; the mean of the match-quality distribution, μ_{ϵ}^{x}, along with an additional target, the shotgun-marriage/pregnancy rate of the 1970s. The parameters of this calibration are shown in Column 2 of Table 7, and the empirical targets for the 1970s in Table 8(b). The parametrization now implies a much lower value for the utility from sex, 7.4 instead of the 12.9 required in the first specification, because the shotgun option reduces the fear of pregnancy in the sex market.

The experiments in the right side of the table show that the model can match either the decline of the shotgun rate, or the decline of the marriage rate, but not both together. The main result is Column "Calib 1" in the 1990-95 section of the table. There the experiment is exactly as the one in Table 8(a); the cost of CC2 and the access probability for unmarried women are both reset so that the model matches the pill-usage rate of non-mothers by marital status. As in the earlier experiment, the marriage rate declines and the UM birth rate increases, but the shotgun rate barely moves. In Column "Calib 2", we also allow the mean of the match-quality distribution, μ_{ϵ}^{x}, to decline, so as to help the model match the shotgun rate, but this actually drives up the marriage rate, as the sex market becomes much less attractive. In fact it is not possible to reduce the match quality sufficiently to generate a realistic decline in the shotgun rate, because that would drive women out of the sex market altogether. The problem is that improved contraception does not affect the decisions of women once they are pregnant, since there is no abortion, and with K=1, contraception is irrelevant to mothers, regardless of marital status.

6.3 Specification 3: abortion

In Table 8(c) we re-calibrate the model to allow for abortion. We assume the mean cost of abortion is zero and that the probability that an abortion is allowed has increased. For the experiment, only the abortion probability, the CC2 cost and the CC2 probability are allowed to vary from their 1970s values. The calibrated parameters, shown in Table 7, Column 3, imply that the probability of being allowed an abortion rises over time from 0.25 to .55; since the corresponding abortion ratios are 0.2 and 0.5, respectively, this means 80% of pregnant unmarried women in the model would have preferred to abort in the 1970s and 90% in the 1990s.

The results of the experiment are shown in Table 8(c). The calibration can replicate the marriage decline and generates a slight decline in shotgun weddings, but instead of doubling over time, the birth rate to unmarried women falls drastically, to less than a half of the 1970s level. The reason for this failure is clear; unmarried pregnant women always had strong abortion incentives; by raising the value of unmarried non-mothers, the improved birth-control regime has increased the incentive for abortion, and the higher probability that abortion is permitted. AYK deal with this problem by assuming that women with high abortion costs are drawn into sex by competition for husbands. An alternative to this story is that life for unmarried mothers has improved relative to the value of remaining an unmarried non-mother.

6.4 Specification K = 2

Suppose that women can have up to two children, and, for greater realism, let's allow for access to the pill in the 1970s. The additional parameters required for calibration, shown in Table 9, are the marginal values of children for unmarried and married women, α_w^1, α_m^1 , the cost and access probability of the pill in the 1970s, and the utility reduction imposed on marriages by step kids, α_m^2. The corresponding targets are the birth rates to women with one child, by marital status, respectively, the fraction of non-mothers using the pill in the 1970s, by marital status, and the marriage rate of unmarried mothers with one child. As might be expected, allowing unmarried mothers to match further reduces the penalty of unwanted pregnancy, and reduces in turn the calibrated utility flow from sex, to 6.5, from the value of 13 we saw in the first calibration.

As before, the experiment consists of re-setting the access probabilities for abortion and the pill, as well as the cost of the pill, so as to match the usage rates of the pill and abortion for the 1990s. The requirement that the model match the pill usage rates for the 1970s and the 1990s has a lot of bite; the parameterization implies that there was only a small increase in the accessibility of the pill for unmarried women, from 0.35 to 0.55, while the cost actually has to increase, from 0.66 to 0.93 to match the lack of growth in married use rates. In order to match the rise in the abortion ratio, the access to abortion doubles according to the calibration, from 0.35 to 0.755, which seems plausible given the change in legal status of abortion over the period.

The results for the experiment, shown in Table 10, show that both the marriage and the shotgun rates now decline together; accounting for about 60% and 72%, respectively of the empirical changes, while the birth rate to unmarried non-mothers increases 75%, rising to 5.6%, equivalent to about 58% of the empirical increase.

This confirms the argument that motivates the paper, that improved birth-control could account for the decline in the shotgun rate as well as the shifting birth and marriage rates. The rate of sexual activity of the unmarried non-mothers rises from 26% to 61%, about 62% of the observed change.

The results for unmarried mothers (of one one child) are more mixed, which is not entirely unexpected, given that with K=2, they are the ones now facing exclusion from matching markets should they have a child. In terms of the non-targeted statistics for the 1970s, the model succeeds in generating a high sex-activity rate, about 71%, compared to a target of 74%, while the pill usage rate for married mothers is 60%, compared to 55% in the data. The shotgun rate is 17% , compared to 25% for unmarried mothers in the 1970s; for the 1990s, the model generates a rate of 8.4% per pregnancy, very close to the 8.8% in the data. However for sexually active unmarried mothers, the pill usage rate is only 22% in the model, compared to 50% in the data. [22] The birth rates to unmarried mothers, decline in the model from 18% to 10% whereas in the data the decline is more modest, from 17% to14.5%. This suggests that, quantitatively, there are still gains to be had from allowing a higher maximum number of children, but as there is no reason to expect a qualitiative change, we defer that to future research.

7 CONCLUSIONS

The main contribution of the current paper was to develop a model of fertility decisions both in and out of marriage over many periods. The other contributions of the paper include 1) the argument is set in a model environment that is much richer in terms of lifecycle than previous models, so it can be much more easily calibrated to annual data than the two-period models that are usually used in the literature on marriage and fertility. The model is based on directed search, so the inefficiency results that characterize random-search models do not apply here. 2)The model is based on an equilibrium with competing markets, a new thread in the search literature. As in Kennes and Knowles, 2010, our structure allows for an

[22]This suggests that unmarried mothers were more like married women in terms of access to the pill, so it may be more realistic in future to assume the restriction on the pill applies only to non-mothers.

equilibrium analysis with irreversible children; unlike that paper, we consider an alternative to marriage, the "market" for unmarried sex.

Our one-period example suggests that improved birth control for single women is a plausible story that can potentially explain all of the shift in marriage and unmarried birth rates. Improved access to birth-control explains the fall in marriage rates and the rise in unmarried birth rates, through an increase in the value of casual sex for unmarried women. We found that this insight carries through to a life-cycle model, calibrated to US data, in which only women without children could participate in the marriage and sex markets. However as AYK point out, one of the most important margins in the unmarried birth rate is the probability that unmarried pregnant women will marry; as in AYK we refer to this colloquially as the rate of "shotgun" marriage. This simple version of the model could not match simultaneously the decline of the shotgun rate and the rise in the unmarried birth rate. We saw that this was because when single mothers are shut out of the matching markets, liberalizing birth-control made the penalty for unmarried motherhood more severe.

