# FAMILYSCAPE 3.0:
# Architectural Overview

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## Introduction

This technical paper documents the architecture of FamilyScape 3.0, a microsimulation model of pregnancy and childbearing developed by researchers at Child Trends, The Brookings Institution's Center on Children and Families, and Georgetown University's McCourt School of Public Policy. FamilyScape simulates the key antecedents of pregnancy (sexual activity, contraceptive behavior, 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 readily lends itself to policy simulations, since its parameters can easily be changed under the assumption that a given intervention has an effect on individual behavior. Its parameters were developed through extensive analysis of a wide range of real-world data sources, although most of the parameters for the "3.0" version of the model were estimated using the 2006 – 2010 cycle of the National Survey of Family Growth (NSFG).

The "1.0" and "2.0" versions of FamilyScape are described in detail in Thomas and Monea (2009) and Thomas et al. (2013), respectively. These earlier models were 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 interventions designed to increase condom use. The results of these simulations are documented in numerous papers and reports, including Sawhill et al. (2013), Sawhill et al. (2010), Thomas (2014), Thomas (2012a), Thomas (2012b), and Thomas (2012c). The updated version of FamilyScape differs from earlier iterations of the model in several different ways. The most important differences are as follows:

- FamilyScape 3.0 produces more realistic variation in pregnancy rates by contraceptive method.

- The new version of the model more accurately simulates patterns of contraceptive switching.
- The new version of the model benchmarks contraceptive use, switching, and efficacy at the couple level, rather than the individual level. As a result, FamilyScape 3.0 more realistically models dual-method use and other couple-level dimensions of contraceptive behavior.
- In addition to replicating real-world monthly coital frequency distributions, FamilyScape 3.0 is designed to replicate real-world distributions of sexual activity across months.
- The new version of FamilyScape uses two more years' worth of data than did most of the modules for the 2.0 version of the model.
- Whereas the simulation population for the 1.0 and 2.0 versions of the model contained both men and women, the new model's simulation population is comprised solely of women, and behaviors are simulated using real-world data on women's self-reports of sexual activity, contraceptive use, and fertility outcomes. This change facilitated the implementation of many of the other enhancements described above.

The last of these points merits further discussion. Previous versions of FamilyScape explicitly modeled the formation and dissolution of opposite-sex relationships, and the model's marital and nonmarital relationship formation modules were designed to ensure that women who participated in relationships were paired with men whose demographic characteristics were similar to their own.[1] However, due in large part to the fact that the relevant real-world data provide much less information on the contraceptive histories of men than of women, earlier versions of the model did not directly condition relationship formation on contraceptive use. In other words, when a given woman's partner was selected from among the pool of available men, the matching process did not

[1] For more information on the simulation of relationships within earlier versions of FamilyScape, see Thomas and Monea (2009) and Thomas et al. (2013).

account for the contraceptive method(s, if any) being used by that woman or by her potential male partners. Also important is the fact that, while women were allowed to switch contraceptive methods over the course of the simulation, the data constraints described above precluded us from explicitly simulating contraceptive switching among men.

In order to circumvent these data limitations and improve the model's accuracy in the simulation of contraceptive behavior at the couple level, we limit the simulation population for FamilyScape 3.0 to women, and we model all simulated behaviors using data that reflect women's self-reported histories of sexual activity, contraceptive use (including the use of male-controlled methods), and fertility outcomes. This approach allows us to model couple-level distributions of contraceptive use and contraceptive switching in a more realistic way than was the case for the previous iterations of the model. FamilyScape 3.0 might therefore be described as a "single-sex" model, given that the simulation population includes only women, and since the model's parameters are based solely on women's self-reports. One could alternatively think of the new version of FamilyScape as a "couple-level" model that accounts for both male and female sexual and contraceptive behaviors, but that uses women as the analytical focal point for the simulation of these behaviors.

In the next section, we offer a general overview of FamilyScape's architecture. In subsequent sections, we provide more detailed descriptions of the way in which each of the model's modules was constructed.

## Overview of the Model

FamilyScape 3.0 is a static microsimulation model designed to reproduce real-world fertility-related behaviors and outcomes as observed between 2006 and 2010.[2] 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 for various phenomena of interest. The women in the model's simulation population are heterogeneous: each of them is assigned a set of demographic characteristics that help to govern the various actions that they will take over the course of the simulation. More specifically, the model's simulation population is nationally representative of women who are of childbearing age with respect to marital status, age, race, educational attainment, and socioeconomic status (SES), and simulated behaviors and outcomes are allowed to vary across these demographic dimensions.

As is the case in the real world, women within the simulation behave autonomously and sometimes inconsistently. For example, some women in the model are more likely than others to use a particular method of contraception, but women may also switch methods as the simulation progresses. Each of FamilyScape's inputs (sexual activity, contraceptive behavior, etc.) is simulated so as to ensure that aggregate measures of the resulting behaviors are consistent with 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 women who rely on various types of contraception, the incidence of childbearing among teens and adults, abortion rates within and

[2] Static models such as FamilyScape 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 switch contraceptive methods as analysis time passes. This dimension of the model is described in the discussion of "Stage II" below and in Appendix II 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).

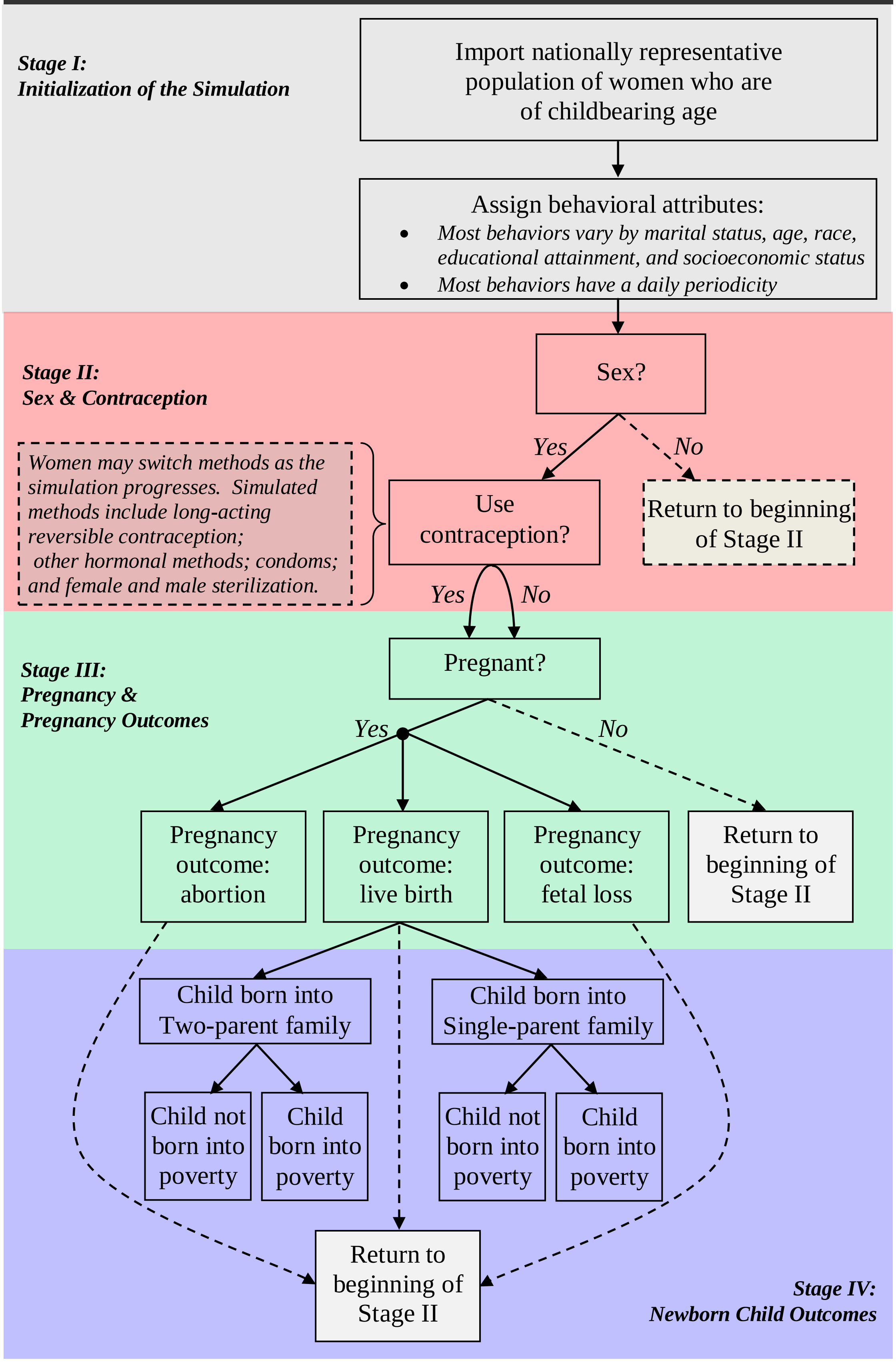
outside of marriage, etc.) to their equivalent real-world benchmarks. As will be discussed later, FamilyScape performs quite well in this regard.

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 nationally representative group of women who are assigned a set of behavioral attributes as a function of their demographic characteristics. In the second stage, sexual activity (or a lack thereof) is simulated, and contraceptive use (or a lack thereof) is modeled among women who have sex. In the third stage, some sexually active women become pregnant, and each pregnancy eventually results in a birth, an abortion, or a fetal loss. The model's fourth and final stage accounts for the fact that each birth is either to a married mother 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 this 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 rate at which women have sex; the frequency with which sexually active women use contraception; the types of male-controlled and female-controlled contraception that they use; the number of women who switch onto and off of various contraceptive methods; the frequency with which women 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 most of these dynamics according to marital status and the other demographic characteristics enumerated above.

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, a woman who does not have sex today may do so tomorrow; a sexually active woman who 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 four stages. The next several subsections describe these stages in more detail.

**Figure 1: Summary Diagram of the FamilyScape 3.0 Simulation Model**



**Stage I: Initialization of the Simulation**

Figure 2 depicts the process by which the simulation is initialized. We start with the female respondent file of the 2006 – 2010 NSFG, which contains a nationally representative sample of women who are between 15 and 44 years of age. Using the survey's demographic sampling weights, we extract a group of 20,000 women to be included in the simulation population.[3] Because we use the NSFG's sampling weights to extract observations, the demographic characteristics of FamilyScape's simulation population should match closely the weighted characteristics of the sample from which it was drawn. As is documented in Appendix I, this is in fact the case.

When we import observations from the NSFG into the simulation population, we retain information on their marital status, age, race, educational attainment, and SES.[4] We then use each woman's demographic characteristics to assign her a set of attributes (e.g., sexual proclivities, contraceptive types, contraceptive switching propensities, etc.) that are subsequently used to model the various behaviors and outcomes that are simulated by FamilyScape. The next several subsections describe these simulation procedures in more detail.

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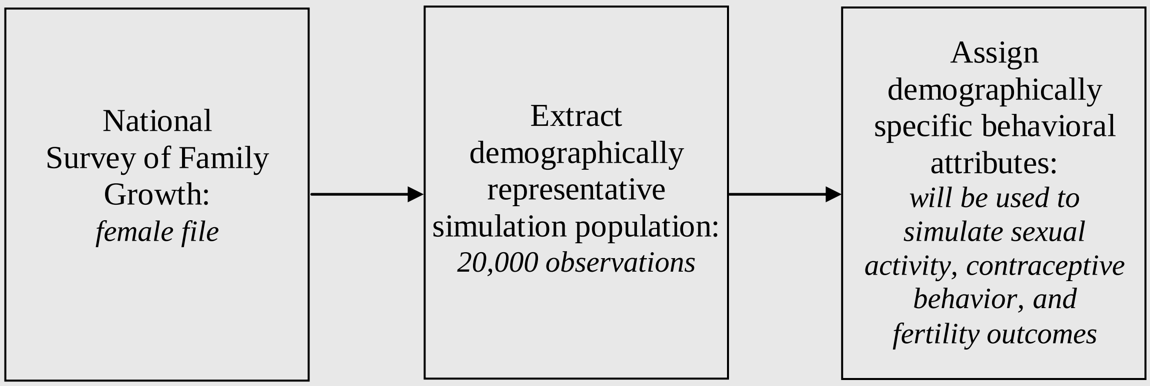
[3] In fact, the 2006 – 2010 NSFG contains only about 12,000 female respondents in total. We extract a simulation population of 20,000 by sampling observations with replacement.

[4] In order to make various aspects of the FamilyScape's simulations more tractable, we do not simulate divorces or new marriages. Thus, married women remain married and unmarried women remain unmarried for the duration of the simulation. See Appendix I for more information on this topic.

**Figure 2: Diagram of FamilyScape's Stage I Rules for Initialization of the Simulation**




We would also note that no single dataset contains the breadth of information necessary to estimate all of the model's many input parameters. Thus, once these women are imported into the simulation, we use data from a variety of different sources to develop the various parameters that govern their decisions about sexual activity, contraceptive use, etc. For reasons of internal consistency, we parameterize the model using data from 2006 - 2010 whenever possible and, when data from these years are not available, we use information from the closest available year. We use 2006 – 2010 data because these are the most recent years for which NSFG files were available when FamilyScape 3.0 was being developed.[5]

**Stage II: Sexual & Contraceptive Behavior**

Figure 3 shows FamilyScape's rules governing sexual and contraceptive behavior. We begin by detailing the model's sexual behavior module. The parameters for this component of the model were developed using real-world data on sexual activity across months (these data reflect the number

[5] After we completed work on the current version of FamilyScape, a new cycle of NSFG data for 2011 – 2013 was released. However, detailed pregnancy-rate estimates have not yet been published for this time more recent period, which is to say that there would not be sufficient external benchmarks to allow us thoroughly to validate the model's results if it were parameterized using the new cycle of NSFG data. Thus, FamilyScape 3.0 was developed using data from the most recent time period for which the model's results can currently be externally validated.

of months over the course of a year during which a woman was sexually active) and coital frequency within months (these data reflect the number of days on which a woman had intercourse during a sexually active month).[6] FamilyScape's process for simulating sexual activity is thus comprised of two steps. First, we identify the months (if any) during which a given woman will be sexually active over the course of a given year of analysis time. And second, we identify the specific days on which she will have sex during a month when she is sexually active. Because the married and unmarried populations have fundamentally different distributions of coital frequency, we calibrate the model's sexual activity module separately for these two groups.

Regarding the first of the two steps described above, our analysis of data from the NSFG suggests that, over the course of a year, many women have sex at least once per month, others have no sex, and the remainder fall in between these two extremes. Women in the latter group are distributed relatively evenly across months, which is to say that the share of women who are sexually active for one month per year is roughly similar to the share of women who are sexually active for two months per year, which is itself similar to the share of women who are sexually active for three months, and so forth. We therefore place each woman in the simulation population into one of three "annual sexual activity" categories: "highly active," "moderately active," or "inactive." We use the results of our analyses of NSFG data to 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. Women who are assigned to the "highly active" category are sexually active during each month of a given year within the simulation, women in the "inactive" category are sexually inactive for the entire year, and women in the "moderately active" category are assigned to be sexually active for between one and eleven months.

[6] Given that we are interested in modeling the incidence of pregnancy and childbearing, FamilyScape's sexual behavior modules only simulate the occurrence of heterosexual vaginal intercourse.

Among women in the NSFG who are sexually active in a given month, the within-month distribution of coital frequency is similar to the above-described distribution of sexual activity across months. In other words, women can readily be grouped into "high," "medium," and "low" categories with respect to their within-month coital frequency. In order to develop the model's parameters governing coital frequency during a sexually active month, we therefore use NSFG data to assign women to one of three different groups, again as a function of their demographic characteristics. We also vary women's chances of falling into each of these groups as a function of their "annual sexual activity" type, as described above. Using the results of our NSFG analyses as benchmarks, we then calibrate the model to ensure that sexually active women placed into the "low within-month coital frequency" category have sex between one and four times in a given month; that women in the "moderate within-month coital frequency" category have sex between five and 13 times a month; and that women who are placed in the "high within-month coital frequency" category have sex more than 13 times a month.

