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FAMILYSCAPE 2.0:
An Architectural Overview

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December 2013

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Introduction

This technical paper documents the architecture of FamilyScape 2.0, a microsimulation model of family formation that was developed for the Brookings Institution's Center on Children and Families (CCF). The model was developed under the auspices of CCF's Social Genome Project, which studies the determinants of social mobility from birth through middle age. FamilyScape 2.0 simulates the key antecedents of pregnancy (sexual activity, contraceptive use, and female fecundity) and many of its most important outcomes (e.g., childbearing within and outside of marriage, children's chances of being born into poverty, and abortion). The model lends itself readily to policy simulations, since any of its inputs can easily be changed under the assumption that a given intervention has a particular effect on individual behavior. Its parameters were developed through extensive analysis of a wide range of real-world data sources, although most parameters for the "2.0 version" of the model were estimated using the 2006 – 2008 cycle of the National Survey of Family Growth.

FamilyScape 2.0 is the successor to an earlier iteration of the same model (henceforth, "FamilyScape 1.0"), which is described in detail in Thomas and Monea (2009). FamilyScape 1.0 has been used to simulate the effects of policies such as a national evidence-based sex education program targeted on at-risk youth, an expansion in states' Medicaid family planning programs, and a mass media campaign designed to increase condom use. The results of these simulations are documented in a variety of papers and reports, including Sawhill et al. (2010), Thomas (2012a), Thomas (2012b), and Thomas (2012c). FamilyScape 2.0 will be used to conduct similar sorts of simulations.

The updated version of FamilyScape differs from its predecessor in a number of ways. The most important differences between the two versions of the model are as follows:

- The new version of the model explicitly simulates the use of Long-Acting Reversible Contraceptive methods (LARCs). In the previous version of the model, LARC users were collapsed into a broader "hormonal methods" category.
- Unlike its precursor, FamilyScape 2.0 accounts for heterogeneity in the consistency and correctness of contraceptive use. This heterogeneity is simulated by allowing for demographic variation in the effectiveness of various methods.
- While the model's contraceptive efficacy parameters were previously derived using relatively simple back-of-the-envelope calculations, the equivalent parameters for FamilyScape 2.0 are constructed by combining published pregnancy rates for typical contraceptive users with the results of clinical trials and our own independent analyses of the NSFG.
- In FamilyScape 2.0, non-contracepting women are allowed to begin using contraception as the simulation proceeds, and contracepting women are allowed to switch between methods or to discontinue contraceptive use altogether. The previous version of the model did not allow for these sorts of changes in contraceptive behavior.
- In addition to replicating real-world monthly coital-frequency distributions for married and unmarried women, FamilyScape 2.0 now matches another important benchmark of sexual activity: the percentage of women who do not have sex for an entire year.
- The new version of FamilyScape is parameterized using more recent data (2006 – 2008) than was the original version of the model (2002). Most analyses of the 2006 – 2008 National Survey of Family Growth were performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger. The contributions of the Child Trends team were critical to the successful development of FamilyScape 2.0. We thank them for their outstanding work.

- We switched programming languages between the two versions of the model. FamilyScape 1.0 was developed in the Java programming language as an agent-based model, and it relied on each agent's spatial position in a simulated "social environment" to determine whether he or she met a potential romantic partner during the model's relationship-formation stage. In contrast, the new version of FamilyScape has been developed in Stata as a more traditional microsimulation model, and there is no spatial component to its simulation structure. We implemented this change in order to ensure that in-house staff will be able to maintain the model and perform simulations with relative ease.

The first six of these points will be addressed in considerable detail later in this report. With respect to the last point, we would note simply that, aside from the way in which relationships are formed, the new version of FamilyScape functions in much the same way as did the previous version of the model. And although the mechanics of the relationship-formation module are somewhat different in FamilyScape 2.0, the two versions of the model produce matches that are of similar quality. The removal of the spatial simulation component of the model also means that, unlike its predecessor, FamilyScape 2.0 does not produce visualizations of the individual-level behaviors and outcomes that it simulates. Beyond these (analytically unimportant) distinctions, however, the other dissimilarities enumerated above constitute the most salient differences between the two versions of the model.

In the next section, we give a brief "bird's-eye" overview of FamilyScape's architecture. In subsequent sections, we then provide more detailed descriptions of the way in which each of the model's modules was constructed.

Overview of the Model

FamilyScape 2.0 is a static microsimulation model designed to reproduce real-world family formation behaviors and outcomes as observed between 2006 and 2008.[1] The model has a daily periodicity, which is to say that each increment in analysis time corresponds to a single day. Behaviors and outcomes are simulated at the individual level and are then aggregated to produce population-wide estimates of various phenomena of interest. The individuals in the model's simulation population are heterogeneous: each of them is assigned a set of demographic and behavioral characteristics that help to govern the various decisions that they will make over the course of the simulation. The model is populated with a group of individuals whose gender, age, race, education, socioeconomic-status (SES), and marital-status profiles are consistent with the characteristics of the members of a nationally representative dataset.

As is the case in the real world, individuals within the simulation behave autonomously and often inconsistently. For example, some individuals in the model will be more inclined than others to have sex on a given day, and a given couple will be more likely to have sex on some days than on others. Each of FamilyScape's inputs (relationship formation, sexual activity, contraceptive use, etc.) is simulated so as to ensure that aggregate measures of the resulting behaviors are consistent with demographically specific benchmarks that were produced from extensive analysis of several different data sources. We then validate the model by comparing its outputs (rates of pregnancy among teens and adults, the incidence of childbearing within and outside of marriage, the frequency of abortion,

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[1] Static models such as FamilyScape 2.0 are distinguished by the fact that they do not allow individuals within the simulation to age or evolve as analysis time passes. There is, in fact, one respect in which certain individuals *do* evolve over the course of the simulation. Specifically, some women change their contraceptive regime as analysis time passes. This dimension of the model is described in the discussion of "Stage III" below and in Appendix III later in this document. For more information on microsimulation models in general and on static models in particular, see Citro and Hanushek, (1991), Harding (2007), Merz (1994), and Mitton et al. (2000).

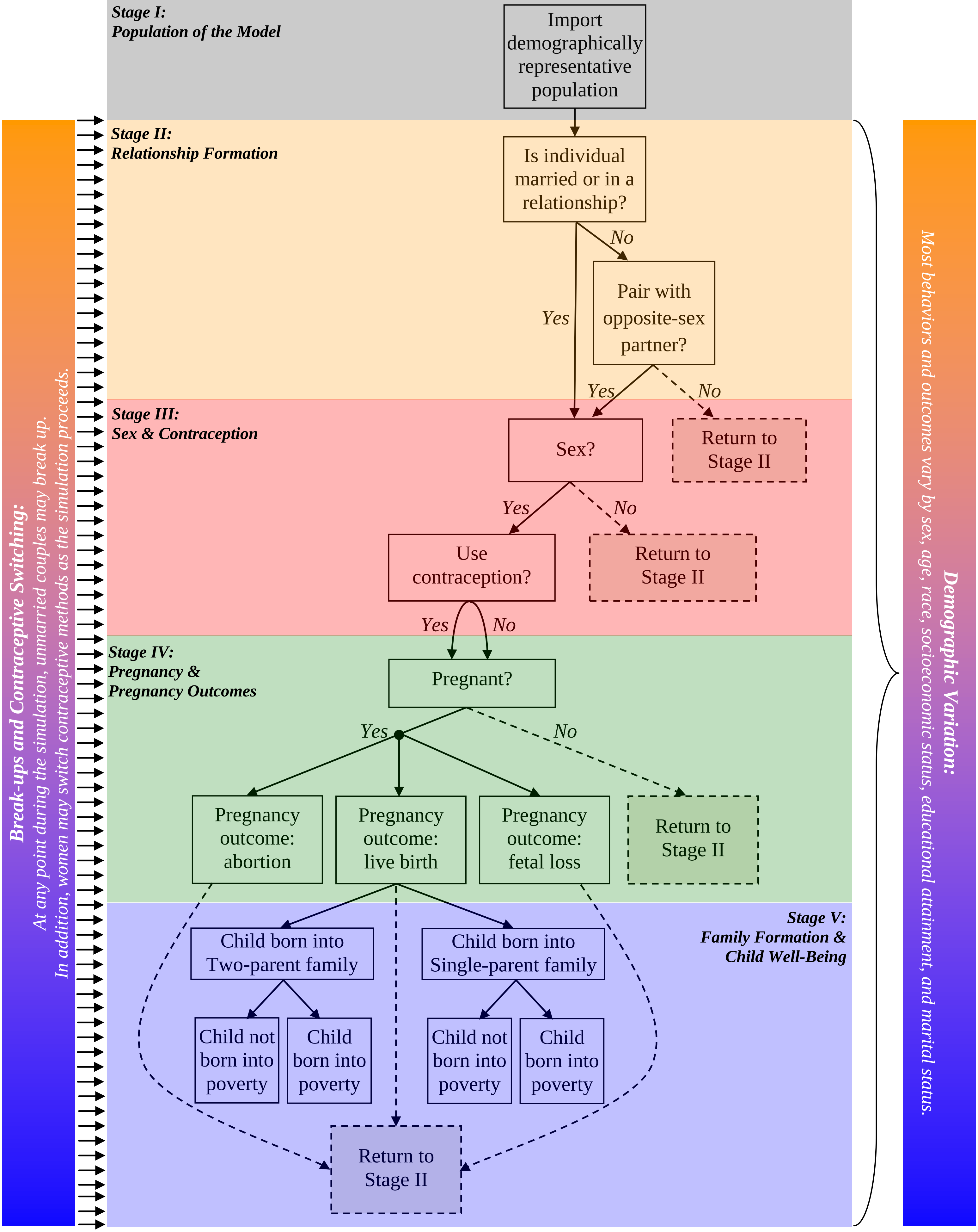
etc.) to their equivalent real-world benchmarks. As will be discussed later, FamilyScape generally performs quite well in this regard, especially for the unmarried population.

Figure 1 diagrams FamilyScape's overall structure and delineates the various stages of the simulation. During the first stage, the model is populated with a group of individuals whose demographic characteristics match those of the members of a nationally representative dataset. In the second stage, opposite-sex relationships of varying duration are formed among some individuals. In the third stage, sexual activity (or lack thereof) is simulated among married and unmarried couples, and contraceptive use (or lack thereof) is simulated among couples who have sex. In the fourth stage, some sexually active couples become pregnant, and each pregnancy eventually results either in a birth, an abortion, or a fetal loss. The model's fifth and final stage accounts for the fact that each birth is either to a married couple or to a single mother. Largely as a function of the structure of the family into which a child is born, a poverty status is also assigned to each newborn child during the model's fifth and final stage.

All of FamilyScape's input dynamics are aligned to real-world data. Information from a wide range of sources is used to ensure that the model realistically simulates the share of people who are married; the share of unmarried people who are in relationships; the rate at which married and unmarried couples have sex; the frequency with which sexually active couples use contraception; the types of contraception that they use; the number of women who switch onto and off of various contraceptive methods; the frequency with which couples using various types of contraception (or none at all) become pregnant; the share of pregnancies that result in live births, abortions, and fetal losses; the typical gestation periods for each of these pregnancy outcomes; and the share of births that occur within and outside of poverty. The model is designed to produce realistic variation in these dynamics according to individuals' demographic characteristics.

We would also emphasize that, because the model simulates these behaviors and outcomes on a daily basis, they may or may not occur anew on each new day. Thus, an unattached individual who did not enter into a relationship yesterday may do so today; a couple that does not have sex today may do so tomorrow; a sexually active couple that will not become pregnant tomorrow may conceive on the day after; and so forth. Figure 1 therefore only illustrates the broad contours of the simulation's stages. Figures 2 through 6 diagram these stages in more detail.

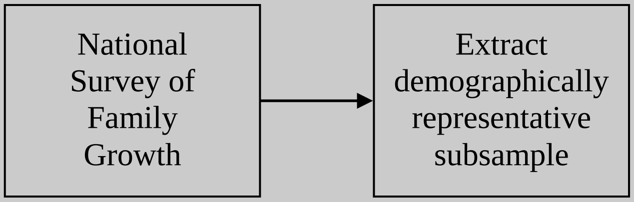
Figure 1: Summary Diagram of the FamilyScape 2.0 Simulation Model



Stage I: Population of the Model

Figure 2 shows the process by which the model is populated. We start with the male and female respondent files of the 2006 – 2008 National Survey of Family Growth (NSFG), which contain nationally representative samples of men and women who are between 15 and 44 years of age. Using the sample's demographic weights, we extract a subsample of 10,000 observations to use in our simulation.

Figure 2: Diagram of FamilyScape's Stage I Rules for Populating the Model



Because we use the NSFG's sampling weights to extract our subsample, the simulation population should have roughly the same demographic characteristics as the weighted full NSFG dataset. Table 1 presents characteristics for the weighted full 2006 – 2008 NSFG sample and the population of individuals that was extracted from the NSFG and imported into the simulation model. These tabulations demonstrate that the sample of individuals in our simulation population is indeed nationally representative.

Table 1: Demographic Comparison of the Full NSFG and the FamilyScape Simulation Population

	Full NSFG (weighted)	Population for FamilyScape Simulation
	Percent	Percent
15-19 (%)	17.1	16.7
20-24 (%)	16.6	16.3
25-29 (%)	16.7	17.0
30-44 (%)	49.6	50.1
Average age	29.5	29.6
White (%)	62.2	61.7
Black (%)	13.3	13.1
Hispanic (%)	17.8	18.0
Other (%)	6.7	7.3
Less than High School (%)	25.6	24.9
High School Degree (%)	24.0	24.2
More than High School (%)	50.4	50.9
Low SES (%)	22.0	22.2
High SES (%)	78.0	77.8
Unmarried (%)	58.3	59.1
Married (%)	41.7	40.9
Male (%)	50.2	50.2
Female (%)	49.8	49.8
N	13,386	10,000

Notes: The "full NSFG" estimates were derived using the male and female respondent files from the National Survey of Family Growth (NSFG) 2006-2008. Estimates for the "Population for FamilyScape Simulation" were derived using a demographically weighted subsample from the same NSFG dataset. Demographic weights were used to calculate summary statistics for the "full NSFG" sample, but not for the FamilyScape simulation population.

We should note that no single dataset contains the breadth of information necessary to estimate all of the model's many input parameters. Thus, once these individuals are imported into the simulation, we use data from a variety of different sources to estimate the various parameters that govern their decisions about relationship formation, sexual activity, contraceptive use, etc. For reasons of internal consistency, we parameterize the model using data from 2006 - 2008 whenever possible and, when data from these years are not available, we use information from the closest available year. We use 2006 - 2008 data because these are the most recent years for which NSFG files were available when FamilyScape 2.0 was being developed.[2]

Stage II: Relationship Formation & Dissolution

Figure 3 illustrates the process by which relationships are formed among members of the simulation population.[3] The model is initialized to ensure that the marriage rate among members of the simulation population is equivalent to the proportion married among 15-to-44-year-old respondents in the 2006 – 2008 NSFG. FamilyScape does not simulate divorces or new marriages. Thus, married couples remain married and unmarried individuals remain unmarried for the duration of the simulation. The model does, however, allow for the formation and dissolution of nonmarital relationships. Specifically, on most days on which a woman is unmarried, she is paired with a demographically similar male who functions as a "relationship candidate" for the woman in question on that day.[4] Once a woman is paired with a male relationship candidate, those two individuals jointly decide whether or not to enter into a relationship. If and when a relationship is initiated, the couple must decide on each subsequent day whether or not to continue their relationship. A nonmarital relationship may therefore last for as little as a single night, or it may continue

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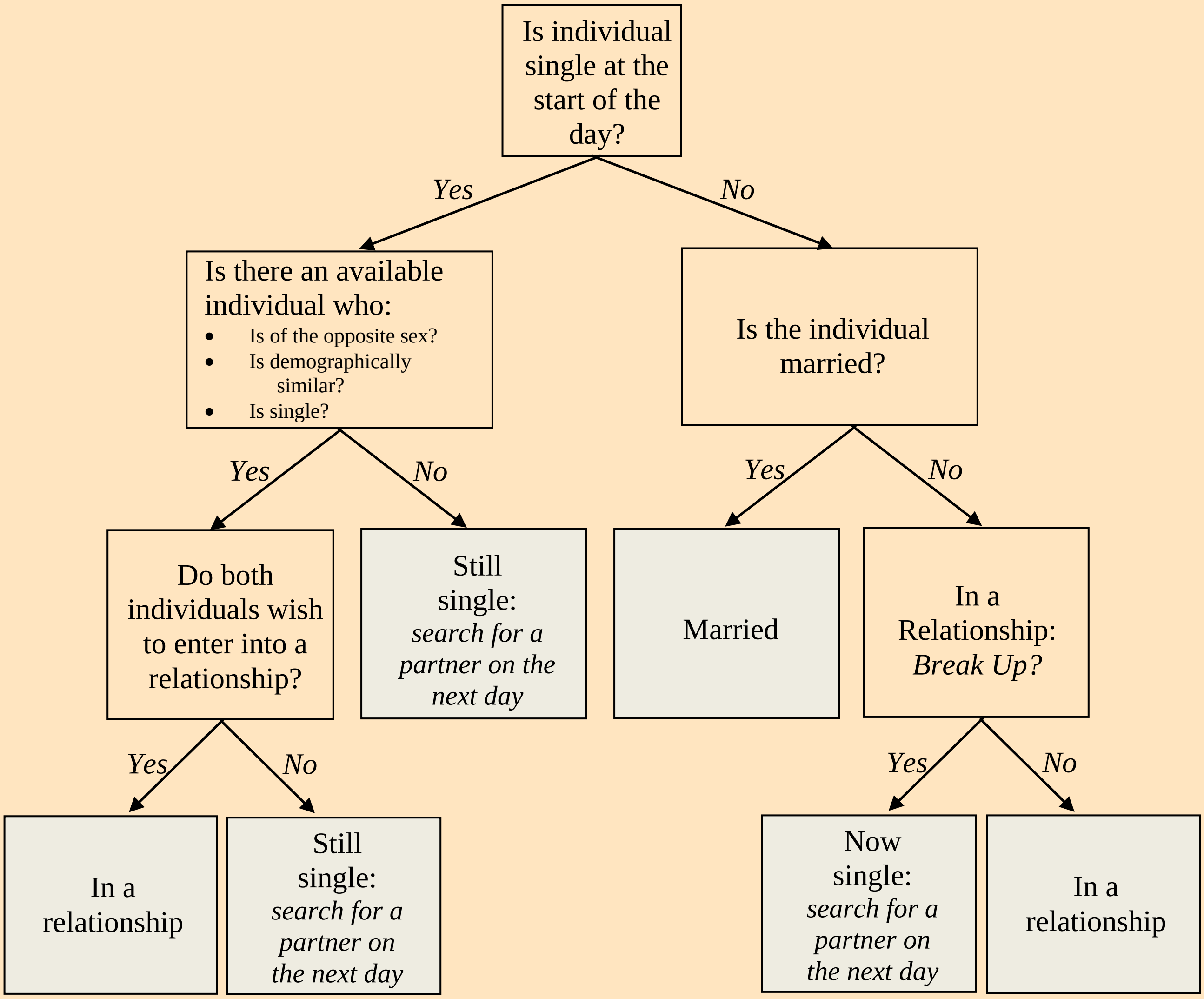
[2] Two additional years' worth of data have recently been made available for the cycle of the NSFG that we use to populate and parameterize FamilyScape 2.0. However, these data were not yet available during the development of most aspects of the model. Thus, although the full NSFG cycle corresponds to the years 2006 – 2010, we typically use only data from the 2006 – 2008 portion of that cycle when developing the model's parameters. We use a demographic weight specific to the 2006 – 2008 portion of the NSFG sample for the purposes of extracting FamilyScape's simulation population and developing the model's parameters. Because these data were gathered over a period of about three years, FamilyScape's results should be considered to correspond to the average annual conditions that prevailed over that time frame, rather than to the conditions prevailing during a single one-year period. The only exception to this rule involves the parameterization of the female contraceptive-switching module. Because the 2009 and 2010 NSFG data were available when the contraceptive–switching module was added to FamilyScape 2.0, we estimated the model's switching parameters using the full 2006-2010 NSFG sample of women in order to mitigate sample size problems. See Appendices I and III for further discussion of this topic.

[3] See Appendix II for a more technical description of FamilyScape's relationship-formation modules.

[4] In fact, because of modest demographic imbalances between women and men in the real world and therefore also in FamilyScape's simulation population, there are not demographically appropriate male "relationship candidates" available for every woman in the model at every point in analysis time. However, we are able to identify demographically similar male relationship candidates for approximately 75% of women in the model on any given day.

indefinitely. Individuals in the simulation population are assigned a set of numerical values reflecting the probabilities that they will enter into new relationships or end ongoing ones. These values are assigned in such a way as to ensure that the share of unmarried individuals within the model who are participating in relationships is consistent with the findings of our analysis of data from the General Social Survey (GSS), which suggests that, at any given time, about half of single people are in relationships.

Figure 3: Diagram of FamilyScape's Stage II Rules Governing Relationship Formation on a Single Day



Stage III: Sexual Activity & Contraceptive Use

Figure 4 shows FamilyScape's rules governing sexual activity and contraceptive use.[5] Because studies tend to show that survey respondents often over-report their rates of sexual activity – and since women in the NSFG report somewhat lower average levels of sexual frequency than do men – we use data only on women's self-reported coital frequency to implement FamilyScape's coital-frequency module. A couple's decision as to whether to have sex on a given day is therefore determined by the female partner, and some women in the simulation are more inclined than others toward sexual activity. Our analysis of NSFG data suggests that a substantial share of women have little or no sex, that another large portion of women have a moderate amount of sex, and that a small number of women have sex on an almost-daily (or even a more-than-daily) basis. We therefore place each woman into one of three sexual-proclivity categories: "inactive," "moderately active," or "highly active."[6]

Using the results of our analyses of 2006 – 2008 NSFG data, we vary women's chances of being placed into each of these three groups as a function of marital status, age, race, education level, and SES. We then calibrate the model's sexual-behavior component to ensure: a) that most of the women in the "inactive" category rarely or never have sex; b) that most of the individuals in the "highly active" category have sex regularly; c) that most of the individuals in the "moderately active" category have sex more often than those in the "inactive" group but less often than those in the "highly active" group; and d) that the aggregate distribution of coital frequency among the members of the simulation population approximates the equivalent real-world distribution as measured in the

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[5] See Appendix III for a thorough treatment of the technical details of FamilyScape's sexual-activity and contraceptive-use modules.

[6] For additional detail on this topic, see Appendix III.

NSFG.[7] Because our preliminary analyses indicated that the married and unmarried populations have fundamentally different distributions of coital frequency, we calibrate this component of the model separately for these two groups. We also parameterize FamilyScape's sexual-activity and relationship-formation modules so as to ensure: a) that the average annual number of sexual partners among sexually active unmarried individuals within the simulation is similar to its real-world equivalent; and b) that the simulated percent of women who are sexually inactive for an entire year approximates its real-world equivalent.[8]

FamilyScape 2.0 also simulates contraceptive use. Using benchmark data on the method of contraception used at last sex among 2006 – 2008 NSFG respondents, women in the model are assigned to one of four contraceptive-method categories: users of the pill, patch, or ring (PPR); long-acting reversible contraceptive method (LARC) users; women who are sterilized; and women who do not use any form of female-controlled contraception (i.e., female non-contraceptors).[9] Using the same data source, we assign men either to be condom users, to be sterilized, or to be male non-contraceptors.[10] Men who are designated as condom users are further assigned to be either "unconditional condom users" or "conditional condom users." Men in the "unconditional condom use" category use condoms when they have sex regardless of whether or not their partners are using

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[7] We should note that a woman's placement into a particular category does not guarantee that she will experience a specific level of sexual activity in the simulation. For example, a woman who is placed into the "highly active" category may in fact have little or no sex if she remains single for much of the simulation. Thus, while a woman's sexual proclivity is strongly correlated with the amount of sex that she has, this correlation is by no means perfect.

[8] See Appendices II and III for additional detail as to how these aspects of the model were calibrated.

[9] We use the term "sterilization" to refer both to natural sterility and to surgical sterilization. The following contraceptive methods are considered to be LARCs for the purposes of this discussion: intrauterine devices, hormonal implants, and injectables. The PPR category captures women who use oral contraception, the contraceptive patch, the NuvaRing, and emergency contraception. For purposes of simplicity, we also assign the small proportion of women in the NSFG who use other non-hormonal, female-controlled contraceptive methods to this category. These methods include diaphragms, female condoms, foams, jellies/creams, suppositories/inserts, the Today sponge, and natural family planning.

[10] Because withdrawal is a male-controlled contraceptive method, and for purposes of simplicity, we consider male respondents in the NSFG to be condom users if they report the use of withdrawal as their primary contraceptive method.

contraception, and men in the "conditional condom use" category only use condoms if their partners are not using contraception.

As we do for sexual behavior, we use the results of our NSFG analyses to vary individuals' chances of falling into each of these contraceptive categories according to their marital status, age, race, education level, and SES. We also vary female contraceptive use by sexual-proclivity type. Thus, if women who report being relatively more (or less) sexually active in our real-world data also report being relatively more (or less) likely to use a particular type of female-controlled contraception (or not to use any contraception at all), that dynamic is captured in the estimation of the model's input parameters for this module.

When FamilyScape's contraceptive-switching module is activated, non-contracepting women are allowed to begin using contraception, and contracepting women are allowed to discontinue contraceptive use or to switch methods. Switching is simulated on a monthly basis, which is to say that the types of female contraception used by a woman can vary across, but not within, months. Women can switch between three female-specific contraceptive categories: LARCs, PPRs, and non-use of female-controlled contraception.[11]

The parameters governing method switching in FamilyScape 2.0 are derived from a sample of sexually active 2006-2010 NSFG female respondents.[12] Switching probabilities vary according to the demographic attributes of the woman (marital status, race, age, and educational attainment) and the

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[11] Due to sample size limitations in real-world data, we do not model flows of women into and out of the "sterilized" contraceptive category.