We dealt with this challenge by allowing women with children to have more children and to participate in the marriage and sex markets. This contributed an important aspect of realism to the model, as in the 1970s about half of unmarried births were to women with children. We required the calibration to match marriage and births rates to women with one child already, and the usage rates of the pill as well as the ratio of abortions to pregnancies. Despite these additional restrictions, the model with multiple children demonstrated that improved birth control could explain roughly 60% of the sexual revolution.

The growing share of children in single-parent households since the 1970s is not just a function of unmarried births; rising divorce rates also create single-parent families. Our analysis only addresses the unmarried-births aspect, and within that, the role of improvements in birth-control technology; this narrow scope is justified, we feel, by the technical challenges. Repeated opportunities to remarry and to have children were critical for our analysis; to get there we abstracted from important features such as aging, human-capital investment in children or the impact of means-tested government transfers. There are also important features of marriage, such as divorce, and the margin between cohabitation and marriage, that are ignored by both the current paper and the bulk of the related literature[23]. However it is easy to see that the approach used here can be extended to deal with these and other features of marriage and fertility.

Single-parent families are also a recurring issue in the design of social policy. Although

[23]As a first pass, this neglect is not entirely unjustified, as cohabitation for many appears to be a form of extended courtship rather than a substitute for marriage. Spain and Bianchi (1996, p. 49) state that the majority of marriages formed since 1985 began as cohabitation. Overall, they say, cohabitation accounts for 6% of US households.

our analysis included children, the model, is far too abstract in this respect to consider the consequences of the marriage-fertility transition on children's welfare. To what extent the current model can be extended to deal with the welfare issues associated with child raising remains an open and important question for further work in this area.

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APPENDIX

Statistic	Data		% Change
	1970	1995	
Share of births due to unmarried women	0.1	0.3	200%
Fraction of kids in single mom households	0.13	0.22	69%
Fraction of mothers unmarried	0.11	0.25	127%
Fraction of kids living with Both Parents	0.82	0.62	-24%
Birth Rate to unmarried women	0.027	0.046	70%

Table 1: *Changes in Aggregate Marital Indicators* . Fraction married based on Census computations for women aged 18-44. Single mothers based on *Living Arrangements of Children Under 18 Years Old: 1960 to Present*. *Umarried birth share from* NCHS Data Brief No. 18, May 2009.

Statistic	Data		Varying Only			Holding Constant		
	1973	1995	Married Fraction	Married Birth Rate	Unmarried Birth Rate	Married Fraction	Married Birth Rate	Unmarried Birth Rate
	1	2	3	4	5	6	7	8
Fraction married	0.740	0.530	0.530	0.740	0.740	0.740	0.530	0.530
Birth Rate to married women	0.100	0.085	0.100	0.085	0.100	0.085	0.100	0.085
Birth Rate to unmarried women	0.027	0.046	0.027	0.027	0.046	0.046	0.046	0.027
Unmarried Share of Births								
Computed	0.087	0.324	0.193	0.100	0.139	0.160	0.290	0.220
Data	0.100	0.300						
Relative Size of Change			45%	6%	22%	69%	15%	44%

Table 2: *Decomposition of Unmarried Share of Births*

	1970	1990	Hold Constant				
			Sex	CC1	CC2	Abort/Preg	Marr/Preg
	1	2	3	4	5	6	7
Not Sterile	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Sexually Active	0.25	0.75	0.25	0.77	0.77	0.77	0.77
Using CC1	0.25	0.24	0.24	0.24	0.09	0.24	0.24
Pregnancy| CC1	0.2	0.2	0.15	0.15	0.15	0.15	0.15
Using CC2	0.15	0.61	0.61	0.25	0.61	0.61	0.61
Pregnancy| CC2	0.05	0.08	0.08	0.08	0.08	0.08	0.08
Pregnancy| No CC	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Abortion|Pregnancy	0.2	0.47	0.47	0.47	0.47	0.2	0.47
Marriage|Pregnancy	0.65	0.2	0.2	0.2	0.2	0.2	0.65
Births|Unmarried	0.026	0.048	0.015	0.105	0.068	0.070	0.020

Table 3: *Decomposition of the change in unmarried birth rates 1970-1995*. Statistics are not all directly comparable, as sources differ in age-groups, methods and dates. Using CC1 value for 1970 is conjectured, so as to match unmarried birth rate

Statistic	Data 1970	Data 1995	% Change
Share of births due to unmarried women	0.1	0.3	200%
Fraction of kids in single mom households	0.13	0.22	69%
Fraction of mothers unmarried	0.11	0.25	127%
Fraction of kids living with Both Parents	0.82	0.62	-24%
Birth Rate to unmarried women	0.027	0.046	70%

Table 1: *Changes in Aggregate Marital Indicators* . Fraction married based on Census computations for women aged 18-44. Single mothers based on *Living Arrangements of Children Under 18 Years Old: 1960 to Present. Umarried birth share from* NCHS Data Brief No. 18, May 2009.

	No Kids		Mothers	
	Single	Married	Single	Married
Age	21.008	26.651	31.048	31.372
High-School	0.671	0.760	0.483	0.664
College	0.292	0.304	0.121	0.190
Degree	0.105	0.162	0.040	0.077
Prev. Mar.	0.026	0.082	0.273	0.107
Birth rate	0.015	0.222	0.079	0.099
Marriage rate	0.110	-	0.087	-
Cohabiting	0.000	-	0.001	-
Pill	0.158	0.342	0.204	0.252
Phys. Admin	0.002	0.017	0.075	0.069
No BC	0.485	0.364	0.219	0.154
Sexually Active	0.314	0.986	0.763	0.981

Table 4(a): *Means of NSFG sample, 1969-72*. Shaded areas are based on NSFG singles only. "Phys. Admin" refers to contraceptive methods administered by a physician, such as IUD.

	No Kids		Mothers	
	Single	Married	Single	Married
Age	23.975	29.936	31.296	33.758
High-School	0.863	0.955	0.738	0.880
College	0.541	0.583	0.242	0.390
Degree	0.327	0.441	0.137	0.281
Prev. Mar.	0.087	0.102	0.559	0.199
Birth rate	0.035	0.169	0.060	0.077
Marriage rate	0.082	-	0.083	-
Cohabiting	0.038	-	0.082	-
Pill	0.324	0.278	0.182	0.149
Phys. Admin	0.012	0.008	0.045	0.022
No BC	0.236	0.362	0.259	0.162
Sexually Active	0.749	0.948	0.737	0.955

Table 4(b): *Means of NSFG sample, 1990-95*. "Phys. Admin" refers to contraceptive methods administered by a physician, such as IUD.