See Appendix II for additional detail on FamilyScape's sexual behavior modules. As is discussed in that appendix, FamilyScape produces distributions of sexual behavior that closely match the comparable distributions as measured using data from the NSFG, both with respect to the number of sexually active months over the course of a year and the number of acts of intercourse within a sexually active month.

We now describe the model's procedures for simulating contraceptive behavior. We assign to each woman a "contraceptive type," which reflects her choice of both male- and female-controlled methods, using self-reported data on contraceptive use among female NSFG respondents. With respect to female-controlled methods, we simulate the use of three different categories of contraception: long-acting reversible contraceptive methods (LARC); other hormonal methods such as the pill, patch, or ring (PPR); and female sterilization.[7] With respect to male-controlled methods, we simulate the use of condoms and male sterilization.[8] We also allow for the possibility that a woman will not use any female- or male-controlled methods (indeed, a substantial number of women fall into this category in the NSFG, and therefore also within FamilyScape's simulation population). Because we use women's self-reports on their own (female-controlled) methods and their partners' (male-controlled) methods, we are able to model dual-method use at the couple level.[9] In other words, some women are assigned to the use of PPRs and condoms; others are assigned to use LARC and no male-controlled methods; others are assigned to condoms and no female-controlled method; and so forth.

As we do for sexual behavior, we use the results of our NSFG analyses to vary women's chances of assuming a given contraceptive type according to her marital status, age, race, education level, and

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[7] We use the term "sterilization" to refer both to natural sterility and to surgical sterilization. The following contraceptive methods are considered to be LARC methods 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 contraceptive sponge, and natural family planning.

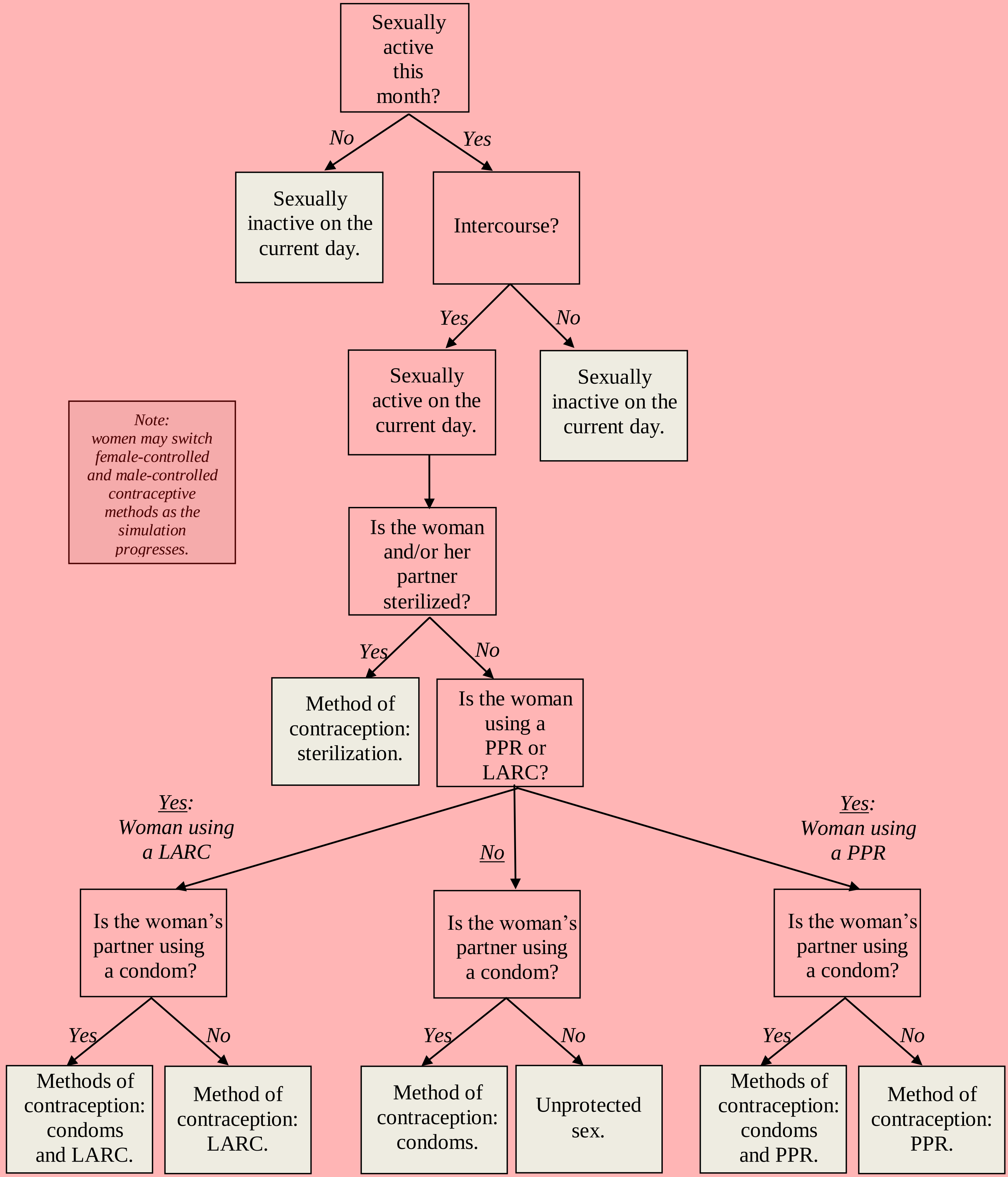
[8] Because withdrawal is a male-controlled method, and for purposes of simplicity, we collapse condom users and users of withdrawal into a single contraceptive category. Thus, a woman whose partner uses withdrawal is considered to rely on condoms for the purposes of FamilyScape's simulations. As is discussed further Appendix II, condoms and withdrawal have roughly similar levels of estimated effectiveness. For contraceptive categories that contain several different methods, FamilyScape's estimates of contraceptive efficacy represent a weighted average of the relevant methods' efficacies (see Appendices II and III for more details).

[9] We develop FamilyScape's contraceptive use parameters via analysis of NSFG data documenting the most effective female- and male-controlled methods that female respondents report having used in a given month. The model's parameters governing dual-method use are designed to replicate a series of benchmarks that reflect the share of female NSFG respondents who report use of a given female-controlled method (e.g., oral contraception) and a given male-controlled method (e.g., condoms) in the same month. In point of fact, when an NSFG respondent reports having relied on both a female- and a male-controlled method in the same month, she may or may not have used those two methods at the same time. As is discussed in Appendix II, the model's contraceptive failure rates are calculated under the assumption that members of the simulation population who are assigned to dual-method contraceptive categories may not make simultaneous use of the female- and male-controlled methods to which they are assigned. In other words, FamilyScape's contraceptive failure rates for dual-method users take into consideration both the efficacies of the relevant methods and the likelihood that they are used simultaneously.

SES. We also vary contraceptive choice as a function of both annual sexual activity type and within-month coital frequency type. Thus, if women who report having relatively more (or less) intercourse in our real-world data also report being relatively more (or less) likely to use a particular type of contraception (or not to use any contraception at all), that dynamic is captured in the estimation of this module's parameters.

Over the course of the simulation, non-contracepting women are allowed to begin using contraception, and contracepting women are allowed to discontinue contraceptive use or to switch methods. Women are allowed to begin (or to discontinue) the use of both female- and male-controlled methods as the simulation proceeds. The parameters governing method switching in FamilyScape 3.0 are derived from a sample of sexually active 2006 – 2010 NSFG female respondents. Switching probabilities vary according to the demographic attributes of the woman and the contraceptive method(s, or lack thereof) that she had previously been using. As is discussed in Appendix II, FamilyScape produces distributions of couple-level contraceptive use and contraceptive switching that are similar to the relevant benchmarks taken from the NSFG.

**Figure 3: Diagram of FamilyScape's Stage II Rules Governing Sexual Behavior and Contraceptive Use in a Single Day**



**Stage III: Pregnancy & Pregnancy Outcomes**

Figure 4 diagrams the model's procedures for simulating pregnancies and pregnancy outcomes. As is the case in the real world, a woman's chances of becoming pregnant after having sexual intercourse during the simulation depend on her 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 she and her partner using. FamilyScape 3.0 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 modifies her (age-adjusted) fecundity level accordingly. We assign age- and day-specific fecundity estimates based on our synthesis of the results of several published clinical studies.[10]

In most cases, 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.[11] As such, we instead simulate variation in the consistency and correctness of contraceptive use by modeling variation across demographic groups in the risk of pregnancy associated with the use of a given method. 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

[10] 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 III for a comprehensive discussion of the way in which FamilyScape 3.0 models female fecundity.

[11] 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 II for additional discussion of this topic.

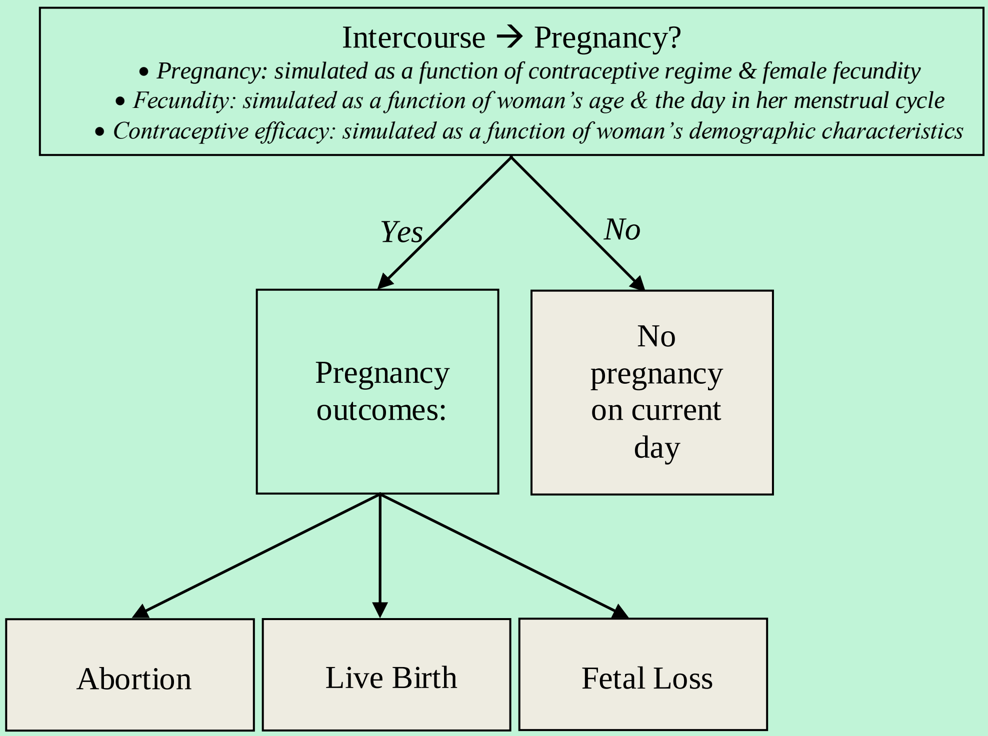
described above with NSFG data on the pregnancy rates and coital frequencies of contraceptive users falling into various demographic groups.[12] The one exception to this rule is sterilization, which we assume to have a 100% efficacy rate for all users. See Appendix III for a detailed discussion of FamilyScape's contraceptive efficacy module.

Once a woman in the simulation becomes pregnant, that pregnancy eventually results in a live birth, an abortion, or a fetal loss.[13] 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.

[12] Our contraceptive efficacy estimates are calculated under the assumption that the user does not switch methods or discontinue contraceptive use. 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 described above. See Appendices II and III for thorough descriptions of FamilyScape's switching and efficacy modules, respectively. We would also note that we model a "failure rate" for women who use no contraception. In other words, even for a woman not using any contraception, we adjust downward the predicted probability of pregnancy from a single act of intercourse that is initially assigned to her as a function of our fecundity equations. We make this adjustment based in large part on evidence demonstrating that, in point of fact, women who self-report as non-contraceptors often rely on withdrawal and/or natural family planning methods. See Appendix III for further discussion of this topic.

[13] 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, women 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 III for additional discussion of the way in which FamilyScape 3.0 simulates pregnancy outcomes and gestation periods.

**Figure 4: Diagram of FamilyScape's Stage III Rules Governing Pregnancy Outcomes**

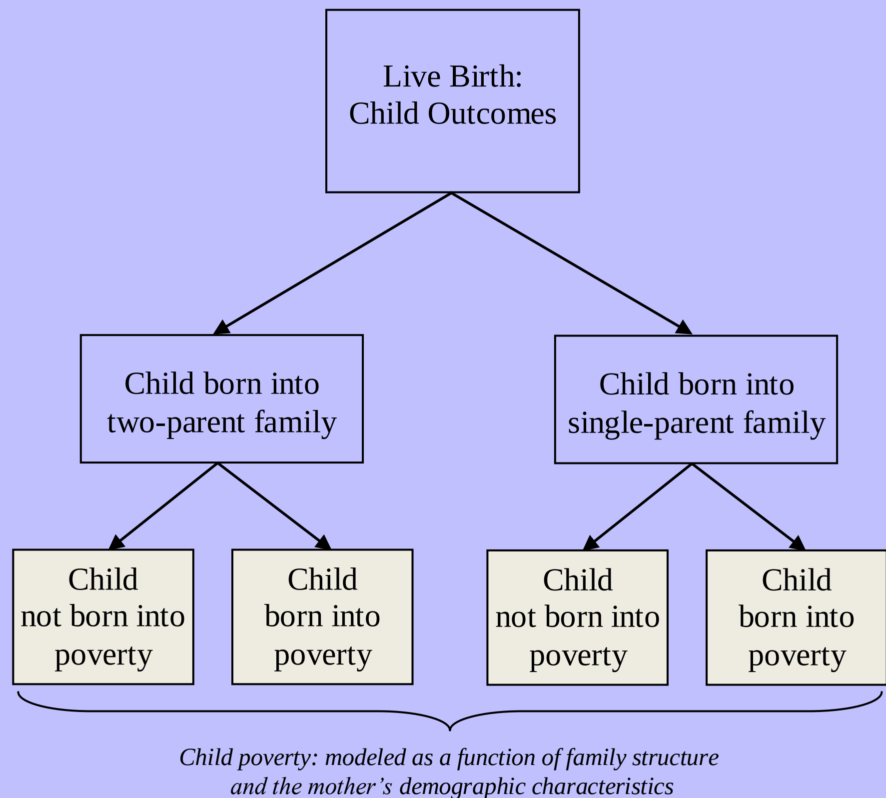



**Stage IV: Newborn Child Outcomes**

Figure 5 shows FamilyScape's procedures for simulating newborn child outcomes. Because the model tracks the marital status of each woman 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.[14]

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

**Figure 5: Diagram of FamilyScape's Stage IV Rules Governing Newborn Child Outcomes**



## Validation

Having provided a brief overview of the model'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 3.0 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 with the equivalent benchmarks from real-world data.[15]

For both the married and unmarried populations, FamilyScape 3.0 approximates real-world outcomes quite well. Among unmarried women, simulated annual rates of pregnancy, birth, and abortion are within about three percent of their targets. Among married women, the simulated pregnancy rate is within about four percent of its benchmark, and birth and abortion rates are almost identical to their corresponding real-world benchmarks.[16]

[15] Because of the extent of uncertainty about the precise shape of the age-fecundity profile for older women, we have concluded that outcomes for women aged 40 and over should generally be excluded when results are reported for FamilyScape simulations (see Appendix III for further discussion of this topic). For Figures 6 and 7, 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. As such, the simulation results shown here represent averages calculated over 100 separate one-year runs of the model. See Appendix I for further discussion of this topic.