[12] While women in the NSFG report the types of methods that they used in the months leading up to their interviews, the NSFG does not provide comparable longitudinal data on male contraceptive use. For this reason, we do not model male contraceptive switching in FamilyScape 2.0. And as noted in a previous footnote, because method switching within a calendar year is relatively rare, we develop contraceptive-switching parameters using data from the entire 2006-2010 NSFG cycle in order to mitigate sample size problems.

contraceptive method (or lack thereof) that she is initially using. Because analyses of NSFG data show that the number of women who switch methods more than once during a single calendar year is quite small relative the entire population of women who are at risk of method switching, we make the simplifying assumption that women in the simulation population can switch at most once during a 365-day segment of analysis time.[13]

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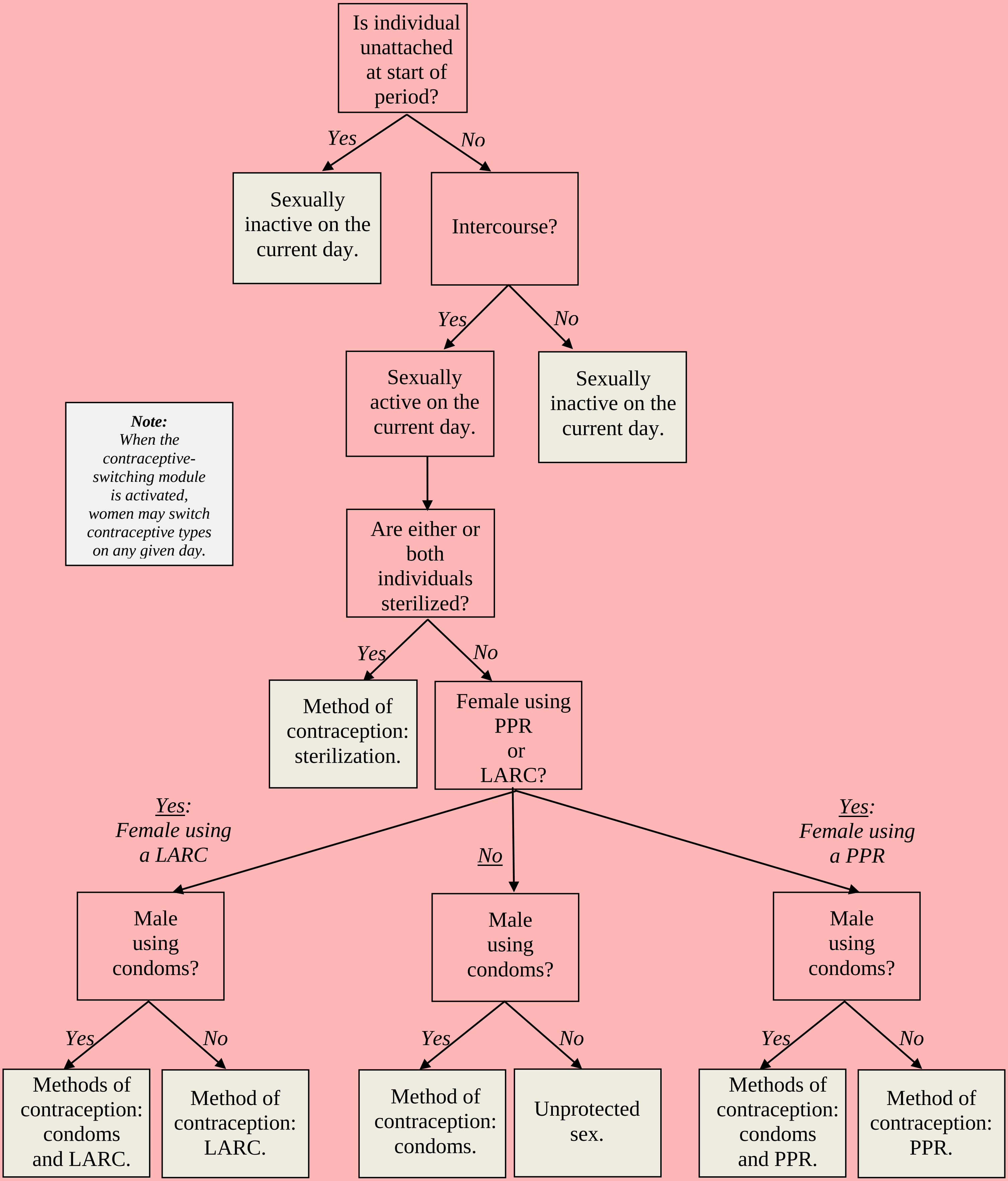
[13] See Appendix III for further discussion of this topic.

Figure 4: Diagram of FamilyScape's Stage III Rules Governing Sexual Behavior and Contraceptive Use in a Single Day



Note:
When the contraceptive-switching module is activated, women may switch contraceptive types on any given day.

Stage IV: Pregnancy & Pregnancy Outcomes

Figure 5 shows the model's procedures for simulating pregnancies and pregnancy outcomes. As is the case in the real world, a couple's chances of becoming pregnant after having sexual intercourse during the simulation depend on the woman's level of fecundity (i.e., her probability of becoming pregnant from a single act of unprotected intercourse) and on the effectiveness of the contraceptive method(s, if any) that the couple is using. FamilyScape 2.0 allows for variation in a woman's level of fecundity as a function of her age and the day in her menstrual cycle. Thus, as the simulation advances from one day to the next, it also updates each woman's menstrual calendar and adjusts her fecundity level accordingly. We assign age- and day-specific fecundity estimates based on our synthesis of the results of several published clinical studies.[14]

Except in the case of sterilization, a contraceptive method's effectiveness depends at least in part (and often quite heavily) on the consistency and correctness with which it is used. However, sufficient real-world data do not exist to allow us explicitly to model realistic variation in these dimensions of contraceptive behavior.[15] As such, we instead simulate variation in the consistency and correctness of contraceptive use by allowing methods' effectiveness to differ across demographic groups. This decision is rooted in the fact that there is substantial demographic variation in pregnancy rates among the users of a given method. We calculate demographically specific efficacy rates for most methods by combining the fecundity estimates described above with NSFG data on the pregnancy rates and coital frequencies of contraceptive users falling into various

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[14] For the purposes of parameterizing FamilyScape's fecundity module, we rely primarily on Royston's (1982) results because his model has the unique benefit of allowing the probability of pregnancy to vary simultaneously as a function of the woman's age and her menstrual calendar. However, we also make a number of age-specific adjustments to Royston's model. See Appendix IV for a comprehensive discussion of the way in which FamilyScape 2.0 models female fecundity.

[15] For example, the available real-world data are not detailed enough to allow us to simulate the proportion of oral contraceptors who miss one pill per month, the proportion who miss two pills per month, and so forth. Moreover, even if such data did exist, we would not be able to produce credible estimates of the decrease in contraceptive efficacy associated with missing a certain number of pills per month. See Appendix III for additional discussion of this topic.

demographic groups.[16] As is suggested above, the one exception to this rule is sterilization, which we assume to have a 100% efficacy rate for all users. See Appendix IV for a detailed discussion of FamilyScape's contraceptive efficacy module.

Once a couple in the simulation becomes pregnant, that pregnancy eventually results in a live birth, an abortion, or a fetal loss.[17] We use information from the National Center for Health Statistics' National Vital Statistics System, the Guttmacher Institute's 2008 Abortion Provider Survey, and the NSFG to assign an outcome to each new pregnancy as a function of the mother's marital status and demographic characteristics.

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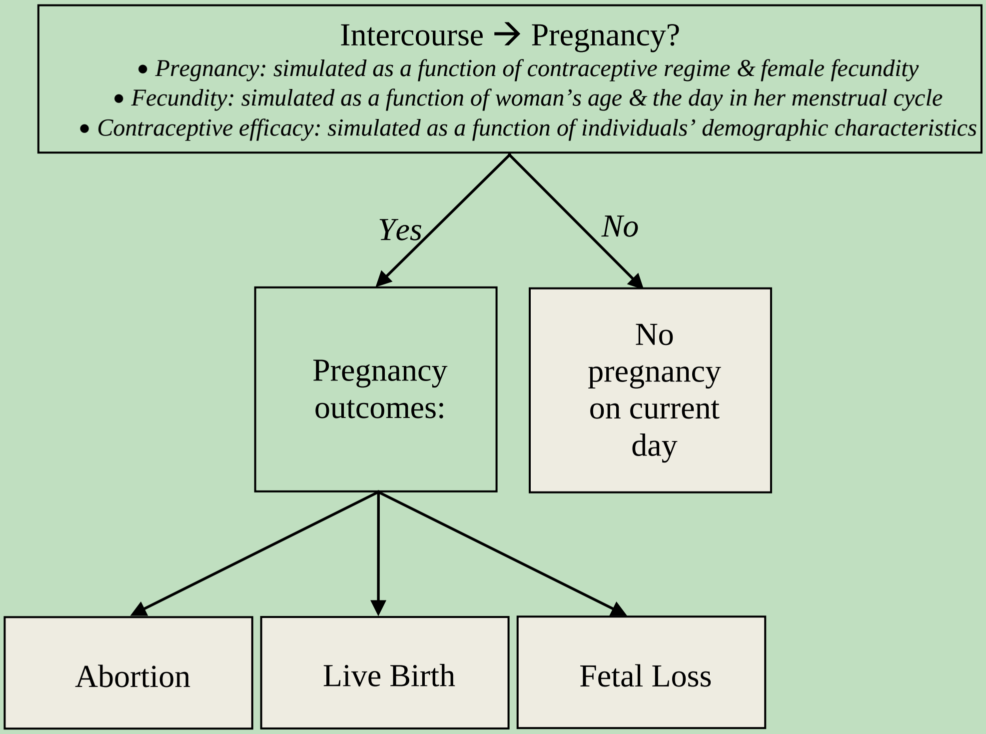
[16] Our contraceptive efficacy estimates are calculated under the assumption that the user does not switch methods. Thus, the dimension of "consistency" that is captured by our efficacy estimates corresponds not to the propensity to switch methods but instead to the likelihood of (for example) missing a certain number of pills per month. Contraceptive switching is explicitly modeled in a separate module. See Appendices III and IV for thorough descriptions of FamilyScape's switching and efficacy modules, respectively.

[17] Fetal losses are often referred to as "miscarriages," although this terminology is technically imprecise. We use the term "fetal loss" to refer to pregnancies that fail to result in a live birth for reasons other than induced abortion. We should also note that, after they become pregnant, couples within the simulation may continue to have sex, although they obviously cannot become pregnant again for the duration of the woman's pregnancy. We use data from a variety of different sources to define the lengths of the gestation periods for each pregnancy outcome. In addition, because women are typically unable to become pregnant again for a period of time after their pregnancies end, we extend these gestation periods somewhat in order to model the proper duration of time during which women are infertile after having experienced a pregnancy. See Appendix IV for further discussion of the way in which FamilyScape 2.0 simulates pregnancy outcomes and gestation periods.

Figure 5: Diagram of FamilyScape's Stage IV Rules Governing Pregnancy Outcomes



Stage V: Family Formation & Child Well-Being

Figure 6 shows FamilyScape's procedures for simulating family formation and child well-being. Because the model tracks the marital status of each individual in the simulation, it also automatically tracks the structures of the families – specifically, whether they are married-parent or single-parent – into which children are born. When presenting results from FamilyScape's simulations, we almost always disaggregate our results (e.g., rates of pregnancy, birth, abortion, etc.) by marital status. For each new live birth, we also assign a poverty status to the newborn child as a function of the mother's marital status and demographic characteristics.[18]

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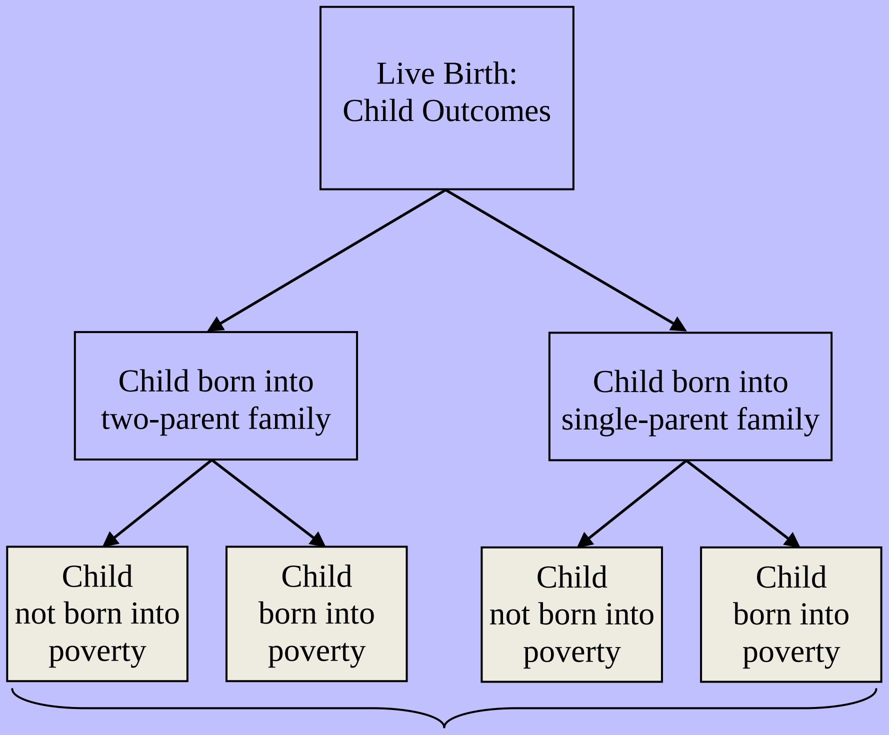
[18] See Appendix V for a more detailed description of FamilyScape's poverty-simulation module.

Figure 6: Diagram of FamilyScape's Stage V Rules Governing Family Formation and Child Well-Being



Child poverty: modeled as a function of family structure and the mother's demographic characteristics

Simulation Results

Having provided a brief overview of FamilyScape's architecture, we now present summary results from a series of diagnostic runs of the model. As was discussed at the beginning of this paper, FamilyScape 2.0 can be validated by comparing its key outcomes to their real-world equivalents. Figures 7 and 8 compare annual pregnancy, birth, and abortion rates among unmarried and married women from a set of FamilyScape simulations to the equivalent benchmarks from real-world data.[19] For unmarried couples, the model approximates real-world outcomes quite well: the annual rate of pregnancy is about one percent higher in the real world than in the simulation, and real-world targets for birth and abortion rates are both within about two percent of their simulated equivalents. Among married couples, however, real-world pregnancy, birth, and abortion rates are all more than 25 percent below their simulated analogues.[20]

The finding that FamilyScape 2.0 over-simulates pregnancies and pregnancy outcomes among married couples is not new: the "1.0 version" of the model over-simulated pregnancies and births among married women to an even greater extent than does FamilyScape 2.0.[21] Since policymakers tend to be primarily interested in reducing rates of out-of-wedlock pregnancy and childbearing, our first priority is to ensure that FamilyScape produces realistic results for the unmarried population,

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[19] Because of the extent of uncertainty about the precise shape of the age-fecundity profile for older women, we have concluded that the simulated prevalence of pregnancies and pregnancy outcomes among women aged 40 and over are unreliable and that outcomes for this group should generally be excluded when results are reported for FamilyScape simulations (see Appendix IV for further discussion of this topic). For Figures 7 and 8, simulated and real-world pregnancy rates are therefore tabulated using only data on women under the age of 40. We concluded after a series of exploratory analyses that, by conducting about 100 distinct simulation runs, we are able to ensure that average measures of the model's outcomes across runs are not influenced unduly by outliers. The simulation results shown here therefore represent averages calculated over 100 separate one-year runs of the model. See Appendix I for further discussion of this topic.

[20] See Table A17 in Appendix IV for a more detailed comparison of simulated and real-world pregnancy and pregnancy-outcome rates for a variety of different demographic groups.

[21] Thomas and Monea (2009).

and that goal has been achieved. However, we also continue to explore various theories as to why the model over-simulates pregnancies for married couples. The most important lessons of the data shown in Figures 7 and 8 are that, when FamilyScape is used to conduct policy simulations targeted on married women, the model's results should be interpreted with a measure of caution and users should focus on estimated *changes* in pregnancy rates, rather than on their absolute levels.[22] On the other hand, both changes and levels can be considered to be reliable when the model is used to simulate policies targeted on unmarried women.

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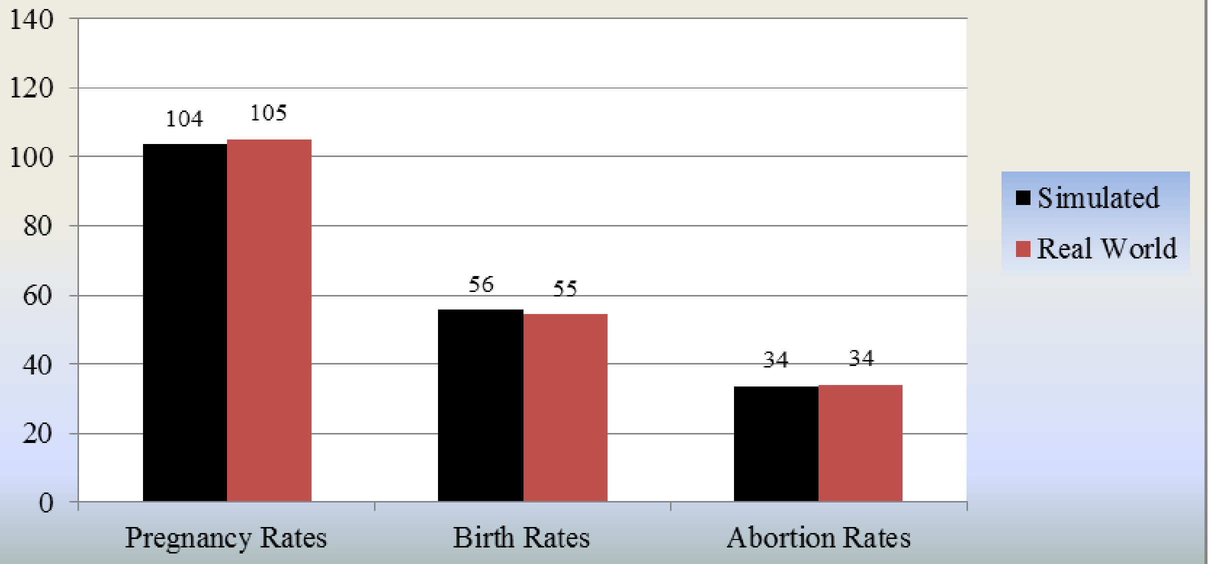
[22] Thomas and Monea (2009) show that a reduction in simulated sexual activity (and therefore in the pregnancy rate) among married couples in FamilyScape's simulation population has a negligible impact on the results of policy analyses. Thus, the model's over-simulation of pregnancies among married women is unlikely to affect its ability to perform credible policy simulations.

Figure 7:
Simulated and Real-World Pregnancy, Birth, and Abortion Rates*

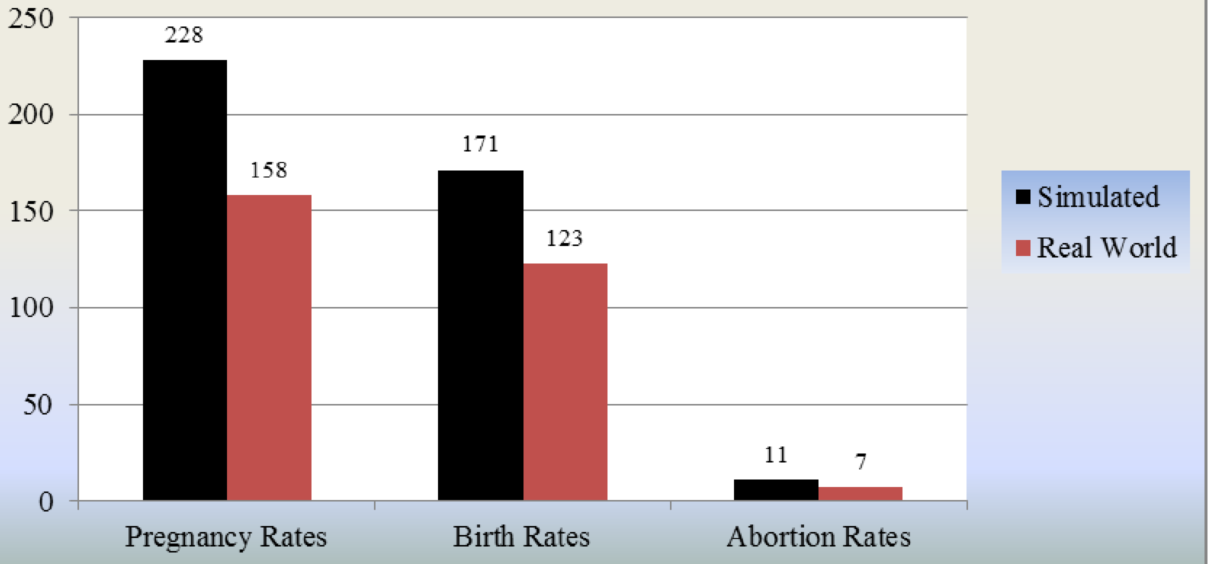
Per 1,000 Unmarried Women Ages 15-39



**Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 2.0 simulation model.*

Figure 8:
Simulated and Real-World Pregnancy, Birth, and Abortion Rates*

Per 1,000 Married Women Ages 15-39



**Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 2.0 simulation model.*

Conclusion

FamilyScape 2.0 realistically simulates the most important proximate antecedents of pregnancy, including sexual activity, contraceptive use, and female fecundity. Among unmarried women in particular, the model produces rates of pregnancy that are close to their real-world equivalents. Data from a variety of sources are integrated into the model in order to ensure that these behaviors and outcomes vary realistically according to demographic characteristics such as marital status, gender, age, race, educational attainment, and SES. The appendices that follow provide substantial additional detail regarding the way in which each of the model's components functions.

TECHNICAL APPENDICES

Appendix I: General Characteristics of the Model

This appendix discusses several cross-cutting issues that have relevance for all of FamilyScape's modules. Specifically, we discuss FamilyScape's periodicity, the model's quasi-steady-state framework, the role that random processes play in the implementation of the model's various modules, the data sources that were used to produce FamilyScape's simulation population and to derive its many parameters, and our reasons for selecting the demographic covariates that are incorporated into the model's simulation structure.

Periodicity

FamilyScape 2.0 has a daily periodicity. We chose to denominate analysis time in this way because the key behavioral antecedents of pregnancy – namely, sexual intercourse and contraceptive use – can occur on a daily basis, if not more frequently.[23] Moreover, sexual pairings in the real world are often of very short duration.[24] Defining the model's periodicity on an annual, monthly, or even weekly basis could therefore obscure potentially important variation in the behaviors that help to determine the incidence of pregnancy and childbearing. As such, FamilyScape allows individuals to engage anew in these behaviors on each new day.

Simulation of Dynamic Behaviors within a Static Framework

In many respects, FamilyScape 2.0 functions as a steady-state model, which is to say it reproduces in perpetuity the general conditions that were observed in the real-world data used to develop its baseline parameters. For instance, FamilyScape 2.0 continuously replicates real-world monthly coital

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[23] Only a very small portion of the population report having sex on more than a daily basis (Thomas and Monea, 2009). For the purposes of our simulations, we make the simplifying assumption that sexual intercourse occurs no more than once per day.

[24] Thomas and Monea (2009).

frequency distributions for an average month during 2006-2008. The model also reproduces in perpetuity the daily proportion of unmarried individuals who are participating in nonmarital relationships, the monthly distributions of male- and female-specific contraceptive method use, and the average number of sexual partners that women have per year (to name a few examples).

The lone exception to this rule is FamilyScape's contraceptive-switching module, which is a dynamic component of the model that systematically changes the contraceptive mix of a fixed cohort of individuals over time. For instance, our descriptive tabulations of NSFG data show that, for a given cohort of women, the number of contracepting non-white women who become non-contraceptors over the course of a year exceeds the annual flow of non-contracepting non-white women into the LARC and PPR categories. As a result, the incidence of non-contraception is slightly higher for a given cohort of minority women at the end of a given year than at the start of that year.

Because the size and composition of the FamilyScape population are held constant over analysis time, the model's population functions as a fixed cohort. As a result, imputing real-world switching probabilities to women in FamilyScape would gradually, but systematically, alter the demographic composition of female contraceptors. Over the course of a single simulated year, such changes would mirror realistic developments in female contracepting behaviors for a given cohort. After several years of simulated switching, however, the contraceptive mix among women in the model would increasingly diverge from real-world levels, since the same set of contraceptive-switching probabilities would be applied again and again to a never-aging, never-changing population of women.[25]

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[25] Put differently, contraceptive switching introduces a set of absorbing states into FamilyScape 2.0. If, for instance, FamilyScape's contraceptive-switching module were activated for 100,000 days, almost all non-white women would be

For this reason, we only activate FamilyScape's contraceptive-switching module for a single year of simulation time. More specifically, we first allow all other behaviors and outcomes (e.g., relationship formation and sexual activity) to reach steady states. We then allow female contraceptive method switching to occur for a 365-day window during which we also record data on any desired simulation outputs (e.g., pregnancies, abortions, children born into poverty). In practice, this translates into activating FamilyScape's contraceptive-switching module on simulation day 1000 and then collecting data for days 1000 to 1365. As such, all reported simulation results produced by FamilyScape 2.0 correspond specifically to outcomes as measured over this period of analysis time.

Modeling of Random Processes

As is made clear in the remaining appendices, most of FamilyScape's modules include some element of randomness. As the simulation proceeds, random processes govern the chances that a given individual will enter into a relationship, the likelihood that a married or unmarried couple will have sex on a given day, the probability that a couple will use contraception when they have sex, and so forth. A brief exposition of the way that FamilyScape 2.0 models these random processes may prove useful to readers who are not familiar with microsimulation modeling.

At the outset of the simulation, each member of the simulation population is assigned a set of probabilities that are subsequently used to model various aspects of his or her behavior. Some of these probabilities (e.g. the likelihood of using a particular contraceptive method) are imputed using regression equations that include demographic covariates, while others (e.g. the model's relationship-entry propensity) are the same for everyone in the model. When an individual has to make a

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female non-contraceptors and almost all white women would use female-controlled contraception -- a contraceptive mix that is clearly at odds with real-world data.

decision about whether to take a particular action, we draw a random number between 0 and 1, and the individual engages in the behavior in question if that draw falls below the relevant probability.[26] When there are multiple categories for our behavioral variables, we model the relevant decision as a series of binary choices. For a choice with three options, for example, we first model whether individuals choose option one (as opposed to options two or three). For all individuals who do not choose the first option, we then model the choice between option two and option three. This approach is functionally equivalent to the modeling of simultaneous choices from among all available options, but it is substantially easier to implement.

Because of FamilyScape's heavy reliance on random variation, no two runs of the model are exactly alike. We therefore report simulation results using data that are averaged over multiple runs of the model. Our objective is to conduct enough simulation runs to prevent outliers from exercising undue influence over average measures of FamilyScape's aggregate outcomes across runs. We concluded after a series of extensive exploratory analyses that, when the model is run about 100 distinct times, distributions of its results are consistently unimodal and approximately symmetric. Thus, the results reported throughout this paper are from 100 one-year quasi-steady-state runs. In other words, each time that a simulation is performed, the model is first allowed to reach a steady state, after which the contraceptive-switching module is activated and outcomes are tracked for one year's worth of analysis time. This process is repeated 100 times – each time with a different seed number for Stata's random-number generator – in order to produce 100 years' worth of simulated

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[26] Imagine, for example, that someone has a 70% probability of engaging in a particular behavior. When a random draw is taken from a uniform (0,1) distribution, there is a 70% chance that the result of that draw will be equal to a value less than 0.7 and a 30% chance that the resulting value will be greater than this threshold. Thus, for the individual in question, if the result of a random draw is less than 0.7, he or she will engage in the behavior in question and, if the draw is greater than this threshold, he or she will not.

data.[27] Figures A1 through A3 show distributions for the rates of pregnancy, childbearing, and abortion generated by the model across 100 distinct runs. As is suggested above, all three distributions are unimodal and approximately symmetric.

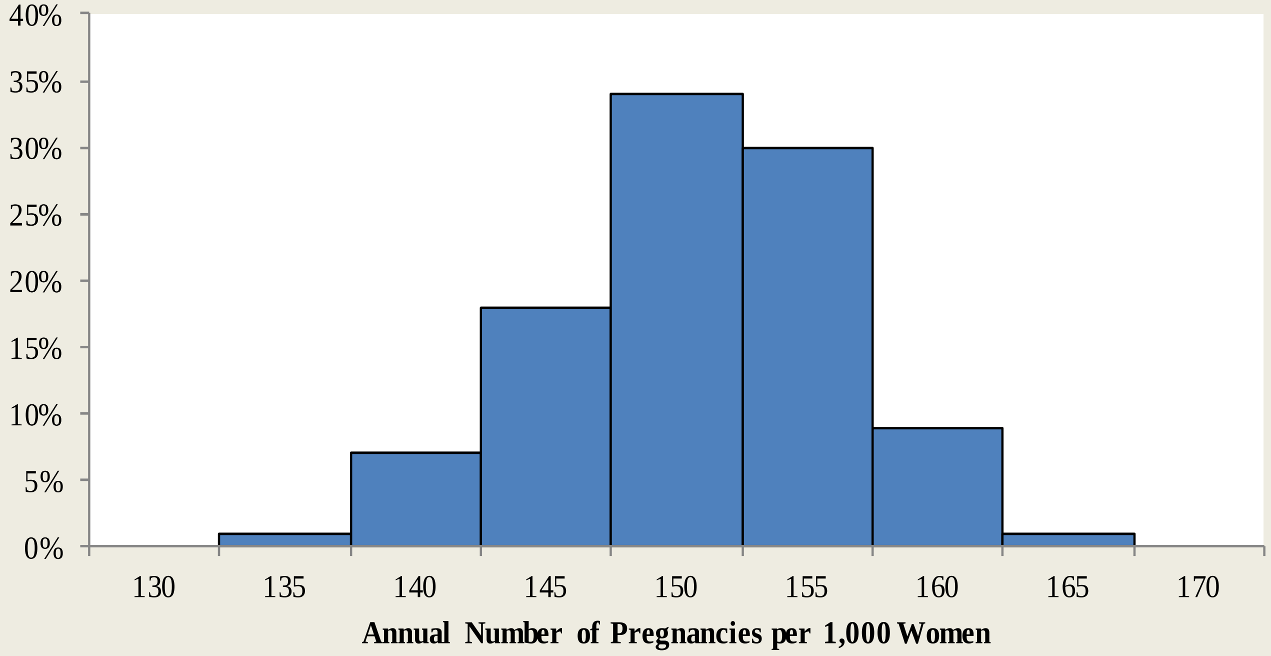

Figure A1: Distribution of Annual Pregnancy Rates

From 100 Runs of the FamilyScape 2.0 Simulation Model,
Among All Women Aged 15-39

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[27] The values provided by Stata's "random" number generator are in fact only quasi-random, not truly random. Stata will produce the same sequence of quasi-random numbers every time it is given the same seed number. Thus, initializing the model repeatedly with different seed numbers ensures variation not only among individuals within each run but also across different runs of the model.