Sub-Sample		Sample Period	
		1969-71	1990-95
Age <=25	No Kids	0.482	0.142
	Kids>0	0.191	0.102
Age>25	No Kids	0.144	0.102
	Kids>0	0.064	0.062
Full Sample		0.450	0.100

Table 5(a): *Shotgun Wedding Rate per Pregnancy*
Based on NSFG women aged 18-44.

Sub-Sample		Sample Period	
		1969-71	1990-95
Age <=25	No Kids	0.160	0.155
	Kids>0	0.163	0.202
Age>25	No Kids	0.082	0.080
	Kids>0	0.074	0.058
Full Sample		0.150	0.112

Table 5(b): *Shotgun Wedding Rate per Marriage*.
Based on NSFG women aged 18-44.

Parameter	Value
1 effect of kids on utility	-20
2 utility from sex	8
3 mean of sex-cost distribution	1
4 std of sex-cost distribution	1
5 marriage surplus	5
6 Male participation cost	1
7 Married birth rate	0.2

Table 6: *Parameters used in example*.

<table>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="2">(3)</th><th rowspan="2">Parameter</th></tr>
<tr><th>1970</th><th>1990</th><th>1970</th><th>1990</th><th>1970</th><th>1990</th></tr>
<tr><td colspan="2">-0.407</td><td colspan="2">-0.396</td><td colspan="2">-0.396</td><td>alpha0_m</td></tr>
<tr><td colspan="2">-0.51</td><td colspan="2">-0.367</td><td colspan="2">-0.425</td><td>SinUtil</td></tr>
<tr><td colspan="2">12.914</td><td colspan="2">7.416</td><td colspan="2">7.416</td><td>usf_x</td></tr>
<tr><td colspan="2">9.909</td><td colspan="2">10.151</td><td colspan="2">9</td><td>mu_kappa</td></tr>
<tr><td colspan="2">0.406</td><td>0.403</td><td>0.4</td><td colspan="2">0.403</td><td>Cost_CC1</td></tr>
<tr><td></td><td>1.292</td><td>--</td><td>1.25</td><td>--</td><td>1.25</td><td>Cost_CC2</td></tr>
<tr><td>--</td><td>--</td><td>--</td><td>--</td><td>1</td><td>0.65</td><td>AbortMean_1990</td></tr>
<tr><td>--</td><td>--</td><td>-25.691</td><td>-38.597</td><td>-24</td><td>--</td><td>mu_eps_x</td></tr>
<tr><td>--</td><td>--</td><td>--</td><td>--</td><td>0.3</td><td>--</td><td>AbAllowProb1970</td></tr>
<tr><td>--</td><td>0.395</td><td>--</td><td>0.4</td><td>--</td><td>0.98</td><td>Pill Prob</td></tr>
</table>

Table 7: *Parameter values for calibrated models with K=1*.

Women with no children				
1970-73		1990-95		Statistic
Data	Model	Data	Model	
0.263	**0.315**	0.117	**0.073**	Marriage Rate
0.2	0.135	0.823	0.572	UM Sex Rate
0.03	**0.037**	0.071	**0.112**	UM Birth Rate
0.336	0	0.371	0.37	UM Pill Rate, No Kids
0.3	0.37	0.268	0.313	Mar Birth Rate
0.518	0	0.381	0.368	Mar Pill Rate
0.302	0.34	0.421	0.293	Mar No CC Rate

Table 8(a) *Results with K=1; No abortion, no shotgun weddings, no Pill in 1970s*. Shaded numbers are calibration targets.

Women with no children					
1970-73		1990-95			Statistic
Data	Model	Data	Calib 1	Calib 2	
0.263	**0.29**	0.117	**0.14**	**0.31**	Marriage Rate
0.2	0.239	0.823	0.533	0.161	UM Sex Rate
0.03	**0.035**	0.071	**0.052**	**0.025**	UM Birth Rate
0.336	0	0.371	0.47	0.498	UM Pill Rate, No Kids
0.469	0.484	0.144	0.457	0.214	Shotgun Rate, No Kids
0.3	0.351	0.268	0.279	0.275	Mar Birth Rate
0.518	0	0.381	0.391	0.404	Mar Pill Rate
0.302	0.326	0.421	0.283	0.312	Mar No CC Rate

Table 8(b) *Results with K=1;Extension to shotgun weddings, no Pill in 1970s*.Shaded numbers are calibration targets. In Calib 1 the match-quality distribution is kept constant; in Calib 2 the match quality is allowed to deteriorate to match the shotgun rate.

Women with no children				Statistic
1970-73		1990-95		
Target	Model	Target	Model	
0.263	**0.256**	0.117	**0.13**	Marriage Rate
0.2	0.231	0.823	0.532	UM Sex Rate
0.03	**0.027**	0.071	**0.01**	UM Birth Rate
0.336	0	0.371	0.376	UM Pill Rate, No Kids
0.469	0.417	0.144	0.37	Shotgun Rate, No Kids
0.3	0.316	0.268	0.161	Mar Birth Rate
0.518	0	0.381	0.394	Mar Pill Rate
0.302	0.359	0.421	0.304	Mar No CC Rate
0.2	0.209	0.5	0.529	Abortion Rate

Table 8(c) *Results with K=1;Now with abortion, in addition to shotgun weddings, no Pill in 1970s*.

1970	1990	Parameter	Role
-0.752		α^2_m	Utility for step-kids
-0.499		α^0_m	Effect of no kids on married utility
0.348		α^1_w	Marginal effect of kids on women's utility
1.005		α^1_m	Marginal effect of kids on married utility
-0.403		α_s	Utility effect of being single
6.119		u^x	Utility from sex
15.014		$\mu_\varkappa$	Mean child-timing shock
0.453		θ_1	Cost of CC method 1
0.663	0.93	θ_2	Cost of CC method 2
-7.09		μ^x_ε	Mean match quality in sex market
0.35	0.754	μ_A	Abortion access probability
0.347	0.55	μ_P	CC2 access probability

Table 9: *Parameters for model with K=2 and access to the Pill (CC2) in the 1970s*.