[16] See Table A10 in Appendix III for a comparison of simulated and real-world pregnancy and pregnancy-outcome rates for several different demographic subgroups.

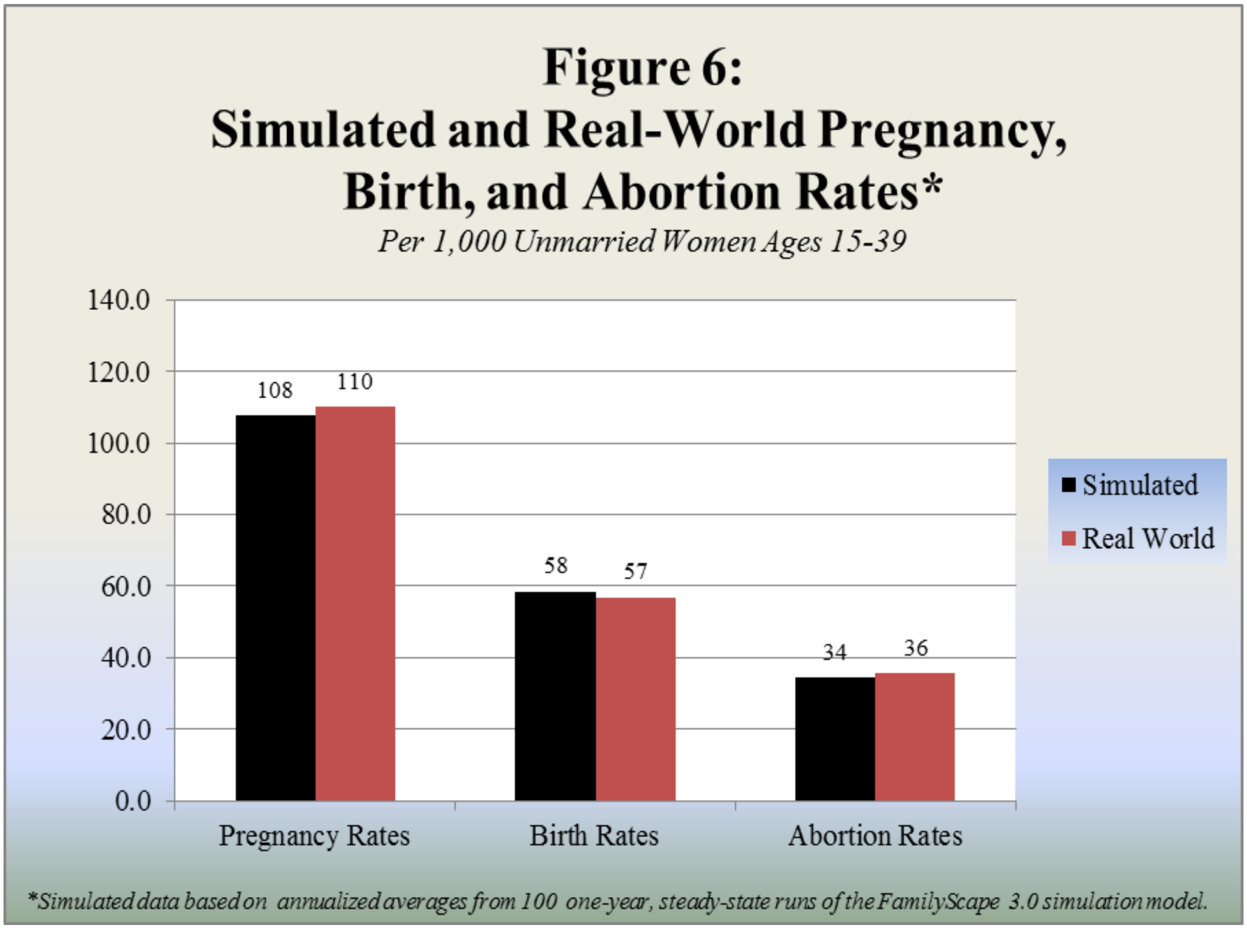


Figure 6:
Simulated and Real-World Pregnancy, Birth, and Abortion Rates*
Per 1,000 Unmarried Women Ages 15-39
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
108
110
58
57
34
36
Pregnancy Rates
Birth Rates
Abortion Rates
Simulated
Real World
*Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.

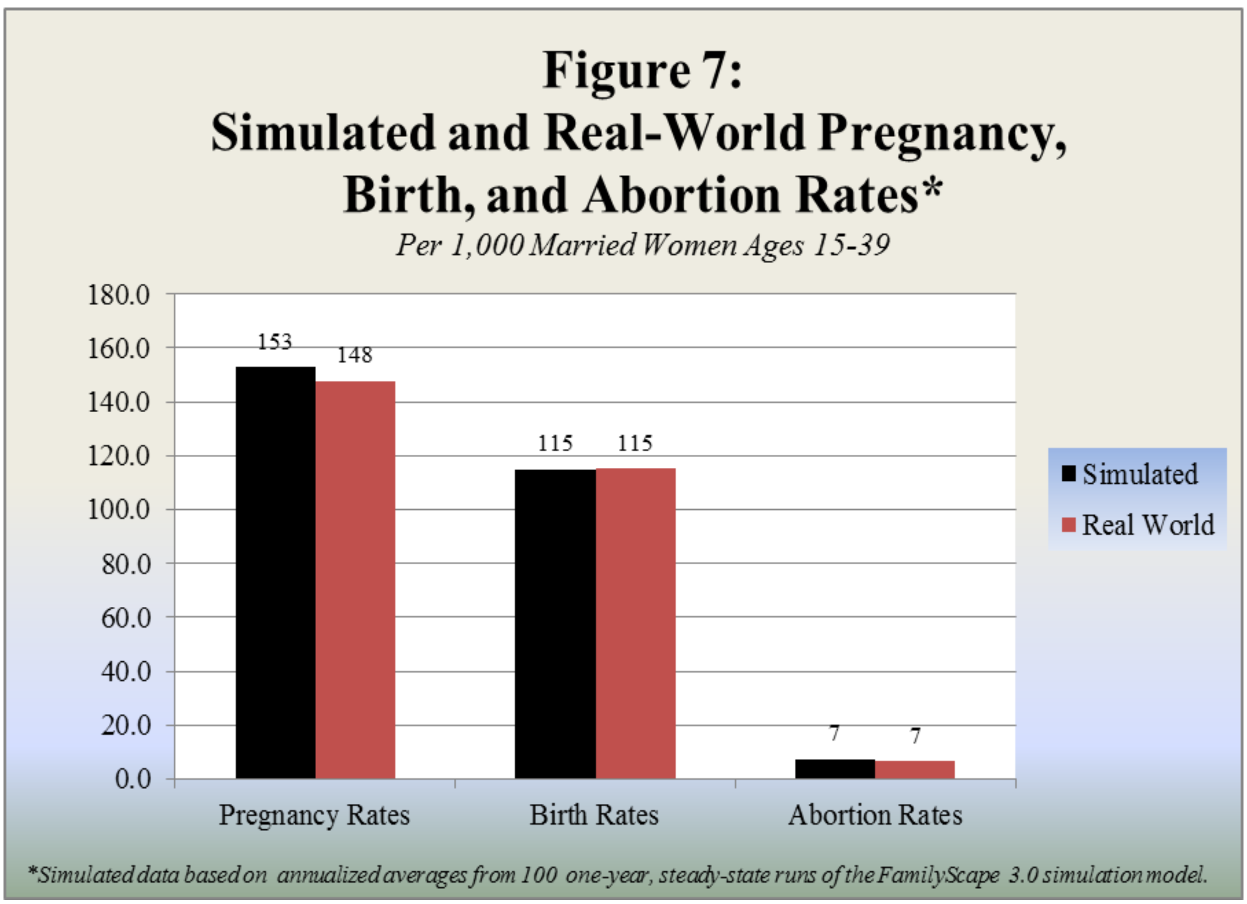
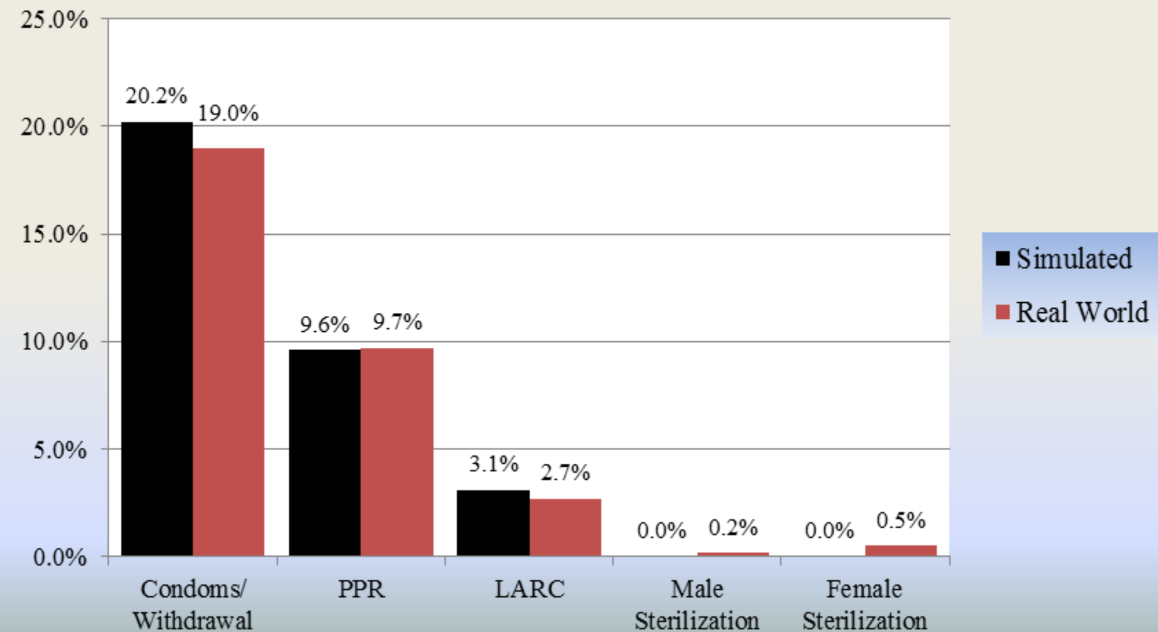


Figure 7:
Simulated and Real-World Pregnancy, Birth, and Abortion Rates*
Per 1,000 Married Women Ages 15-39
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
153
148
115
115
7
7
Pregnancy Rates
Birth Rates
Abortion Rates
Simulated
Real World
*Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.

FamilyScape also realistically models the risk of pregnancy associated with the use of the contraceptive methods incorporated into the simulation. Figure 8 reports simulated and real-world estimates of the probability of becoming pregnant within a year of typical use among women who fall into each of the model's contraceptive categories. For all categories, FamilyScape's annual method-specific pregnancy probabilities are quite similar to their real-world counterparts.[17]

**Figure 8:**
**Simulated and Real-World Method-Specific, Typical-Use Annual Pregnancy Probabilities***




**Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.*

[17] The real-world benchmarks shown here are weighted averages of contraceptive failure rates reported by Trussell (2011a). These estimates are not disaggregated by marital status because Trussell does not report separate estimates for married and unmarried women. There is wide variation in the available estimates of the risk of pregnancy among women who do not use contraception, but FamilyScape's simulated annual pregnancy probability among noncontraceptors is roughly equidistant from two of the most relevant real-world benchmarks. Appendix III provides an explanation of our methods for calculating simulated and real-world pregnancy probabilities for all contraceptive categories.

## Conclusion

FamilyScape 3.0 realistically simulates the most important proximate antecedents of pregnancy, including sexual activity, contraceptive behavior, and female fecundity. The model also produces rates of pregnancy, birth, abortion, and contraceptive failure that closely match their real-world equivalents. Data from a variety of sources are integrated into our simulations 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 functioning of each of the model's subcomponents.

# TECHNICAL APPENDICES

## Appendix I: Initialization of the Simulation

This appendix details the process by which FamilyScape's simulations are initialized. We also address several cross-cutting issues that have relevance for all of the model's modules. Specifically, we discuss FamilyScape's periodicity, its 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 its simulation population and to derive its many parameters, the demographic characteristics of the simulation population, and the way in which these characteristics are used to facilitate the simulation of FamilyScape's core behaviors and outcomes.

### Periodicity

FamilyScape 3.0 has a daily periodicity. We chose to denominate analysis time in this way because some of the most important antecedents of pregnancy – in particular, sexual behavior and female fecundity – can change on a daily basis. 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 women to engage anew in these behaviors on each new day.

### The Simulation of Dynamic Behaviors within a Static Framework

In most respects, FamilyScape 3.0 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 continuously replicates real-world monthly coital frequency distributions and pregnancy-outcome distributions during 2006 – 2010. 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 among the members of the simulation population over time.  For instance, our descriptive tabulations of NSFG data show that, among 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 model's other contraceptive categories.  As a result, the simulated incidence of non-contraception is slightly higher for 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 mirror realistic developments in female contraceptive behaviors within the simulation population.  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.[18]

For this reason, we only activate FamilyScape's contraceptive switching module for a single year of analysis time.  More specifically, we first allow all other behaviors and outcomes (e.g., sexual activity, pregnancy, and childbearing) to reach steady states, and we then allow contraceptive switching to occur over a 365-day window during which we also record data on any desired simulation outputs (e.g., pregnancies, abortions, children born into poverty, etc.).  As such, all reported simulation

[18] Put differently, contraceptive switching introduces a set of absorbing states into FamilyScape 3.0.  If, for instance, FamilyScape's contraceptive switching module were activated for 100,000 days, almost all non-white women would be non-contraceptors and almost all white women would use contraception -- a contraceptive mix that is clearly at odds with real-world data.

results produced by FamilyScape 3.0 correspond specifically to outcomes as measured over this one-year period of analysis time.

**Modeling of Random Processes**

As is made clear in the remaining appendices, all of FamilyScape's modules include some element of randomness. Over the course of the simulation, random processes govern the chances that a given woman will have sex on a given day, the probability that a she will use contraception when she has sex, and so forth. A brief exposition of the way that FamilyScape 3.0 models these random processes may therefore 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 her behavior. As is discussed further in the final section of this appendix, these probabilities (e.g. the likelihood of using a particular contraceptive method or methods) are typically imputed using regression equations that include demographic covariates (some equations also include behavioral controls, as detailed below). When an individual has to make a decision about whether to take a particular action, we randomly select a number from a uniform (0,1) distribution, and the woman engages in the behavior in question if that draw falls below the relevant probability.[19] When a choice is made from among more than two options, we model the relevant decision as a series of binary choices. For a choice with three options, for example, we first model whether women choose option one (as opposed to

[19] Imagine, for example, that a woman 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 woman in question, if the result of a random draw is less than 0.7, she will engage in the behavior in question and, if the draw is greater than this threshold, she will not.

options two or three). For all women 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 easier to implement in practice.