Figure A2: Distribution of Annual Birth Rates

From 100 Runs of the FamilyScape 2.0 Simulation Model, Among All Women Aged 15-39

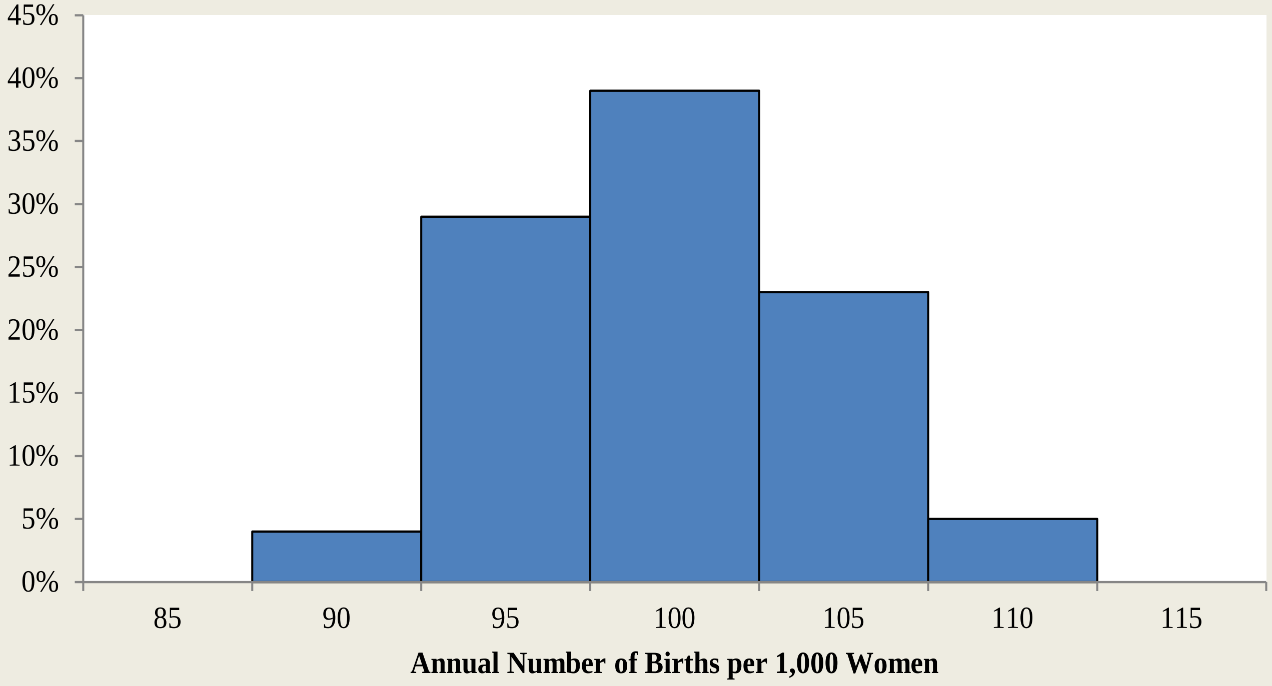

Figure A3: Distribution of Annual Abortion Rates

From 100 Runs of the FamilyScape 2.0 Simulation Model, Among All Women Aged 15-39

Data Sources

We populate the simulation model using data from the combined adult male and female respondent files of the 2006 – 2008 National Survey of Family Growth (NSFG). NSFG respondents were between the ages of 15 and 44 when they participated in the survey.[28] Sample members were asked a wide range of questions pertaining to their sexual activity, contraceptive use, and fertility-related outcomes. When its weights are applied, the NSFG's joint age-gender-race-ethnicity distribution is consistent with the equivalent distribution for the national population from which it was drawn.[29] We therefore create FamilyScape's simulation population by probabilistically selecting (with replacement) 10,000 observations using sample members' individual demographic weights.

Two additional years' worth of data have recently been made available for the cycle of the NSFG that we use to populate and parameterize FamilyScape 2.0. However, much of the work on the model was conducted before these data were made publically available. Thus, although the full NSFG cycle corresponds to the years 2006 – 2010, we use only observations from the 2006 – 2008 portion of that cycle to create FamilyScape's simulation population. We use a weight specific to the 2006 – 2008 portion of the NSFG sample for the purposes of extracting FamilyScape's simulation population and developing the model's parameters. As such, the simulation population's demographic characteristics are similar to those of the weighted 2006 - 2008 NSFG sample. Because these data were gathered over a period of about three years, FamilyScape's results should be considered to correspond to the average annual conditions that prevailed over that three-year time

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[28] In fact, four male members of the sample were 45 years old. These observations were dropped from the dataset before it was used to populate the model.

[29] National Center for Health Statistics (2011).

frame, rather than to a single one-year period. A year's worth of simulated data should therefore be roughly reflective of the average annual outcomes observed during that period.[30]

The NSFG contains much – but not all – of the information necessary to parameterize the model. We therefore use data from other sources as necessary to estimate the model's parameters. We use data from the latter portion of the previous decade for this purpose whenever possible and, when data from this period are not available, we use information from the closest available time period.[31]

Choice of Demographic Covariates

As we import individual observations into FamilyScape 2.0, we retain information on some of their demographic characteristics. Specifically, we retain individual-level information on gender, age, race, educational attainment, SES, and marital status. We operationalize SES using a measure of maternal educational attainment.[32] Variation is simulated in FamilyScape's behavioral inputs and key outcomes according to these characteristics.

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[30] As is discussed in greater detail below, this is actually true only after the model reaches a quasi-steady state. At the outset of the simulation, relationships have yet to be formed among unmarried individuals, and – once married and unmarried couples become pregnant – births do not occur until about nine months after the day of conception. After less than two years of analysis time have elapsed, the model produces approximately realistic rates of relationship formation, sexual activity, pregnancy, and childbearing. Out of an abundance of caution, we only use the model's output data from day 1,000 and beyond to measure our outcomes of interest. As is discussed later in this appendix, we produce annualized simulation results by averaging a year's worth of data from 100 different runs of the model. The data used to produce these annualized results correspond to a period spanning from day 1000 to day 1365 for each simulation run.

[31] The other data sources used to parameterize the model include (but are not limited to) the 2009 Current Population Survey (CPS); the 1998 General Social Survey; the Guttmacher Institute's 2008 Abortion Provider Survey; and the 2008 version of the National Center for Health Statistics' National Vital Statistics System.

[32] On the use of maternal education as a proxy for SES, see Bornstein et al. (2003). We considered the possibility of including a variety of other covariates in the model, but we decided not to do so for three reasons. First, the simulation already contains nearly 500 input parameters, and we wanted to achieve some measure of modeling parsimony. Adding more covariates to the model would substantially increase the number of parameters that we would be required to estimate. Second, the results of various statistical tests suggested that the realism of the model would not be meaningfully enhanced by the inclusion of these additional covariates (for example, when building the "1.0 version" of the model, we considered the possibility of accounting for religious affiliation and/or religiosity in the various regression models used to develop FamilyScape's parameters, but we found that – regardless of how these characteristics were measured – the relevant coefficients were almost always extremely small in magnitude and were usually statistically insignificant). And third, the general consensus among the experts advising us during the early stages of the FamilyScape

Table A1 shows the categorical specifications that were chosen for each demographic characteristic. We selected these specifications either based on the results of econometric analyses or because we were compelled to do so by the limitations of data available to us. They are also quite consistent with the categorical definitions that are typically used in the broader literature on population studies and family formation.[33]

Table A1: Specification of FamilyScape's Covariates

	Age Group	Race	Educational Attainment	SES	Marital Status
Categories	15-19	White	Less than high school	Mother had less than a high school degree	Unmarried
	20-24	Black	High school degree	Mother had at least a high school degree	Married
	25-29	Hispanic	More than high school		
	30-44	Other			

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project was that the characteristics listed above were the most important for us to include on substantive and policy grounds.

[33] The "high school degree" education category contains individuals who have earned either a high school diploma or a General Educational Development credential but have not pursued any further formal education. The "other" race category encompasses Asians, Native Americans, and all other individuals who do not self-identify as white, black, or Hispanic. The specification of FamilyScape's race covariate was somewhat obvious, although we could have chosen instead to use a white/non-white dummy variable. Primarily for policy reasons, we concluded that it would be preferable for us to be able to disaggregate our race-specific results in a more fine-grained fashion. We parameterize several of the model's modules using the results of regression models that were estimated using these demographic variables as covariates. In exploratory work conducted when the "1.0 version" of the model was being developed, we considered the possibility of using several alternate specifications of education and age. For education, we also considered models using a continuous variable. For age, we considered models using a continuous variable; continuous and squared variables; and continuous, squared, and cubed variables. According to the results of various statistical tests, the variable specifications described in Table A1 usually performed at least as well as – if not better than – these alternate specifications. Following standard convention, we use maternal education as a proxy for SES. We previously considered several alternate specifications of SES in our coital-frequency and contraceptive-use regressions. Specifically, we considered a continuous variable, a four-category variable (less than high school, high-school degree, some college, and a college degree or more), and a tripartite variable (less than high school, high-school degree, and more than high school). The results of various statistical tests indicated that a dummied version of this variable was preferable, although it was not obvious whether the variable's breakpoint should be at "less than a high-school degree/at least a high school degree" or at "high school degree or less/some college." We chose to use the former breakpoint because this definition of SES has the advantage of producing a slightly more balanced distribution.

We considered the question of whether to account for interactions between these variables in the regression models described in subsequent appendices. However, when constructing the "1.0 version" of the model, we compared the results of several different statistical tests and various goodness-of-fit measures for models that did and did not include interaction terms.[34] We estimated a large number of models – some included interaction terms only for race and SES, some only included interactions for education and age, some included a full set of interaction terms, and so forth. The results of these analyses generally suggested that the inclusion of interaction terms in the regressions used to parameterize the simulation would add little to its ability to capture meaningful real-world demographic variation in our outcomes of interest. Thus – and in the interest of parsimony – we do not allow for interactions between demographic characteristics in the simulation.[35]

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[34] Specifically, we examined Bayesian Information Criteria, Oaxaca decompositions results, various R^2 measures, and individual and joint tests of statistical significance. For more information on these analyses, see Thomas and Monea (2009).

[35] As is described above, FamilyScape's demographic covariates are defined such that there are four different race categories, four age categories, three education categories, two SES categories, and two marital-status categories. If we were to specify separate, demographically specific probabilities to simulate each behavior and outcome that is included in the simulation, we would have to estimate 4*4*3*2*2 = 192 separate parameters in many cases. We rely instead on regression results. Because we typically estimate separate regression models by marital status, we parameterize most demographically specific dimensions of the simulation using 2*(4+4+3+2) = 26 separate parameters. The use of regression models without interaction terms as opposed to demographically specific probabilities therefore reduces by a factor of more than seven the number of estimated values that are needed to parameterize many aspects of the model.

Appendix II: Relationship Formation & Dissolution

This appendix describes FamilyScape's procedures for modeling the creation and dissolution of opposite-sex relationships. We begin by discussing the simulation of non-marital relationships among single individuals. We then describe the process by which marital matches are created at baseline among the married individuals that are imported into the model.

The Simulation of Non-Marital Relationships

At the beginning of the simulation, all unmarried individuals are single (which is to say that none of them are participating in nonmarital relationships). However, as analysis time passes, opposite-sex relationships begin to be formed by some single individuals.[36] A simulated relationship may last indefinitely, or it may be terminated after as little as a single day. These "relationships" should therefore not be thought of as automatically corresponding with stable romantic pairings. Rather, they simply function as necessary pre-requisites for sexual intercourse (in fact, they are often quite durable, but that need not be the case in order for a couple to have sex in the short term). We use the term "relationship" to describe all such arrangements for ease of exposition. However, the reader should bear in mind that this term is being used rather loosely.

On each day within the simulation, most single women are paired with demographically similar males who function as "relationship candidates" for those women.[37] Once a woman is paired with a

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[36] Since we are interested primarily in modeling the incidence of pregnancy and childbearing, we do not simulate same-sex relationships.

[37] Individuals are considered to have common demographic characteristics if they fall into the same age, race, education, and SES categories. See Table A1 in Appendix I for an overview of the ways in which these categories are defined. Appropriate relationship candidates cannot be identified for about a quarter of single women in the simulation population on a given day. This phenomenon is primarily attributable to the fact that there are modest demographic imbalances between women and men in the real world and that these imbalances are reflected in FamilyScape's

male relationship candidate, those two individuals jointly decide whether or not to enter into a relationship. An individual's generic willingness to enter a relationship is represented by a fixed "relationship-entry probability" that is assigned to him or her at the beginning of the simulation. These fixed probabilities do not vary across individuals, which is to say that all single men and women in the model are assigned the same relationship-entry probability. For a given pair of potential relationship partners on a given day, separate random draws are taken from a uniform (0,1) distribution. If the individual's draw falls below his or her relationship-entry probability, then that individual is willing to start a relationship with his or her potential partner. A couple will form a relationship only if both potential partners wish to do so.

Each individual is also assigned a fixed probability that helps to determine his or her likelihood of exiting a relationship. Once again, these fixed probabilities do not vary across individuals. On every day that a pair of individuals are in a relationship, separate random draws are taken from a uniform (0,1) distribution and, if both individuals' draws fall below their respective "relationship-exit probabilities," then the relationship comes to an end. Depending on the values of the random draws that are taken over time to determine whether a couple will break up, their relationship may be dissolved after as little as a single day, or it may last indefinitely. Our tabulations of data from the 1998 General Social Survey (GSS) indicate that about 50 percent of unmarried men and women between the ages of 15 and 44 report that they are currently "romantically involved." We therefore set FamilyScape's relationship-entry and break-up probabilities in such a way as to ensure that about

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simulation population. This fact has no implications for the model's ability to simulate the appropriate number of nonmarital relationships.

half of unmarried individuals in the simulation are participating in relationships at any given point in time.[38]

The share of unmarried individuals who participate in relationships and the durations of those relationships both depend on the specification of these probabilities. For example, if the model's relationship-entry probability is quite high and the relationship-exit probability is quite low, then substantial numbers of unmarried individuals will be participating in long-term relationships. Similarly, if entry and exit probabilities are both high, then a large share of the unmarried population will be cycling in and out of short-term relationships; if entry probabilities are low and exit probabilities are high, then a relatively small number of people will be participating in relationships, and these relationships will tend not to last for very long; and so forth.

Thus, there are a number of different parameterizations of the model's relationship-formation module that would produce the desired result of ensuring that about half of the unmarried population is participating in a relationship at any given point in time. Some of these parameterizations correspond with a norm of relatively shorter-term relationships, while others correspond with a norm of relatively longer-term relationships. We calibrate this component of the model to ensure both that the appropriate share of unmarried individuals are participating in relationships and that the simulated average annual number of sexual partners among unmarried

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[38] GSS respondents were asked specifically whether they had a "main romantic involvement." The 1998 GSS is the most recent iteration of the survey in which sample members were asked this question. For our purposes, it would be ideal if respondents had answered in the affirmative even if they only had a casual sexual partner(s). It is likely, however, that some casual sexual relationships were not captured in responses to this question. On the other hand, it is also likely that some of the affirmative answers to this question referred to relationships that were homosexual rather than heterosexual. As is discussed below, we compensate for these potential drawbacks by parameterizing the model to ensure that both the distribution of annual vaginal coital frequency and individuals' average annual number of heterosexual partners are similar to their real-world targets (because of the way that FamilyScape 2.0 is structured, it is much more important that the model hits these two targets than that it simulates precisely the correct proportion of individuals who are participating in relationships).

individuals is roughly consistent with our tabulations of NSFG data reported in Chandra et al. (2011), which suggest that sexually active unmarried women between the ages of 15 and 44 have an average of about two sexual partners per year.[39] In exploring FamilyScape's parameter space, we first calibrated the model's coital-frequency module (which is discussed in detail in Appendix III) and then identified a combination of relationship-entry and relationship-exit probabilities that: a) cause about half of unmarried people to be in relationships at any given point in analysis time; and b) produce an average annual number of sexual partners among sexually active unmarried women (about 2.1) that is close to the aforementioned real-world benchmark.[40]

Figure A4 presents relationship-participation results from a representative run of the model when it is parameterized in this fashion. Within about 200 periods, the model reaches a quasi-steady state in which about half of unmarried individuals are participating in relationships.

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[39] For the purposes of this discussion, women are defined as being "sexually active" if they have sex at least once per year.

[40] We considered the possibility of varying individuals' relationship-entry and relationship-exit probabilities by their demographic characteristics. However, because the simulation of relationships within FamilyScape 2.0 functions primarily as a necessary prerequisite for sex – and since the model does in fact vary sexual proclivity by individual characteristics – we concluded that also allowing for demographic variation in relationship formation would complicate the model unnecessarily. See Appendix III for a discussion of the method by which coital frequency is conditioned on individual demographic characteristics.

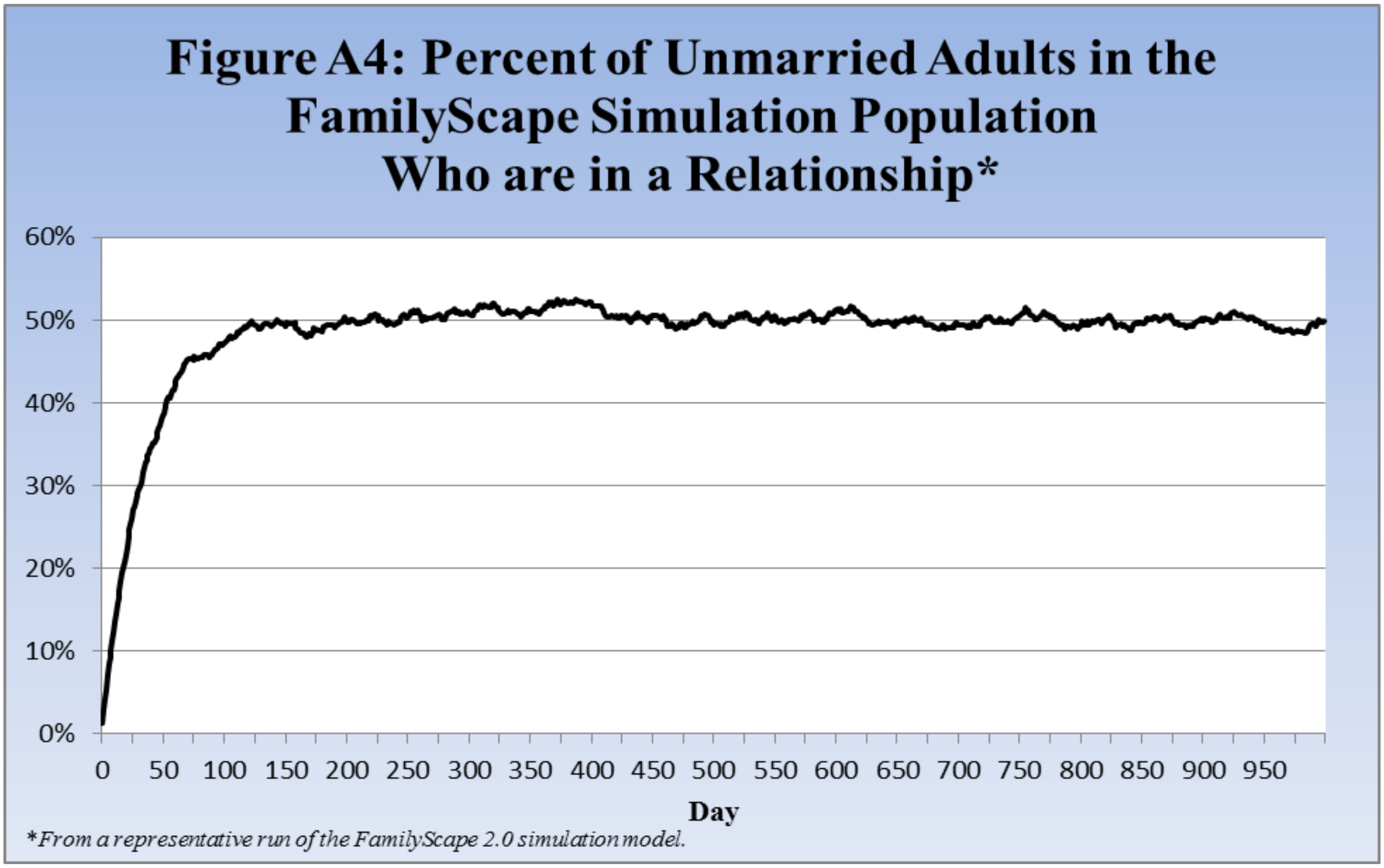

Figure A4: Percent of Unmarried Adults in the FamilyScape Simulation Population Who are in a Relationship*

**From a representative run of the FamilyScape 2.0 simulation model.*

The Simulation of Marriages at Baseline

Somewhat less than half of 2006 – 2008 NSFG sample members – and thus, somewhat less than half of the individuals imported into the simulation – are married. However, because the NSFG is a sample of individuals rather than of households or families, respondents' spouses are not included in the dataset. Before importing our extracted subsample into the model, we therefore simulate marital matches between demographically similar individuals who are coded as married. In the first phase of the marriage simulation, we create random matches between individuals who fall into the same age, race, education, and SES categories. We then begin gradually to relax our matching criteria by allowing as-yet-unmatched individuals to marry if they are similar along most (or some), but not all, of these demographic dimensions. We continue this process until we have created as many matches as possible among the members of the simulation population who were coded as married in the NSFG.[41]

After this process is completed, the proportion married within the simulation population (about 41 percent) is very close to the proportion married among the national population of 15-to-44-year-olds as measured in the 2006 – 2008 NSFG (about 42 percent). Table A2 compares the extent of marital homogamy among the participants in our simulated marriages and among married March 2009 Current Population Survey (CPS) respondents. Due in large part to the premium placed on match quality within our marriage module, simulated marriages are more homogamous than are their real-world equivalents.[42]

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[41] There are somewhat fewer married men than married women in the subsample of individuals that were extracted from the NSFG to populate the simulation model. As a result, we are left at the end of the matching process with a handful of women who reported being married in the NSFG, but for whom we were unable to identify a spouse from among the available pool of married men. These "married-but-unmatched" women constitute about 3% of the total number of individuals in FamilyScape's simulation population whose NSFG records show that they are married. For the purposes of the simulation, we switch the marital statuses of the members of this group from married to unmarried.

[42] The comparison of age-specific match quality is somewhat awkward, since the men and women participating in simulated marriages are all between the ages of 15 and 44. This restriction artificially inflates the extent of age-specific homogamy among simulated marriages. In order to create a comparison group that is as similar as possible to the married members of the simulation population, the CPS sample is limited to couples in which the wife falls into this age range.

Table A2: Comparison of Match Quality Among Real-World Marriages in the CPS and Simulated Marriages Created Using the NSFG

	Marriages in the CPS	Simulated Marriages from the NSFG
Same age (%)	12.8	9.4
Woman older than man (%)	18.8	43.2
Man older than woman (%)	68.4	47.4
Mean difference in years (woman - man)	-2.87	-0.48
Same education (%)	71.2	93.8
Women has more education than man (%)	17.7	6.0
Man has more education than woman (%)	11.1	0.2
Same race (%)	88.7	97.3

Note: Simulated marriages were created using observations between the ages of 15 and 44 from a weighted subsample of the National Survey of Family Growth's (NSFG) 2006-2008 male and female respondent files. The data reported here on real-world marriages were taken from the March 2009 Current Population Survey (CPS). In order to create a CPS subsample that is as comparable as possible to the group among whom marriages were simulated using the NSFG, demographic characteristics for married CPS respondents are reported here only for couples in which the wife is between the ages of 15 and 44.

Note that FamilyScape 2.0 does not simulate the creation of new marriages or the dissolution of existing ones. We hope to add marriage and divorce modules to a future version of the model. We would note, however, that – even though FamilyScape does not model new marriages and divorces after the initial partnering process – the prevalence of marriage among the individuals that populate the model is consistent with the share of individuals who are married within the population at large. Thus, while FamilyScape 2.0 not account for the "flow" of individuals into and out of the married population, it does realistically capture the "stock" of married couples as reflected in the real-world data that were used to produce the model's baseline population.

Appendix III: Sexual Activity & Contraceptive Use

The first section of this appendix describes FamilyScape's methods for modeling coital frequency among married and unmarried individuals. The second section then describes our procedures for simulating contraceptive use (or lack thereof) among sexually active couples and female-specific contraceptive method switching.

Coital Frequency

In order to engage in sexual activity on a given day, an individual in the simulation must be part of a marriage or a non-marital relationship. In FamilyScape 2.0, the decision to engage in sexual intercourse depends entirely on the woman's preferences. We model decision-making about coitus in this way because men in the NSFG tend to report higher levels of sexual activity than do women.[43] However, because the aggregate amount of heterosexual intercourse among men and women should be the same, it seems likely that one or both of the two sexes have a systematic tendency to misreport their true level of sexual activity. Small-scale studies of sexual behavior generally find that respondents are more likely to over-report the amount of sex that they have than they are to under-report it [44] Thus – and since women tend to report having less sex than men – we make the assumption that women's self-reports of sexual activity are more reliable than are men's. We therefore calibrate the model's coital-frequency module using only data on women's sexual activity. In other words, the real-world distributions of coital frequency discussed here and the regression results presented in Table A3 below are estimated using data only on women's self-reported coital frequency.

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[43] For more information on this topic, see Thomas and Monea (2009)

[44] Jaccard et al. (2002), Graham et al. (2003).

In FamilyScape 2.0, a woman's willingness to have sex is governed by a "sexual-proclivity" probability that is assigned to her at the outset of the simulation. On each day that a woman is married or in a relationship, a random draw is taken from a uniform (0,1) distribution and compared with her probability. If the value of that draw falls below her probability, then she and her partner have sex on that day.

Sexual-proclivity probabilities vary across women but are fixed over time. They are assigned in such a way as to produce simulated distributions of sexual activity among married and unmarried individuals that approximate their real-world equivalents.[45] In order to reproduce these distributions within our simulation, we first assign each woman to one of three sexual-proclivity groups: "highly active," "moderately active," or "inactive." Women are assigned to proclivity groups using the results of several different regressions. Each regression model has a binary dependent variable indicating whether or not respondents fall into a particular category based upon the frequency with which they have sex.[46] These regressions are conducted using 2006 – 2008 NSFG female

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[45] In earlier versions of the model, we structured the sexual-behavior module to ensure that all members of the simulation population had roughly similar amounts of sex and then pegged the average level of simulated coital frequency to the appropriate real-world target. However, we discovered that this approach was inducing a substantial over-simulation of the number of pregnancies relative to real-world pregnancy rates. This result was a function of the fact that there are "diminishing marginal returns to intercourse," so to speak, in terms of the cumulative risk of becoming pregnant. In other words, because the relationship between the probability of pregnancy and coital frequency is exponential, the incremental increase in the cumulative risk of experiencing a pregnancy is larger if one has sex for the second time than if one has sex for, say, the twenty-second time. In light of this consideration, FamilyScape was restructured to ensure that it approximates the entire real-world distribution of sexual activity, rather than just the mean. Once this enhancement was implemented, the model produced pregnancy rates that were much closer to their relevant real-world targets.