Women with no children				Statistic	Women with one child			
1970-73		1990-95			1970-73		1990-95	
Target	Model	Target	Model		Target	Model	Target	Model
0.263	**0.281**	0.117	**0.196**	Marriage Rate	0.144	0.156	0.103	0.13
0.25	0.271	0.823	0.621	UM Sex Rate	0.744	0.711	0.827	0.738
0.03	**0.032**	0.071	**0.056**	UM Birth Rate	0.171	0.18	0.145	0.1
0.336	0.26	0.371	0.351	UM Pill Rate	0.503	0.22	0.414	0.264
0.469	0.418	0.144	0.185	Shotgun Rate	0.25	0.173	0.088	0.084
0.3	0.212	0.268	0.199	Mar Birth Rate	0.253	0.233	0.258	0.236
0.518	0.669	0.381	0.436	Mar Pill Rate	0.548	0.601	0.373	0.407
0.302	0.327	0.421	0.385	Mar No CC Rate	0.15	0.387	0.334	0.481
0.2	0.199	0.5	0.49	Abortion Rate				

Table 10 *Results with K=2; Pill in 1970s*.

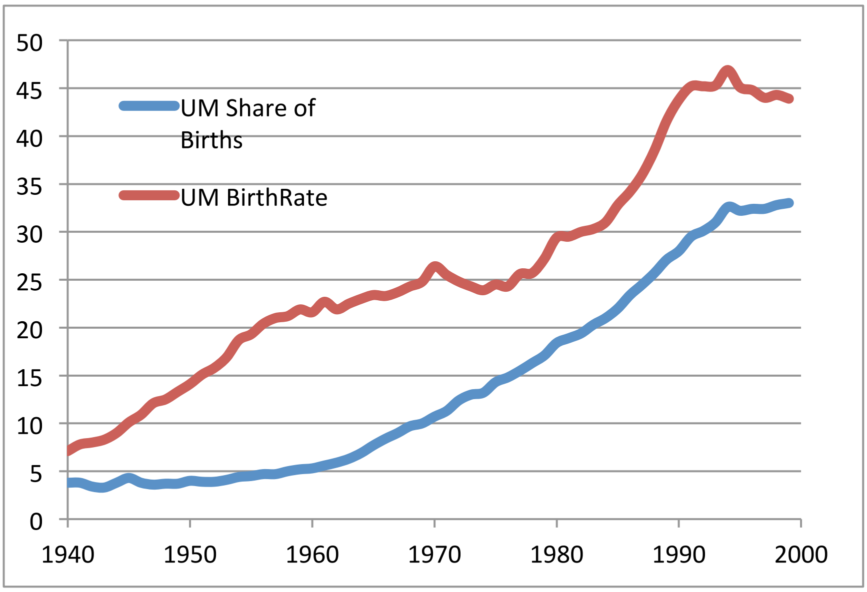

Figure 1(a): *US Birth Rate per Unmarried Woman aged 15-44 (annual per mil) and Unmarried Share of All Births*. Based on Table 1 of Ventura and Bachrach(2000).

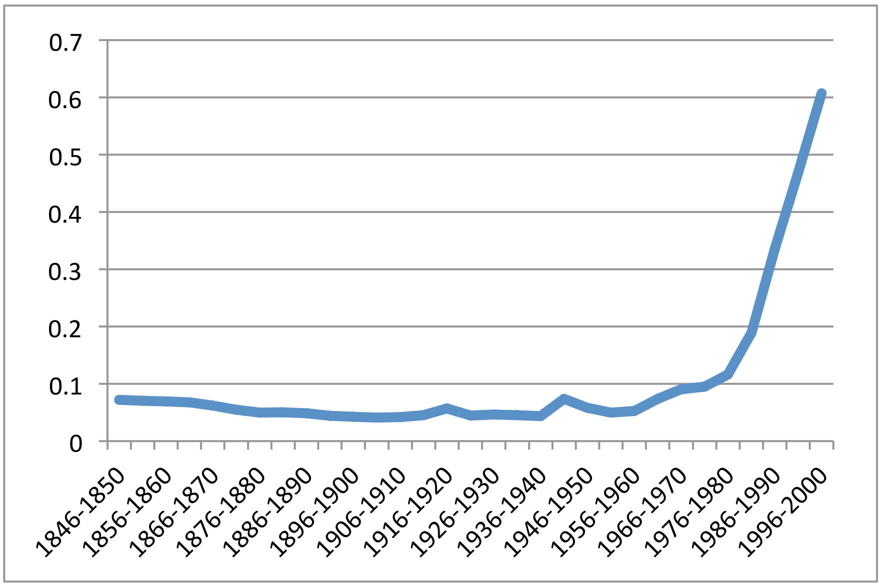

Figure 1(b): *UK Unmarried Share of All Births*. Based on *Birth Statistics - Historical Series of Statistics from Registrations of Births in England and Wales, 1837-1983*, by Population Censuses & Surveys Office.

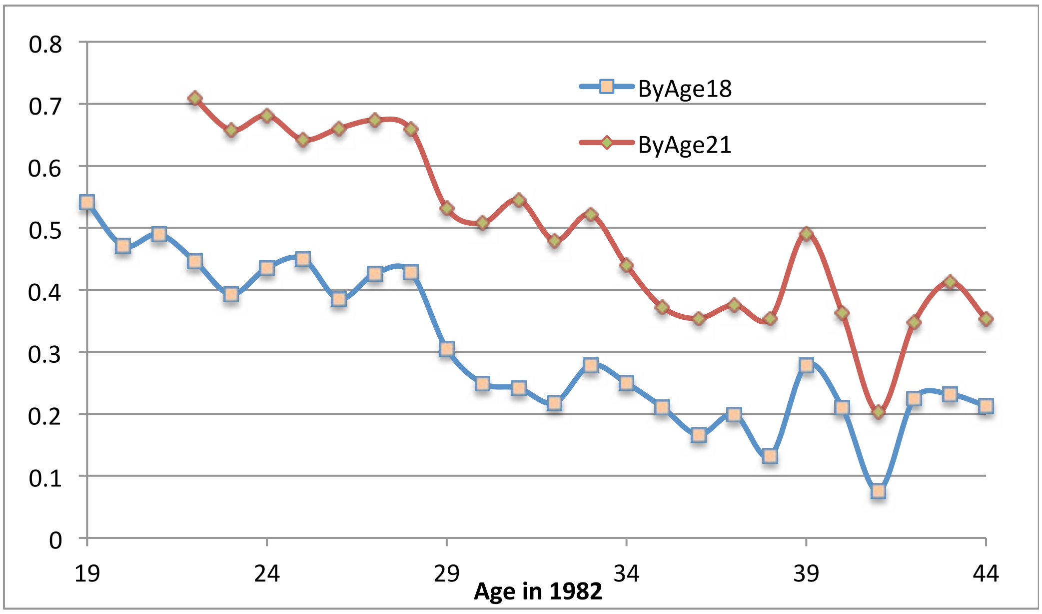

Figure 2(a): Fraction of women who had unmarried sex by age 18 or 21. Based on author's computations from representative sample of women in 1982 wave of NSFG.