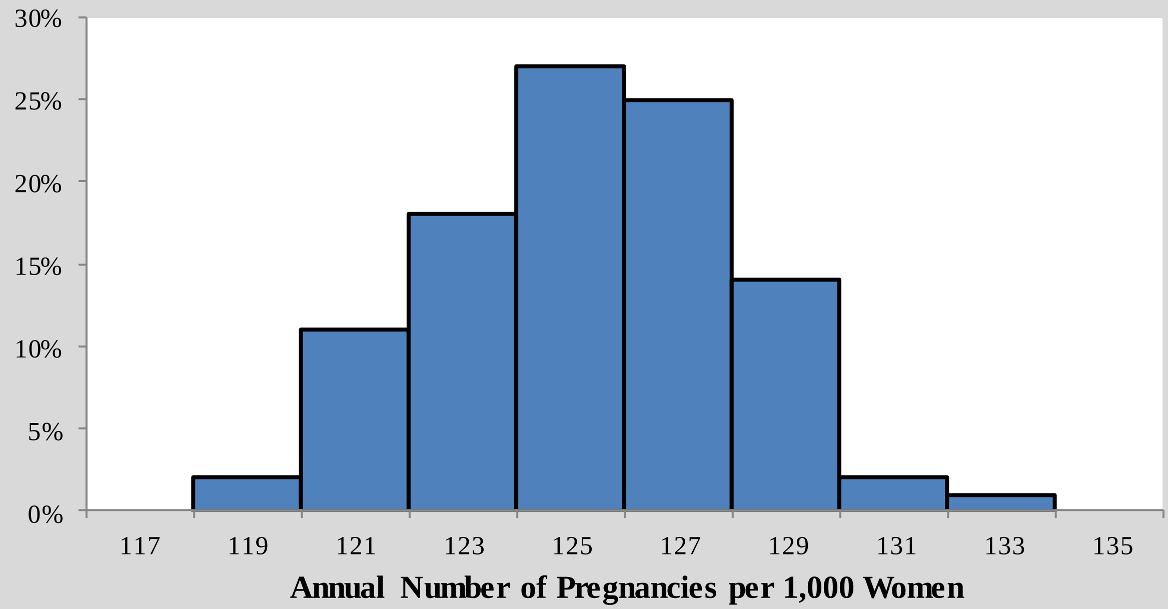
Because of FamilyScape's heavy reliance on random variation, no two runs of the model are exactly alike. We therefore report simulation results using data that are averaged over multiple runs of the model. Our objective is to conduct enough simulation runs to prevent outliers from exercising undue influence 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 inputted into Stata's random-number generator – in order to produce 100 years' worth of simulated data.[20] 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 roughly symmetric.

[20] 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 that it is given the same seed number. Thus, initializing the model repeatedly with different seed numbers ensures variation not only between individuals within each run but also across different runs of the model.

**Figure A1: Distribution of Annual Pregnancy Rates**

*From 100 Runs of the FamilyScape 3.0 Simulation Model*

*Among all Women Aged 15 - 39*



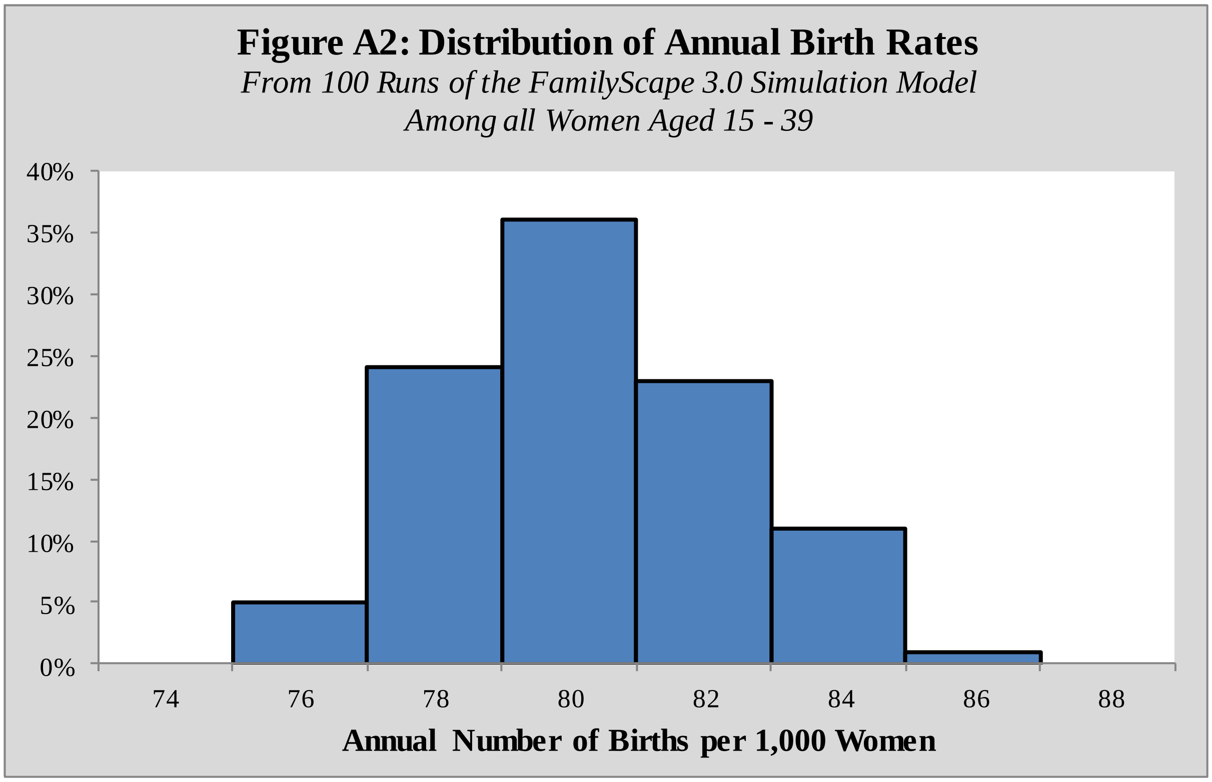


Figure A2: Distribution of Annual Birth Rates
From 100 Runs of the FamilyScape 3.0 Simulation Model
Among all Women Aged 15 - 39
40%
35%
30%
25%
20%
15%
10%
5%
0%
74
76
78
80
82
84
86
88
Annual Number of Births per 1,000 Women

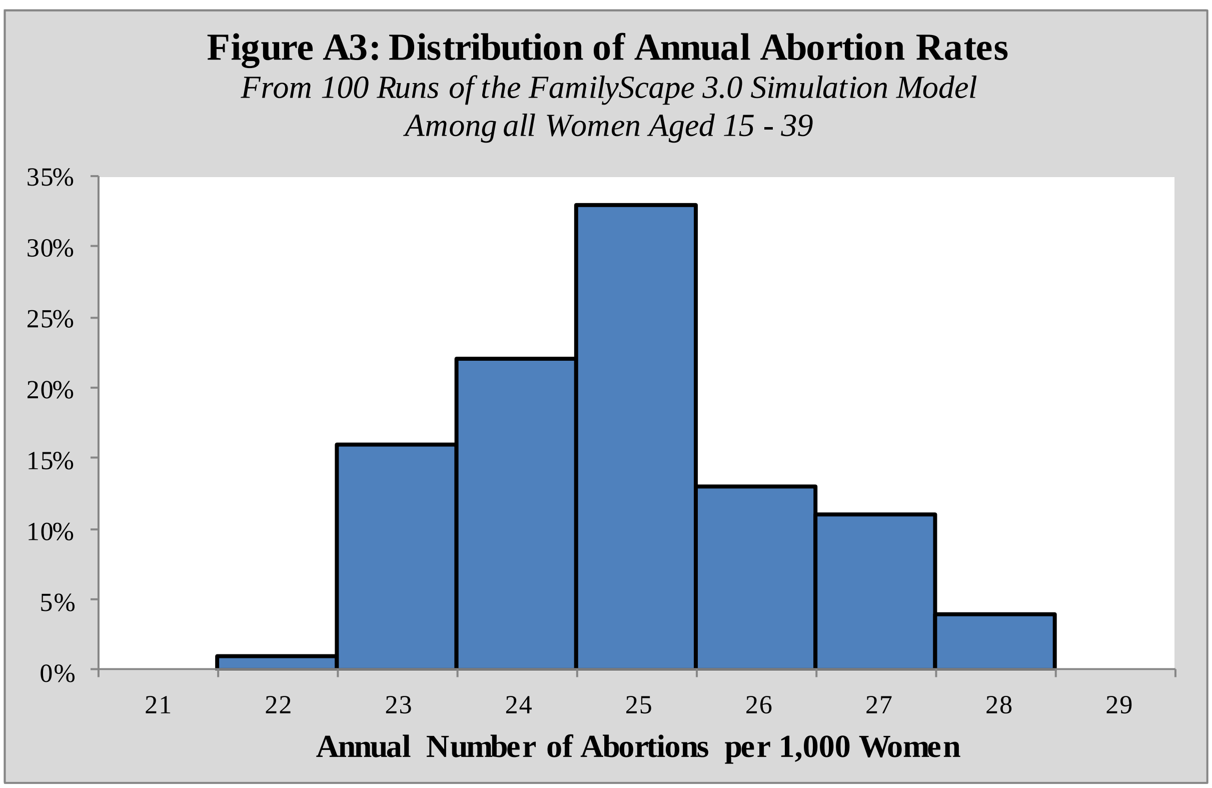


Figure A3: Distribution of Annual Abortion Rates
From 100 Runs of the FamilyScape 3.0 Simulation Model
Among all Women Aged 15 - 39
35%
30%
25%
20%
15%
10%
5%
0%
21
22
23
24
25
26
27
28
29
Annual Number of Abortions per 1,000 Women

**Data Sources**

We populate the model using data drawn from the adult female respondent file of the 2006 – 2010 National Survey of Family Growth (NSFG). NSFG respondents were between the ages of 15 and 44 when they participated in the survey.[21] 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.[22] We create FamilyScape's simulation population by probabilistically selecting (with replacement) 20,000 observations using respondents' sampling weights. Given that these data were gathered over a period of four years (interviews were conducted between July of 2006 and June of 2010), FamilyScape's results should be considered to correspond to the average annual conditions that prevailed over that four-year time 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.[23]

The NSFG contains much – but not all – of the information necessary to parameterize FamilyScape. We therefore use data from other sources as necessary to estimate the model's parameters. We use

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[21] In fact, seven sample members in the NSFG's 2006 – 2010 female respondent file were 45 years old, and another 97 had missing data for one or more of the demographic covariates (described in detail below) that are used to model behaviors within the simulation. These observations were dropped from the dataset before respondents were extracted to populate the model. Thus, while the full NSFG female respondent file contains data on 12,279 respondents, FamilyScape's simulation population was created by randomly sampling from among a subset of 12,175 (12,279 – 7 – 97) members of the original sample. The descriptive statistics for the NSFG sample that are reported in Table A2 below correspond to sample members who were eligible to be selected into FamilyScape's simulation population.

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

[23] As is discussed above, this is actually true only after the model reaches a quasi-steady state.

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.[24]

**Demographic Covariates**

As we import individual observations into the simulation population, we retain information on some of their demographic characteristics. Specifically, we retain individual-level information on marital status, age, race, educational attainment, and SES. We operationalize SES using a measure of maternal educational attainment.[25] We usually simulate variation in FamilyScape's behavioral inputs and key outcomes according to each of these characteristics. 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 the data available to us. They are also consistent with the categorical definitions that are often used in the broader literature on population studies and family formation.[26]

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[24] The other data sources used to parameterize the model include (but are not limited to) the Guttmacher Institute's 2008 Abortion Provider Survey, the United States Census Bureau's 2009 Current Population Survey, and the 2008 release of data from the National Center for Health Statistics' National Vital Statistics System.

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

[26] The "high school degree" education category contains women 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 women who do not self-identify as white non-Hispanic, black non-Hispanic, 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 might be preferable for us to be able to disaggregate our race-specific results in a more fine-grained fashion. We parameterize most 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;

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

**Table A1: Specification of FamilyScape's Covariates**

As is discussed in the main body of this paper, the characteristics of FamilyScape's simulation population should closely match the characteristics of the weighted sample from the NSFG's 2006 – 2010 female respondent file, given that we use the survey's demographic weights when we extract our simulation population. Table A2 reports the characteristics of the weighted female NSFG sample and the population of women who were imported from the NSFG into the simulation. These tabulations demonstrate that the characteristics of the women in the model's simulation population are indeed very similar to those of the weighted female NSFG sample.

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 considered several different specifications of SES in our regression analyses. 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.

**Table A2: Demographic Comparison of the Full NSFG and the FamilyScape Simulation Population**

| | 2006 - 2010 NSFG (weighted) | Population for FamilyScape Simulations |
|---|---|---|
| | Percent | Percent |
| *15-19 (%)* | 17.1 | 16.9 |
| *20-24 (%)* | 16.8 | 16.6 |
| *25-29 (%)* | 17.1 | 17.6 |
| *30-44 (%)* | 49.0 | 48.9 |
| *Average age* | 29.5 | 29.5 |
| *White non-Hispanic (%)* | 61.8 | 61.9 |
| *Black non-Hispanic (%)* | 14.4 | 14.2 |
| *Hispanic (%)* | 17.0 | 17.3 |
| *Other (%)* | 6.8 | 6.7 |
| *Less than High School (%)* | 24.0 | 23.7 |
| *High School Degree (%)* | 23.8 | 24.7 |
| *More than High School (%)* | 52.2 | 51.7 |
| *Low SES (%)* | 22.3 | 22.6 |
| *High SES (%)* | 77.7 | 77.4 |
| *Unmarried (%)* | 58.6 | 58.8 |
| *Married (%)* | 41.4 | 41.2 |
| *N* | 12,175 | 20,000 |

*Notes: The NSFG tabulations were derived using data on women from the female respondent file of the National Survey of Family Growth (NSFG) 2006 - 2010. Estimates reported in the "Population for FamilyScape Simulation" column were derived using a demographically weighted sample extracted from the same dataset. Demographic weights were used to calculate summary statistics for the NSFG sample, but not for the FamilyScape simulation population.*

We would also note that FamilyScape 3.0 makes the simplifying assumption that that all individual demographic characteristics remain fixed over the course of the simulation. As a result, the model does not simulate the formation of new marriages or the dissolution of existing ones. As is shown in the table above, however, the prevalence of marriage among the women who populate the simulation is consistent with the share of women in the NSFG who are married. Moreover, the annual number of new marriages is only about 7 per 1,000 females and that the annual rate of divorce is only about 4 per 1,000 females.[27] If FamilyScape were to model new marriages and divorces, it would therefore simulate changes in marital status for only a small number of women each year. Thus, while the model does not account for the (limited, in any given year) "flows" of women into and out of the married population, it does realistically capture the "stock" of married women as reflected in the real-world data that were used to produce the model's baseline population.

**Parameter Estimation**

As has already been discussed, we assign most of the model's behavioral parameters to members of the simulation population using the results of regression analyses. These regressions were estimated using real-world data, and each model includes as covariates some or all of the demographic characteristics enumerated above. Some regressions also include controls for certain behavioral characteristics. For example, when we estimate regressions models for the purpose of assigning an initial contraceptive type to each member of the simulation population, we control for "annual sexual activity type" and "within-month coital frequency type," both of which are described in the main body of this paper and in Appendix II. Likewise, we model the probability of contraceptive switching as a function of whether the woman was pregnant in the previous month and of her initial contraceptive type (i.e., the contraceptive type assigned to her at the outset of the simulation). For a woman who switches methods multiple times, we additionally condition the probability of "higher-order" switching on her most recent contraceptive type and on the number of times that she has switched methods during the current year.

[27] Based on the authors' analysis of data reported in National Center for Health Statistics (2015).