[46] Because there are differences between the coital-frequency distributions of the married and unmarried populations, we specify the breakpoints that define their coital-frequency categories somewhat differently. Specifically: unmarried NSFG respondents were deemed to be in the "inactive" category if they had no sex during the previous 28 days; they were considered to be in the "highly active" category if they had sex more than 14 times; and they were considered to be in the "moderately active" category if their level of sexual activity fell in between these two thresholds. Married respondents were considered to be in the "inactive" category if they had sex less than three times during the previous 28 days; they were considered to be in the "highly active" category if they had sex more than 14 times; and they were considered to be in the "moderately active" category otherwise.

respondent data on vaginal coital frequency over the previous four weeks.[47] Separate models are estimated for married and unmarried female respondents, and a full set of demographic covariates are included in each regression.[48] See Table A3 for a complete set of regression estimates.[49] The coefficients from these regressions are incorporated into the simulation in order to determine women's chances of falling into each of the three sexual-proclivity groups. These imputed values are then compared with the results of a series of random draws from a uniform (0,1) distribution in order to assign each woman to a particular sexual-proclivity category.

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[47] NSFG respondents provide information on their coital frequency over the four-week period leading up to the day on which the survey was administered. The survey distinguishes between heterosexual and homosexual sex and between vaginal intercourse and other forms of sexual activity. Given that we are principally interested in the incidence of pregnancy and childbearing, we limit our definition of sexual activity to heterosexual vaginal intercourse.

[48] Most of the NSFG analysis required to develop parameters for FamilyScape's sexual-proclivity module was performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger.

[49] In fact, because our three sexual-proclivity categories are exhaustive and mutually exclusive, only two sets of regression coefficients are required to calculate an individual's relative chances of falling into each of these three groups. Thus, we actually only incorporate the "moderately active" and "highly active" regression results into the simulation model. The coefficients incorporated into the simulation for the "moderately active" regression are exactly as reported in Table A3, but the coefficients in the simulation model for the "highly active" regression are different from the coefficients reported here. This is because, in the simulation, individuals are assigned to the "highly active" sexual-proclivity category conditional on not having been assigned to the "moderately active" category. Thus, the "highly active" coefficients incorporated into FamilyScape 2.0 are from a version of this regression that is limited to observations that do not fall into the "moderately active" category. For ease of exposition, however, we report "unconditional" regression results for all analyses in Table A3.

Table A3: Sexual-Proclivity Regression Results

	Inactive		**Moderately Active**		**Highly Active**	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
	t-value	*t-value*	*t-value*	*t-value*	*t-value*	*t-value*
Age Dummy: 20-24	-0.180	0.218	0.070	-0.096	0.110	-0.122
	*-4.63****	*2.07***	*1.48*	*-0.43*	*3.37****	*-0.77*
Age Dummy: 25-29	-0.178	0.184	0.108	0.001	0.070	-0.185
	*-4.35****	*2.37***	*2.29***	*0.01*	*2.54***	*-1.18*
Age Dummy: 30-44	-0.094	0.257	0.036	-0.042	0.059	-0.215
	*-2.48***	*3.71****	*0.84*	*-0.21*	*2.29***	*-1.37*
Education Dummy: High School Degree	0.069	-0.123	-0.065	0.105	-0.005	0.018
	*2.03***	*-2.78****	*-1.51*	*2.12***	*-0.17*	*0.57*
Education Dummy: More than High School	0.111	-0.122	-0.059	0.115	-0.052	0.007
	*3.47****	*-2.67*	*-1.91**	*2.76****	*-1.78**	*0.25*
Race Dummy: Black	0.015	0.043	0.067	-0.038	-0.082	-0.005
	0.46	*0.85*	*2.05***	*-0.70*	*-3.83****	*-0.27*
Race Dummy: Hispanic	0.015	-0.024	-0.014	-0.002	-0.001	0.026
	0.40	*-0.73*	*-0.33*	*-0.05*	*-0.02*	*0.93*
Race Dummy: Other	-0.004	0.078	0.036	-0.092	-0.032	0.014
	-0.06	*1.35*	*0.57*	*-1.45*	*-0.65*	*0.22*
SES Dummy	0.012	-0.020	-0.055	0.052	0.043	-0.032
	0.35	*-0.56*	*-1.46*	*1.16*	*1.61*	*-1.17*
Constant	0.300	0.145	0.622	0.542	0.077	0.312
	*7.18****	*2.00***	*12.97****	*2.73****	*2.58***	*1.92**
P-Value for Joint Test of Age Covariates	0.000	0.000	0.108	0.378	0.006	0.042
P-Value for Joint Test of Education Covariates	0.004	0.017	0.150	0.025	0.159	0.831
P-Value for Joint Test of Race Covariates	0.956	0.328	0.190	0.482	0.001	0.762
N	2,956	2,578	2,956	2,578	2,956	2,578

Notes: All parameters were estimated using the female respondent files from the National Survey of Family Growth (NSFG) 2006-2008. An unmarried respondent is coded as having a low sexual proclivity if she had not had sexual intercourse in the four weeks prior to her interview, as having a moderate proclivity if she had sex between one and fourteen times during this period, and as having a high proclivity if she had sex fifteen or more times during this period. A married respondent is coded as having a low sexual proclivity if she had sex less than three times in the four weeks prior to their interview, as having a moderate proclivity if she had sex between three and fourteen times during this period, and as having a high proclivity if she had sex fifteen or more times during this period. The excluded age, education, and race categories are as follows: age group 15-19, an educational attainment of less than a high school degree, and the white race category. The SES dummy is set equal to one if the respondent's mother had an educational attainment equal to or greater than a high school degree and zero otherwise. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

At the outset of the simulation, each woman is assigned a fixed sexual-proclivity probability by taking a random draw from one of several different beta distributions.[50] The ranges of these distributions are defined differently, and the particular distribution from which an individual's draw is taken depends upon his or her marital status and sexual-proclivity type. These distributional ranges are specified such that, among individuals who are of the same marital status, the probabilities of those in the "highly active" category are at least as high as the probabilities of those in the "moderately active" category and the probabilities of those in the "moderately active" category are at least as high as the probabilities of those in the "inactive" category.

After extensive exploration of the model's parameter space, we identified a set of sexual-proclivity probability ranges that: a) produce distributions of married and unmarried monthly coital frequency that roughly approximate their real-world equivalents; and b) approximate the real-world proportion of unmarried and married women who are sexually inactive for an entire year.[51] Figure A5 compares the 28-day distribution of coital frequency among unmarried 2006 – 2008 NSFG respondents with the equivalent simulated distribution after the model has been parameterized in this fashion. Figure A6 shows the same comparison for married couples. In both instances, the simulated and real-world distributions are roughly comparable.[52]

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[50] Originally, we attempted to calibrate FamilyScape's sexual activity module by drawing sexual-proclivity probabilities from a variety of different uniform distributions. However, we found that, in order to replicate both the monthly coital frequency distributions and the percentage of women who are sexually inactive for an entire year, we needed to use a more flexible probability distribution.

[51] Given that there are three sexual-proclivity types and two marital statuses, there are 2*3 = 6 possible distributions from which an individual's sexual-proclivity probability might be assigned. The ranges for these distributions are as follows: among unmarried women, those in the "inactive" category are randomly assigned sexual-proclivity probabilities from a 0.05*Beta(1,17) distribution; those in the "moderately active" category are randomly assigned probabilities from a 0.95*Beta(2,9)+0.05 distribution; and those in the "highly active" category are assigned probabilities from a 0.55*Beta(5,1)+0.45 distribution. Among married women, those in the "inactive" category are randomly assigned probabilities from a 0.2*Beta(1,5) distribution; those in the "moderately active" category are randomly assigned probabilities from a 0.9*Beta(1,5)+0.1 distribution; and those in the "highly active" category are assigned probabilities from a 0.9*Beta(2,1) distribution.

[52] These figures show distributions of coital frequency as measured over a four-week period. For reasons detailed in Appendix I, the results shown here are averaged over 100 separate runs of the model. The real-world and simulated 28-

FamilyScape 2.0 simulations also roughly replicate the real-world proportion of women who are sexually inactive for an entire calendar year. While NSFG tabulations show that about a third of unmarried women are sexually inactive during a year, approximately 20 percent of unmarried women in FamilyScape do not have sex and about 30 percent of unmarried women in FamilyScape have intercourse three times or less annually. Between one and two percent of married women in FamilyScape's simulation population women do not engage in sexual intercourse in a given year, as compared to two percent of married female NSFG respondents.[53]

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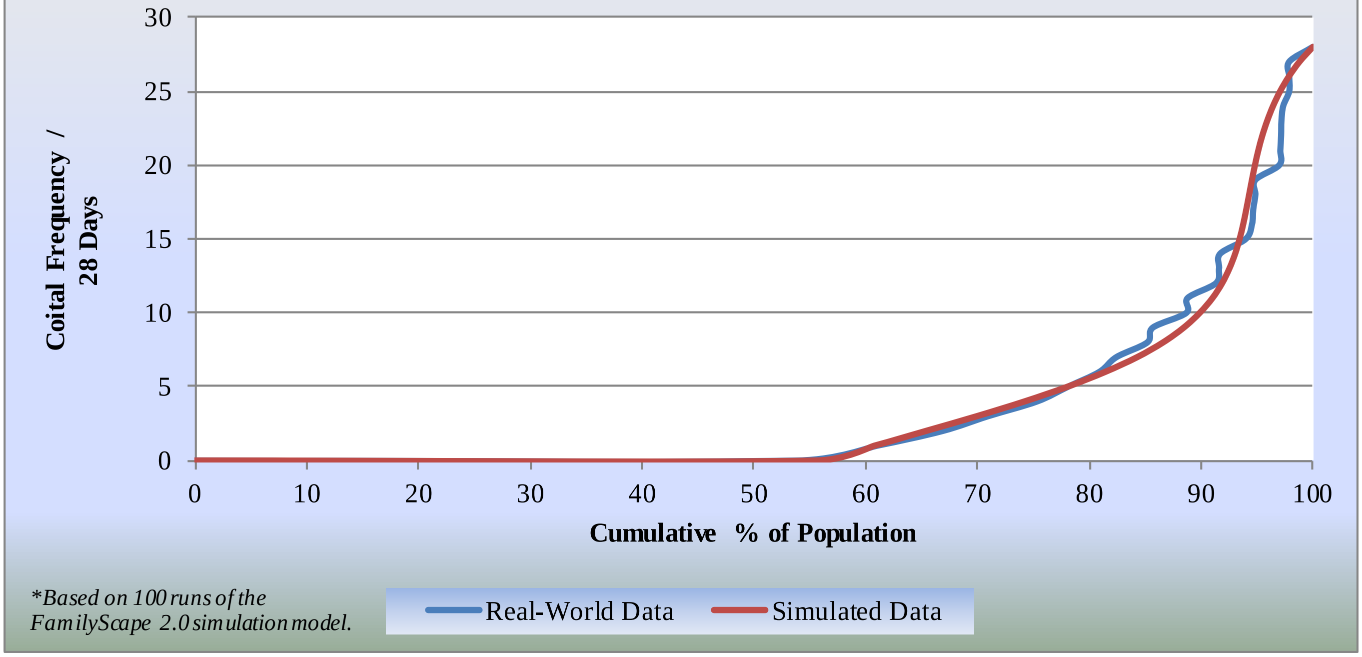
day distributions shown in Figures A5 and A6 are similar, but they are not identical to each other. The differences between the two sets of distributions are driven largely by the fact that, within the simulation, an individual's sexual-proclivity probability is strongly correlated with – but is not perfectly predictive of – the frequency with which he or she will have sex. For example, an individual who is placed into the "highly active" category may in fact have little or no sex if he or she remains single for much of the simulation or is paired with a partner who has a low sexual proclivity. Thus, the mixing of sexual-proclivity types in the formation of relationships and the random variation that is inherent to the simulation process prevent us from being able to replicate perfectly the real-world distribution of sexual activity. However, earlier sensitivity analyses showed that modest distributional differences such as the ones shown here are too small to have a meaningful impact on the model's results (Thomas and Monea, 2009).

[53] While FamilyScape's broad sexual-proclivity categories prevent the exact replication of this benchmark, sensitivity analyses indicate that the risk of pregnancy per act of intercourse is small enough that these differences in sexual inactivity have little impact on the model's performance.

Figure A5: Coital Frequency Distributions in Real-World and Simulated Data*

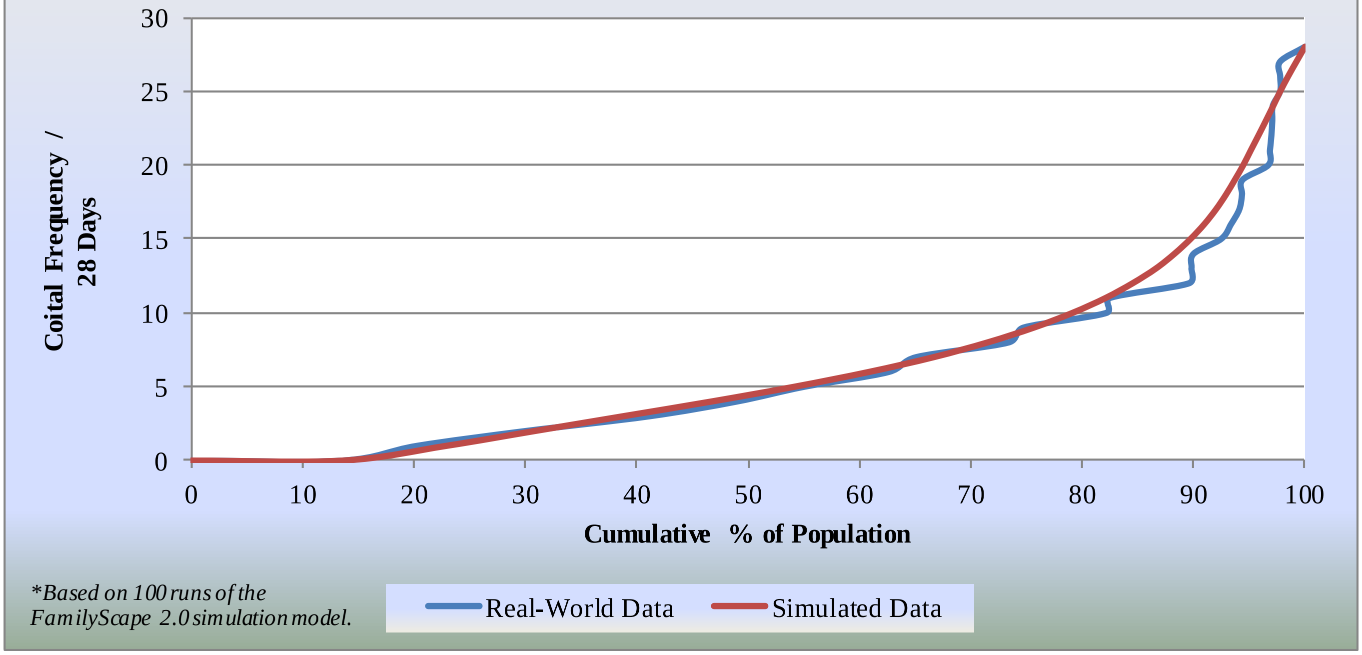
(*Unmarried Population*)



**Based on 100 runs of the FamilyScape 2.0 simulation model.*

Figure A6: Coital-Frequency Distributions in Real World and Simulated Data*

(*Married Population*)



**Based on 100 runs of the FamilyScape 2.0 simulation model.*

Contraceptive Use

FamilyScape 2.0 simulates both contraceptive use (or a lack thereof) and contraceptive switching among sexually active individuals. At the start of a simulation run, members of FamilyScape's simulation population are assigned to the use of particular method (or of no method at all) according to their demographic characteristics. Once simulated rates of sexual activity and nonmarital relationship formation and dissolution have stabilized, FamilyScape's contraceptive-switching module is activated and sexually active women are allowed to switch onto different forms of female-controlled contraception. Activation of the contraceptive-switching module occurs on day 1000 of each simulation run. Due to data limitations, contraceptive switching is not modeled for male members of FamilyScape's simulation population.[54]

Definitions and Initial Assignment of Contraceptive Methods

The initial assignment of members of FamilyScape's simulation population to different contraceptive methods is governed by a set of regressions that predict the probability of using various types of contraception among 2006-2008 NSFG respondents. The dependent variables for these regressions are based on NSFG variables recording the reported method of contraception used at the respondent's most recent sexual encounter.[55] Contraceptive type is assigned separately for men and women. Specifically, men are assigned either to be condom users, sterilized, or male non-contraceptors (i.e., men who do not use male-controlled contraception). Women are assigned to be users of long-acting reversible contraceptive methods (LARCs); users of the pill, patch, ring, or

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[54] As is discussed in an earlier footnote, the NSFG does not contain contraceptive calendar data for men (as it does for women) that record the methods used by respondents in the months leading up to their interviews. Hence the fact that we are unable to model method switching for men.

[55] The universe of respondents for these variables was limited by the survey's administrators to men and women who reported having had sex at least once in the past twelve months.

other hormonal methods (PPRs); sterilized; or female non-contraceptors (i.e., women who do not use any form of female-controlled contraception).[56]

All contraceptive-use regressions are estimated separately for married and unmarried individuals, and regressions include a full complement of demographic covariates. In addition, all female-specific contraceptive models control for sexual-proclivity status in order to ensure that the simulation accounts for any correlations that might exist between the frequency with which women have sex and their likelihood of using contraception when doing so. In the next two subsections, we discuss separately the methods by which men and women are assigned to various types of contraceptive use.

Male Contraceptive Use

At the outset of the simulation, we impute to each male member of the simulation population a pair of probabilities reflecting his chances of falling into either of two condom-use categories: unconditional condom use (i.e., the use of condoms regardless of whether one's partner is using contraception) and conditional condom use (i.e., the use of condoms only when one's partner is not contracepting).[57] As is suggested above, we assign men to condom categories using parameters that were developed via analysis of the male respondent file of the 2006 – 2008 NSFG.[58] Respondents were asked a series of questions about what method(s, if any) they used the last time that they had sex. If a man reports that he used a condom and that his partner used contraception at his last

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[56] Details on the specific contraceptive methods included in each of these contraceptive categories can be found in the subsection below entitled "Female Contraceptive Use."

[57] For purposes of simplicity, and because withdrawal is a male-controlled contraceptive method, we consider male NSFG respondents to be condom users if they report that withdrawal is their primary contraceptive method. Throughout the discussion that follows, then, we describe men as "condom users" if they rely on either condoms or withdrawal as their primary method of contraception. We would note that Hatcher et al. (2009) show that condoms and withdrawal have somewhat similar levels of estimated effectiveness (85% versus 73%), where a method's "effectiveness" is defined as one minus the annual pregnancy rate among users of that method.

[58] Most of the NSFG analysis required to develop parameters for FamilyScape's contraceptive-use modules was performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger.

sexual encounter, he is considered to be an unconditional condom user. Similarly, if a male respondent reports that, the last time he had sex, he did not use a condom and his partner did not use contraception, he is considered to be a non-condom user. However, if a respondent reports that he used a condom and that his partner did not use contraception, it is not clear whether he is an unconditional or a conditional condom user; similarly, if he reports that he did not use a condom but that his partner used contraception, it is not obvious whether he is a conditional condom user or a non-condom user. Table A4 summarizes these scenarios.

Table A4: Condom-Use Types

Did partner use contraception at last intercourse?	**Did male respondent use a condom at last intercourse?**	
	Yes	*No*
Yes	Unconditional Condom User	Conditional Condom User *or* Non-Condom User
No	Unconditional Condom User *or* Conditional Condom User	Non-Condom User

More information is required if we are to assign men in the upper-right-hand and lower-left-hand cells of Table A4 to the appropriate condom-use category. In addition to the "method used at last sex" variable, the NSFG also contains a variable indicating the number of times that a respondent reports having used a condom during intercourse in the last four weeks, which – together with the variable on coital frequency over the same period – can be used to estimate the percentage of recent sexual encounters in which respondents report having used a condom. We use these estimates to assign men in the two ambiguous scenarios described above to a usage category. Specifically, for men who report that they did not use condoms the last time they had sex but that their partners did use contraception, we assume that they are non-condom users if they are estimated never to have used condoms, and we assume that they are conditional condom users if they are estimated to have used condoms at least some of the time. For men who report that they used condoms the last time they had sex and that their partners did not use contraception, we assume that they are unconditional condom users if they are estimated to have used condoms every time that they had sex, and we assume that they are conditional condom users if they are estimated to have used condoms only some of the time.[59] Based on these assumptions, we create binary "unconditional condom use" and "conditional condom use" variables for male NSFG respondents, and we use these variables to estimate the aforementioned regressions of the probabilities of falling into these categories. The results of these regressions are then used to impute a condom-use status to each man in FamilyScape's simulation population.

We also use regression coefficients to assign men a probability of being sterilized.[60] As was the case with our simulation of condom use, we impute sterilization status based on variables in the NSFG indicating what method(s, if any) respondents used the last time that they had sex.
Sterilization is simulated only among the pool of men who are not assigned to be conditional or unconditional condom users (in other words, we make the simplifying assumption that sterilized men do not use condoms). In addition to FamilyScape's standard set of covariates, all

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[59] About 51 percent of the 4,255 non-sterilized men in our NSFG sample fell into one of the two "ambiguous" categories described above. Our calculations indicate that almost eighty percent of the members of these groups either used condoms every time they had sex or never used condoms. These men were categorized as unconditional condom users and non-condom users, respectively. The remaining share of individuals are estimated to have used condoms during some, but not all, of their sexual encounters. These men were coded as conditional condom users.

[60] The NSFG distinguishes between respondents who are surgically sterilized and those who are naturally sterile. For FamilyScape's purposes, it is unimportant whether an individual is sterile for surgical or natural reasons. When conducting analyses of NSFG data in order to parameterize FamilyScape 2.0, we therefore code respondents as being "sterilized" even if they are sterile for natural reasons. Thus, throughout this discussion, we use the term "sterilization" to refer both to natural sterility and to surgical sterilization.

contraceptive-use equations for married men also contain a variable accounting for their wives' sterilization statuses in order to ensure that the model properly simulates the distribution of contraceptive use both at the individual level and at the couple level.[61] Men in the NSFG who are not sterilized and who do not fall into either condom-use category are deemed to be non-contraceptors.[62]

Having assigned male NSFG respondents to contraceptive-use groups, we regress the probability of their falling into each of these categories on their demographic characteristics and – for married men – their wives' sterilization statuses. See Table A5 for a complete set of male contraceptive-use regression results.[63] We use the coefficients from these regressions to impute probabilities for the male members of the simulation population of falling into each contraceptive-use category. For every man in the simulation, we then take a series of random draws from a uniform (0,1) distribution at t=0 and compare the results of those draws to his contraceptive-use probabilities in order to assign him to the use of a particular contraceptive method (or to the use of no method).

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[61] Our procedure for determining the sterilization status of a respondent's partner (in terms of the way in which we define sterilization) is the same as the procedure described in the previous footnote for determining a respondent's own sterilization status. We control for wives' sterilization in the married men's equation in order to ensure that the simulation properly models the couple-level distribution of contraceptive use. For example, consider a scenario in which 20 percent of married men and 20 percent of married women are sterilized. One extreme possibility is that only 20 percent of married couples are sterilized (if all sterilized men are married to sterilized women), and the other is that 40 percent of couples are sterilized (if it is never the case that sterilized people are married to each other). In earlier analysis of NSFG data, we concluded, first, that the real world is closer to the latter extreme than to the former one; and, second, that the failure to account for this dynamic in our regression models would result in a substantial under-simulation of the percent of FamilyScape's married couples in which at least one member is using contraception. As is discussed in the next subsection, we also condition married women's PPR and LARC use on their spouses' sterilization statuses. However, we do not implement equivalent provisions for unmarried couples. We elected not to do so in the interest of parsimony, and because it seems intuitively likely that married individuals would be more prone than unmarried individuals to consider their partners' sterilization statuses when deciding what method(s, if any) of contraception they themselves should use.

[62] Male non-contraceptors may, however, be partnered with women who use female-controlled contraception.

[63] In fact, many of our contraceptive-use imputations are limited to subsets of observations who are not using other methods. For example, men in FamilyScape's simulation population are only eligible be assigned to the "conditional condom use" category if they are not already assigned to be unconditional condom users. The model's conditional condom use parameters are therefore derived from regressions that are limited to NSFG respondents who are not defined as unconditional condom users. For ease of exposition, however, we report "unconditional" regression results for all analyses in Table A5.

Table A5: Male Contraceptive-Use Regression Results

	Sterilization		Unconditional Condom Use		Conditional Condom Use	
	Unmarried Men	Married Men	Unmarried Men	Married Men	Unmarried Men	Married Men
	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*
Age Dummy: 20-24	0.028	-0.014	-0.179	-0.705	0.001	0.092
	1.41	*-0.17*	*-4.11****	*-4.11****	*0.05*	*2.32***
Age Dummy: 25-29	0.035	-0.012	-0.406	-0.765	0.030	0.089
	*1.74**	*-0.17*	*-8.83****	*-4.50****	*0.78*	*2.42***
Age Dummy: 30-44	0.115	0.179	-0.547	-0.788	0.017	0.098
	*3.15****	*2.17***	*-12.29****	*-4.82****	*0.66*	*3.39****
Education Dummy: High School Degree	-0.038	0.050	0.055	0.007	0.030	0.010
	-1.42	*1.24*	*1.48*	*0.28*	*0.95*	*0.40*
Education Dummy: More than High School	-0.071	0.036	0.148	0.090	0.023	-0.020
	*-2.20***	*0.91*	*3.49****	*3.15****	*0.78*	*-0.76*
Race Dummy: Black	-0.005	-0.130	-0.004	0.009	0.038	-0.004
	-0.31	*-4.45****	*-0.09*	*0.27*	*1.32*	*-0.16*
Race Dummy: Hispanic	-0.010	-0.064	-0.013	0.084	0.041	0.050
	-0.33	*-1.67**	*-0.27*	*2.45***	*1.74**	*1.64*
Race Dummy: Other	-0.008	-0.149	-0.175	0.045	0.133	0.078
	-0.24	*-4.06****	*-3.56****	*1.00*	*1.78**	*1.73**
SES Dummy	0.050	0.022	-0.001	-0.016	-0.034	0.040
	*1.79**	*0.71*	*-0.02*	*-0.61*	*-1.04*	*1.90**
Partner's Sterility Dummy	--	-0.086	--	-0.084	--	-0.082
		*-2.73****		*-4.37****		*-5.47****
Constant	-0.005	0.024	0.747	0.860	0.073	-0.041
	-0.19	*0.38*	*13.66****	*5.14****	*2.60***	*-2.02***
P-Value for Joint Test of Age Covariates	0.008	0.000	0.000	0.000	0.805	0.013
P-Value for Joint Test of Education Covariates	0.065	0.466	0.004	0.000	0.580	0.405
P-Value for Joint Test of Race Covariates	0.979	0.000	0.006	0.059	0.109	0.073
N	5,670	6,042	5,670	6,042	5,670	6,042

Notes: All parameters were estimated using the male respondent files from the National Survey of Family Growth. (NSFG) 2006-2008. The excluded age, education, and race categories are as follows: age group 15-19, an educational attainment of less than a high school degree, and the white race category. The SES dummy is set equal to one if the respondent's mother had an educational attainment equal to or greater than a high school degree and zero otherwise. The Partner's Sterility indicator is set equal to one if the respondent's wife was sterilized and zero otherwise. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

Female Contraceptive Use

We use essentially the same procedures as the ones described in the previous subsection to assign a share of women in FamilyScape's simulation population to the use of LARCs, PPRs, or sterilization. Women who are not sterilized and are not assigned to be users of LARCs or PPRs are female non-contraceptors, which is to say that they do not employ any form of female-controlled contraception.[64] FamilyScape's LARC category encompasses intrauterine devices, hormonal implants, and injectables. The PPR category captures women who use the pill, patch, or ring. For purposes of simplicity, we also classify as PPR users the small proportion of women who use emergency contraception or non-hormonal, female-controlled contraceptive methods. These methods include diaphragms, female condoms, foams, jellies/creams, suppositories/inserts, the Today sponge, and natural family planning.