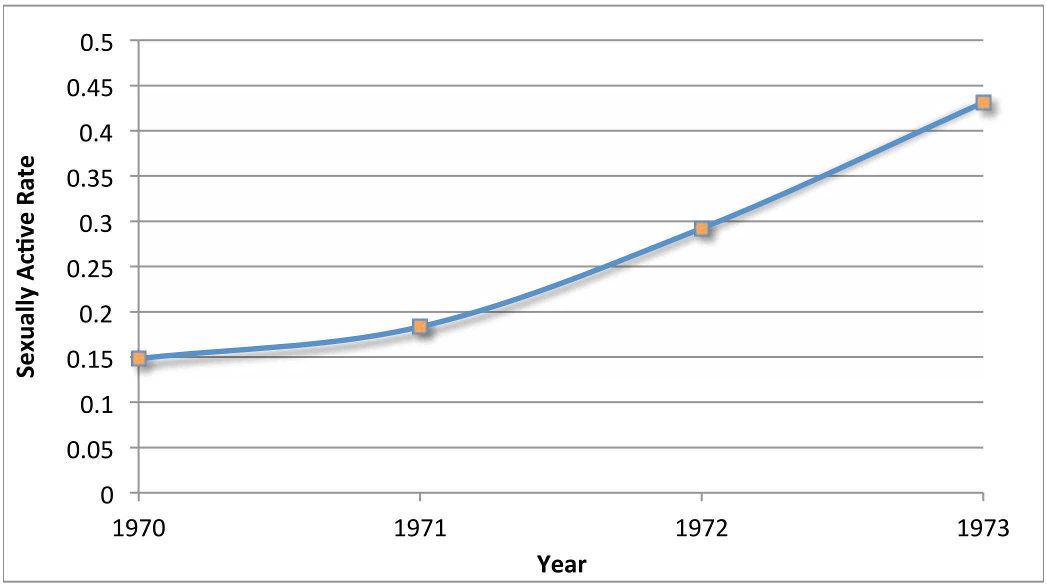

Figure 2(b): *Sexually active fraction of unmarried NSFG 1973 sample*. Fraction of unmarried, non-pregnant months with a sexual relationship.

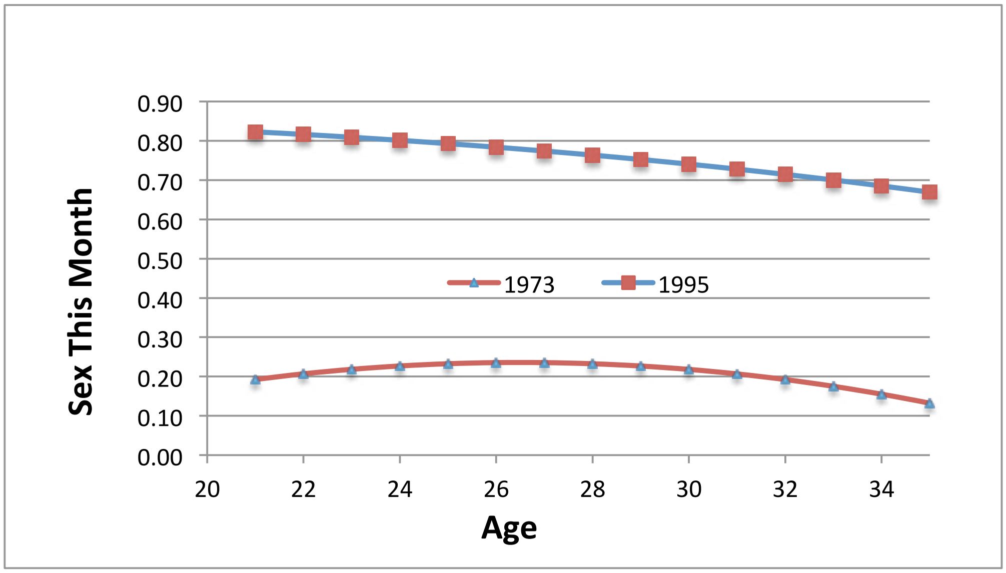

Figure 3(a): *Probability that an unmarried woman with no children has sex in a given month*. Predicted age profiles for non-pregnant women computed from regression equations estimated on NSFG 1973 and 1995

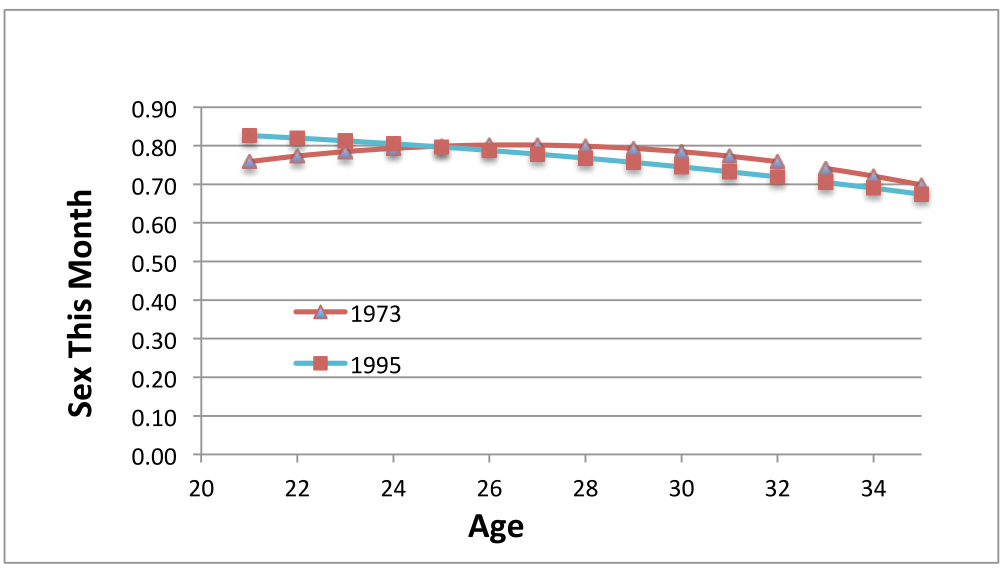

Figure 3(b): *Probability that an unmarried woman with one child has sex in a given month*. Predicted age profiles computed from regression equations estimated on NSFG 1973 and 1995