Table A3 provides a summary of the covariates included in each set of regression equations. In addition, the table reports the number of unique outcomes that are modeled by each set of regressions and the number of equations required to model those outcomes. For instance, there are three possible outcomes for a given pregnancy (i.e., each pregnancy will result in a birth, an abortion, or a fetal loss), and we use two equations to model these three outcomes. One regression models the probability that a given pregnancy will result in a birth; a second regression models the probability that the pregnancy will result in an abortion given that it did not result in a birth; and the residual probability reflects the likelihood that the pregnancy will result in a fetal loss. As is indicated in the table, we estimate separate regression equations for married and unmarried women for each outcome.[28] The table also describes the functional form for each set of regressions. As an example, we use the results of hazard models to simulate contraceptive switching behavior (this approach allows the probability of switching to vary as a function of analysis time), and we use the

[28] A bit more of an explanation may be helpful to the reader regarding the number of outcomes and the number of regression equations used to implement the model's contraceptive behavior modules. As is discussed further in the next appendix, FamilyScape 3.0 allows women to assume one of eight different contraceptive types, each of which corresponds to a different combination of female-controlled and male-controlled methods (or to the use of no female-controlled and/or no male-controlled contraception). More specifically, each woman is assigned to one of the following eight contraceptive categories: 1) no female-controlled method & no male-controlled method; 2) no female-controlled method & condom; 3) PPR & no male-controlled method; 4) PPR & condom; 5) LARC & no male-controlled method; 6) LARC & condom; 7) female not sterilized & male sterilized; and 8) female sterilized. Regarding these latter two categories, we do not model the choice of male-controlled methods for women who are sterilized or of female-controlled methods for women whose partners are sterilized because we make the simplifying assumption that sterilization is 100% effective (in other words, we assume that the use of methods other than sterilization will have no effect on the risk of becoming pregnant among women in the latter two contraceptive categories). With respect to the regressions that model initial contraceptive type and the choice of methods after a switch, we only need to estimate seven different equations, for the reasons outlined above. However, we take a different approach when modeling the probability of switching methods. More specifically, we estimate separate equations for every one of our "origin contraceptive types" with the exception of female sterilization (we make the simplifying assumption that sterilized women will not seek surgical reversal of their sterilization) and, for married women, male sterilization (we also make a simplifying assumption that married women with sterilized spouses will not change sexual partners during the simulation and that these women's sterilized partners will not seek reversal of their sterilization). We define a woman's "origin contraceptive type" as her contraceptive type at the beginning of the segment of analysis time over which we model the probability that she will switch methods. For each of these "method-specific" regressions, there are two outcomes: "switch" and "no switch." Because of the limited amount of data in the NSFG on contraceptive switches that occur after a woman's first switch, we are unable to estimate separate equations modeling the probability of "higher-order switching" for each origin contraceptive type. Instead, we estimate only one regression per marital-status group, and we include a series of contraceptive type dummies as covariates in these regressions.

results of logistic regression models to simulate the choice of contraception among women who switch methods.[29]

[29] As is noted at the bottom of Table A2, we include a set of month dummies to allow the baseline hazard to vary over time when we model the probability of switching methods. Although the equations that model the choice of methods after a contraceptive switch are not hazard models, we concluded after a set of exploratory analyses that these regressions should nonetheless include controls for the point in time at which the switch occurred. Due to sample-size limitations, however, we were unable to include a complete set of month dummies in these "method-choice" regressions. As such, we instead include in these regressions a continuous month variable and a quadratic month term. We address this issue further in Appendix II.

## Table A3: Overview of FamilyScape's Regression Specifications*

| *Regression Characteristics* | *Dependent Variable*: Annual Sexual Activity Type | Within-Month Coital Frequency Type | Initial Contraceptive Type | Probability of Switching Contraceptive Types *For the first contraceptive switch*** | Probability of Switching Contraceptive Types *For higher-order contraceptive switches**** |
|---|---|---|---|---|---|
| Separate Equations Estimated by Marital Status? | Y | Y | Y | Y | Y |
| Number of Outcomes | 3 | 3 | 8 | 2 | 2 |
| Number of Regressions Estimated for Each Marital-Status Category | 2 | 2 | 7 | 7 *(for unmarried women)*<br>6 *(for married women)* | 1 |
| Functional Form | Logistic Regression | Logistic Regression | Logistic Regression | Logistic Hazard | Logistic Hazard |
| Demographic Covariates: | | | | | |
| *Age* | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Race* | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Education* | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Socioeconomic Status* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Behavioral Covariates: | | | | | |
| *Annual Sexual Activity Type* | | ✓ | ✓ | | |
| *Within-Month Coital Frequency Type* | | | ✓ | | |
| *Pregnant in the Previous Month* | | | | ✓ | ✓ |
| *Number of Previous Contraceptive Switches* | | | | | ✓ |
| *Origin Contraceptive Type* | | | | ✓ | ✓ |
| *Most Recent Contraceptive Type* | | | | | ✓ |

**All regression models were estimated using data on female NSFG respondents except for: a) FamilyScape's pregnancy-outcome regressions, which additionally use data from the National Vital Statistics System and the Guttmacher Institute's Abortion Provider Survey; and b) the child-poverty regressions, which were estimated using Current Population Survey data.*

***For the probability of switching methods for the first time, we estimate separate regressions for each origin contraceptive type except female sterilization (under the simplifying assumption that sterilized women will not undergo surgical reversal of their sterilization) and, for married women, male sterilization (under the simplifying assumptions that each woman who is married to a sterilized man will have the same spouse throughout the simulation and that her spouse will not undergo surgical reversal of his sterilization). All regressions also include a set of monthly baseline hazard dummy variables.*

| Table A3, Continued: Overview of FamilyScape's Regression Specifications* | | | | |
|---|---|---|---|---|
| | ***Dependent Variable*** | | | |
| ***Regression Characteristics*** | New Contraceptive Type *After the first method switch *** | New Contraceptive Type *After higher-order method switches*** | Pregnancy Outcomes *Among women who experience a pregnancy* | Probability that a Child will be Born into Poverty *Among women whose pregnancy results in a birth* |
| Separate Equations Estimated by Marital Status? | Y | Y | Y | Y |
| Number of Outcomes | 8 | 8 | 3 | 2 |
| Number of Regressions Estimated for Each Marital-Status Category | 7 | 7 | 2 | 1 |
| Functional Form | Logistic Regression | Logistic Regression | Ordinary Least Squares | Linear Probability Model |
| Demographic Covariates: | | | | |
| *Age* | ✓ | ✓ | ✓ | ✓ |
| *Race* | ✓ | ✓ | ✓ | ✓ |
| *Education* | ✓ | ✓ | | ✓ |
| *Socioeconomic Status* | ✓ | ✓ | | |
| Behavioral Covariates: | | | | |
| *Annual Sexual Activity Type* | | | | |
| *Within-Month Coital Frequency Type* | | | | |
| *Pregnant in the Previous Month* | ✓ | ✓ | | |
| *Number of Previous Contraceptive Switches* | | ✓ | | |
| *Origin Contraceptive Type* | ✓ | ✓ | | |
| *Most Recent Contraceptive Type* | | ✓ | | |

**All regression models were estimated using data on female NSFG respondents except for: a) the pregnancy-outcome regressions, which additionally use data from the National Vital Statistics System and the Guttmacher Institute's Abortion Provider Survey; and b) the child-poverty regressions, which were estimated using Current Population Survey data.*

***Regression equations also include a continuous month variable and a quadratic month variable.*

A smaller number of FamilyScape's parameters were generated using an approach other than regression-based estimation. For instance, a fecundity level is imputed to each member of the simulation population on each day by plugging her age and the day in her menstrual cycle into one of several equations that we developed by synthesizing the results of a number of different clinical studies.[30] Similarly, a woman is assigned a contraceptive failure rate as a function of the method(s, if any) that she is using, her age, and her marital status. More specifically, we estimate subgroup failure rates by plugging the characteristics of each contraception-age-marital-status group (e.g., that group's monthly pregnancy rate and average monthly coital frequency) into an equation that was developed specifically for the purpose of modeling single-act contraceptive failure rates within FamilyScape's simulation framework. Table A4 briefly describes the estimation approach that was used to develop each of FamilyScape's non-regression-based parameters. The table also reports the demographic and/or behavioral dimensions along which these parameters vary. As an example, a pregnancy's gestation period varies only according to its outcome (e.g., a birth will have a notably longer gestation period than will an abortion or a fetal loss). The remaining appendices explain, in considerably greater detail, our methods for developing all of FamilyScape's regression-based and non-regression-based parameters.

[30] Each of these studies is described in Appendix III.

**Table A4: Overview of FamilyScape's Non-Regression-Estimated Parameters**

| | ***Dependent Variable*** | | |
|---|---|---|---|
| | Female Fecundity* | Contraceptive Failure** | Gestation Periods*** |
| Estimation Approach | Equations developed via syntheses of published studies | Original data tabulations | Synthesis of published estimates |
| Covariates | Age, day in menstrual cycle | Marital status, age, contraceptive type | Pregnancy outcome |

**See Appendix III for a discussion of the studies whose findings were used to generate FamilyScape's fecundity parameters.*

***FamilyScape's contraceptive failure probabilities are generated by plugging parameters that were estimated via analysis of data on female NSFG respondents (e.g., the monthly pregnancy rates and average within-month coital frequencies of women who use a given method, are of a given marital status, and fall into a given age category) into an equation that was developed for the purpose of modeling single-act contraceptive failure rates.*

****FamilyScape's gestation periods are extended to account for the period of time after a pregnancy ends during which a woman is infertile. The durations of these post-pregnancy fertility periods, like the gestation periods that precede them, vary according to the pregnancy's outcome. See Appendix III for a complete listing of the studies whose results were synthesized to generate the model's gestation-period and post-pregnancy-infertility parameters .*

## Appendix II: Sexual & Contraceptive Behavior

The first section of this appendix details FamilyScape's methods for modeling sexual behavior, and the second section describes our procedures for simulating contraceptive behavior among sexually active women.

**Sexual Behavior**

FamilyScape's sexual behavior modules are parameterized using self-reported data on the frequency of heterosexual vaginal intercourse among female respondents in the 2006 – 2010 NSFG.[31] FamilyScape 3.0 models a woman's sexual behavior via two separate modules. The first module identifies the months within a given year of analysis time during which a woman will be sexually active, and the second module identifies the days within a sexually active month on which she will have intercourse. We discuss each of these modules in turn below.

Simulation of Sexual Activity Across Months

We developed FamilyScape's parameters governing sexual activity across months by analyzing data on the number of months in the past year during which female NSFG respondents report having had intercourse at least once. We define any such month as a "sexually active month." About a third of unmarried women in the NSFG report that they were not sexually active during any month in the year prior to their interview, and a slightly smaller proportion report that they were sexually active during each of the last twelve months. The remaining share (a little more than a third) report that they were sexually active for between one and eleven of the previous twelve months, and these

[31] As is discussed in a footnote in the main body of this paper, we do not simulate other types of sexual activity because FamilyScape is designed specifically to model the incidences of pregnancy and pregnancy outcomes such as childbearing and abortion.

women are distributed relatively uniformly between one and eleven months of sexual activity. The substantial majority (nearly 80%) of married women report that they were sexually active in each of the previous twelve months, and the rest of the married population is distributed roughly evenly between zero and eleven months of sexual activity over the course of the past year.

Given these findings, we assign some members of FamilyScape's simulation population to be sexually inactive throughout each year of analysis time, we assign other women to be sexually active in each month of the year, and we assign the remaining share of women to be sexually active for between one and eleven months out of the year. Using the results of regression models (which are estimated separately for married and unmarried NSFG sample members), we provide each woman with a probability of falling into each of these three "annual sexual activity" categories as a function of her age, race, educational attainment, and SES. We then use these probabilities to place women into annual sexual activity categories according to the approach outlined in Appendix I.

For a woman in the "moderately active" category (i.e., for a woman who is assigned to be sexually active for between one and eleven months out of the year), we randomly draw an integer between one and eleven (inclusive) at the beginning of the simulation to assign her a number of sexually active months, and we then randomly select the specific months when she will be sexually active during a given year. While annual sexual activity types vary across women according to their demographic characteristics, these designations are fixed over time. In other words, a woman assigned to the "inactive" category will remain sexually inactive for all twelve months during each year of analysis time, a woman assigned to the "highly active" category will be sexually active in all twelve months of each simulated year, and the number of sexually active months for a woman in the "moderately active" category will remain fixed from year to year (as will the specific months of the year during which she will be sexually active).

Figures A4 and A5 report annual distributions of across-month sexual activity for women in the NSFG and in FamilyScape's simulation population.[32] As is shown in these two figures, the simulated and real-world distributions of annual sexual activity are generally quite comparable.

[32] For reasons detailed in Appendix I, the results shown here (and in all other figures and tables that present diagnostic simulation results) are averaged over 100 separate runs of the model.

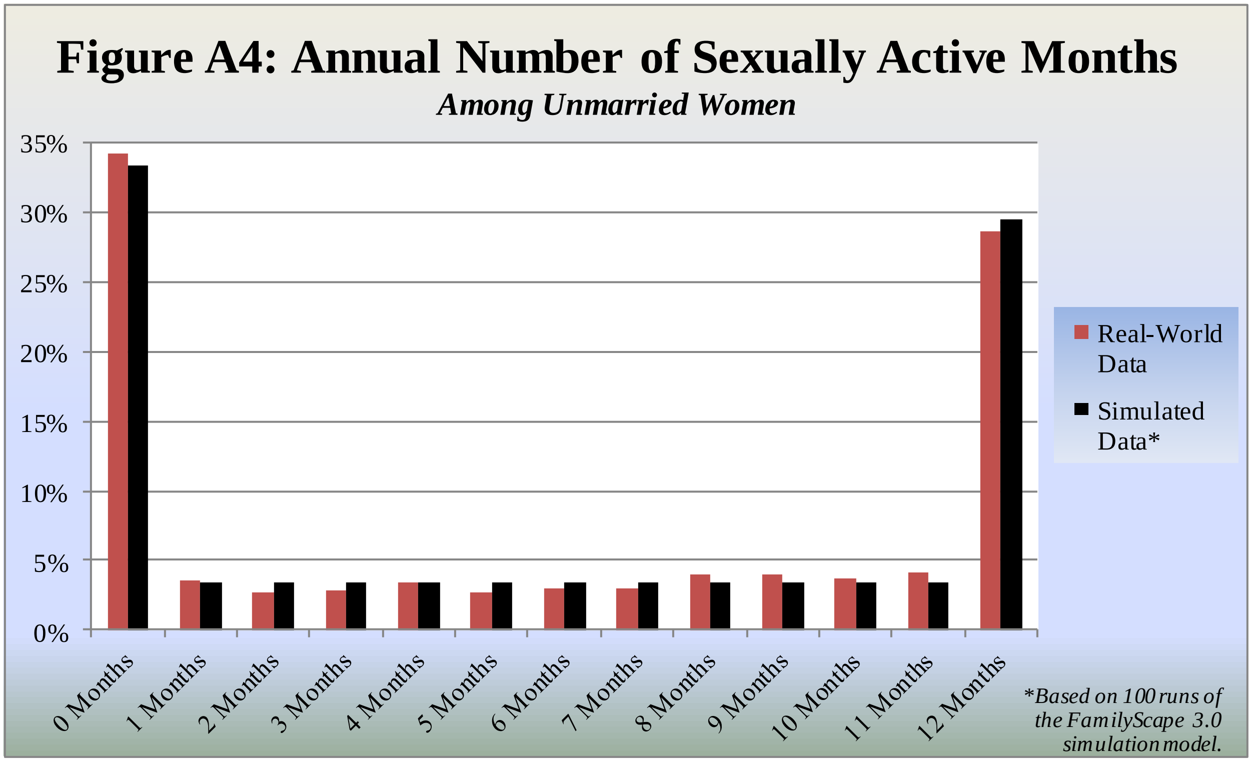
Figure A4: Annual Number of Sexually Active Months
Among Unmarried Women
35%
30%
25%
20%
15%
10%
5%
0%
0 Months
1 Months
2 Months
3 Months
4 Months
5 Months
6 Months
7 Months
8 Months
9 Months
10 Months
11 Months
12 Months
Real-World Data
Simulated Data*
*Based on 100 runs of the FamilyScape 3.0 simulation model.