As was the case with men, we generate the parameters necessary to assign women to a contraceptive-use category via a set of regression analyses that were performed using the 2006 – 2008 NSFG. Separate models are estimated for married and unmarried women. These regressions contain a full complement of demographic covariates, a set of dummy variables measuring sexual-proclivity type, and – for the LARC and PPR regressions for married women – a binary variable measuring the sterilization statuses of respondents' spouses.[65] Each woman's contraceptive-use probabilities are compared to the results of a series of draws from a uniform (0,1) distribution at the outset of the simulation in order to assign her to the use of a contraceptive method (or to the use of

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[64] Female non-contraceptors may, however, be partnered with men who use condoms.

[65] In an earlier footnote, we describe our rationale for conditioning contraceptive use on partner's sterilization status for married individuals but not for unmarried individuals. Note here, however, that we do not condition married female sterilization status on spousal sterilization because we have already inserted a comparable covariate into the male sterilization regression. If we were to "double-condition" by also placing a spousal sterilization variable in the female married sterilization equation, we would likely be over-simulating the use of sterilization at the couple level within the married population.

no method at all). Table A6 reports the results of our female contraceptive-use regressions.[66]

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[66] As was the case for our male contraceptive-use imputations, our imputations for women are sometimes limited to subsets of individuals who are not using other methods. For example, women in FamilyScape's simulation population are only eligible be assigned to the PPR category if they are not already assigned to be LARC users. The model's PPR parameters are therefore derived from regressions that are limited to NSFG respondents who are not defined as LARC users. For ease of exposition, however, we report "unconditional" regression results for all analyses in Table A6.

Table A6: Female Contraceptive-Use Regression Results

	Sterilization		**LARC**		**PPR**	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
	t-value	*t-value*	*t-value*	*t-value*	*t-value*	*t-value*
Age Dummy: 20-24	0.048	0.158	0.002	-0.348	-0.052	0.103
	*3.14****	*4.94****	*0.12*	*-1.51*	*-0.99*	*1.49*
Age Dummy: 25-29	0.156	0.253	0.005	-0.349	-0.100	0.080
	*5.73****	*6.07****	*0.22*	*-1.53*	*-2.34***	*1.24*
Age Dummy: 30-44	0.369	0.471	-0.025	-0.356	-0.221	-0.011
	*9.88****	*10.71****	*-1.35*	*-1.62*	*-5.32****	*-0.20*
Education Dummy: High School Degree	0.018	-0.092	-0.001	-0.011	0.136	0.071
	0.65	*-1.68**	*-0.04*	*-0.49*	*3.42****	*2.57***
Education Dummy: More than High School	-0.111	-0.234	-0.012	-0.007	0.241	0.213
	*-3.68****	*-4.51****	*-0.68*	*-0.29*	*7.19****	*7.31****
Race Dummy: Black	0.031	0.156	0.038	0.018	-0.172	-0.083
	1.22	*3.29****	*2.25***	*0.72*	*-6.51****	*-2.67****
Race Dummy: Hispanic	-0.003	0.007	0.035	0.050	-0.111	-0.043
	-0.08	*0.15*	*1.74**	*3.61****	*-3.24****	*-1.43*
Race Dummy: Other	0.037	-0.029	-0.024	-0.006	-0.095	-0.162
	0.69	*-0.54*	*-1.16*	*-0.26*	*-1.54*	*-5.02****
SES Dummy	-0.038	-0.046	-0.019	0.013	0.031	-0.022
	-1.16	*-1.65*	*-0.86*	*0.73*	*0.95*	*-0.62*
Moderate Sexual Proclivity Dummy	-0.003	0.050	0.021	0.016	0.094	-0.001
	-0.11	*1.84**	*1.37*	*0.74*	*2.92****	*-0.03*
High Sexual Proclivity Dummy	0.048	0.162	0.014	0.015	0.012	-0.057
	1.29	*2.57***	*0.58*	*0.55*	*0.31*	*-1.41*
Partner's Sterility Dummy	--	--	--	-0.069	--	-0.174
				*-5.37****		*-6.18****
Constant	0.042	-0.012	0.066	0.405	0.233	0.113
	1.28	*-0.24*	*2.45***	*1.90*	*5.28****	*1.61*
P-Value for Joint Test of Age Covariates	0.000	0.000	0.352	0.258	0.000	0.011
P-Value for Joint Test of Education Covariates	0.000	0.000	0.706	0.886	0.000	0.000
P-Value for Joint Test of Race Covariates	0.627	0.009	0.015	0.005	0.000	0.000
N	2,956	2,578	2,956	2,578	2,956	2,578

Notes: All parameters were estimated using the female respondent files from the National Survey of Family Growth (NSFG) 2006-2008. The excluded age, education, and race categories are as follows: age group 15-19, an educational attainment of less than a high school degree, the white race category, and the low sexual proclivity category. The SES dummy is set equal to one if the respondent's mother had an educational attainment equal to or greater than a high school degree and zero otherwise. The Partner's Sterility indicator is set to one if the respondent's husband is sterile and zero otherwise. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

Adjustments to Initial Contraceptive-Use Probabilities

As is discussed in Appendix IV, we model contraceptive efficacy by using data on female NSFG respondents and the results of clinical studies to estimate, for the users of a given method, their annual pregnancy rate; their average annual coital frequency; and their average fecundity level. This information is used to calculate the method's "efficacy rate," which we define as the proportional reduction in the risk of pregnancy at a given act of intercourse that is produced by the use of that method. These contraceptive efficacy estimates are then incorporated into FamilyScape's parameter set in order to adjust sexually active couples' per-act pregnancy probabilities as a function of their contraceptive regimes.

For the purposes of the calculations described above, NSFG respondents are considered to be "users" of a given method if they report having used that method at least once over the course of a 28-day period.[67] However, the contraceptive-use probabilities described in the previous two subsections are assigned using NSFG data on the method of contraception used at last sex. Because the number of people using a given method over an entire month will typically be larger than the number of people using that method at a given act of intercourse, there is a discrepancy between the ways in which contraceptive users are defined in the regressions described above and in the contraceptive efficacy calculations described in the next appendix. It is important that these two definitions ultimately be compatible with one another.[68] We therefore adjust the initial

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[67] In fact, an NSFG respondent is considered to be a user of a given method if: a) he or she used that method at least once in the past four weeks; and b) it is the most effective method that he or she used during the month in question. For the sake of simplicity, we ignore the latter condition in the discussion here.

[68] Given that some NSFG respondents report that they used contraception at least once in the past month but that they did not do so at last sex, it is likely that the pregnancy rate (and therefore the "contraceptive failure" rate) will be higher among all respondents who report that they used a given method in the past month than among individuals who report both that they used this method in the past month and that they used it at last sex (since consistent contraceptive users presumably constitute a smaller share of the former group than of the latter group). Thus, if FamilyScape's

contraceptive-use probabilities that are produced using the regression estimates from Tables A5 and A6 in order to achieve this objective.

Our tabulations of data from the 2006 – 2008 NSFG suggest that the numbers of married and unmarried women who report having used contraception at least once in a given month are about 5% and 7% higher, respectively, than the numbers of women who report having used contraception at last sex.[69] We therefore apply scalars to individuals' initial contraceptive-use probabilities within FamilyScape 2.0 in order to increase the number of contraceptive users by 5% among married individuals and by 7% among unmarried individuals. Because there should be virtually no difference between the number of people who "used" sterilization at last sex and the number of people who "used" sterilization at least once in the previous four weeks, we do not increase the number of sterilized individuals as part of this process. In order to achieve our benchmarks, we therefore increase the number of users of methods other than sterilization by somewhat more than the amounts reflected in the estimates referenced above. Because our targets differ by marital status, we use separate scalars for married and unmarried individuals. However, scalars do not vary by demographic group or by type of contraceptive method within marital-status categories. After these scalars are applied, the increase in the number of contraceptive method users meets the above-

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contraceptive-efficacy module were parameterized with data on all "monthly users" of a given method while the contraceptive-use module relied only on data for individuals who used that method at last sex, the model's parameters would suggest that the efficacy rate experienced by the users of the method in question is lower than is actually the case – or, alternatively, that too few individuals are using this method, given the way in which we define the method's failure rate. As is discussed above, we correct for this potential problem by increasing modestly the number of individuals in FamilyScape's simulation population who are designated as users of various contraceptive methods. The reader may be wondering why we did not use identically specified measures of contraceptive type to parameterize both modules. Unfortunately, this was not a viable option. We were unable to use a "monthly" measure to parameterize FamilyScape's contraceptive-use module because: a) we assign men in FamilyScape's simulation population to different contraceptive categories based on the responses of male NSFG sample members; and b) the only contraceptive-use measure available for male NSFG respondents records the method(s) used at last sex. We were also unable to use a "method-used-at-last-sex" measure to parameterize the model's contraceptive efficacy module because the NSFG's contraceptive calendar data used to estimate pregnancy rates among users of various methods reflect "monthly use." Thus, we were compelled to use different contraceptive measures to parameterize these two modules.

[69] These tabulations were performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger.

referenced targets, and the way in which contraceptive users are defined is the same within FamilyScape's contraceptive-use and contraceptive efficacy modules.

Female-Specific Contraceptive Switching

Once FamilyScape's relationship-formation and sexual-activity modules have reached a steady state, the model's contraceptive-switching module is activated. Because some demographic groups in the real world (and therefore also in the model) are more likely than others to engage in certain contraceptive-switching patterns, different contraceptive categories would ultimately become absorbing states for different demographic groups if we were to allow the model to run in perpetuity after the contraceptive-switching module was activated. We therefore develop real-world estimates of the probability of engaging in various types of contraceptive switches over a one-year period and then parameterize the model so as to ensure that simulated switching patterns are accurate for the first year of analysis time that elapses after the switching module has been activated. All reported results from FamilyScape simulations correspond to this one-year period.[70]

FamilyScape's contraceptive-switching module allows female contraceptors to switch to new female-controlled methods or to stop using female contraception entirely, and non-contraceptors are allowed to begin using contraception. More specifically, non-contraceptors can begin using LARCs or PPRs; LARC users can switch to PPRs or become female non-contraceptors; and PPR users can become either female non-contraceptors or LARC users. It is also important to note, however, that most women in the simulation population will not switch contraceptive types at all: most LARC users will continue using LARCs, most non-contraceptors will not begin using contraception, and so forth. In other words, while women in the model have the *opportunity* to alter their contraceptive

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[70] As is discussed in Appendix I, this period spans from day 1000 to day 1365.

behavior over the course of the simulation, most of them will not in fact choose to do so.[71] Because the NSFG does not contain contraceptive-calendar data for men, we are unable to develop parameters for a male switching module. Thus, FamilyScape 2.0 allows for changes in female but not male contraceptive type. In addition, due to sample size limitations in the relevant real-world data, the population of sterilized women in the model remains fixed over time.

The core of FamilyScape's method-switching module is parameterized using the results of survival analyses of data taken from the 2006 – 2010 NSFG.[72] The unit of observation for these analyses is the person-month, and method switching (or lack thereof) is correspondingly simulated on a monthly basis. In the next two subsections, we describe the way in which we constructed the analysis sample and the dependent variables for these regressions. We then present results from our regression models of switching behavior and explain the way in which the coefficients from those regressions are incorporated into FamilyScape's architecture to simulate method switching. We conclude this portion of the appendix with a comparison of switching patterns among women in FamilyScape with their real-world equivalents.

Analysis Sample

Among the most common reasons for switching off of contraception are pregnancy and sexual inactivity, and among the most common reasons for switching from the use of no method to the use

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[71] See Table A9 for a comparison of simulated and real-world switching patterns.

[72] As is discussed in a footnote earlier in this paper, much of the work on FamilyScape 2.0 was conducted prior to the release of data from the full NSFG 2006-2010 cycle. Thus, most aspects of the model were parameterized using data only from the 2006 – 2008 portion of the most recent NSFG cycle. However, we parameterized FamilyScape's contraceptive-switching module after data from the full 2006-2010 cycle were available. In order to mitigate sample size problems, we therefore developed parameters for the switching module using data from the complete 2006-2010 NSFG cycle.

of contraception are the completion of a pregnancy and the resumption of sexual activity.[73] However, from the standpoint of developing FamilyScape's parameters, contraceptive switches related to pregnancy and sexual inactivity are analytically unimportant: incorporating into the model's architecture the capacity to switch pregnant women off of contraception during periods of pregnancy and sexual inactivity would have no impact on its ability to simulate realistic pregnancy, birth, and abortion rates.

For this reason, we eliminate from the analysis sample for our hazard models all person-months in which the woman in question is not at risk of pregnancy, and we simulate switches within FamilyScape only among women who are similarly at risk. To put it another way, because we are only interested in modeling method switching to the extent that it impacts a woman's risk of pregnancy, we narrow our NSFG analysis sample to person-months in which a woman is sexually active and fertile, and we only simulate contraceptive switching among women in FamilyScape who meet the same criteria. Person-months are therefore excluded from the sample for the NSFG contraceptive-switching analyses if the respondent in question is already pregnant, is completely sexually inactive, or is temporarily infertile after the resolution of a pregnancy.[74] Because sample size limitations prevent us from being able to model switches into and out of the "sterilized" contraceptive category, we also exclude all person-months in which a woman reports being sterile.

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[73] For instance, our analyses of 2006-2010 NSFG data suggest that roughly half of all annual female-specific contraceptive switches occur during a month in which the woman is either sexually inactive or pregnant.

[74] The NSFG does not provide information on the duration of post-pregnancy infertility. In Appendix IV, however, we review the literature on this topic and conclude that, on average, postpartum infertility lasts for about 98 days; post-abortion infertility lasts for about 14 days; and post-miscarriage infertility lasts for about seven days. Because the NSFG only measures contraceptive behavior on a monthly basis, we exclude from our analysis sample all person-months that are within four months of a birth or within one month of an abortion. We make no such exclusion for pregnancies resulting in fetal losses.

For the remainder of this discussion, we refer to a month in which a non-sterilized woman is not infertile, sterilized, pregnant, or sexually inactive as a month in which she is "at risk of pregnancy."[75]

Very few women in the NSFG who are at risk of pregnancy switch contraceptive methods more than once during a given year.[76] As a result, there are not sufficient data to allow us to model multiple annual method switches in a credible way. Thus, our contraceptive-switching regression analyses account for a maximum of one switch per woman per year. Each woman can contribute up to 24 months' worth of data to these analyses. We use the following steps to construct our analysis sample of women who are at risk of method switching:

1. We use the NSFG's monthly contraceptive-calendar data to identify, for all female respondents between the ages of 15 and 44, the most recent month that is at least one year prior to the respondent's interview date and in which the woman was at risk of pregnancy. In the discussion below, we refer to this month as "Origin Month 1." If there are no months in a given respondent's contraceptive calendar that meet these criteria, the woman in question does not contribute any data to our contraceptive-switching survival analyses.
2. We then repeat the process described in the previous step, except that we "begin" with Origin Month 1, rather than with the interview date. In other words, we identify the most recent month that is at least one year prior to Origin Month 1 and in which the woman was at risk of experiencing a pregnancy.[77] In the discussion below, we refer to this month as "Origin Month 2." If there are no months in a given respondent's contraceptive calendar that meet the criteria described in this step, the woman in question can contribute at most

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[75] Note that a month in which a woman *becomes* pregnant is in fact considered to be an "at-risk-of-pregnancy" month, since she was obviously at risk of pregnancy when the month began.

[76] Specifically, our analysis of female NSFG respondents who are at risk of pregnancy suggests that multiple switches within a given year occur among approximately six percent of those initially using LARCs, among about four percent of those initially using PPRs, and among less than one percent of women who are not initially using female-controlled contraception.

[77] Female NSFG respondents can provide as many as 48 months' worth of contraceptive-use data.

one year's worth of data to our contraceptive-switching survival analyses (see the next step for additional details).

3. Starting at Origin Month 1 for a given woman (assuming that such a month exists for the woman in question), we move forward one year in her contraceptive calendar, and we retain for the purposes of constructing our analysis sample all months in which the woman was at risk of pregnancy. For respondents for whom Origin Month 1 exists, the process described in this step thus yields no more than twelve months of person-month data to be added to the analysis sample. Call the months generated by the process described in this step "Contraceptive Calendar Period 1."[78]
4. Starting at Origin Month 2 for a given woman (assuming that such a month exists for the woman in question), we once again move forward one year in her contraceptive calendar, retaining all months in which the woman was at risk of pregnancy. For respondents for whom Origin Month 2 exists, the process described in this step yields no more than twelve months of person-month data to be added to the analysis sample. Call the months generated by the process described in this step "Contraceptive Calendar Period 2."

As is stated above, this process thus yields a maximum of 24 months' worth of data per person that can be incorporated into the analysis sample for the contraceptive-switching regressions. The first month of each Contraceptive Calendar Period is used to define a woman's "Origin Method" (i.e., her initial contraceptive type) for that year, while all subsequent months in the relevant Contraceptive Calendar Period are used to estimate the monthly probabilities that she switches off of her Origin Method. We implemented Steps 2 and 4 (rather than simply using data from

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[78] For instance, suppose that Origin Month 1 for given a female NSFG respondent corresponds to May of 2005 and that, during the period spanning from May of 2005 to April of 2006, she was at risk of pregnancy only in May and June of 2005 and February of 2006. This woman's Contraceptive Calendar Period 1 would consist only of these three person-months.

Contraceptive Calendar Period 1) in order to enlarge our sample size and improve the precision of our parameter estimates. Because FamilyScape's contraceptive-switching parameters are intended to model switching patterns over a single year, Contraceptive Calendar Period 1 and Contraceptive Calendar Period 2 are treated as though they are unrelated to each other in the development of our simulation parameters. In other words, for a woman who contributes data from both Period 1 and Period 2 to the analysis sample, the survival analyses essentially treat the two periods as though they had been provided by different individuals. Thus, a woman's presumed hazard of switching is the same in a given month from the first Contraceptive Calendar Period as in the corresponding month from the second Period.

This approach may seem somewhat complicated, but it has the great benefit of allowing us to develop an analysis sample whose composition (all at-risk person-months from up to two separate one-year periods) is well-aligned with the needs of the model, which simulates contraceptive switching on a monthly basis over the course of a year of analysis time among women who are at risk of experiencing a pregnancy.

Variable Definitions

The NSFG's contraceptive-calendar variables provide monthly data on the types of contraceptive methods that respondents used in the months preceding their interview. Respondents can list up to four different methods used during a month in which they were sexually active. For the purposes of our analysis, we must define each month as corresponding with the use of a specific method (or of none at all). For women who list the use of multiple methods in a month, we assign the person-months in question to the use of the most effective of the methods listed. We assume that LARCs are more effective than PPRs and that PPRs are more effective than the use of no contraceptive method.[79] For each Contraceptive Calendar Period, we thus define a woman's Origin Method according to the most effective female-specific method that she reported using in the first month. We define a method switch to be any month-to-month change in a woman's most effective female-controlled contraceptive method. As is stated above, few "at-risk" women in our NSFG sample switch contraceptive methods more than once during a year, and we are therefore unable precisely to model multiple method switches. Thus, we simply estimate the probability that a woman switches *at least once* over the course of a year, and we right censor any person-months in a given Contraceptive Calendar Period that follow a woman's first switch.

We use the data and variables described above to estimate two sets of models, namely: a) discrete-time hazard models predicting the probability that a woman will switch off of her Origin Method; and b) logistic regressions predicting the new contraceptive method (or lack thereof) chosen by women who switch contraceptive types. We present results from both sets of regressions below.

Hazard Models

Our survival analyses are logistic regressions that model the monthly probability of switching contraceptive type, conditional on not having switched at an earlier month in the year (henceforth, the "hazard of switching"). As is stated above, for each Contraceptive Calendar Period, we censor (i.e., we exclude from the analysis) all person-months following the first observed contraceptive switch. Because data from the Origin Month (i.e., the first month of a given Contraceptive Calendar Period) are used to define a respondent's Origin Method, and since we model switching between but not within months, women are not considered to be at risk of switching during the first month of a Contraceptive Calendar Period, even though they are (by definition) considered to be at risk of

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[79] Because we are interested in how the use of female-controlled contraceptive methods changes over time, women who rely solely on male contraception – e.g., condoms – are labeled as non-contraceptors for the purposes of these analyses.

pregnancy during that month. Consequently, for a given Contraceptive Calendar Period, our hazard models account only for switching that occurs in months subsequent to the relevant Origin Month.

Month dummies are included in the regression to model the baseline hazard of switching. Switching probabilities are also allowed to vary by age, educational attainment, race, and whether the woman experienced pregnancy-related infertility in the prior calendar month.[80] Regressions are estimated separately by Origin Method (LARC, PPR, and no female contraception) and by marital status. The results from these six regressions are presented in Table A7. The first column of data in the table reports results from a regression of the hazard of switching off of LARCs among unmarried women; the fourth column reports results from a model of the hazard of switching off of PPRs among married women; and so forth.

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[80] We include this "recent-pregnancy" indicator because women who unintentionally become pregnant in the recent past as a result of contraceptive failure may be more likely to switch methods in the months to come. Due to sample size limitations, we use a single "non-white" indicator to capture racial differences rather than including separate black, Hispanic, and "other race" dummies. For the same reason, we also exclude our standard SES indicator from these regressions.

Table A7: Female-Specific Method Switching Regression Results

	LARC		PPR		Noncontraception	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*
Age Dummy: 25-29	-0.527	-0.644	-0.106	-0.103	-0.691	-0.411
	*-1.98***	*-1.47*	*-0.69*	*-0.50*	*-4.32****	*-1.08*
Age Dummy: 30-44	-1.149	-1.399	-0.473	-0.507	-1.495	-1.017
	*-3.54****	*-3.30****	*-2.82****	*-2.56****	*-6.95****	*-2.84****
Education Dummy: High School Degree	-0.615	-0.779	-0.481	-0.002	-0.144	-0.699
	*-2.30***	*-1.68**	*-2.52***	*-0.01*	*-0.77*	*-1.58*
Education Dummy: More than High School	-0.663	-0.678	-0.451	-0.164	0.372	0.066
	*-2.34***	*-1.67**	*-2.68****	*-0.52*	*2.31***	*0.18*
Race Dummy: Nonwhite	0.110	-0.354	0.559	-0.224	-0.360	0.368
	0.45	*-1.08*	*4.28****	*-1.11*	*-2.69****	*1.38*
Pregnant Last Month Dummy	2.307	1.649	2.146	2.620	2.531	3.547
	*3.57****	*1.21*	*4.67****	*4.60****	*9.07****	*7.84****
Month Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
N (person-months)	5,047	4,419	20,065	14,134	25,420	25,690

Notes: All parameters were estimated using the female respondent files from the National Survey of Family Growth (NSFG) 2006-2010. The excluded age, education, and race categories are as follows: age group 15-24, an educational attainment of less than a high school degree, and the white race category. Coefficients are reported as log-odds. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

Method-Selection Models

Among female NSFG respondents who switch methods, we use logistic regressions to model the selection of a new contraceptive method (or of no contraception). For women who discontinue the use of LARCs, we estimate the probability of not using any form of female contraception (as opposed to using PPRs); for women who discontinue the use of PPRs, we predict the probability of becoming female non-contraceptors (as opposed to becoming LARC users); and for female non-contraceptors who start using female-controlled contraception, we estimate the likelihood of using PPRs (as opposed to becoming LARC users). As was the case with the regression results displayed in Table A7, separate models are estimated by Origin Method and marital status, and contraceptive selection is allowed to vary by age, race, and educational attainment. Dummies measuring the timing of the focal switch within the Contraceptive Calendar Period are also included.[81] Results from these analyses are summarized in Table A8.

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[81] Due to sample size issues, the "recent pregnancy" indicator was imprecisely estimated in our initial analyses of these regression models. We therefore dropped this variable from our method-selection models. Problems with small sample sizes also required that we include dummy variables for ranges of months, rather than for each individual month (note that we included individual month dummies in the hazard models whose results are reported in Table A7). These time-period indicators help to control for unobservable characteristics that are associated with both method selection and the length of time over which a female method switcher chooses to remain on her Origin Method. In other words, among women who switch contraceptive methods, the preferences of those who wait relatively longer to do so may differ in systematic (but unmeasurable) ways from the preferences of those who switch relatively quickly.

Table A8: Female-Specific Method Selection Regression Results

	LARC to Noncontraception		**PPR to Noncontraception**		**Noncontraception to PPR**	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
	t-value	*t-value*	*t-value*	*t-value*	*t-value*	*t-value*
Age Dummy: 25-29	0.397	2.177	-0.471	-0.443	0.273	-0.436
	0.67	*2.56****	*-1.02*	*-0.41*	*0.60*	*-0.44*
Age Dummy: 30-44	0.672	2.738	0.567	-1.012	-0.097	-1.107
	1.06	*3.26****	*1.08*	*-0.96*	*-0.17*	*-1.26*
Education Dummy: High School Degree	0.253	-0.325	0.750	2.004	-0.344	0.708
	0.45	*-0.36*	*1.43*	*2.22***	*-0.79*	*0.83*
Education Dummy: More than High School	0.018	-2.090	1.148	1.446	1.216	1.719
	0.03	*-2.60****	*2.42***	*1.91**	*3.07****	*2.30*
Race Dummy: Nonwhite	0.353	-1.348	0.882	-1.295	-0.916	0.350
	0.74	*-2.02***	*2.23***	*-2.00***	*-2.50***	*0.43*
Time-Period Dummy: Months 2-7	-0.049	0.560	0.950	2.605	1.718	0.647
	-0.10	*0.67*	*2.08***	*2.69****	*4.53****	*0.57*
Time-Period Dummy: Months 8-12	0.658	-0.125	1.224	3.482	2.059	1.078
	0.83	*-0.13*	*2.03***	*2.90****	*3.48****	*1.15*
N (person-years)	179	85	589	390	516	142

Notes: All parameters were estimated using the female respondent files from the National Survey of Family Growth (NSFG) 2006-2010. The excluded age, education, and race categories are as follows: age group 15-24, an educational attainment of less than a high school degree, and the white race category. The time-period dummy corresponding to months 2-7 is set equal to one if the respondent switched methods during months 2 through 7 of a Contraceptive Calendar Period, and the time period-dummy corresponding to months 8-12 is set equal to one if the respondent switched methods during the last five months of a Contraceptive Calendar Period. Coefficients are reported as log-odds. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

Simulation Methods

The parameter estimates from Table A7 are used to assign monthly method-switching propensities to women in FamilyScape. During the one-year period in which the contraceptive-switching module is activated, women who are at risk of pregnancy and who have not yet switched contraceptive type are eligible to switch methods on a monthly basis.[82] More specifically, the year of analysis time under consideration is subdivided into twelve months. At the completion of each month, FamilyScape identifies all non-pregnant, fertile, non-sterilized women who had sex for the first time that year during the month that just ended. For a given woman in the simulation population who meets all of these criteria, her contraceptive type during the month in question constitutes her Origin Method. In each subsequent month in which she remains at risk of pregnancy and has not yet switched methods, FamilyScape filters her through the appropriate method-switching regression and assigns her a monthly probability of switching contraceptive type (note that a woman's predicted monthly probability of switching will change from month to month because of the fact that our regression models allow the baseline hazard of switching to vary on a monthly basis). These method-switching probabilities are then compared to the results of random draws from a uniform (0,1) distribution in order to determine which women switch their contraceptive type.[83]

Women who are predicted to switch are then assigned probabilities of choosing various methods using the coefficients from the regressions summarized in Table A8. These probabilities are

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[82] Recall that women in the model are allowed switch their contraceptive methods at most once during the year in which the switching module is activated.

[83] In order to align FamilyScape's simulation structure with the type of month-by-month contraceptive switching that is recorded in the NSFG, women in the simulation are only at risk of switching on their first sexually active, non-pregnant, fertile day of each month.

compared to the results of random draws from a uniform (0,1) distribution in order to assign female method switchers to a new method of contraception (or to no method at all).