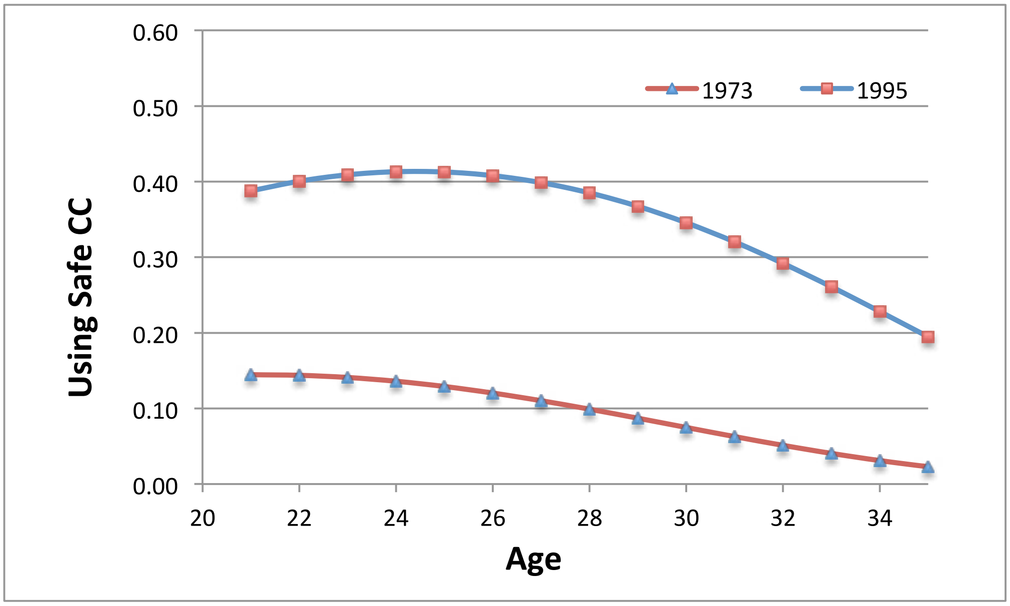

Figure 4(a): *Probability that an unmarried woman with no children is using a highly-effective birth-control method in a given month*. Predicted age profiles for non-pregnant women computed from regression equations estimated on NSFG 1973 and 1995.

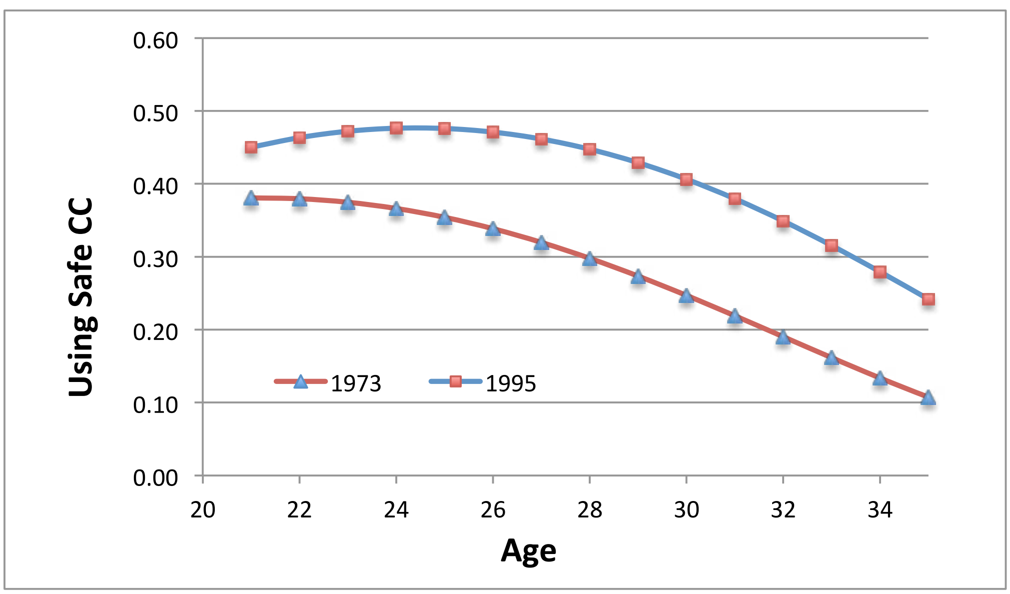

Figure 4(b): *Probability that an unmarried woman with one child is using a highly-effective birth-control method in a given month*. Predicted age profiles for non-pregnant women computed from regression equations estimated on NSFG 1973 and 1995.