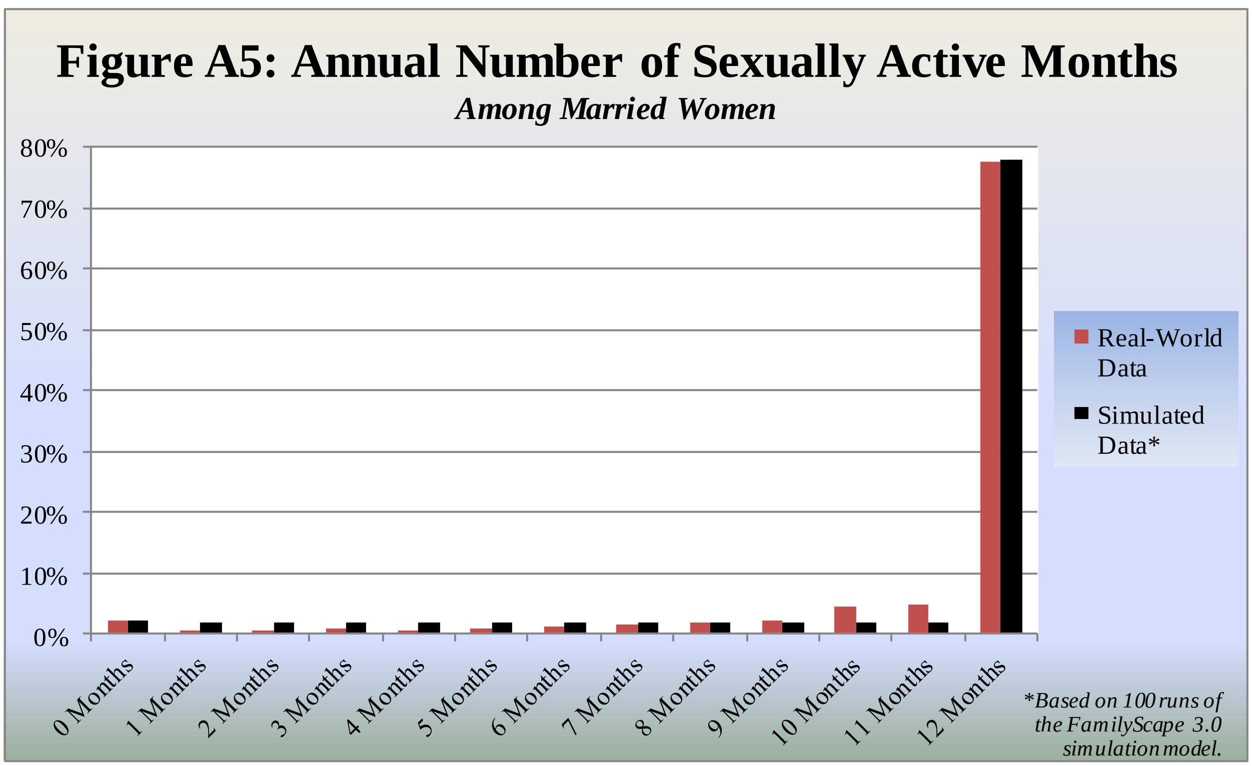
Figure A5: Annual Number of Sexually Active Months
Among Married Women
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 Months
1 Months
2 Months
3 Months
4 Months
5 Months
6 Months
7 Months
8 Months
9 Months
10 Months
11 Months
12 Months
Real-World Data
Simulated Data*
*Based on 100 runs of the FamilyScape 3.0 simulation model.

Simulation of Coital Frequency Within Months

In the discussion that follows, we use the term "coital frequency" to refer to the number of days on which a sexually active woman has intercourse over a specified period of time. The relevant data in the NSFG measure coital frequency over a 28-day period, whereas FamilyScape's coital frequency module models the frequency of intercourse on a monthly basis. We therefore begin by describing the distribution of four-week coital frequency in the NSFG, and we then discuss the way in which we use these data to model monthly coital frequency within FamilyScape.

As is the case for annual sexual activity, our analysis of NSFG data on women's 28-day coital frequency suggests that they can be grouped relatively straightforwardly into one of three groups. More specifically, during a sexually active four-week period, about 48% of unmarried women have sex between one and four times, about 36% have sex between five and twelve times, and about 16% have sex more than twelve times. The four-week distribution of coital frequency is broadly similar for sexually active married women, among whom 42%, 47%, and 11%, respectively, fall into these three categories. We use the NSFG to estimate regressions that model sexually active respondents' chances of falling into these "high," "moderate," and "low" coital frequency groups as a function of their demographic characteristics and the number of months during which they were sexually active over the past year. We once again estimate separate regression models for married and unmarried women, and we use the results of these regressions to assign each member of FamilyScape's simulation population a set of probabilities of reflecting her chances of falling into each of these three coital frequency groups. We then place women in FamilyScape into coital frequency groups using the approach outlined in Appendix I.

Once a woman is given a coital frequency type, we randomly assign her a number of days of intercourse that falls within the range corresponding to the category into which she has been placed. As is stated above, the NSFG's coital frequency data are denominated over a 28-day period, whereas FamilyScape's within-month coital frequency module models number of days of intercourse over a one-month (30-day) period. We therefore derive FamilyScape's within-month coital frequency parameters by multiplying the thresholds for our three NSFG-based categories by 30/28 = 1.07.[33] As such, for a woman who is assigned to the "low within-month coital frequency" group, we randomly select an integer between one and four (inclusive) at the beginning of each sexually active month to determine the number of days on which she will have intercourse. In the same way, we randomly draw an integer between five and 13 (inclusive) for a sexually active woman who falls into the "moderate within-month coital frequency" group, and we randomly draw an integer between 14 and 30 (inclusive) to model coital frequency among sexually active women who fall into the "high within-month coital frequency" group.[34] We then take a series of random draws to determine the particular days of the coming (sexually active) month on which she will have intercourse.

As is the case for FamilyScape's assignment of annual sexual activity types, the model's within-month coital frequency types are fixed over time. However, we take new draws to model the number of days of intercourse and the specific days on which coitus occurs at the beginning of each

[33] In practice, this process only affects the break point between the top two categories (the relevant break point falls between 13 and 14 for FamilyScape's coital frequency module, whereas the comparable break point falls between 12 and 13 in the NSFG-based distribution) and the maximum level of coital frequency (which is 30 for FamilyScape's coital frequency module and 28 in the NSFG's four-week distribution).

[34] Only a very small portion of the population reports 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.

new month of analysis time. Thus, although a woman's coital frequency type remains constant, her sexual behavior will nonetheless change from month to month as the simulation proceeds.[35]

Figure A6 compares the distribution of 28-day coital frequency among unmarried NSFG respondents with the equivalent distribution from a series of FamilyScape simulations.[36] Figure A7 shows the same comparison for married women. These graphs include data on women who have no sex over a given four-week period as a means of further validating the model's capacity to simulate sexual inactivity. For both groups, the simulated and real-world distributions of coital frequency are very similar.

[35] For example, assume that a woman falls into the "low within-month coital frequency" group and that she is sexually active during the third, sixth, and eleventh months of a given year. Recall that women in the low coital frequency group will have sex no less than once per month but no more than four times per month. The woman in question might therefore have sex two times in month three, one time in month six, and four times in month eleven.

[36] Figures A6 and A7 present 28-day coital frequency distributions (rather than monthly distributions) because this is the period of time over which the NSFG's coital frequency data are measured

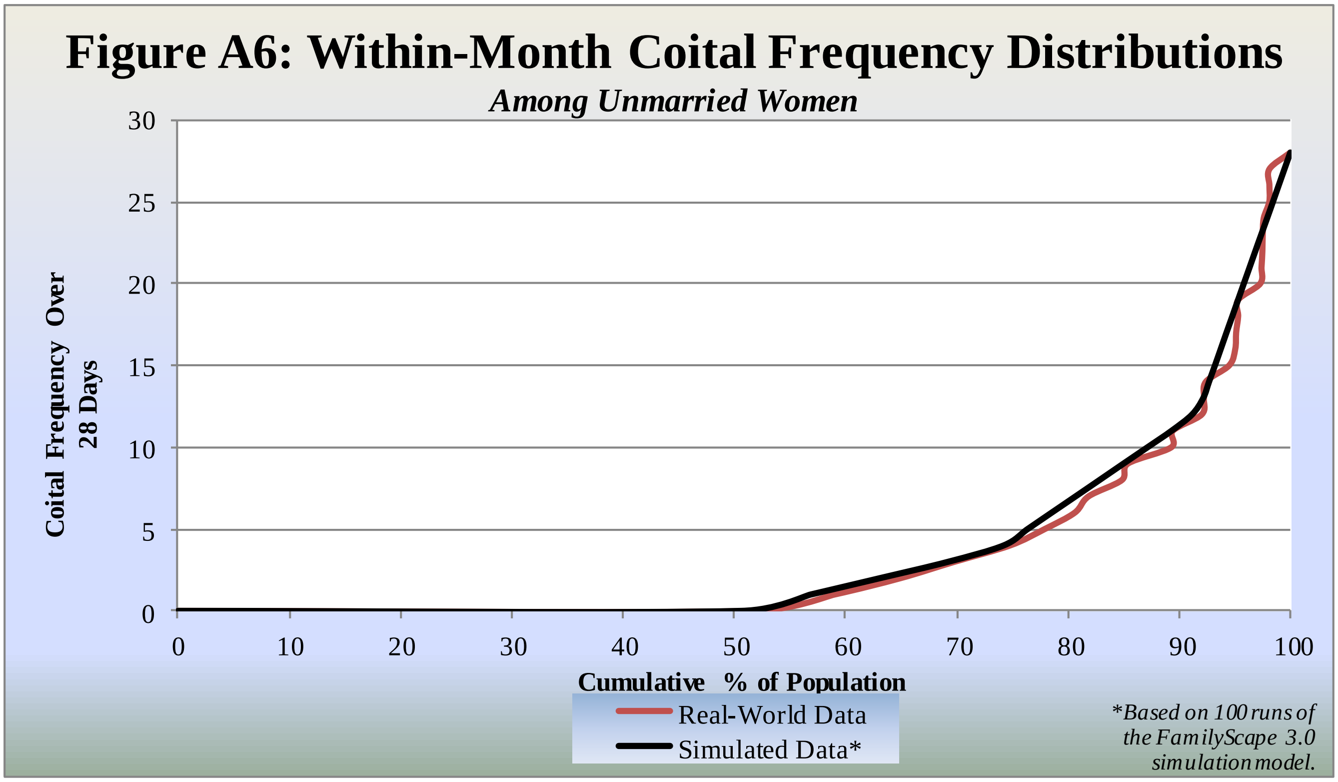

Figure A6: Within-Month Coital Frequency Distributions
Among Unmarried Women
Coital Frequency Over 28 Days
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Cumulative % of Population
Real-World Data
Simulated Data*
*Based on 100 runs of the FamilyScape 3.0 simulation model.


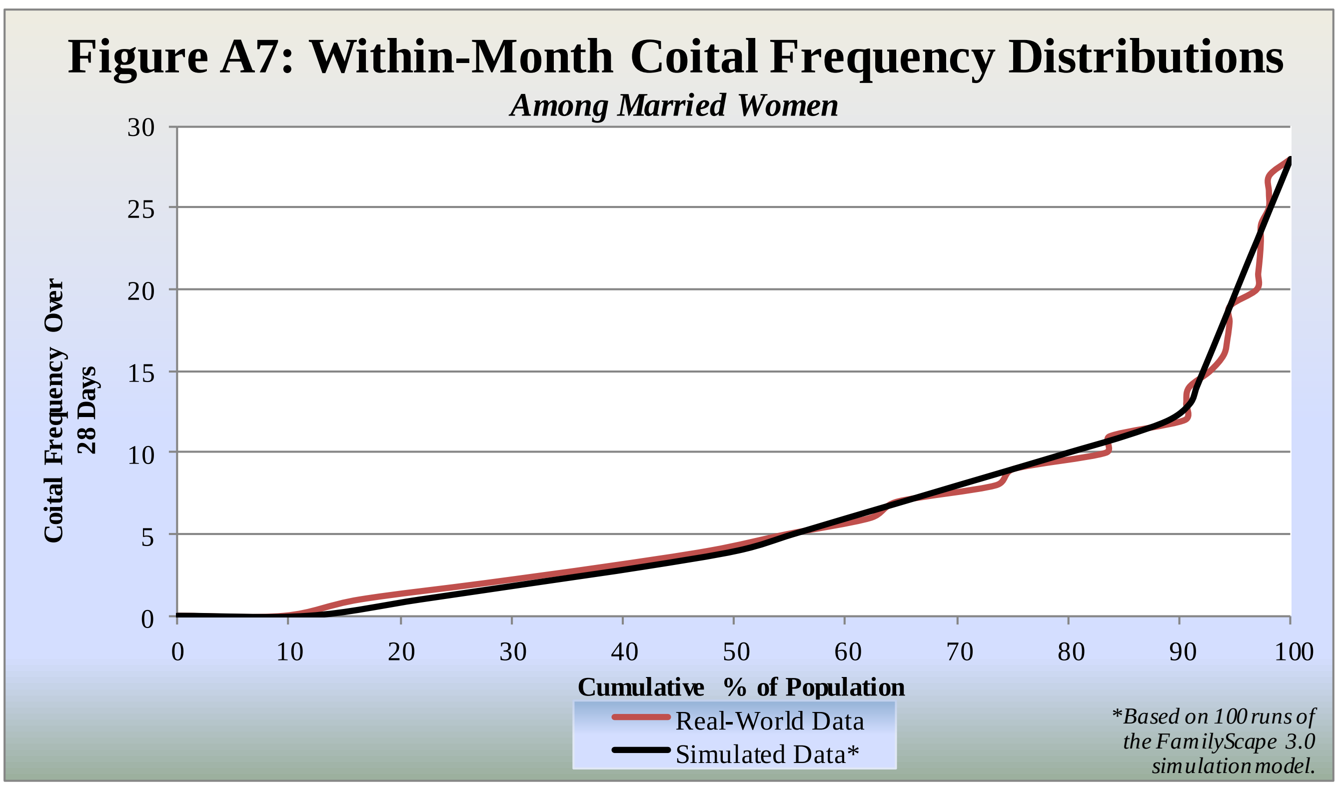

Figure A7: Within-Month Coital Frequency Distributions
Among Married Women
Coital Frequency Over 28 Days
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Cumulative % of Population
Real-World Data
Simulated Data*
*Based on 100 runs of the FamilyScape 3.0 simulation model.

**Contraceptive Behavior**

FamilyScape 3.0 simulates both contraceptive use (or a lack thereof) and contraceptive switching among sexually active women. At the start of a simulation run, members of FamilyScape's simulation population are initially assigned to the use of a particular female-controlled and/or male-controlled method (or to the use of no method at all) according to their demographic and behavioral characteristics. Once simulated rates of pregnancy and childbearing have stabilized, FamilyScape's contraceptive switching module is activated and sexually active women are eligible to change contraceptive types.[37] The discussion below begins with a treatment of FamilyScape's procedures for assigning initial contraceptive types, after which we detail the model's switching module. We conclude this portion of the appendix with a description of the way in which we model the consistency and correctness of method use.

Assignment of Initial Contraceptive Type

The initial assignment of contraceptive types is governed by parameters derived from a series of regressions that predict the probability of using various sorts of contraception among female 2006 – 2010 NSFG respondents. The dependent variables for these regressions are based on self-reported data recording the most effective female- and male-controlled methods (if any) that women report having used. More specifically, we use data on contraceptive use during the first month of the past year in which women report that they were sexually active and were not pregnant.[38] Some of these contraceptive categories reflect the use of a female-controlled method (e.g., a PPR) but no male-

[37] See Appendix I for a discussion of our reasons for simulating contraceptive switching only after the other components of the model have reached steady states.