Validation

Table A9 reports simulated and real-world switching rates and method-selection distributions by Origin Method and marital status.[84] Simulated switching behaviors approximate real-world patterns relatively closely, both in terms of women's propensities to switch methods over the course of a year and in terms of the methods selected by women who switch contraceptive types.

Table A9: Comparisons of Real-World and Simulated Female Contraceptive-Switching and Method-Selection Patterns

			Destination Method Distributions for Women who Switch					
	Percent of Women that Switch during Year		**LARC**		**PPR**		**No Female Contraception**	
Origin Method	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
Simulated Data								
LARC	28.4%	17.3%	--	--	40.8%	39.4%	59.2%	60.6%
PPR	18.2%	22.9%	14.3%	3.7%	--	--	85.7%	96.3%
No Female Contraception	14.5%	4.6%	15.3%	21.2%	84.7%	78.8%	--	--
Real-World Data								
LARC	27.0%	18.2%	--	--	36.4%	39.5%	63.6%	60.6%
PPR	18.6%	22.6%	11.0%	4.9%	--	--	89.0%	95.1%
No Female Contraception	10.8%	4.3%	14.5%	20.8%	85.5%	79.3%	--	--

Notes: Real-world estimates are based on the sample of women in the 2006-2010 NSFG that was used to estimate parameters for FamilyScape's contraceptive-switching and method-selection modules. See the text of the paper for a detailed discussion of the construction of this analysis sample. The real-world switching rates reported here thus reflect the probability that women who are at risk of pregnancy switch contraceptive methods at least once during the next eleven consecutive months. Equivalent switching rates were simulated for a cohort of women in FamilyScape who were at risk of pregnancy (i.e., sexually active and fertile) during the first month of the relevant year of simulated analysis time (i.e., days 1000-1030). Simulated results were generated using data from one hundred one-year runs of the FamilyScape 2.0 model.

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[84] Real-world switching rates and method-selection distributions are estimated using the same analysis sample of female NSFG respondents that was used to parameterize FamilyScape's contraceptive-switching module.

Consistency and Correctness of Contraceptive Use

The reader should bear in mind that, within the context of FamilyScape's architecture, the concept of contraceptive *consistency* is distinct from the concept of contraceptive *switching*. As an example, a woman who is considered to be a pill user during every month of a given year (because oral contraception is the most effective method that she uses in each month) might also be an inconsistent contraceptor (if she misses a certain number of pills per month). The exposition in this section addresses the latter consideration.

In order directly to simulate inconsistency of contraceptive use, we would require two pieces of information. First, we would need data on the distribution of consistency of method use. For example, we would require information on the proportion of oral contraception users who typically miss one pill per month, the proportion who miss two pills per month, and so forth. And second, we would require information on the relationship between the efficacy of each method and the consistency with which it is used. For example, we would require information on the decline in the efficacy of oral contraception when one pill is missed, the further decline in efficacy when two pills are missed, and so forth. We would also require similar sorts of information in order to simulate variation in the correctness of contraceptive use (i.e., the extent to which contraception is used as intended).

Such data do not exist. We have therefore chosen not to attempt directly to incorporate these dynamics into FamilyScape. Instead, we capture much of the variation in consistency and correctness of contraceptive use by allowing the efficacy levels of the methods incorporated into the model to vary across demographic groups. There are substantial differences between demographic groups in the pregnancy rates experienced by users of various methods. Much of this variation occurs across age, race, and marital-status categories. For example, our tabulations of the 2006 – 2008 NSFG suggest that the annual pregnancy rate among unmarried white women over the age of 30 who rely on condoms throughout the year is about 6%, while the comparable pregnancy rate among unmarried black female condom users under the age of 25 is about 31%. In addition, pregnancy rates among users of oral contraception are about three times higher among women falling into the latter category than among women falling into the former category.[85]

We assume that this variation in pregnancy rates reflects demographic differences in the consistency and correctness of method use among contraceptors. As is discussed in Appendix IV, we explicitly simulate demographic variation in contraceptive efficacy rates. In so doing, we therefore indirectly account for heterogeneity in the consistency and correctness with which various methods are used.[86]

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[85] These tabulations were performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger.

[86] It is important to note that the pregnancy rates reported in the previous paragraph are limited to "continuous" contraceptive users. Or, more precisely, they were calculated using only data on person-month observations for whom the method in question was the most effective method used. Thus, the demographic variation in pregnancy rates detailed above is not driven by group differences in contraceptive-switching propensities. In the same way, we ensure that the contraceptive-efficacy and contraceptive-switching modules are conceptually distinct components of FamilyScape's architecture by using information on pregnancy rates among "continuous" contraceptors to develop the model's efficacy parameters.

Appendix IV: Pregnancy & Pregnancy Outcomes

This appendix is divided into four sections. In the first section, we detail our methods for modeling female fecundity. The second section reviews the model's contraceptive efficacy module and provides a discussion of the way in which pregnancies are simulated in FamilyScape 2.0. The third section begins by outlining the model's procedures for determining whether each simulated pregnancy results in a live birth, an abortion, or a fetal loss and then follows with a description of our methods for calculating the real-world benchmarks used to evaluate the accuracy of FamilyScape's results. And in the fourth and final section, we discuss the parameterization of the model's gestation-period module.

Fecundity

Each time that a couple has sex during the simulation, there is some probability that the woman will become pregnant. The occurrence of pregnancy is simulated by taking a random draw from a uniform (0,1) distribution whenever a couple has sex and comparing the value of that draw to the woman's probability of conceiving from a single act of intercourse. If the value of the draw is less than the woman's probability of experiencing a pregnancy, she becomes pregnant. A woman's pregnancy probability is determined by two factors: a) her underlying level of fecundity (i.e., her physiological capacity to conceive), and b) the effectiveness of the contraceptive method(s, if any) that she and/or her partner are using. We address the first of these two considerations here, and we provide a detailed discussion of the latter consideration in the next section.

A small number of studies have reported estimates of the probability of conceiving from a single act of unprotected sex.[87] Because FamilyScape 2.0 has a daily periodicity and allows for variation by age in its key behaviors and outcomes, it is critical that the model's fecundity module allows conception probabilities to vary both by age and by day in the menstrual cycle.[88] Royston's (1982) empirical model accounts for such variation. As is discussed below, there are other ways in which this model is less than ideally suited for the purpose of parameterizing FamilyScape's fecundity module. However, Royston's study provides the only empirically derived parameters of which we are aware that articulate variation in conception probabilities simultaneously by age and day in the menstrual cycle. We therefore use estimates from this study to parameterize FamilyScape, but we also make a series of adjustments to them in order to improve their compatibility with our model's simulation structure.

Royston estimates parameters for the following equation:

$$p(conception)_{i,t} = (\kappa_0 - \kappa_1 * [A_i - \bar{A}]) * \alpha_t, \qquad \textbf{Eq. 1}$$

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[87] See, for example, Barrett and Marshall (1969), Dixon et al. (1980), Royston (1982), and Wilcox et al. (1995).

[88] We use the terms "fecundity" and "conception probability" interchangeably throughout this discussion. The reader may wonder why it is important that the model allow conception probabilities to vary by day in the menstrual cycle. The reason is that the estimated cumulative probability of experiencing a pregnancy over multiple acts of intercourse is different if one allows for realistic variation in daily conception probabilities than if one constrains the probability of conception to be the same for all acts of intercourse, even if one's "uniform conception probability" is equal to the average of the true underlying daily conception probabilities. Consider, for example, a scenario in which the probability of conceiving at the first act of intercourse is .3 and the probability of conceiving at the second act of intercourse (conditional on not having conceived at the prior act of intercourse) is .1. The true cumulative probability of experiencing a pregnancy over these two sexual encounters is [1-(1-.3)*(1-.1)] = .37. However, if one were to assign an "average conception probability" to both acts of intercourse, one would instead conclude that the cumulative conception probability is $[1-(1-.2)^2] = .36$. More generally, the use of "average daily conception probabilities" rather than "true daily conception probabilities" within the simulation would imply levels of cumulative pregnancy risk that are lower than is actually the case. For this reason – and because FamilyScape 2.0 has a daily periodicity – it is important that the model incorporate realistic variation in daily conception probabilities.

where $p(conception)_{i,t}$ is the probability that individual *i* will conceive if she has unprotected sex on day *t*; A_i is the age of individual *i*; $\bar{A}$ is the mean age of all of the women in the author's sample; κ_0 and κ_1 are econometrically estimated parameters that capture the age-dependent likelihood of fertilization; and α_t is a vector of generic probabilities of ovular fertilization that vary by the day in the menstrual cycle.[89]

As is discussed above, we make several adjustments to Royston's initial fecundity estimates in order to enhance their compatibility with FamilyScape's structure. First, although Royston's model theoretically assigns non-zero conception probabilities to every day of a woman's menstrual cycle, he estimates his model's parameters for a 14-day interval ranging from day 4 to day 17 of a woman's cycle. Consequently, we assume zero conception likelihoods on days that fall outside of this fertility window.[90] We also top-code daily pregnancy likelihoods at 40% because Royston's in-sample point estimates of predicted daily conception probabilities never exceed this threshold.[91]

Finally, since Royston derived his estimates from a sample of women aged 20-39 (Royston, 1982; Barrett and Marshall, 1969), we adjust his model's imputed fecundity levels for women near the

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[89] The mean age of the participants in the Royston's sample was 32, and he estimates the values of $\varkappa_0$ and $\varkappa_1$ to be .48 and .022, respectively. The latter two parameters are used to measure the (age-specific) probability that a woman is capable of becoming pregnant in a given cycle. This probability is less than one for a variety of reasons. For instance, in any given menstrual cycle, it is possible that a) ovulation does not occur, b) defects in the egg preclude any possibility of fertilization, or c) the embryo aborts prior to being registered as a pregnancy in the study. Thus, the bracketed portion of Equation 1 reflects the probability that such events do *not* occur. The "α_t" component of Equation 1 is modeled using the following functional form: $\alpha_t = \exp(-[t_{ov} - t]/\lambda_s)$ for all $t < t_{ov}$; $\alpha_t = 1$ for $t = t_{ov}$; and $\alpha_t = \exp(-[t - t_{ov}]/\lambda_e)$ for all $t > t_{ov}$, where *t* is an index for the day in the menstrual cycle, t_{ov} is the day of ovulation, λ_e is the average life of the egg in days, and λ_s is the average life of the sperm in days. Royston estimates the value of λ_s to be 1.47, and he estimates the value of λ_e to be .7.

[90] Although our assumption of a 14-day fertile window is consistent with the assumptions underlying Royston's analysis, most studies tend to find that the fertile window is narrower than this. While estimates of the length of the fertility window vary greatly in the literature, ranging from less than two days (Bongaarts, 1983) to over ten days (Vollman, 1977), most studies indicate that the fertility window is between six and eight days long (Colombo and Masarotto, 2000; Dunson et al., 2000). However, FamilyScape's (adjusted) conception probabilities are very small in the tails of the model's 14-day fertility period, and we have concluded that it would be inappropriate for us to assume a narrower fertility window if we are to use Royston's equation as the basis for FamilyScape's fecundity module.

[91] While Royston's point estimates do not exceed 40%, his model allows the theoretical probability of conception to rise as high 0.85 for a small number of cases (e.g., women in their early 20's on the day of ovulation).

upper and lower bounds of FamilyScape's age distribution. Royston's model imposes a linear constraint on the age-fecundity relationship, suggesting that fecundity is the highest for the youngest women in his sample and declines at a constant rate as women age. While this restriction on the model's functional form may have been appropriate given the age range of the women in Royston's sample, it is unrealistic with respect to women in the tails of our model's age distribution. A survey of the fecundity literature shows that the probability of conception increases during the early years of female reproductive development (Treloar, 1974; Weinstein et al., 1990), peaks in the early twenties (Treloar, 1974; Wood, 1989), declines steadily until the mid-thirties (McDonald et al., 2011), and then drops dramatically during the late thirties and early forties (Menken et al., 1986; Schwartz and Mayaux, 1982; Lass et al., 1998). In order to incorporate these nonlinearities into our model, we construct fecundity scaling factors for each of the following age groups: a) 15-23 year-olds, b) 35-39 year-olds, and c) 40-44 year-olds. The calculations and assumptions used to derive each of these adjustments are described separately below.

Fecundity Scaling Factors: Women Aged 15 to 23

The onset of menstruation – also known as menarche – typically marks the point at which a woman becomes physiologically capable of conceiving. Several factors, including variability in ovarian cycle length and inconsistent ovulation, are known to depress fertility during the early years of female reproductive development.[92] Unfortunately, while there is a consensus in the literature that fecundity levels increase into a woman's early twenties (Treolar, 1974; Wood, 1989), we are unaware of any study that has estimated the precise shape of the conception probability curve for adolescents. We therefore adopt Leridon's (2004) practice of modeling fecundity for younger females as a linear function of age and the timing of menarche.

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[92] Treloar (1974), Wood and Weinstein (1988).

We begin by assuming the likelihood of pregnancy to be zero at age 12, which is the approximate average age of menarche in the United States.[93] We then assume that the probability of conception (averaged across all days in the menstrual cycle) peaks at age 23. While studies indicate that fecundity peaks during the early 20s (Wood, 1989), no analysis of which we are aware estimates with precision the age at which maximum fecundity is attained. We have chosen to allow the fecundity profile to peak at 23 because this age corresponds roughly to the midpoint of the age range spanning from 20 to 25. We assume that fecundity rises linearly from age 12 to its peak at age 23, and we define this maximum fecundity level as the mean probability of conception (averaged across all days in the menstrual cycle) that Royston estimates for a 23 year-old woman.[94] These two end points, combined with the aforementioned assumption of linearity, give rise to the following menarche-based fecundity model:

$$P(Conception|Age)_{Menarc\ he} = -.05087 + .00424 * Age, \qquad \textit{Eq. 2}$$

where $P(Conception|Age)_{Menarche}$ is the probability of conception averaged across all days in the menstrual cycle and Age ranges from 12 to 23.[95]

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[93] Anderson and Must (2005).

[94] Our decision to model fecundity as a linear function of age for younger women was influenced by Leridon (2004), who used a similar approach to develop his pregnancy simulation model.

[95] The parameters for Equation 2 were derived as follows. First, we used Royston's original model to calculate the mean daily fecundity probability (.046635), averaged across all days in the menstrual cycle, for a 23-year-old woman. Second, we calculated a slope by determining the rate at which fecundity would need to increase with each year of age in order to rise (linearly) from zero at age twelve to .046635 at age 23. This calculation implied a slope of (.046635/(23-12)) ≈ .00424. And finally, we calculated the intercept that would be required to set fecundity equal to zero for a twelve-year-old. This calculation yielded an intercept value of (-1)*(12*.00424) ≈ -.05087.

Daily conception probabilities produced by the original Royston model are scaled relative to the linear model described above. Mathematically, this scaling process can be described as follows:

$$P(Conception|Age = i, Day = j)_{Corrected} \quad =$$

$$P(Conception|Age = 23, Day = j)_R * \frac{P(Conception|Age = i)_{Menarche}}{P(Conception|Age = 23)_R}, \qquad \textbf{\textit{Eq. 3}}$$

$$i \in \{15, 16, \ldots, 23\}, \quad j \in \{1, 2, \ldots, 28\},$$

where $P(Conception|Age = i, Day = j)_{Corrected}$ is the adjusted probability of conception for a woman of age i on the j^{th} day of her menstrual cycle; $P(Conception|Age = 23, Day = j)_R$ is the daily, age-based probability of conceiving as predicted by the original Royston model; $P(Conception|Age = i)_{Menarche}$ represents the probability of conception averaged across all days in the menstrual cycle under our "menarche-adjusted" model for a woman with i years of age; and $P(Conception|Age = 23)_R$ represents the probability of conception averaged across all days in the menstrual cycle under Royston's original model for a 23-year-old woman.[96] Once these adjustments are made, average conception probabilities among 15-23 year-old women in FamilyScape's simulation population are about 41% lower than the comparable unadjusted probabilities produced by Royston's base equation.

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[96] We assume for the purposes of these calculations that the daily variation in fecundity for women under the age of 23 is proportionally equivalent to the daily variation in fecundity for 23-year-olds. Thus, the fecundity level for a woman of age i (where $15 \leq i \leq 23$) on the j^{th} day of her menstrual cycle is assumed to be equal to the product of the fecundity level of a 23-year-old woman on the same day in her cycle and a scaling factor that reflects the extent to which fecundity is lower for a woman of age i than for a 23-year-old woman. This scalar is captured in Equation 3 via the expression in which $P(Conception|Age = i)_{Menarche}$ is divided by $P(Conception|Age = 23)_R$.

Fecundity Scaling Factors: Women Aged 35 to 39

Extant literature suggests that the age-related decline in female reproductive capacity is marked by two notable drops in fecundity levels. The first occurs at approximately age 35 (Schwartz and Mayaux, 1982; Spira, 1988), while a second, even-steeper drop-off follows at around age 40 (Abdalla et al., 1993; Teruya et al., 2006). As is discussed above, however, Royston's model assumes that fecundity declines linearly with age.

To correct our estimates for the earlier of these two "fecundity cliffs," we use the findings of Dunson et al. (2002) to adjust conception probabilities for 35-39 year-old women.[97] The authors estimate a decrease of approximately 50% in the probability of conception (averaged across all days in the menstrual cycle) for women aged 35 to 39 relative to women aged 19 to 26. We apply this age-based fecundity ratio to the original Royston model in order to derive corrected daily conception probabilities for 35-39 year olds. Specifically, we calculate:

$$P(Conception|Age = i, Day = j)_{Corrected} =$$

$$P(Conception|Age = i, Day = j)_R * \frac{[0.5 * P(Conception|Age_{19-26})_R\,]}{P(Conception|Age_{35-39})_R}, \qquad \textit{Eq. 4}$$

$$i \in \{35, 36, \dots, 39\}, \quad j \in \{1, 2, \dots, 28\},$$

where $P(Conception|Age = i, Day = j)_{Corrected}$ is the adjusted probability of conception for a woman of age i on the j^{th} day of her menstrual cycle; $P(Conception|Age = i, Day = j)_R$ is the daily, age-based

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[97] Although other studies estimate similar drops in fecundity levels for 35-39 year olds, we ultimately selected Dunson et al. (2002) for this fecundity correction because of this study's comparability with Royston (1982). Specifically, both studies estimate pregnancy probabilities using survey data drawn from a sample of non-contracepting European women. Moreover, the pregnancy, ovulation, and fetal-loss metrics employed by the two authors are almost identical. These similarities, in terms of both sample selection and study design, allow us to loosen some of the assumptions needed to adjust Royston's conception probabilities.

probability of conceiving predicted by the Royston model (after the above-referenced adjustments for women aged 15 – 23 have been made); and $P(Conception|Age_{19\text{-}26})_R$ and $P(Conception|Age_{35\text{-}39})_R$ represent estimates produced by the Royston model of the mean probability of conception (averaged across all days in the menstrual cycle) for women aged 19 to 26 and for women aged 35 to 39, respectively.[98] As a result of these adjustments, average conception probabilities for 35-39 year-olds in the model are reduced by about 35%.

Fecundity Scaling Factors: Women Aged 40 to 44

In the case of women aged 40 and over, the process of constructing an accurate fecundity scaling factor is complicated by the fact that most studies estimating natural conception probabilities among non-contracepting populations fail to include this older demographic in their samples. Lass et al. (1998), however, estimate distinct conception probabilities for 40, 41, 42, 43 and 44 year-old women who are undergoing in vitro fertilization (IVF) treatment. More importantly, the authors supply conception rates for a comparable sample of under-40-year-old IVF patients, meaning that we can construct ratios that compare IVF conception probabilities for women under the age of 40 and women over the age of 40.[99]

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[98] The validity of this correction hinges on two main assumptions, namely: a) that our "corrected Royston" estimates are accurate reflections of the probability of conception among women aged 19 to 26; and b) that the percent change in conception probabilities between 19-26 year olds and 35-39 year olds is accurately measured by Dunson et al. (2002). Given these assumptions, Equation 4 multiplies the average conception probability for women aged 19 to 26 by 50% in order to produce a "corrected average conception probability" for women aged 35 to 39. We then calculate the ratio of this "corrected average probability" to the "initial average probability" produced by Royston's original equation for women aged 35 to 39 and apply that ratio to the age-and-day-specific conception probabilities produced by the Royston equation for women in this age group. This process produces a set of fecundity estimates for women aged 35-39 whose average is equal to 50 percent of the assumed average fecundity level for women aged 19-26.

[99] For the purposes of this portion of our discussion, conception rates are defined as the number of pregnancies divided by the total number of in vitro cycles initiated. Unfortunately, the authors do not provide an age range for their under-40 reference group. As a result, we make the simplifying assumption that the ages for the "under-40" group in the authors' sample are uniformly distributed between 20 and 39.

As in the case of younger women and 35-39 year-olds, these age-based ratios are then applied to Royston's daily conception probabilities in order to derive corrected conception probabilities for women in the model who are between the ages of 40 and 44. We calculate corrected fecundity estimates for women in their forties using the following equation:

$$P(Conception|Age = i, Day = j)_{Corrected} \quad =$$

$$P(Conception|Age = i, Day = j)_R * \frac{P(Conception|Age = i)_L}{P(Conception|Age_{Under\ 40})_L} * \frac{P(Conception|Age_{Under\ 40})_R}{P(Conception|Age = i)_R}, \qquad \textbf{\textit{Eq. 5}}$$

$$i \in \{40, 41, \dots, 44\}, \;\; j \in \{1, 2, \dots, 28\},$$

where $P(Conception|Age = i, Day = j)_{Corrected}$ is the adjusted probability of conception for a woman of age i on the j^{th} day of her menstrual cycle; $P(Conception|Age = i, Day = j)_R$ is the daily, age-based probability of conceiving predicted by the Royston model (once the other two sets of fecundity adjustments described above have been made); $P(Conception|Age_{Under40})_L$ and $P(Conception|Age = i)_L$ represent Lass et al.'s estimates of the mean probability of conception (averaged across all days in the menstrual cycle) for women under the age of 40 and for women of age i, respectively; and $P(Conception|Age_{Under40})_R$ and $P(Conception|Age = i)_R$ represent Royston's estimates of the mean probability of conception (averaged across all days of the menstrual cycle) for women under the age of 40 and for women of age i, respectively.[100]

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[100] Our calculations in Equation 5 rely on a set of "IVF ratios" that are constructed by taking the quotient of Lass et al.'s estimate of the IVF conception probability for women of age i (where $40 \leq i \leq 44$) and their estimate of the IVF conception probability for women under 40. We calculate separate ratios for each year of age between 40 and 44, and we assume that each "IVF ratio" reflects the true ratio of the fecundity of women of age i to the fecundity of women under 40. Under this assumption, we divide each "IVF ratio" by a comparably specified "Royston ratio" (again, we construct separate "Royston ratios" for each year of age between 40 and 44). We then apply the appropriate age-specific "ratio of ratios" to the age-and-day-specific fecundity estimates produced by the original Royston equation for women of age i. After these adjustment factors are applied to our fecundity estimates for women over 40, the proportional differences between the average fecundity of women in their forties and the average fecundity of women under 40 are comparable to the equivalent proportional differences observed by Lass et al. (1998).

These adjustments ultimately result in a decrease of about 43% in the average conception probability for 40-44 year-olds relative to the baseline estimates supplied by the Royston model.[101] It is probable, however, that our IVF-adjusted conception probabilities still overstate the reproductive capacity of 40-44 year-old women. Artificial reproductive treatments have been shown to delay the effects of age on fecundity (Leridon, 2004), which is to say that conception probabilities likely decline with age at a faster rate for naturally conceiving populations than for women enrolled in IVF programs.[102] As a result, we believe that our conception probabilities for women 40 and over serve as an upper bound for the true reproductive capabilities of this older demographic.

Once the fecundity adjustments described above have been applied, the modified Royston estimates are imported into FamilyScape 2.0 and used to assign daily conception probabilities. Specifically, at t=0, every woman in the simulation population is randomly assigned to one of the 28 days in the normal menstrual cycle, and their menstrual calendars are updated daily as the simulation proceeds. The model assumes that all women will have regular 28-day cycles and that they will always ovulate on the 14th day of their cycles.[103] Each time that a couple has sex, our corrected versions of Royston's estimates are used to calculate an initial conception probability as a function of the woman's age and the day in her cycle. We then compute a final probability of conception by taking the product of this corrected probability and the "failure rate" of the contraceptive method(s, if any)

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[101] It is important to note that each fecundity adjustment builds upon the previous fecundity corrections described in this appendix. Thus, the adjustment of conception probabilities for 40-44 year olds explicitly incorporates the changes that we made to the conception probabilities of 15-23 year olds and 35-39 year olds.

[102] As a cursory test of this proposition, we compared Royston's age-specific conception probabilities (averaged across all days in the menstrual cycle) with the age-specific IVF conception probabilities reported in Teruya et al. (2006) for women between the ages of 24 and 34. IVF conception probabilities were found to decrease at a markedly slower rate than were Royston's conception probabilities, providing further support for the notion that IVF treatment slows the age-based decline of fecundity.

[103] As described in an earlier footnote, the Royston model explicitly accounts for the probability that fertilization is not possible in a given menstrual cycle. Thus, although FamilyScape 2.0 assumes that ovulation always occurs on the 14th day of a woman's cycle, the model's daily pregnancy probabilities do in fact account for the likelihood of anovulatory menstrual cycles.

that the couple is using. The next section describes the way in which we derive FamilyScape's contraceptive failure rates.

Contraceptive Failure

In much of the relevant literature, a contraceptive method's "failure rate" is defined as the pregnancy rate experienced by the users of that method over some specified period of time.[104] For our purposes, however, failure rates must be defined somewhat differently. It is perhaps simplest to explain our approach mathematically. Assume that a woman has intercourse n times over a one-year period, and assume further that her fecundity level (i.e., the probability that she will conceive at a given act of intercourse if she does not use contraception) is given by f. Thus, the woman's probability of avoiding pregnancy from a single act of intercourse is $(1-f)$, her probability of avoiding pregnancy over n acts of intercourse can be assumed to be $(1-f)^n$, and her risk of experiencing a pregnancy over n acts of intercourse is $(1 - (1-f)^n)$. Now assume that the woman in question uses a contraceptive method that reduces her risk of pregnancy by 95% each time she has sex. We define this method's "failure rate" to be $(1-.95) = .05$. According to this mathematical formulation, the woman's single-act conception probability is now $.05*f$, and her conception probability over n acts of intercourse is $(1 - (1-(.05*f))^n)$. More generally, we can think of a method's failure rate, c, as one minus its "efficacy rate," where contraceptive efficacy in this context is defined as the proportional reduction in the risk of pregnancy at a given act of intercourse that is brought about by the use of that method.

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[104] See, for example, Fu et al. (1999), Moreau et al. (2007), and Trussell et al. (1999). Pregnancy rates are often expressed as the number of pregnancies that occur per 1,000 women in the population at large. However, for the purposes of the discussion in this section, we follow the standard practice within the contraceptive efficacy literature of defining pregnancy rates in percentage terms.