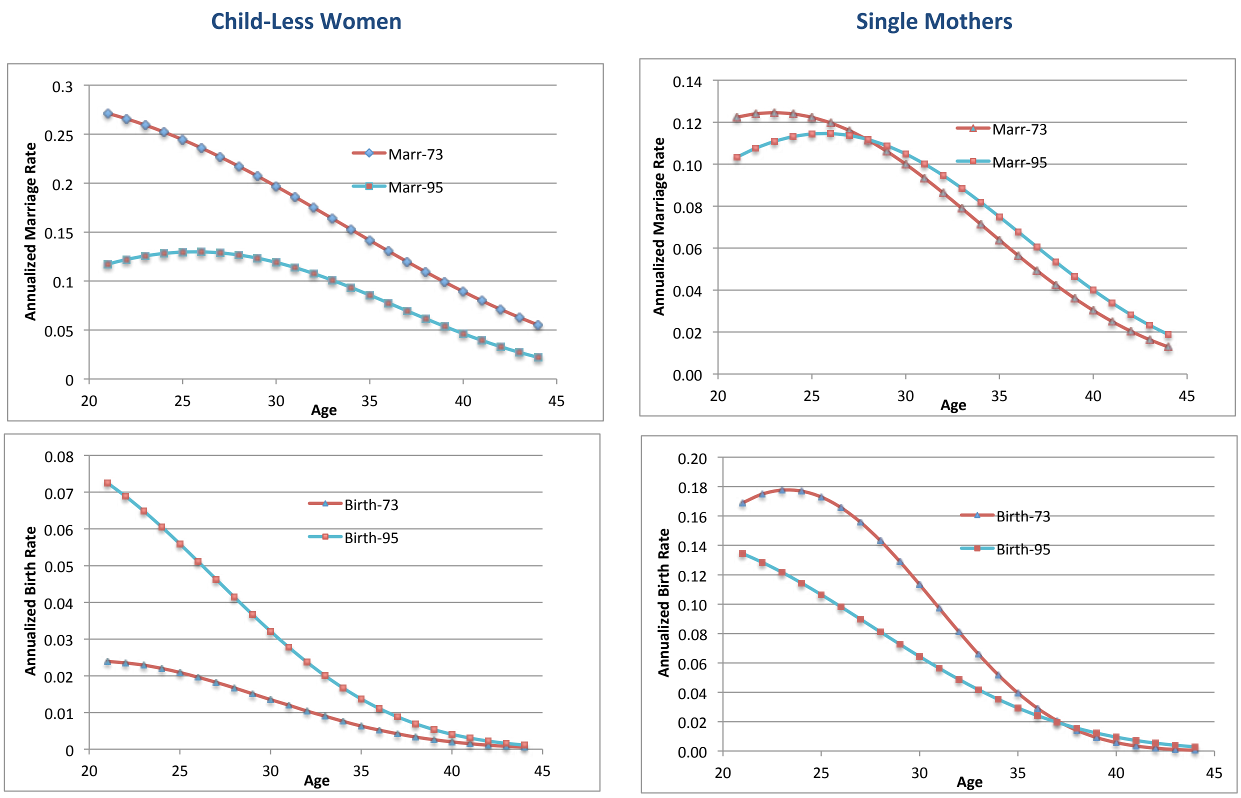

Figure 5: *Estimated Age Profiles for Marriage and Birth Rates*. Single Women in the NSFG waves for 1973 and 1995. Re-weighting of 1973 sample as described in text to correct for omission of never-married singles with no live births. Controls in estimation include co-habitation and previous marriages.

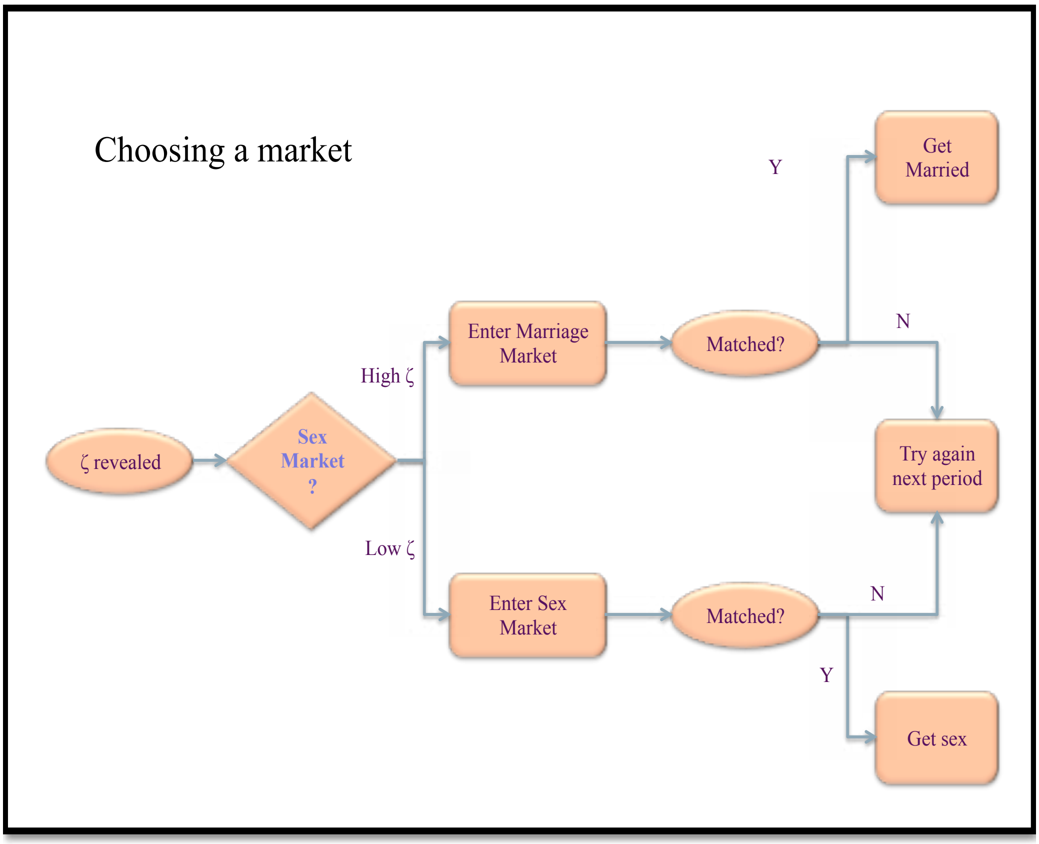

Figure 6(a): *The timing of market decisions*.

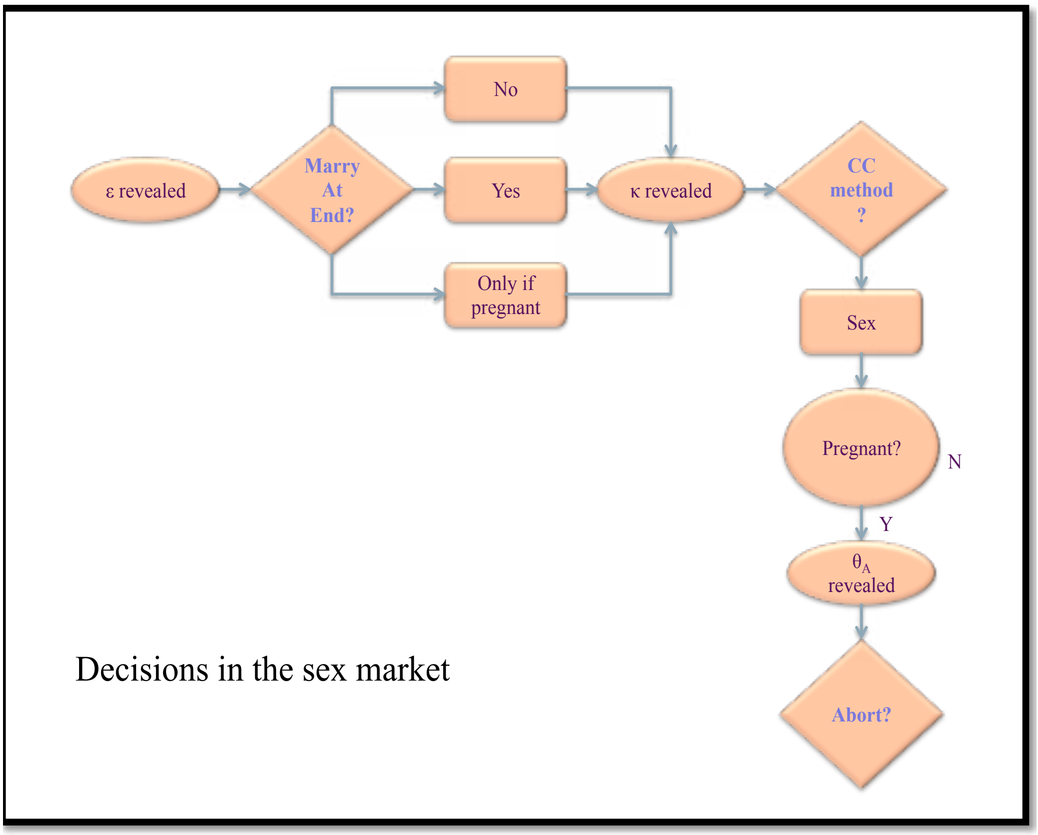

Figure 6(b): *The timing of decisions by unmarried couples*.