[38] As is discussed later in this section, our initial contraceptive assignment regressions control for within-month coital frequency type in order to ensure that the simulations capture the correlation between sexual behavior and contraceptive use. Data on within-month coital frequency are available only for female NSFG respondents who were sexually active during the four weeks leading up to their interview. As such, we limit the analysis sample for these regressions to person-months corresponding to women who were sexually active in the 28-day period prior to their interview.

controlled method or of a male-controlled method (e.g., condoms) but no female-controlled method. Other categories reflect the use of both a female-controlled method and a male-controlled method, and a final category corresponds to nonuse of either male or female contraception. As is discussed further below, FamilyScape therefore simulates both single-method and dual-method contraceptive use. Our initial contraceptive assignment regressions are estimated separately for married and unmarried women, and these equations include a full complement of demographic covariates. In addition, all regressions control for annual sexual activity type and within-month coital frequency type in order to ensure that the model's parameters account for the correlation between the frequency with which women have sex and their likelihood of using contraception when doing so.[39]

With respect to female-controlled methods, women in the NSFG can be assigned to the use of one of three different broadly defined types of contraception: long-acting reversible contraceptive methods (LARC); the pill, patch, ring, or other reversible female-controlled methods (PPRs); and female sterilization. The LARC category encompasses intrauterine devices, hormonal implants, and injectables. As its name implies, 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, reversible, female-controlled contraceptive methods. These methods include diaphragms, female condoms, foams, jellies/creams, suppositories/inserts, the contraceptive sponge, and natural family planning. The regressions that model the use of male-

[39] These regressions also include interactions between our annual sexual activity and within-month coital frequency dummies. We include these interaction terms in order to capture any idiosyncrasies that might exist in the contraceptive behavior of women whose sexual episodes are sporadic (such that they are sexually active for a limited number of months in a given year) but high-frequency (such that they have many episodes of intercourse during the few months in which they are sexually active).

controlled methods account separately for the use of condoms and male sterilization.[40] Because withdrawal is a male-controlled contraceptive method, and since withdrawal and condoms have similar levels of efficacy, we make the simplifying assumption that women in the NSFG rely on condoms if they report that withdrawal is their most effective male-controlled method.[41] For each category that combines different methods, FamilyScape's estimates of contraceptive efficacy represent a weighted average of the relevant methods' efficacies.[42] Also important is the fact that, as noted above, women in the NSFG (and therefore in the simulation population) are assigned to a "no method" category if they do not use any form of female- or male-controlled contraception.

If a woman in the NSFG reports that she used at least one female-controlled method and no male-controlled method in the relevant month, she is assigned to a "single-method" contraceptive category that corresponds to the most effective female-controlled form of contraception that she reports having used. Likewise, if a woman reports that she relied on at least one male-controlled method but did not use any female-controlled contraception, she is assigned to a single-method category reflecting the most effective male-controlled contraception upon which she relied. If, on the other hand, she reports that she used at least one female-controlled and at least one male-controlled method in the relevant month, she is assigned to a "dual-method" contraceptive category that reflects the most effective female- and male-controlled methods that she reports having used. The reader should note that, when an NSFG respondent reports having relied on both a female- and

[40] 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 (unless a woman is temporarily infertile because she is pregnant or was recently pregnant, considerations that are not relevant to this discussion and are instead addressed in Appendix III). When conducting analyses of NSFG data in order to parameterize FamilyScape, we therefore code female respondents as being "sterilized" even if they or their partners are sterile for natural reasons other than a current pregnancy or post-pregnancy infertility. Throughout this discussion, then, we use the term "sterilization" to refer both to surgical sterilization and to natural (non-pregnancy related) sterility.

[41] Trussell (2011a) concludes that the annual, continuous-use pregnancy rates of women who rely on condoms and withdrawal are 18% and 22%, respectively.

[42] See Appendix III for a thorough explication of FamilyScape's contraceptive efficacy module.

a male-controlled method in the same month, she may not have used those two methods at the same time. However, we calculate FamilyScape's contraceptive failure rates under the assumption that members of the simulation population who are assigned to dual-method contraceptive categories may not make simultaneous use of the female- and male-controlled methods to which they are assigned. Thus, the model's contraceptive failure rates for dual-method users take into consideration both the efficacies of the methods in question and the likelihood that those methods are used simultaneously.

We would also note that, for women who are sterilized, we do not model the use of male-controlled methods. Similarly, for unsterilized women whose partners are sterilized, we do not model the use of female-controlled methods. Thus, all sterilized women in the NSFG are placed into the same "female sterilized" category regardless of the male-controlled methods (if any) being used by their partners. Similarly, all female respondents with sterilized partners are are placed into a single "male sterilized" category regardless of their own method choice (save for women who are also themselves sterilized and are therefore placed into the "female sterilized" category). We are not required to model the partner's method for individuals relying on sterilization because, as is discussed further in Appendix III, we make the simplifying assumption that sterilization is 100% effective. In other words, we assume that women in the simulation will not experience a pregnancy so long as they or their partners are sterilized, since almost no pregnancies occur to women in the NSFG who are sterilized and/or are partnered with a sterilized man. This approach had the benefit of allowing us to minimize the demands that we placed on the limited amount of relevant real-world data when we developed the model's contraceptive failure parameters.

To summarize, then, women in the NSFG are assigned to one of eight couple-level contraceptive categories: 1) no female-controlled method & no male-controlled method; 2) no female-controlled method & condom; 3) PPR & no male-controlled method; 4) PPR & condom; 5) LARC & no male-controlled method; 6) LARC & condom; 7) female not sterilized & male sterilized; and 8) female sterilized. We employ the results of the aforementioned initial contraceptive assignment regressions to provide each woman in the simulation with a probability of falling into each of these contraceptive categories. Using the approach described in Appendix I, we then use these probabilities to assign an initial contraceptive type to each member of the simulation population at the outset of the simulation. Women retain these contraceptive types at least until the point in analysis time at which we begin to simulate contraceptive switching.

Table A5 compares distributions of contraceptive method use among women in the NSFG to distributions of initial contraceptive types in FamilyScape's simulation population. The estimates reported in this table reflect the choice of methods among women who are sexually active and are not pregnant. The table confirms that FamilyScape produces distributions of couple-level contraceptive use that are closely matched to the relevant benchmarks from the NSFG.

**Table A5: Comparison of Distributions of Simulated Initial Contraceptive Type and Real-World Contraceptive-Use, by Marital Status***

| *Female-Controlled Method (if any)* | *Male-Controlled Method (if any)* | Unmarried Women | Married Women | All Women |
|---|---|---|---|---|
| **Simulated Data** | | | | |
| None | None | 11.6% | 15.1% | 13.4% |
| None | Condom | 32.1% | 19.2% | 25.5% |
| PPR | Nothing | 19.4% | 20.0% | 19.7% |
| PPR | Condom | 13.5% | 3.9% | 8.6% |
| LARC | Nothing | 5.9% | 6.7% | 6.3% |
| LARC | Condom | 1.6% | 0.3% | 1.0% |
| Any Method Other Than Sterilization | Sterilization | 2.6% | 11.9% | 7.3% |
| Sterilization | Any Method | 13.3% | 22.9% | 18.2% |
| *Total* | | *100%* | *100%* | *100%* |
| **Real-World Data** | | | | |
| None | None | 12.6% | 15.5% | 14.0% |
| None | Condom | 31.9% | 19.4% | 25.6% |
| PPR | Nothing | 19.7% | 19.8% | 19.7% |
| PPR | Condom | 13.9% | 3.9% | 8.8% |
| LARC | Nothing | 5.6% | 6.6% | 6.1% |
| LARC | Condom | 1.7% | 0.3% | 1.0% |
| Any Method Other Than Sterilization | Sterilization | 2.1% | 11.7% | 7.0% |
| Sterilization | Any Method | 12.6% | 22.8% | 17.8% |
| *Total* | | *100.0%* | *100.0%* | *100.0%* |

**Simulated estimates reflect initial contraceptive assignment among members of FamilyScape's simulation population. Real-world estimates were produced via tabulations of data reflecting the most effective couple-level method(s) used in the most recent sexually active month of the past year among female members of the National Survey of Family Growth's 2006 - 2010 sample.*

Contraceptive Switching

Once FamilyScape begins to produce stable rates of pregnancy and childbearing, 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 adopt certain 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.[43] We therefore develop real-world estimates of the probability of switching contraceptive types over a one-year period and then parameterize the model so as to ensure that simulated switching patterns are as accurate as possible during the first year of analysis time that elapses after the switching module has been activated. All of FamilyScape's reported simulation results correspond to this one-year period.

The switching module allows most contraceptors to switch to different methods or to stop using contraception entirely, and non-contraceptors are allowed to begin using contraception. As is discussed below, women are allowed to switch contraceptive types multiple times over the course of a year, but they are only considered to be eligible for method switching during months in which they are at risk of pregnancy. It is also important to note that many women in the real world (and therefore also in the simulation population) do not switch contraceptive types at all: a large share of women using LARC will continue to do so throughout the year; many non-contraceptors will not begin using contraception; and so forth.

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

FamilyScape's switching module is parameterized using results from four different sets of regression models, each of which is estimated using 2006 – 2010 NSFG data: a) discrete-time hazard models predicting the probability that a woman will switch methods for the first time during a given twelve-month segment; b) hazard models predicting the probability of a "higher-order" contraceptive switch among women who have already switched methods at least once during the twelve-month segment; c) regressions that predict the contraceptive type assumed by a woman who switches contraceptive methods for the first time; and d) regressions that predict the contraceptive type assumed by a woman who has engaged in a higher-order method switch. In the next subsection, we discuss the way in which we constructed the analysis sample used to estimate these regressions. We then describe our regression specifications, after which we detail our procedures for simulating method switching. We conclude this exposition by comparing metrics of switching behavior among women in FamilyScape with their real-world equivalents.

*Analysis Sample*

The unit of observation for our hazard models analyses is the person-month, and FamilyScape correspondingly simulates contraceptive switching (or a lack thereof) on a monthly basis. Because we are only interested in modeling method switching to the extent that it impacts a woman's chances of becoming pregnant, we narrow the analysis sample for our hazard models to person-months in which a woman is at risk of pregnancy, and women in the simulation are eligible to switch contraceptive types only during months in which they are similarly at risk. Thus, person-months are excluded from the analysis sample for our hazard models if the respondent in question was pregnant at the beginning of the month or was sexually inactive throughout the month. As will be discussed further, we do not model switching out of the "female sterilized" contraceptive category. Nor do we model switching out of the "male sterilized" category among married women. We therefore also exclude from our analysis sample all person-months in which a woman (either married or unmarried) reports being sterile and/or in which a married woman reports relying on male sterility. For the remainder of this discussion, we refer to a month in which a woman is not pregnant, sterile, married to a sterile man, or sexually inactive as a month in which she is "at risk" of pregnancy.[44]

Female NSFG respondents can provide up to 48 months' worth of data on contraceptive use. Our sample incorporates as many at-risk person-months as are available for each woman. Once we have identified all such months for a given woman, we partition them into as many twelve-month intervals as possible, starting with the earliest available at-risk month. For most women, the available number of at-risk months is not a multiple of twelve. In all such cases, we create a final, "partial" interval comprised of all months that remain after the end of the most recent twelve-month interval. For instance, assume that a woman provides 27 at-risk months to our analysis sample. We divide these data into two twelve-month intervals and one three-month interval, where the three-month interval is the closest in time to the woman's interview date.

A given interval may not correspond to a continuous succession of months if, for example, a woman becomes pregnant or is sexually inactive for a period of time. For the purposes of our survival analyses, such "interrupted" intervals are treated in the same way as continuous intervals. We would also note that, because FamilyScape is parameterized to model switching patterns over a single year, different real-world intervals for the same woman are treated as though they are unrelated to each other. As an example, if a respondent contributes two twelve-month intervals to the analysis sample, the hazard models treat these two periods as though they had been provided by different individuals. This approach has the benefit of allowing us to develop an analysis sample whose

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

composition (all at-risk person-months from up to four separate one-year periods) is well-aligned with the needs of the model, which simulates contraceptive switching on a monthly basis over a year of analysis time among women who are at risk of experiencing a pregnancy.

We implement a series of censoring rules to transform these intervals into "segments" of person-month data that are then used to estimate the hazard of method switching. For the purposes of our "first-switch" hazard models, person-month observations are censored after the month in which a woman switches methods for the first time during a given interval (and if the woman does not switch methods during the interval, then all twelve person-months are incorporated into the first-switch analysis sample in the form of a single segment). Once a woman switches methods, she enters the risk pool for higher-order switching, so long as there are months remaining in the focal interval after the occurrence of the first switch.

We assign a contraceptive type to each at-risk person-month in our sample using the classification system outlined earlier in this appendix, and we define a method switch to be any month-to-month change in a woman's contraceptive type. However, we do not model contraceptive switching among sterilized women or among married women whose partners are sterilized. These exceptions are rooted in the fact that, during a given year, sterilized women rarely undergo surgical reversal of their sterilization and married women rarely discontinue the use of male sterilization.[45] Thus, there are not sufficient real-world data to allow us to simulate these dimensions of contraceptive switching in a credible way. Moreover, even if we were able to simulate these types of switches, our results would barely be affected, given that they are so uncommon.

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[45] Our analyses of the NSFG suggest that, over the course of a calendar year, fewer than two percent of sterilized women discontinue the use of female sterilization and only about two percent of married women with sterilized husbands discontinue the use of male sterilization.

*Hazard Models*

We model the monthly probability of contraceptive switching using logistic hazard regressions. All regressions include month dummies to model the baseline hazard of switching, and we estimate separate models for married and unmarried women. Because we define a woman as having switched methods if her contraceptive type in a given month differs from her contraceptive type in the previous month, women are not considered to be at risk of switching during the first month of a segment, even though they are (by definition) considered to be at risk of pregnancy during that month. We define a woman's "origin contraceptive type" according to her contraceptive type at the beginning of the relevant segment. For the regressions that model the probability of a first contraceptive switch, we estimate separate equations for each origin type. However, because of the limited amount of data on women who switch methods multiple times during a given twelve-month interval, we are unable to estimate separate equations by origin method for the regressions that model the probability of higher-order switches. We instead use data from each interval on all at-risk person-months after the first switch to estimate a single model of the hazard of engaging in a higher-order switch.[46] These "higher-order regressions" include in a series of dummy variables controlling for origin contraceptive type. This is true even for women who switch methods multiple times.

Whenever possible, estimated switching probabilities are allowed to vary by age, educational attainment, race, and whether the woman was pregnant in the prior calendar month.[47] The regressions that model the probability of higher-order switching also control wherever possible for

[46] For example, assume that a woman switches methods during the second, fifth, and eighth months of a twelve-month interval. This woman would ultimately contribute a segment of two months to the estimation of the "first-switch" regression and would contribute three segments – a three-month segment spanning from month three to month five, a three-month segment spanning from month six to month eight, and a four-month segment spanning from month nine to month twelve – to the estimation of the higher-order switching regressions.

[47] We include this "recent pregnancy" indicator because women who unintentionally became pregnant in the recent past as a result of contraceptive failure may be more likely to switch methods in the months to come.

the number of previous contraceptive switches and for the woman's most recent contraceptive type (since, for a woman who engages in a higher-order switch, her origin contraceptive type will usually differ from her most recent type). However, because of the small number of women in the NSFG who discontinue the use of certain methods, we were sometimes unable to estimate models that contained a full set of covariates. In such cases, we collapsed covariate categories as needed and, if necessary, removed some controls from the relevant regression. As an example, in the regression that models first-switch probabilities among unsterilized and unmarried women whose partners are sterilized, we omitted the indicator for whether the woman was pregnant in the prior month. Similarly, for the regression that models the probability of a first switch among married LARC-Condom users, we replaced our standard set of individual month dummies with linear and quadratic month terms. Our goal in developing these specifications was to extract as much information as possible from our data in a way that would still allow for reliable estimation of our regression models.

*Method Selection Models*

Among NSFG respondents who switch methods, we use logistic regressions to model the choice of a new contraceptive type. Our approach for modeling method selection among contraceptive switchers is comparable to our approach for modeling initial contraceptive assignment. For example, assume that a woman switches out of the LARC-condom category. She is eligible to assume any of the other seven contraceptive types included in FamilyScape. We estimate separate regressions to model the probability of falling into each of these contraceptive categories. We also estimate separate models by marital status. Wherever possible, these regressions control for a full complement of demographic covariates, the woman's origin contraceptive type, and whether she was pregnant in the previous month. We also include variables measuring the timing of the focal switch within the relevant segment.[48] For regressions that model method selection after a higher-order switch, we also control whenever possible for the woman's number of previous switches and for her most recent contraceptive type. However, as was the case for our regressions that model the probability of contraceptive switching, we were sometimes compelled by limited sample sizes to collapse control-variable categories or to exclude covariates from some regressions.