As is discussed in Appendix III and in the main body of this paper, FamilyScape 2.0 allows for demographic variation in most methods' failure rates. More specifically, we model variation in contraceptive failure rates by age (15-24, 25-29, 30-44), race (White, Hispanic, Black), and marital status (married, unmarried). However, we make the simplifying assumption that, within demographic groups, failure rates are homogenous. Our approach thus yields the following generalized equation:

$$P(Pregnant)_{i,j} = (1 - [1 - (c_{i,j} * f_{i,j})]^{n_{i,j}}) \, , \qquad \textbf{\textit{Eq. 6}}$$

where $P(Pregnant)_{i,j}$ is the annual probability of experiencing a pregnancy for women who are in demographic subgroup i and are using method j; $f_{i,j}$ gives the mean fecundity level (averaged across all relevant ages and all days in the menstrual cycle) for women in demographic group i who use method j; $n_{i,j}$ gives the average coital frequency for women in demographic group i who use method j; and $c_{i,j}$ gives the contraceptive failure rate experienced by women in demographic group i who use method j.[105] Using our adjusted Royston model to produce age-specific estimates of $f_{i,j}$ and the female respondent file of NSFG 2006-08 to generate demographically specific estimates of $P(Pregnant)_{i,j}$ and $n_{i,j}$, we then employ the following re-statement of Equation 6 to solve for $c_{i,j}$:

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[105] In the previous section, we discuss the fact that our fecundity estimates allow for variation in conception probabilities by the day in the menstrual cycle. However, for the purposes of the contraceptive failure-rate calculations described here, we make the simplifying assumption that there is no daily variation in conception probabilities. More specifically, we assume here that a woman's conception probability on any given day equals the average of her true conception probabilities across the 28 days of her menstrual cycle. We make this assumption out of practical necessity: there is no straightforward way of incorporating daily variation in fecundity into the contraceptive efficacy calculations shown in Equations 6 and 7. As a result of this simplifying assumption, Equations 6 and 7 somewhat understate the true value of $P(Pregnant)_{i,j}$. However, the results of a series of back-of-the-envelope calculations suggest that our understatement of $P(Pregnant)_{i,j}$ has only a small impact on our contraceptive efficacy estimates. Thus, and in order to ensure the tractability of these calculations, we make the simplifying assumption for all calculations in this section that conception probabilities do not vary by day in the menstrual cycle.

$$c_{i,j} = \frac{1 - \left(1 - P(Pregnant)_{i,j}\right)^{\frac{1}{n_{i,j}}}}{f_{i,j}}. \qquad \textbf{\textit{Eq. 7}}$$

We conduct separate calculations for each distinct combination of i and j.[106] The only exception to this rule is sterilization, which we assume to have a 100% efficacy rate (and therefore a 0% failure rate) for all users.[107] Thus, we estimate demographically specific contraceptive failure rates for condoms, PPRs, and LARCs. We produce demographically specific estimates of $f_{i,j}$ by: a) using the female respondent files of the 2002 and 2006 – 2008 cycles of the NSFG to estimate the average ages of individuals falling into each demographic-contraceptive-method subgroup; b) plugging that age into our adjusted Royston fecundity model; and c) calculating a mean fecundity level (averaged across all days in the menstrual cycle) for the women who are of that age.[108] In order to maintain sufficient sample sizes for all of the demographic-contraceptive-method categories included in our analysis, we eliminate race from our analyses of average ages within demographic-contraceptive-method subgroups (which are then used to calculate values for $f_{i,j}$) and of $n_{i,j}$. For the same reason, we also estimate $f_{i,j}$ and $n_{i,j}$ for only two age groups (15-29, 30-44).

For each contraceptive method (other than sterilization), we allow our estimates of $P(Pregnant)_{i,j}$ to vary simultaneously by age, race, and marital status. However, due once again to unacceptably small

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[106] Most of the NSFG analysis required to develop estimates for the contraceptive failure calculations described in this section were performed by Child Trends' Jennifer Manlove, Kate Welti, and Amanda Berger. Because contraceptive failure rates are meaningless in the absence of sexual intercourse, these analyses were confined to NSFG respondents who had sex at least once in the year prior to their interview.

[107] The rate of pregnancy over several years has been found to be less than one percent among sterilized individuals (Thomas and Roessel, 2008). The reader should also note that individuals who do not use any form of contraception are implicitly assigned a "failure rate" of 1.

[108] The condom is a male-controlled method. However, because pregnancy is a female-specific outcome, we calculate condom failure rates using data on the pregnancy rates, coital frequencies, and fecundity levels of women whose partners rely on condoms. Thus, women are designated as "condom users" for the purposes of these calculations if their partners use condoms.

sample sizes within some cells – and because preliminary analyses indicated that LARC pregnancy rates do not vary significantly by age – we eliminate age as a covariate from our analyses of $P(Pregnant)_{i,j}$ among LARC users. Our estimates of $P(Pregnant)_{i,j}$ are based in large part on results contained in Hatcher et al. (2009), which reports typical-use pregnancy rates among users of various methods. The authors' estimates are drawn from the 1995 NSFG, and they are corrected for the underreporting of abortions among NSFG respondents.[109] However, the pregnancy rates reported by Hatcher et al. do not vary demographically. We therefore make several adjustments to these baseline estimates in order to derive demographically specific annual pregnancy probabilities for each contraceptive method. More precisely, we construct demographically specific pregnancy probability ratios using 2002 and 2006-08 NSFG data and then apply these scalars to the published estimates reported by Hatcher et al.

To generate our "demographic pregnancy-probability scalars," we begin by using logistic regressions to model monthly pregnancy probabilities among sexually active female NSFG respondents who self-identify as a) LARC users, b) PPR users, or c) condom users.[110] These models (which include the demographic controls listed above) are then used to predict average demographically specific monthly pregnancy probabilities for each type of contraceptive user. We subsequently multiply these monthly pregnancy probabilities by a factor of twelve in order to arrive at demographically

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[109] In the nomenclature of population studies, "typical contraceptive use" encompasses both perfect and imperfect use of that method. Some studies separately report typical-use and perfect-use pregnancy rates among contraceptive users. However, because FamilyScape 2.0 assigns a single contraceptive failure rate to all users of a given method who have a given set of demographic characteristics, typical-use rates are better suited to our needs.

[110] Recall from Appendix III that FamilyScape's contraceptive-use parameters are derived from a series of NSFG analyses in which we collapsed users of a variety of different methods into the three categories enumerated above. For example, we designated male respondents in the NSFG as condom users if they relied on either condoms or withdrawal as their primary method of contraception; we designated women as LARC users if they relied on intrauterine devices, hormonal implants, or injectables; and so forth. However, because the calculations described in this section are based in part on the results of a previously published analysis in which contraceptive categories were not similarly collapsed, we base our estimates of $P(Pregnant)_{i,j}$ on the rates of pregnancy among users of the most commonly used method in each of our three broad categories. More specifically, our estimates of $P(Pregnant)_{i,j}$ for the "LARC," "PPR," and "condom" categories are based on data taken from Hatcher et al. (and from our own NSFG analyses) on the pregnancy rates experienced by users of injectable contraception, oral contraception, and condoms, respectively.

tailored annual pregnancy probabilities. Demographically specific pregnancy-rate ratios are then computed for each contraceptive method by dividing the annual pregnancy probability among contraceptive users from a given demographic subgroup by the annual pregnancy probability among all users of that contraceptive method.

We calculate demographically specific annual pregnancy rates for each method by taking the product of Hatcher et al.'s estimates and the appropriate demographically specific pregnancy-rate ratio.[111] Mathematically, this final computation can be expressed as:

$$P(Pregnant)_{i,j} = P(Pregnant)_j^H * \frac{P(Pregnant)_{i,j}^N}{P(Pregnant)_j^N}, \qquad \textbf{\textit{Eq. 8}}$$

where $P(Pregnant)_{i,j}$ is the annual pregnancy rate among people in demographic group i who use contraceptive method j; $P(Pregnant)^H_j$ is Hatcher et al.'s estimate of the annual pregnancy rate among all people who use contraceptive method j; $P(Pregnant)^N_{i,j}$ represents our NSFG-based estimate of the annual pregnancy rate among people of demographic i who use contraceptive method j; and $P(Pregnant)^N_j$ is our NSFG-based estimate of the annual pregnancy rate among all people who use contraceptive method j. Our estimates of the demographically specific annual pregnancy rates produced by Equation 8 are summarized in Table A10.[112]

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[111] Note that, for the purposes of these calculations, we implicitly make the simplifying assumption that the underreporting of abortion among NSFG respondents does not vary systematically between demographic subgroups.

[112] Hatcher et al.'s estimates of $P(Pregnant)^H_j$ (and therefore our estimates of $P(Pregnant)_{i,j}$) are derived using data on typical-use pregnancy rates among "continuous" contraceptors. More specifically, these estimates are produced via analysis of person-month data that are limited to months in which the method in question was the most effective method used. Thus, our estimates of contraceptive efficacy are not affected contraceptive switching behavior. Contraceptive switching is instead modeled using a separate module that is detailed in Appendix III.

Table A10: Demographically Specific Typical-Use Annual Pregnancy Rates

	Condom		LARC		PPR	
	Unmarried	Married	Unmarried	Married	Unmarried	Married
Age 15-24, White	19.94%	23.34%	3.16%	1.22%	8.15%	9.16%
Age 15-24, Black	30.85%	36.06%	6.50%	2.51%	13.45%	15.10%
Age 15-24, Hispanic	27.69%	32.38%	5.09%	1.96%	14.27%	16.02%
Age 25-29, White	12.98%	15.21%	3.16%	1.22%	7.00%	7.86%
Age 25-29, Black	20.14%	23.57%	6.50%	2.51%	11.55%	12.96%
Age 25-29, Hispanic	18.06%	21.14%	5.09%	1.96%	12.25%	13.76%
Age 30-44, White	6.15%	7.21%	3.16%	1.22%	4.57%	5.14%
Age 30-44, Black	9.57%	11.22%	6.50%	2.51%	7.55%	8.48%
Age 30-44, Hispanic	8.57%	10.05%	5.09%	1.96%	8.01%	9.00%

Notes: Failure rates were calculated by combining published estimates reported in Hatcher et al. (2009) with retrospective contraceptive calendar data and pregnancy histories from the 2002 and 2006-2008 cycles of the National Survey of Family Growth. In order to obtain sufficient cell sizes, age was eliminated as a covariate from LARC analyses.

Having calculated annual coital frequencies ($n_{i,j}$), natural fecundity levels ($f_{i,j}$) and yearly pregnancy rates ($P(Pregnant)_{i,j}$), we then use Equation 7 to compute demographically specific probabilities that a contraceptive method fails during a single act of intercourse ($c_{i,j}$). Our estimates of $c_{i,j}$ are displayed in Table A11.

Table A11: Demographically Specific Typical-Use Contraceptive Failure Rates

	Condom		LARC		PPR	
	Unmarried	Married	Unmarried	Married	Unmarried	Married
Age 15-24, White	6.13%	5.85%	0.79%	0.33%	2.11%	1.88%
Age 15-24, Black	10.17%	9.83%	1.65%	0.68%	3.58%	3.20%
Age 15-24, Hispanic	8.94%	8.60%	1.28%	0.53%	3.82%	3.42%
Age 25-29, White	3.84%	3.63%	0.79%	0.33%	1.80%	1.60%
Age 25-29, Black	6.20%	5.91%	1.65%	0.68%	3.04%	2.72%
Age 25-29, Hispanic	5.49%	5.23%	1.28%	0.53%	3.24%	2.90%
Age 30-44, White	3.39%	4.64%	0.79%	0.33%	1.73%	3.53%
Age 30-44, Black	5.37%	7.38%	1.65%	0.68%	2.90%	5.94%
Age 30-44, Hispanic	4.79%	6.57%	1.28%	0.53%	3.09%	6.32%

Notes: Failure rates were calculated according to Equation 7. In order to obtain sufficient cell sizes, age was eliminated as a covariate from LARC analyses.

While it would be possible to assign each contraceptive user in FamilyScape 2.0 to a cell in Table A11, we ultimately use regression analysis to assign contraceptive failure rates to members of FamilyScape's simulation population. The reason for this decision is that using regression equations to simulate behaviors and outcomes in FamilyScape reduces simulation runtime by simplifying the parameterization of the model.[113]

To predict contraceptive failure rates for individuals in FamilyScape 2.0, we first assign each contraceptive user to a failure rate in Table A11 based on her relevant demographic characteristics. Then, for each contraceptive method, we use individual-level data on the members of FamilyScape's simulation population to regress the method's failure rates on the same demographic characteristics that were used to generate those failure rates.[114] Separate regressions are estimated for married and unmarried contraceptive users. The results from these analyses are reported in Table A12.[115]

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[113] See Appendix I for further discussion of this topic.

[114] For the purposes of these analyses, we pool unconditional and conditional condom users into a single contraceptive-method group. We therefore assume that, when condoms are used during intercourse, failure rates do not differ markedly between these two categories of condom users.

[115] Exploratory analyses indicate that the differences are small between our regression-predicted failure rates and the actual failure rates as reported in Table A11.

Table A12: Condom, LARC, and Pill/Hormonal Failure Rate Regression Results

	Condom		LARC		PPR	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*
Age Dummy: 25-29	-0.028 *-133.94****	-0.025 *-225.12****	- -	- -	-0.004 *-106.13****	-0.004 *-17.48****
Age Dummy: 30-44	-0.033 *-201.07****	-0.014 *-142.62****	- -	- -	-0.005 *-164.90****	0.019 *87.97****
Race Dummy: Black	0.030 *152.31****	0.027 *282.08****	0.009 -	0.004 -	0.013 *374.57****	0.022 *100.07****
Race Dummy: Hispanic	0.022 *106.14****	0.019 *291.63****	0.005 -	0.002 -	0.016 *423.56****	0.024 *160.39****
Constant	0.064 *548.19****	0.060 *657.45****	0.008 -	0.003 -	0.022 *1031.07****	0.017 *82.60****
P-Value for Joint Test of Age	0.000	0.000	-	-	0.000	0.000
P-Value for Joint Test of Race	0.000	0.000	-	-	0.000	0.000
N	2,929	2,046	2,929	2,046	2,929	2,046

Notes: All parameters were estimated using data on the female members of FamilyScape's simulation population. The excluded age and race categories are as follows: age group 15-24 and the white and other race categories. Since LARC failure rates are only disaggregated by race/ethnicity, they are perfectly predicted by the race covariates. Hence, t-values are not provided for the LARC regression results. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

If both members of a couple are using their own method of contraception (e.g., if a man is using a condom and a woman is using PPRs), we make the simplifying assumption that the joint failure rate for the couple's contraceptive regime can be expressed as the product of the failure rates for their individual methods.[116]

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[116] Trussell et al. (1990) argue that, if independently operating methods are used perfectly, their efficacies interact multiplicatively. This is not necessarily true when methods are used imperfectly (we thank James Trussell for pointing this out to us). However, in the absence of a tractable alternative, we make the simplifying assumption here that the typical-use joint failure rate for two methods used simultaneously is equal to the product of those methods' individual failure rates.

As was stated earlier in this appendix, FamilyScape 2.0 calculates a couple's probability of conceiving during an act of intercourse by taking the product of the failure rate(s) of the contraceptive method(s, if any) that they are using and the woman's (adjusted, day-and-age-specific) natural fecundity level. The couple's final conception probability is compared with the result of a draw from a uniform (0,1) distribution at each act of intercourse in order to determine whether or not a pregnancy occurs.

Pregnancy Outcomes

In order to assign an outcome for a given simulated pregnancy, we must specify a set of parameters reflecting the relative probabilities that the pregnancy in question will result in a birth, an abortion, or a fetal loss. In order for this process to be carried out in a way that is consistent with the rest of FamilyScape's architecture, these probabilities must be assigned using the results of individual-level regression analyses that control for pregnant women's demographic characteristics. However, due to a variety of limitations in the relevant real-world data, this is a challenging task. The limitations of the pregnancy-outcomes data are severalfold:

- First, no single dataset contains all of the information needed to estimate the incidence of pregnancy. In fact, the most reliable data on births, abortions, and fetal losses all come from different sources. Thus, pregnancy rates are typically calculated by aggregating information from three or four different datasets.
- Second, these data are not all disaggregated in the same way. For example, one can produce estimates that are simultaneously disaggregated by race and marital status for births and fetal losses, but not necessarily for abortions.

- Third, because pregnancy-outcome data come from several different sources and are usually available only at the aggregate level, there is no single, individual-level dataset that can readily be used to estimate regression models of the probability that a pregnancy will result in a given outcome as a function of individuals' demographic characteristics.

Despite these complications, we are able to estimate regression equations that use a subset of FamilyScape's standard demographic characteristics to predict demographically specific probabilities that a simulated pregnancy will result in a live birth, an abortion, or a fetal loss. The steps taken to generate these pregnancy-outcome regressions are as follows:

- **Step #1:** We collect demographically specific data on the incidence of all three pregnancy outcomes.
- **Step #2:** We combine these data in order to derive demographically specific probabilities that a pregnancy will result in each outcome.
- **Step #3:** Pregnancy-outcome probabilities (live birth, abortion, fetal loss) are assigned to women in FamilyScape's simulation population as a function of their demographic characteristics.
- **Step #4:** In order to reduce the computational requirements placed on the model, we conduct regressions for which the dependent variables are these pregnancy-outcome probabilities.[117] Separate regressions are estimated by marital status, and – due to the data limitations described below – each of them controls for age and race, but not for education or SES. The coefficients from these regressions are then used to assign pregnancy-outcome probabilities to each woman in FamilyScape's simulation population.

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[117] As discussed in a footnote in Appendix I, the use of regression equations to predict behaviors and outcomes in FamilyScape 2.0 streamlines simulations. Thus, although it would be possible for us to stop after the assignment of members of FamilyScape's simulation population to demographically specific pregnancy-outcome probability cells (which is achieved in Step #3), implementing Step #4 increases the model's efficiency.

The next three subsections detail our procedures for collecting demographically specific pregnancy-outcome data, as per the first step of the process described above. The subsequent three subsections describe the implementation of Steps 2 through 4.

Step #1a: Collection of Data on the Incidence of Live Births

The most reliable and comprehensive source of information on the national number of births in a given year is the National Vital Statistics System (NVSS), which is maintained by the National Center for Health Statistics (NCHS). The NCHS website allows users to generate tabulations of NVSS birth data that are simultaneously broken down by a variety of different demographic characteristics. We use this tool to produce estimates of the number of births that occurred in 2008.[118] We are able to disaggregate these estimates by all of FamilyScape's demographic covariates except SES. Because we are also unable to disaggregate our abortion and fetal-loss estimates by SES, this covariate is eliminated from the pregnancy-outcomes analysis.

Step #1b: Collection of Data on the Incidence of Induced Abortion

There are two major sources of data on induced abortion in the United States: the Guttmacher Institute's Abortion Provider Survey (APS) and the Centers for Disease Control and Prevention's (CDC) Abortion Surveillance System.[119] The CDC has collected data on the incidence of abortion every year since 1969, and the Guttmacher Institute has done the same on a periodic basis since 1974. While the CDC relies on the voluntary reporting of data from state health departments, the

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[118] See National Center for Health Statistics (2012) for additional information about this online tool.

[119] The term "induced abortion" implies a distinction between pregnancy terminations that are intentional and those that occur spontaneously (i.e., naturally). The latter category of abortion is considered to be a type of fetal loss. The discussion in this subsection is therefore specific to abortions that fall into the former category.

Guttmacher Institute directly surveys almost all known abortion providers.[120] As such, the APS tends to produce higher abortion counts than does the CDC survey and is generally considered to be the more reliable of the two data sources in this regard.[121] We therefore use data from the Guttmacher Institute rather than the CDC to measure the overall incidence of abortion. However, the CDC collects detailed demographic data on abortion patients more often than does the Guttmacher Institute. In fact, Guttmacher analysts sometimes apply the demographic distribution of the CDC's sample to their own raw counts of abortions in order to produce demographically specific estimates of the incidence of abortion.[122] As such, we rely on tabulations of CDC data in order to measure the demographic characteristics of women who have abortions. In other words, we produce demographically specific tabulations of the incidence of abortion by taking the products of a set of distributional percentages that are estimated using 2008 CDC data (e.g., the percent of abortions that are to black women, to white women, to Hispanic women, etc.) and an overall count of abortions that is generated using 2008 Guttmacher data.

Neither of these datasets is available for public use. Thus, we are compelled to use published tabulations of these data for the purposes of parameterizing FamilyScape 2.0.[123] Since we are able to produce birth tabulations that are simultaneously broken down by age, race, education, and marital status, it would be ideal if we were able to obtain abortion estimates that are similarly disaggregated.

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[120] Henshaw and Kost (2008). The APS collects information on the total number of abortions performed in the year of the survey and interpolates data for years in which the survey was not conducted. See Finer and Henshaw (2003) and Jones et al. (2008) for additional detail on the APS's survey procedures. The Guttmacher Institute has performed underreporting surveys in order to determine the extent to which the APS may underestimate the incidence of abortion. They have found: 1) that their sample may exclude as many as half of the providers who perform fewer than 30 abortions per year; and 2) that the actual annual number of abortions may therefore be three to four percent higher than is implied by their survey (Finer and Henshaw, 2003).

[121] The Guttmacher Institute (1997), Saul (1998).

[122] See Henshaw and Kost (2008) for a description of the means by which these two data sources are combined to produce demographically disaggregated abortion estimates.

[123] The NSFG also contains self-reported abortion data. However, abortions have been found to be dramatically underreported in the survey (Jones and Kost, 2007). Thus, we do not consider the NSFG to be a plausible alternative for estimating the incidence of abortion.

However, most recent and publicly available tabulations of the CDC's demographic data are broken down by these characteristics separately but not simultaneously.[124] We have been able to identify a single exception to this rule: Pazol et al. (2011) use CDC data to cross-tabulate the age and race characteristics of women obtaining abortions in 2008. The authors do not, however, include educational attainment in this analysis. Thus, and since we are also unable to produce reliable fetal-loss tabulations that are disaggregated by the mother's educational attainment, we eliminate education from our pregnancy-outcomes analysis, and we use Pazol et al.'s cross-tabulations to measure the covariance between age, race, and the incidence of abortion.[125]

While Pazol and her coauthors disaggregate their estimates of the incidence of abortion by age and race simultaneously, they do not provide separate age-race disaggregations broken out by marital status. They do, however, provide estimates of the percent of abortions that are to married and unmarried women for each race category. We apply these marginal percentages to Pazol et al.'s age-race cross-tabulation in order to derive a distribution of abortions that is simultaneously disaggregated by all three characteristics. We are therefore forced to assume that, within race categories, the marital status of women receiving abortions is unrelated to their age. Although we would prefer not to impose this assumption, we are constrained to do so by the limitations of the data available to us.

Having estimated the percent of abortions that are to women of various ages, races, and marital statuses, we multiply these proportions by an estimate from Guttmacher's APS of the total number

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[124] See, for example, Henshaw and Kost (2008).
[125] See Pazol et al. (2011), Table 21.

of abortions that occurred in 2008 (about 1.21 million) in order to produce demographically specific estimates of the incidence of abortion in that year.[126]

Step #1c: Collection of Data on the Incidence of Fetal Loss

The NVSS and the NSFG are the two most commonly used sources of data on fetal losses. However, the NVSS generally only records information on the small share of fetal losses that occur at gestations of 20 weeks or more, whereas the NSFG contains data on fetal losses at all gestation ages.[127] Moreover, Ventura et al. (2008) note that even fetal losses occurring at 20 weeks and beyond are underreported in the NVSS. We therefore use the NSFG rather than the NVSS to estimate the incidence of fetal loss.

In developing the first version of FamilyScape, we initially considered the possibility of conducting independent analyses of the NSFG in order to produce demographically specific estimates of the frequency with which women of different characteristics experience fetal losses. However, we ultimately concluded that this option was impractical because: 1) the number of pregnancies occurring among NSFG respondents in a single year is relatively small; 2) less than a fifth of pregnancies result in fetal losses; and 3) our simulation accounts for a number of different demographic characteristics. As a result, we were often compelled to estimate the incidence of fetal loss using data on an extremely small number of cases. Our estimates for many demographic subgroups were therefore either implausibly large or implausibly small and/or were highly inconsistent with the results of published analyses.[128]

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[126] The Guttmacher Institute's estimate of the total number of abortions in 2008 was taken from Jones and Kooistra (2011).

[127] Ventura et al. (2008).

[128] For additional discussion of these exploratory analyses, see Thomas and Monea (2009).

Given these concerns, we draw instead upon a set of fetal-loss rates estimated by Ventura et al. (2012). Because Ventura and her coauthors use NSFG data from several different survey years, they are able to mitigate the cell-size problems described above. Ventura et al. estimate the incidence of fetal loss by calculating demographically specific ratios of fetal losses to live births in the NSFG and then applying those ratios to birth counts taken from the NVSS. Underlying this approach are two assumptions: a) that the NSFG produces correct demographically specific fetal-loss-to-live-birth ratios; and b) that the NSFG does not capture the full number of births that occur in a given year. The latter assumption is premised in large part on the fact that the NVSS is widely acknowledged to provide the most comprehensive tally of live births in the United States.

Ventura et al.'s fetal-loss and live-birth estimates are disaggregated by age and race simultaneously.[129] Since their results are not broken down by education – and given the fact that we also encountered problems in our attempts to produce abortion estimates that are disaggregated by education – we elected (as is discussed in the previous subsection) to eliminate this covariate from our pregnancy-outcomes analysis altogether. Ventura and her coauthors also neglect to account for marital status in their age-race disaggregation. We therefore make the simplifying assumption that fetal-loss-to-live-birth ratios do not vary by marital status within age-race groups. In other words, we transform Ventura et al.'s joint age-race distribution into a joint age-race-marital-status distribution by assuming that groups of married and unmarried women who have the same age-race characteristics will also have identical fetal-loss ratios.

The results presented in Table A13 suggest that this is a reasonable assumption. The table shows estimates reported by Ventura et al. (2012) of fetal-loss ratios that are disaggregated simultaneously

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[129] See Ventura et al. (2012), Table 3.

by marital status and race.[130] These results suggest that there is little difference between the race-specific ratios of married and unmarried women.[131] We therefore multiply each (demographically specific) fetal-loss-to-live-birth ratio by the appropriate (demographically specific) NVSS-based count of live births in 2008 in order to produce estimates of the incidence of fetal loss in 2008 for every age-race-marital-status subgroup.

Table A13: Variation in Fetal-Loss-to-Live-Birth Ratio, by Race and Marital Status

	Married Women			Unmarried Women		
	Live Birth Rates	Fetal Loss Rates	Fetal Loss-to-Live Birth Ratios	Live Birth Rates	Fetal Loss Rates	Fetal Loss-to-Live Birth Ratios
White	88.6	22.8	0.257	48.4	12.5	0.258
Black	69.7	21.7	0.311	71.0	22.1	0.311
Hispanic	88.0	19.5	0.222	97.3	21.6	0.222
All	86.9	22.8	0.262	51.8	13.7	0.264

Source: Ventura et al. (2012). Rates are per 1,000 women aged 15-44.

Step #2: Estimation of Pregnancy-Outcome Probabilities

Having produced estimates of the incidence of childbearing, abortion, and fetal loss for each of our age-race-marital-status subgroups, we then transform these raw counts into demographically specific pregnancy-outcome probabilities. We accomplish this objective by: 1) summing the numbers of live births, abortions, and fetal losses for each subgroup in order to produce estimates of the incidence of pregnancy; and 2) using these estimates to produce, for each subgroup, the probabilities that a pregnancy will result in each of the three outcomes. The top three panels of Table A14 detail our estimated pregnancy-outcome probabilities by age and race for unmarried women, married women,

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[130] The authors do not present estimates of fetal-loss ratios that are similarly disaggregated by marital status and age.

[131] More intuitively, there would seem to be little reason to expect that a woman's marital status would affect the likelihood that her pregnancy will result in a fetal loss, since this dynamic is primarily physiological in nature.

and all women. The bottom panel of the table shows the equivalent estimates for all women as reported in Ventura et al. (2012).[132] Our estimated pregnancy-outcome probabilities for all women are quite comparable to the equivalent results reported by Ventura et al.

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[132] Recall that Ventura et al. (2012) do not report tabulations that break out their age-race disaggregations by marital status.