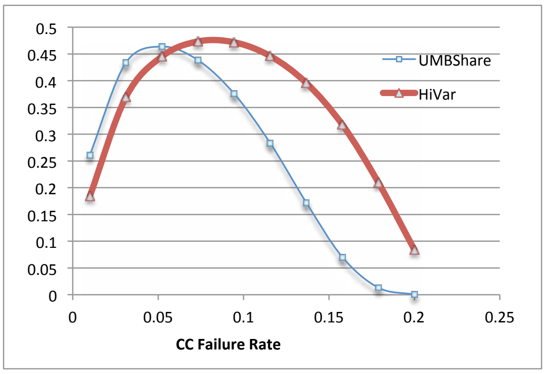

Figure 7(a): *Example Results; unmarried share of births and unmarried birth rate.*

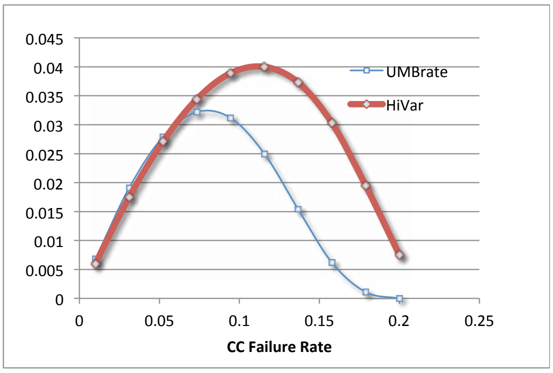

Figure 7(b): *Example Results; unmarried birth rate.*

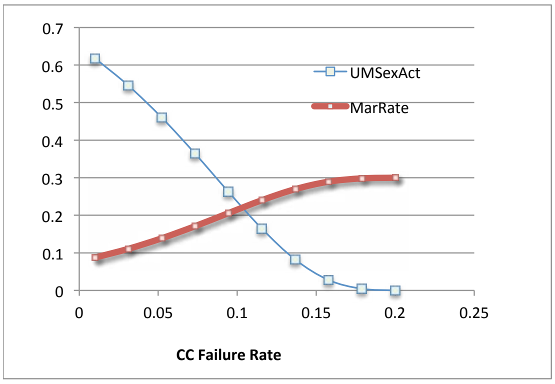

Figure 7(c): *Example Results; Rates of marriage and unmarried sexual activity*

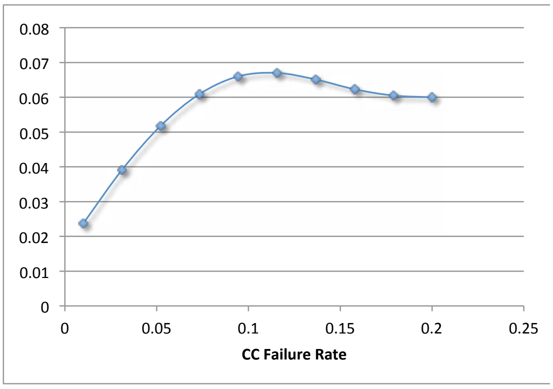

Figure 7(d): *Example Results; aggregate birth rate.*

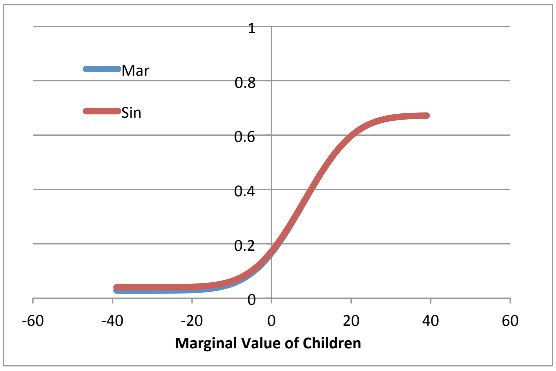

Figure 8a): *Optimal birthrates of married versus singles.*

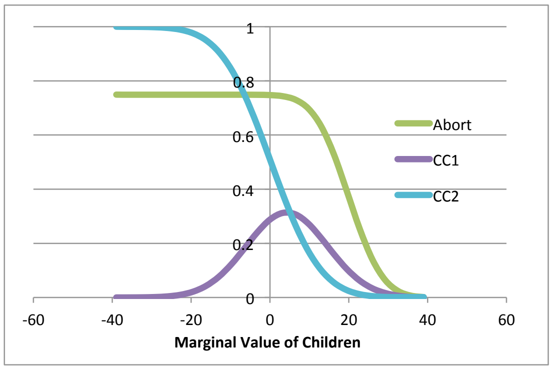

Figure 8b): *Optimal birth-control probabilities of married couples*

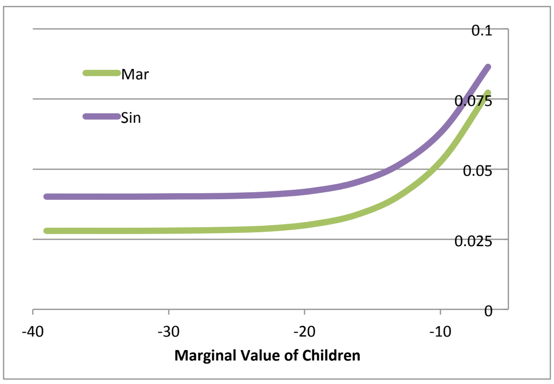

Figure 8c): *Optimal birthrates of married versus singles, low marginal value of children*

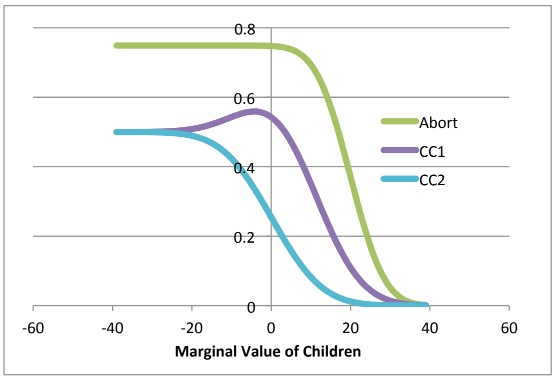

Figure 8d): *Optimal birth-control probabilities of unmarried couples.*

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