Table A14: Live-Birth, Induced-Abortion, and Fetal-loss Probabilities

Estimates for FamilyScape Model

	Live Births					Induced Abortions					Fetal Losses				
						Unmarried Women									
	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All
15-19	0.586	0.524	0.641	0.595	0.584	0.245	0.322	0.166	0.230	0.244	0.169	0.154	0.193	0.175	0.172
20-24	0.584	0.507	0.641	0.581	0.575	0.282	0.369	0.238	0.288	0.297	0.134	0.124	0.121	0.131	0.128
25-29	0.545	0.451	0.639	0.537	0.542	0.331	0.436	0.268	0.349	0.347	0.124	0.113	0.093	0.113	0.112
30-44	0.441	0.360	0.563	0.427	0.451	0.421	0.477	0.280	0.435	0.398	0.137	0.164	0.157	0.139	0.151
All	0.547	0.466	0.623	0.528	0.542	0.314	0.398	0.239	0.336	0.320	0.139	0.136	0.138	0.136	0.138
						Married Women									
	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All
15-19	0.594	0.246	0.624	0.389	0.557	0.234	0.681	0.188	0.497	0.279	0.171	0.073	0.187	0.114	0.164
20-24	0.751	0.566	0.754	0.654	0.730	0.077	0.295	0.104	0.199	0.110	0.172	0.139	0.142	0.147	0.160
25-29	0.792	0.683	0.819	0.763	0.786	0.028	0.146	0.062	0.077	0.048	0.180	0.171	0.119	0.161	0.166
30-44	0.748	0.628	0.746	0.718	0.734	0.019	0.080	0.042	0.049	0.031	0.233	0.292	0.212	0.233	0.234
All	0.759	0.617	0.762	0.717	0.744	0.036	0.160	0.070	0.081	0.057	0.205	0.223	0.168	0.202	0.199
						All Women									
	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All
15-19	0.588	0.509	0.639	0.554	0.580	0.243	0.341	0.170	0.283	0.249	0.169	0.150	0.192	0.163	0.171
20-24	0.656	0.514	0.679	0.613	0.627	0.194	0.359	0.194	0.249	0.234	0.151	0.126	0.128	0.138	0.138
25-29	0.721	0.511	0.726	0.697	0.684	0.115	0.361	0.169	0.156	0.173	0.164	0.128	0.106	0.147	0.143
30-44	0.693	0.469	0.671	0.667	0.654	0.091	0.315	0.139	0.117	0.136	0.215	0.216	0.190	0.217	0.210
All	0.683	0.499	0.682	0.658	0.646	0.136	0.345	0.167	0.160	0.184	0.182	0.156	0.151	0.182	0.170

Estimates from Ventura et al. (2012)

						All Women									
	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All	White	Black	Hispanic	Other	All
15-19	0.596	0.498	0.630	0.500	0.577	0.232	0.357	0.178	0.321	0.255	0.172	0.146	0.187	0.179	0.170
20-24	0.667	0.503	0.670	0.551	0.624	0.181	0.374	0.201	0.256	0.236	0.152	0.123	0.126	0.192	0.141
25-29	0.732	0.502	0.721	0.686	0.685	0.102	0.371	0.172	0.169	0.171	0.166	0.127	0.105	0.144	0.144
30-44	0.690	0.460	0.667	0.671	0.655	0.082	0.322	0.144	0.118	0.134	0.215	0.212	0.188	0.211	0.211
All	0.688	0.489	0.675	0.643	0.646	0.124	0.357	0.173	0.170	0.184	0.183	0.152	0.149	0.187	0.170

Note: Real-world data were taken from Ventura et al. (2012) and the National Center for Health Statistics' NVSS data resource for fetal losses; from Pazol et al. (2011) and Jones and Kooistra (2011) for abortions; and from the National Center for Health Statistics' NVSS data source for live births. See the text of this paper for a detailed explanation of the means by which these data were used to produce the estimates reported here.

Step #3: Creation of Pregnancy-Outcome Variables in FamilyScape 2.0

In Step #3, we use the estimates reported in Table A14 to assign live-birth, abortion, and fetal-loss probabilities to each woman in FamilyScape 2.0 based on her age, race and marital status. For instance, among unmarried Hispanic women in the simulation population who are between the ages of 25 and 29, the probabilities that a simulated pregnancy will result in a live birth, an abortion, and a fetal loss are about 64%, 27%, and 9%, respectively. Thus, Step #3 effectively creates three new pregnancy-outcome-probability variables, each of which serves as a dependent variable for the regression analyses performed in Step #4.

Step #4: Estimation of Pregnancy-Outcome Regressions

In the final step of this process, we use linear regressions to model the pregnancy-outcome probabilities that are created in Step #2 and are assigned to female members of FamilyScape's simulation population in Step #3. Separate models are estimated for married and unmarried women, and each regression controls for the mother's age and race.[133] Table A15 provides complete results for our pregnancy-outcome regressions.[134]

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[133] To be clear, then, individual women in FamilyScape's simulation population constitute the unit of analysis for these regressions. For reasons of parsimony, these regressions do not include interaction terms to account for potential covariance between age and race in these variables' relationship with our pregnancy-outcome probabilities. While it is theoretically possible that our failure to include interaction terms in these models has caused them to produce unrealistic predictions, investigatory analyses have shown that the differences between predicted and actual pregnancy-outcome probabilities are minor.

[134] In fact, because our three pregnancy-outcome categories are exhaustive and mutually exclusive, only two sets of regression coefficients are required to calculate the relative probabilities that a pregnancy will result in each of these three outcomes. Thus, we actually only incorporate abortion and fetal-loss regression results into FamilyScape 2.0. The coefficients incorporated into the simulation model for the abortion regression are exactly as reported in Table A15, but the coefficients in the simulation for the fetal-loss regressions are different from the coefficients reported here. This is because, in the simulation, individuals are assigned fetal-loss probabilities conditional on a pregnancy not resulting in an abortion. Thus, the fetal-loss coefficients incorporated into FamilyScape 2.0 are from versions of the relevant regressions in which the dependent variable reflects the probability that a pregnancy will result in a fetal loss conditional on that pregnancy not being aborted. For ease of exposition, however, we report "unconditional" regression results for all analyses in Table A15.

Table A15: Pregnancy-Outcome Regression Results						
	Fetal Loss		**Abortion**		**Live Birth**	
	Unmarried Women	Married Women	Unmarried Women	Married Women	Unmarried Women	Married Women
	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*	Coefficient *t-value*
Mother's Age Dummy: 20-24	-0.042	-0.019	0.046	-0.125	-0.005	0.144
	*-78.40****	*-5.70****	*59.32****	*-42.60****	*-7.03****	*76.09 ****
Mother's Age Dummy: 25-29	-0.055	0.023	0.095	-0.169	-0.040	0.192
	*-96.60****	*-6.98****	*114.25****	*-58.43****	*-57.83****	*102.88****
Mother's Age Dummy: 30-44	-0.026	0.045	0.164	-0.187	-0.139	0.142
	*-53.98****	*13.69****	*234.85****	*-65.03****	*-236.64****	*76.40****
Mother's Race Dummy: Black	0.002	0.047	0.076	0.073	-0.078	-0.119
	*4.10****	*64.43****	*102.93****	*114.97****	*-126.32 ****	*-292.44****
Mother's Race Dummy: Hispanic	0.005	-0.028	-0.087	0.025	0.082	0.003
	*9.97****	*-54.23****	*-114.23****	*55.05****	*128.36 ****	*11.03****
Mother's Race Dummy: Other	0.000	-0.003	0.004	0.034	-0.003	-0.031
	-0.25	*-4.26****	*3.14****	*56.53****	*-3.55****	*-79.99****
Constant	0.170	0.190	0.245	0.204	0.585	0.606
	*448.21****	*57.87****	*440.12****	*71.15****	*1253.57****	*327.25****
P-Value for Joint Test of Age Covariates	0.000	0.000	0.000	0.000	0.000	0.000
P-Value for Joint Test of Race Covariates	0.000	0.000	0.000	0.000	0.000	0.000
N (unweighted)	2,929	2,046	2,929	2,046	2,929	2,046

Notes: All parameters were estimated using the population of women in FamilyScape. Thus, the unit of analysis for these regressions is the woman, and each regression can be interpreted as reflecting the controlled correlations that exist between the model's covariates and the probability that a pregnancy will result in a particular outcome (say, an abortion) rather than in either of the other two possible outcomes (say, a birth or a miscarriage). Demographically specific probabilities for each outcome were assigned to each observation in order to create the individual-level data necessary to perform these regressions. These probabilities vary by the age, race, and marital status of the female respondent and were calculated using data that are external to the NSFG. Most of the data on fetal losses were taken from Ventura et al (2012); most of the data on abortions were taken from Pazol et al. (2012) and Jones and Kooistra (2011); and most of the data on live births were taken from the National Center for Health Statistics' NVSS data resource. See the text of this paper for a detailed discussion of how these data were used to create the pregnancy-probability dataset used here. The excluded age and race variables are, respectively, age group 15-19 and the white race dummy. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

The coefficients from these regression equations are imported into FamilyScape 2.0 and used to assign permanent pregnancy-outcome probabilities to each woman in the simulation population. Each time a simulated pregnancy occurs, a series of random draws are taken from a uniform (0,1) distribution, and the values of those draws are compared to the appropriate probabilities in order to determine that pregnancy's outcome. As is discussed in the next section, FamilyScape 2.0 produces pregnancy-outcome distributions for most demographic groups that are well-matched to their equivalent real-world benchmarks.

Pregnancy-Outcome Benchmarks and Simulation Results

In order further to assess FamilyScape's accuracy, we compare simulated pregnancy, live-birth, abortion, and fetal-loss rates with their real-world equivalents. Given the challenges that we encountered in our efforts to calculate pregnancy-outcome probabilities, it is perhaps unsurprising that the process of developing appropriate demographically specific benchmarks has also proven to be complicated. As is discussed in earlier sections of this appendix, we are unaware of any recent study that has reported pregnancy and pregnancy-outcome rates that are simultaneously disaggregated by marital status, age, and race.

Recall that, for our pregnancy-outcomes module, we developed many of FamilyScape's parameters using estimates reported in Ventura et al. (2012). However, we consider the results reported by Zolna and Lindberg (2012) to be more appropriate for the purposes of developing pregnancy-rate benchmarks against which to compare FamilyScape's results. Although methodologies and data used by these two studies are quite similar, they differ in that Zolna and Lindberg present pregnancy-rate estimates that are simultaneously broken down by age and marital status, whereas Ventura et al. present simultaneous disaggregations by age and race. Neither paper adds the third "missing dimension" to their cross-tabulations, which is to say that Zolna and Lindberg do not disaggregate their age-marital-status cross-tabulations by race and Ventura et al. do not disaggregate their age-race cross-tabulations by marital status.

While simultaneous disaggregation by race, age, and marital status would have been ideal, we would rather have real-world benchmarks on pregnancy rates that are disaggregated by age and marital status than by age and race, since we will almost always want to distinguish between pregnancies to married and unmarried women when we conduct policy simulations. We therefore benchmark our pregnancy estimates based on tabulations reported by Zolna and Lindberg that are simultaneously disaggregated by age and marital status (and not by any other characteristics). The reader may be wondering why we did not use Zolna and Lindberg's results to develop FamilyScape's pregnancy-outcomes module. By using Zolna and Lindberg's data as the basis for the estimates against which FamilyScape's results are compared, we are able to incorporate an element of independence into our benchmarks, which is to say that the model's simulated outcomes can be compared to real-world estimates that are based in part on published results that are somewhat external to the data used to parameterize the model.[135]

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[135] Later in this subsection, we compare FamilyScape's results to real-world benchmarks, and we show that the model is somewhat less accurate in simulating pregnancies for older women than for younger women. We ultimately conclude that pregnancies among women over the age of 40 should be eliminated when results are reported for FamilyScape simulations. We arrive at this decision after making separate comparisons of simulated and real-world pregnancy rates for married and unmarried women aged 30-34, 35-39, and 40-44. In order to make this comparison, we required real-world pregnancy-rate benchmarks for women in these three age groups. While Zolna and Lindberg report pregnancy rates that are disaggregated by marital status for women aged 30-44, they do not produce results that are broken out for these specific age categories. We therefore produce real-world benchmarks for these three age subgroups by making the following computations. First, we use results reported in Ventura et al. (2012) to calculate the proportions of pregnancies

Compared to the derivation of pregnancy counts, our calculations for live-birth, abortion, and fetal-loss benchmarks are relatively straightforward. For reasons described earlier in this appendix, we use NVSS data from 2008 to produce live-birth counts. Fortunately, these counts are simultaneously disaggregated by age and marital status, meaning that no additional computations are required. To calculate benchmarks for fetal losses, we first use Ventura et al.'s (2012) estimates to calculate the percent of pregnancies that result in a fetal loss for each age group. We then apply these age-based percentages to Zolna and Lindberg's married and unmarried pregnancy counts in order to derive age-specific married and unmarried fetal-loss counts. Note that the assumption underlying this approach is that the percent of pregnancies that result in a fetal loss remains constant between married and unmarried women in a given age group.[136] We calculate demographically specific abortion counts by subtracting fetal-loss and live-birth counts from the total number of pregnancies within each demographic cell. And finally, in order to convert our pregnancy and pregnancy-outcome counts into rates, we specify a set of demographically specific denominators that measure the total number of women in each age-marital-status category. We calculate these denominators using estimates reported in United States Census Bureau (2012), which were themselves derived from the Annual Social and Economic Supplement to the 2008 Current Population Survey.[137]

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among women aged 30-44 (without respect to marital status) that occur to 30-34 year-olds, to 35-39 year-olds and to 40-44 year-olds. And second, we apply this age distribution to Zolna and Lindberg's estimates in order derive pregnancy counts for married and unmarried women aged 30-34, 35-39 and 40-44. In performing these calculations, we make the simplifying assumption that the maternal-age distributions are the same for pregnancies experienced by married and unmarried women between 30 and 44.

[136] For reasons similar to the ones discussed above in our explanation of Step #1c, this would seem to be a sensible assumption.

[137] Zolna and Lindberg (2012) use the same approach to calculate population denominators for their analysis.

Table A16 allows for an assessment of FamilyScape's accuracy in assigning pregnancy outcomes to simulated pregnancies. Specifically, the table compares real-world and simulated percentages of pregnancies that result in either an abortion or a live birth. For almost all demographic subgroups, the model mimics real-world pregnancy-outcome distributions relatively well.

Table A16: Comparison of Real-World and Simulated Pregnancy-Outcome Distributions, by Age and Marital Status

	Percent of Pregnancies that Result in an Abortion			Percent of Pregnancies that Result in a Live Birth		
	Unmarried Women	Married Women	All	Unmarried Women	Married Women	All
Simulated Data						
15-19	23.7	18.4	23.6	59.1	62.1	59.0
20-24	28.3	8.5	20.5	58.6	75.4	65.2
25-29	34.6	4.9	17.0	53.6	78.8	68.5
30-34	39.2	3.5	15.1	45.3	72.9	63.8
35-39	38.9	3.3	13.4	46.2	73.1	65.4
All	32.4	4.8	17.2	53.6	75.1	65.4
Real-World Data						
15-19	28.4	0.3	25.8	54.6	82.7	57.2
20-24	32.3	3.5	23.8	53.7	82.5	62.1
25-29	33.3	4.8	17.2	52.3	80.8	68.4
30-34	35.3	5.0	13.9	48.2	78.4	69.6
35-39	35.9	4.5	13.7	36.7	68.2	59.0
All	32.3	4.5	18.8	51.6	78.0	64.5

Notes: Real-world data were derived using Zolna and Lindberg (2011), Ventura et al. (2012), and the National Center for Health Statistics' NVSS data resource. See the text of the paper for a detailed discussion of how these data were used to produce the estimates reported above. Simulated results were generated using data from one hundred one-year steady-state runs of the FamilyScape model.

Finally, Table A17 presents detailed pregnancy and pregnancy-outcome results from the simulation model and from our real-world benchmark calculations. The table reports annual rates of pregnancy, birth, and abortion per 1,000 women as a function of age and marital status. The top panel of the table displays averaged results from 100 runs of the model under its baseline specification.[138] The bottom panel shows real-world pregnancy and pregnancy-outcome benchmarks as measured using the data described above. Simulated pregnancy rates for unmarried women aged 15-39 overall are within about 1% of their real-world targets. The gap between simulated and real-world pregnancy rates is larger for married women, and the model over-simulates pregnancies and pregnancy outcomes among older women regardless of marital status.

Table A17: Comparison of Real-World and Simulated Pregnancy Outcomes by Age and Marital Status

	Annual Pregnancy Rate (number per 1,000 women)			Annual Abortion Rate (number per 1,000 women)			Annual Live Birth Rate (number per 1,000)		
	Unmarried Women	Married Women	All	Unmarried Women	Married Women	All	Unmarried Women	Married Women	All
Simulated Data									
15-19	49.8	244.3	51.4	11.8	51.4	12.1	29.4	142.9	30.3
20-24	126.5	346.6	169.0	35.8	30.1	34.7	73.9	260.9	110.0
25-29	148.8	329.5	220.6	51.5	16.2	37.5	79.7	259.1	151.0
30-34	133.6	196.8	170.5	52.5	6.9	25.8	60.4	143.2	108.7
35-39	97.3	153.9	132.0	38.1	5.1	17.8	44.7	112.3	86.3
All	103.7	228.0	148.2	33.6	11.0	25.5	55.6	171.2	97.0
Real-World Data									
15-19	67.2	313.9	72.5	19.1	0.9	18.7	36.7	259.7	41.5
20-24	143.5	276.0	167.2	46.3	9.6	39.8	77.0	227.6	103.9
25-29	137.2	206.3	169.3	45.7	9.9	29.1	71.7	166.8	115.8
30-34	109.2	164.5	143.3	38.5	8.3	19.9	52.6	129.0	99.7
35-39	72.0	82.9	79.4	25.8	3.7	10.8	26.4	56.5	46.8
All	105.0	158.0	125.6	34.1	7.1	23.6	54.5	122.7	81.0

Notes: Real-world data were derived using Zolna and Lindberg (2011), Ventura et al. (2012) and the National Center for Health Statistics' NVSS data resource. See the text of the paper for a detailed discussion of how these data were used to produced the estimates reported above. Simulated results were generated using data from one hundred one-year steady-state runs of the FamilyScape model.

We have a number of theories as to why the model over-predicts pregnancy rates for some groups. For example, married respondents may have a stronger tendency than unmarried

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[138] As is discussed in Appendix I, we concluded after a series of exploratory analyses that about 100 runs of the model are required in order to ensure that aggregate measures of FamilyScape's results are not unduly influenced by outliers.

respondents to over-report sexual activity in surveys such as the NSFG. If true, this hypothesis would help explain why the degree to which FamilyScape 2.0 overshoots real-world pregnancy rates is systematically higher for married women than for unmarried women. In addition, the fact that the model over-simulates pregnancies among older women suggests that, even after we have implemented our fertility adjustments, the age-based decline in fecundity within FamilyScape may be too gradual.

Indeed, the magnitude of FamilyScape's over-prediction of pregnancy rates is markedly more pronounced for women aged 40 and over than for women under 40. In light of this finding, and because the fecundity literature is particularly sparse with respect to the shape of the age-fecundity profile for women over the age of 40, we consider the model's simulation of pregnancies among women 40 and older to be at least somewhat unreliable. We have therefore chosen to eliminate women over 40 when reporting results from FamilyScape simulations. Hence the fact that Table A17 here and Figures 7 and 8 in the main body of this paper focus only on pregnancies to women aged 15 to 39.

While we will continue to explore in greater depth the possible reasons for FamilyScape's over-simulation of pregnancies within some groups, it is unlikely that this phenomenon will impair the model's ability to perform reliable policy simulations for women under 40. Thomas and Monea (2009), for instance, illustrate that reducing sexual activity (and, as a result, lowering the pregnancy rate) among married couples has a negligible impact on the results of policy simulations.[139]

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[139] We would also note that FamilyScape 2.0 simulates reasonably accurately the share of pregnancies and pregnancy outcomes that occur to married versus unmarried women. Specifically, the real-world proportions of pregnancies, births, and abortions that occur to married 15-44 year-old women are 0.51, 0.59, and 0.16,

Gestation Periods

When FamilyScape 2.0 assigns an outcome for a newly simulated pregnancy, a gestation period is also assigned to that pregnancy. Women within the simulation are unable to become pregnant again for the duration of their pregnancy's gestation period plus a relatively brief interval of post-pregnancy infertility whose length varies by pregnancy outcome. After canvassing the relevant literature, we have concluded that the typical gestation period for a live birth lasts for between 245 and 273 days subsequent to the day of conception; that the typical gestation period for an abortion is between 14 and 90 days; and that the typical gestation period for a fetal loss is between 28 and 70 days.[140]

Since women are also typically unable to become pregnant again for a period of time after their pregnancy ends, we extend these gestation periods somewhat in order to model the proper duration of time during which women are infertile as the result of a pregnancy. Our literature review suggests that the average period of postpartum infertility lasts for about 14 weeks; that the average period of post-abortion infertility lasts for about two weeks; and that the average period of infertility after a fetal loss lasts for about one week.[141] Once it is determined that a pregnancy will result in a live birth, a random draw is therefore taken from a uniform (343,371) distribution in order to specify the length of the pregnancy's simulated

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respectively, while the equivalent FamilyScape-simulated proportions are 0.58, 0.66, and 0.16, respectively. The real-world benchmarks referenced here are based on published data reported in Ventura et al. (2012).

[140] Information on gestation periods for live births was taken from the NVSS. For more information on gestation periods for induced abortions, see Finer and Henshaw (2003), Gamble et al. (2008), The Guttmacher Institute (2008), Jones et al. (2008), Jones and Kost (2007), and Physicians for Reproductive Choice and Health (2012); and, for more information on gestation periods for fetal losses, see Brown (2008), Everett (1997), MacDorman et al. (2007), Nybo Anderson et al. (2000), Ventura et al. (2008), and Wilcox et al. (1988).

[141] For additional information on postpartum infertility, see Hatcher et al. (2004); for additional information on post-abortion infertility, see Boyd and Holstrom (1972), Hatcher et al. (2004), Lahteenmaki (1993), Vorherr (1973), and World Health Organization (2009); and, for additional information on infertility after a fetal loss, see Miscarriage Support Auckland Inc. (2009) and Perloe (2009).

gestation period. For abortions and miscarriages, equivalent draws are taken from uniform (28,104) and (35,77) distributions, respectively.[142]

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[142] The ranges of these distributions are calculated by taking the sum of the relevant gestation-period and post-pregnancy-infertility-period durations. For example: because the typical gestation period for a live birth lasts for between 245 and 273 days, and since the typical period of post-partum infertility lasts for (14*7) = 98 days, FamilyScape's gestation periods for live births are simulated by taking random draws from a uniform distribution whose lower bound is equal to 245 + 98 = 343 and whose upper bound is 273 + 98 = 371.

Appendix V: Family Formation & Child Well-Being

This fifth and final appendix is relatively brief because our discussion of the processes leading up to the occurrence of childbearing inside and outside of marriage are woven throughout the simulation modules that have already been explicated in the previous four appendices. For example, Appendix III explains the way in which we differentiate between married and unmarried individuals in simulating sexual activity and contraceptive use. These dynamics represent the two most important proximate causes of pregnancy, which in turn is a necessary prerequisite for childbearing. Appendix IV then describes our methods for simulating childbearing (among other pregnancy outcomes) among married and unmarried mothers. Thus, the prior sections of this paper collectively serve as an overview of the way in which we model family formation, since they describe our methods for simulating the antecedents of pregnancy, the occurrence of pregnancy, and the incidence of childbearing within and outside of marriage.[143]

We do, however, describe here the model's poverty-simulation module. This component of the simulation is parameterized using the results of regression models that were estimated with data from the March 2009 CPS, which contains income data for calendar year 2008. The coefficients from these regressions are imported into FamilyScape 2.0 in order to impute, for each newborn child, the probability that he or she will be born into poverty. Because we are interested in the poverty statuses of newborn children in particular, we limit the CPS sample for our regressions to children who were under the age of one at the time that the survey was conducted. While the unit of analysis for these regressions is the child,

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[143] See Table A17 in the preceding appendix for a summary of FamilyScape's simulated rates of marital and non-marital childbearing among various demographic subgroups.

the information for their demographic control variables is taken from the mother. Thus, we regress infants' poverty statuses on their mothers' demographic characteristics.[144] More specifically, these regressions control for the mother's age, education level, and race. Separate regression models are estimated for children born to married and unmarried mothers. See Table A18 for a complete set of poverty-status regression results.[145]

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[144] For the purposes of these analyses, children are assigned a poverty status using the Census Bureau's official poverty measure. For more information on this measure, see DeNavas et al. (2010).

[145] These regressions were weighted using the mother and child's family weight. Because the individuals that populate FamilyScape 2.0 were taken from the NSFG, and for the sake of consistency, we considered the possibility of using the pregnancy file of the NSFG rather than the CPS to perform our poverty regressions. However, we opted not to do so because: a) the CPS is widely considered to be the most reliable dataset for the measurement of poverty; and b) poverty rates among children under the age of one are considerably higher in the NSFG than in the CPS (Thomas and Monea, 2009). Our poverty regressions do not include controls for SES because the necessary data are not available in the CPS.

Table A18: Regression Results for Poverty Status at Birth

	Unmarried Women	Married Women
	Coefficient *t-value*	Coefficient *t-value*
Age Dummy: 20-24	0.115 *1.51*	-0.030 *-0.25*
Age Dummy: 25-29	0.074 *0.92*	-0.076 *-0.65*
Age Dummy: 30-44	0.113 *1.36*	-0.082 *-0.71*
Education Dummy: High School Degree	-0.131 *-2.27***	-0.168 *-3.49****
Education Dummy: More than High School	-0.316 *-5.35****	-0.293 *-6.68****
Race Dummy: Black	0.143 *2.46***	0.090 *2.24***
Race Dummy: Hispanic	0.112 *1.94**	0.073 *2.84****
Race Dummy: Other	0.073 *0.73*	0.032 *1.31*
Constant	0.555 *7.19****	0.387 *3.27****
P-Value for Joint Test of Age Covariates	0.450	0.287
P-Value for Joint Test of Education Covariates	0.000	0.000
P-Value for Joint Test of Race Covariates	0.071	0.003
N	606	1,957

Notes: All parameters were estimated using data on observations in the March 2009 Current Population Survey (CPS) who were under the age of one at the time that their families' interviews were conducted. While the unit of analysis is the child, the demographic information used here reflects the characteristics of the mother. Socioeconomic status is not included as a covariate here because the necessary data are not available in the CPS. The excluded age, education, and race categories are as follows: age group 15-19, an educational attainment of less than a high school degree, and the white race category. One asterisk (*) indicates that the parameter estimate is significant at or beyond the .1 level, two asterisks (**) indicate that the parameter estimate is significant at or beyond the .05 level, and three asterisks (***) indicate that the parameter estimate is significant at or beyond the .01 level.

Each time that a new birth is simulated, the coefficients from these regressions are used to calculate a probability that the newborn child will be born into poverty based on the mother's marital status and demographic characteristics. A random draw is then taken from a uniform (0,1) distribution and compared with this probability in order to assign a poverty status to the child. Table A19 compares the poverty rates of newborn children in our simulation with their real-world equivalents. For most demographic groups, FamilyScape 2.0 approximates real-world child poverty rates reasonably well.

Table A19: Comparison of Real-World and Simulated Poverty Rates Among Newborn Children, by Maternal Marital Status, Age, Race, and Education

	Unmarried Women	Married Women
	Percent	Percent
Real-World Data		
15-19	51.6	30.5
20-24	58.4	17.9
25-29	51.5	9.6
30-34	60.8	6.5
35-39	38.0	7.3
White	46.5	5.5
Black	60.2	16.6
Hispanic	61.0	24.7
Other	60.7	9.0
Less than High School	71.8	38.0
High School Degree	58.1	19.7
More than High School	39.6	3.5
All	54.5	9.9
Simulated Data		
15-19	58.9	29.3
20-24	53.3	18.8
25-29	46.8	11.1
30-34	47.7	8.6
35-39	54.8	8.4
White	44.4	7.9
Black	61.5	17.1
Hispanic	64.5	23.8
Other	47.2	7.9
Less than High School	69.6	36.3
High School Degree	57.0	17.0
More than High School	36.5	3.7
All	51.9	11.1

Notes: Real-world child-poverty estimates were calculated using data on observations in the March 2009 Current Population Survey (CPS) who were under the age of one at the time that their families' interviews were conducted. While the unit of analysis for these estimates is the child, the demographic information used here reflects the characteristics of the mother. Simulation results were generated using data from 100 one-year runs of the FamilyScape model.

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