*Simulation Methods*

During the one-year period of analysis time in which FamilyScape's contraceptive switching module is activated, women at risk of pregnancy are eligible to switch methods. Method switching is simulated on a monthly basis, which is to say that a woman's contraceptive type can vary across, but not within, months. Thus, the year in question is subdivided into twelve months and, at the start of each month, the model identifies all non-sterilized women who: a) will have sex for the first time that year during the upcoming month, and b) are not pregnant. 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 switching regression and assigns her a monthly probability of switching contraceptive types (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 switching probabilities are then used to model contraceptive switching

[48] Problems with small sample sizes required that, rather than employing a full set of month dummies, we instead include in these regressions a continuous month variable and a quadratic month term. These time-period controls help to control for unobservable characteristics that are associated with both method selection and the length of time over which a female method switcher chose to remain on her origin method. In other words, these month variables help to account for the possibility that, 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.

behavior using the approach outlined in Appendix I.[49] Women who are predicted to switch are assigned probabilities of choosing various methods using the coefficients from our method-selection regressions. These probabilities are used to provide a new contraceptive type to each switcher, again according to the approach described in the first appendix.

*Validation of Switching Patterns*

Tables A6 and A7 allow for an assessment of FamilyScape's ability to simulate realistic switching behavior. Both tables report, for women in each origin contraceptive category, the across-month distribution of method choice over a period of up to twelve at-risk months starting with the month in which the origin method was identified. Real-world benchmarks were estimated using the NSFG data described above, and simulated estimates were produced using microdata taken from the period of analysis time during which the model's switching module was activated.[50] Table A6 reports switching estimates for unmarried women, and Table A7 reports the same for married women. For instance, the second row of data in each panel of Table A6 reports estimates of switching behaviors among unmarried women whose origin contraceptive type was "No Female-Controlled Method & Condom." Within the simulation, women in this origin category spend an average of 3.9% of at-risk

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[49] 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 the first sexually active, non-pregnant, fertile day of each month.

[50] For Tables A6 and A7, we develop our estimates of switching behavior using data on contraceptive use only during months in which a given woman is at risk of pregnancy. For example, assume that an unmarried woman's origin contraceptive type is "PPR & Condom" and that she is at risk of pregnancy during months 1, 5, 9, and 12 of the focal year (perhaps because she was sexually inactive during the other months of the year). This woman would provide four months' worth of data for the purpose of estimating the across-month distribution of methods among unmarried women in the "PPR & Condom" group. We use these data to compute $C_j/T$ for each woman, where $C_j$ is the number of at-risk months in which a woman assumes contraceptive type $j$, and $T$ is the total number of at-risk months that a woman experiences, during the focal year. We produce the data reported in these tables by averaging, across 100 runs of the model, our estimates of $C_j/T$ among all women of a given marital status who fall into a given origin category. These calculations are performed at the person level for our FamilyScape-based estimates and at person-year level for our NSFG-based estimates. The difference in units of analysis is a function of the fact that FamilyScape simulates switching behaviors for a single year, whereas we have up to four years' worth of switching data for NSFG respondents.

months during the focal year in the "No Female-Controlled Method & No Male-Controlled Method" category. The corresponding estimate is 3.6% for our NSFG sample.

More generally, the results reported in these tables demonstrate that FamilyScape's simulated switching patterns are generally analogous to their real-world equivalents.[51]

[51] There are a limited number of instances in which simulated and real-world switching patterns diverge noticeably. More specifically, the across-month distribution of simulated method choice for married women in the "LARC & Condom" origin category differs nontrivially from the equivalent real-world distribution. As is shown in Table A5, however, only three tenths of one percent of married women fall into this contraceptive category. These differences between simulated and real-world switching behaviors are thus a function of the very limited amount of data available to model switching behavior among women in this category. This type of imprecision has virtually no impact on FamilyScape's aggregate simulation results because it is relevant for only a handful of women. Indeed, while developing the current version of FamilyScape, we explored a number of different parametric approaches to simulating method switching among members of small contraceptive categories. The model's simulated pregnancy and birth rates were essentially unchanged across these various specifications. For all contraceptive categories other than the one referenced here, simulated and real-world switching behaviors are much better aligned. Taken as a whole, then, the results reported in Tables A6 and A7 indicate that FamilyScape produces realistic patterns of switching for contraceptive categories that contain more than a very small number of women.

## Table A6: Comparisons of Real-World and Simulated Female Contraceptive Switching Behavior *Among Unmarried Women**

| Origin Contraceptive Type | | Contraceptive-Type Distribution Across Twelve Consecutive Months | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Female-Controlled Method* | *Male-Controlled Method* | *Female Method:* Nothing *Male Method:* Nothing | *Female Method:* Nothing *Male Method:* Condom | *Female Method:* PPR *Male Method:* Nothing | *Female Method:* PPR *Male Method:* Condom | *Female Method:* LARC *Male Method:* Nothing | *Female Method:* LARC *Male Method:* Condom | *Female Method:* Anything But Sterilization *Male Method:* Sterilization | *Female Method:* Sterilization *Male Method:* Any Method |
| | | **Simulated Data** | | | | | | | |
| None | None | 88.2% | 4.5% | 2.6% | 0.6% | 2.0% | 0.1% | 0.2% | 1.8% |
| None | Condom | 3.9% | 87.9% | 3.2% | 2.7% | 1.0% | 0.3% | 0.5% | 0.5% |
| PPR | None | 2.7% | 3.3% | 88.8% | 3.1% | 1.2% | 0.1% | 0.3% | 0.6% |
| PPR | Condom | 1.7% | 4.2% | 6.9% | 85.8% | 0.5% | 0.4% | 0.3% | 0.2% |
| LARC | None | 4.1% | 3.5% | 4.6% | 0.6% | 84.5% | 1.4% | 0.2% | 1.0% |
| LARC | Condom | 1.4% | 7.2% | 2.1% | 2.6% | 6.0% | 79.6% | 0.1% | 0.9% |
| Any Method Other Than Sterilization | Sterilization | 1.6% | 3.3% | 0.8% | 0.5% | 0.5% | 0.2% | 92.3% | 0.8% |
| Sterilization | Any Method | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | | **Real-World Data** | | | | | | | |
| None | None | 84.9% | 5.9% | 3.6% | 1.2% | 2.4% | 0.3% | 0.6% | 1.1% |
| None | Condom | 3.6% | 88.4% | 3.1% | 3.3% | 0.7% | 0.2% | 0.4% | 0.3% |
| PPR | None | 4.0% | 4.9% | 86.8% | 2.8% | 1.0% | 0.0% | 0.2% | 0.3% |
| PPR | Condom | 1.3% | 4.8% | 8.1% | 84.8% | 0.3% | 0.5% | 0.1% | 0.1% |
| LARC | None | 5.3% | 3.7% | 4.8% | 0.8% | 83.5% | 1.2% | 0.0% | 0.6% |
| LARC | Condom | 0.9% | 8.3% | 1.0% | 3.0% | 5.2% | 81.3% | 0.1% | 0.3% |
| Any Method Other Than Sterilization | Sterilization | 0.6% | 3.5% | 0.7% | 1.6% | 0.1% | 0.0% | 92.9% | 0.6% |
| Sterilization | Any Method | 0.5% | 0.1% | 0.2% | 0.1% | 0.1% | 0.1% | 0.0% | 99.0% |

**Simulated estimates were produced using data on members of FamilyScape's simulation population.  Real-world estimates were produced using data on female members of the National Survey of Family Growth's 2006 - 2010 sample.*

**Table A7: Comparisons of Real-World and Simulated Female Contraceptive Switching Behavior**
***Among Married Women****

| **Origin Contraceptive Type** | | **Contraceptive-Type Distribution Across Twelve Consecutive Months** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Female-Controlled Method* | *Male-Controlled Method* | *Female Method:* Nothing *Male Method:* Nothing | *Female Method:* Nothing *Male Method:* Condom | *Female Method:* PPR *Male Method:* Nothing | *Female Method:* PPR *Male Method:* Condom | *Female Method:* LARC *Male Method:* Nothing | *Female Method:* LARC *Male Method:* Condom | *Female Method:* Anything But Sterilization *Male Method:* Sterilization | *Female Method:* Sterilization *Male Method:* Any Method |
| | | **Simulated Data** | | | | | | | |
| None | None | 90.6% | 2.6% | 3.5% | 0.3% | 1.0% | 0.0% | 0.7% | 1.3% |
| None | Condom | 4.3% | 90.3% | 1.8% | 0.5% | 0.8% | 0.1% | 1.2% | 0.9% |
| PPR | None | 5.3% | 3.2% | 87.6% | 1.2% | 0.9% | 0.1% | 1.0% | 0.6% |
| PPR | Condom | 3.1% | 5.9% | 4.5% | 84.4% | 0.7% | 0.1% | 1.0% | 0.3% |
| LARC | None | 1.9% | 1.9% | 2.2% | 0.2% | 92.3% | 0.2% | 0.6% | 0.7% |
| LARC | Condom | 0.9% | 7.2% | 0.7% | 0.8% | 9.5% | 79.9% | 0.1% | 0.9% |
| Any Method Other Than Sterilization | Sterilization | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| Sterilization | Any Method | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | | **Real-World Data** | | | | | | | |
| None | None | 88.2% | 3.6% | 4.3% | 0.4% | 1.2% | 0.0% | 0.9% | 1.3% |
| None | Condom | 4.3% | 90.1% | 1.4% | 0.9% | 1.1% | 0.1% | 1.6% | 0.5% |
| PPR | None | 6.8% | 3.5% | 86.5% | 0.7% | 0.8% | 0.0% | 1.2% | 0.6% |
| PPR | Condom | 2.8% | 2.8% | 5.4% | 87.3% | 0.5% | 0.2% | 1.0% | 0.0% |
| LARC | None | 3.2% | 1.8% | 2.6% | 0.2% | 91.2% | 0.1% | 0.6% | 0.4% |
| LARC | Condom | 0.1% | 0.8% | 0.0% | 0.0% | 11.8% | 87.2% | 0.0% | 0.0% |
| Any Method Other Than Sterilization | Sterilization | 0.4% | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | 98.7% | 0.8% |
| Sterilization | Any Method | 0.2% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 99.5% |

**Simulated estimates were produced using data on members of FamilyScape's simulation population. Real-world estimates were produced using data on female members of the National Survey of Family Growth's 2006 - 2010 sample.*

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 (i.e., a woman who does not switch methods over the course of the year) 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 that we do not have. First, we would need data on the distribution of the consistency of method use. For instance, we would require information on the proportion of oral contraceptors 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. As an 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 require similar 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 3.0. Rather, we capture much of the variation in the consistency and correctness of contraceptive use by allowing the efficacies of the methods incorporated into the simulation to vary across demographic groups. There are in fact substantial demographic differences in many methods' efficacy levels. Much of this variation occurs across marital-status and age categories. For example, we estimate that the use of a PPR (and no male-controlled method) reduces the risk of pregnancy from a typical act of intercourse by about 35 percent more among married women in their thirties than among unmarried women in their twenties. We assume that this sort of variation reflects demographic differences in the consistency and correctness of method use among women who fall into different contraceptive categories. As is discussed in Appendix IIII, we explicitly simulate demographic variation in contraceptive efficacy rates. In so doing, we therefore account indirectly for a portion of the heterogeneity that exists in the consistency and correctness with which various methods are used.[52]

[52] FamilyScape simulates variation in contraceptive efficacy using data on the pregnancy rates and behavioral characteristics of women who fall into a given contraceptive category in a given month (see the next appendix for more details). However, recall that we simulate contraceptive switching between, but not within, months. Thus, the switching module captures variation in contraceptive behavior between months, while the efficacy module indirectly captures variation in contraceptive behavior within months. The contraceptive efficacy and contraceptive switching modules therefore constitute conceptually distinct components of FamilyScape's architecture.

## Appendix III: Pregnancy & Pregnancy Outcomes

This appendix is subdivided into six sections. In the first section, we describe our methods for modeling female fecundity. The second section provides an overview of FamilyScape's contraceptive efficacy module. The third section explains the way in which we simulate the occurrence of pregnancy and benchmarks FamilyScape's method-specific pregnancy rates. The fourth section outlines the model's procedures for determining whether each simulated pregnancy results in a live birth, an abortion, or a fetal loss. The fifth section details the parameterization of our gestation-period module. And in the sixth and final section, we compare simulated and real-world metrics for several of FamilyScape's most important fertility-related outcomes.

### Fecundity

Each time that a woman has sex during the simulation, there is some probability that she will become 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 the next section contains a detailed treatment of the latter consideration.

A small number of studies have reported estimates of the probability of conceiving from a single act of unprotected sex.[53] Because FamilyScape 3.0 has a daily periodicity and allows for variation by age in its key behaviors and outcomes, it is critical that the model's fecundity

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

module allows conception probabilities to vary both by age and by day in the menstrual cycle.[54] 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 to 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:

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

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; $\kappa_0$ and $\kappa_1$ are econometrically estimated parameters that capture the age-

[54] 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 3.0 has a daily periodicity – it is important that the model incorporate realistic variation in daily conception probabilities.

dependent likelihood of fertilization; and $\alpha_t$ is a vector of generic probabilities of ovular fertilization that vary by the day in the menstrual cycle.[55]

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.[56] We also top-code daily pregnancy probabilities at 40% because Royston's in-sample point estimates never exceed this threshold.[57]

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 upper and lower bounds of FamilyScape's age distribution. Royston's model

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[55] 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 menstrual cycle. This probability is less than one for a variety of reasons. For instance, in any given 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 "$\alpha_t$" component of Equation 1 is modeled as follows: $\alpha_t = \exp(-[t_{ov} - t]/\lambda_s)$ 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, $\lambda_e$ is the average life of the egg in days, and $\lambda_s$ is the average life of the sperm in days. Royston estimates the value of $\lambda_s$ to be 1.47, and he estimates the value of $\lambda_e$ to be .7.

[56] 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., 2002). 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.

[57] 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).

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 into 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.[58] Unfortunately, while there is a consensus in the literature that fecundity levels increase into a woman's early twenties (Treloar, 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

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

of modeling fecundity for younger females as a linear function of age and the timing of menarche.

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.[59] 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), we know of no analysis that 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. These two end points, combined with the aforementioned assumption of linearity, give rise to the following menarche-based fecundity equation:

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

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.[60]

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59 Anderson and Must (2005).

60 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:

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

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

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

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.[61] 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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[61] 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 about 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.[62] 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:

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

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

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

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; $P(Conception|Age = i, Day = j)_R$ is the

[62] 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.

daily, age-based 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.[63] 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 a 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 IVF patients under the age of 40, meaning that we can construct ratios that compare IVF conception probabilities for women under the age of 40 and women over 40.[64]

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[63] 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.

[64] 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:

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

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

$$i \in \{40, 41, \ldots, 44\}, \quad j \in \{1, 2, \ldots, 28\},$$

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; $P(Conception|Age=i, Day=j)_R$ 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.[65]

[65] 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

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.[66] It is probable, however, that our IVF-adjusted conception probabilities still overstate the fecundity levels 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.[67] As a result, we believe that our conception probabilities for women 40 and over likely serve as an upper bound for the true reproductive capacity of this older demographic.

Once the fecundity adjustments described above have been applied, the modified Royston estimates are imported into FamilyScape 3.0 and used to assign daily conception probabilities. Specifically, at the outset of the simulation, 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.[68] Each time that a woman has sex, our corrected versions of Royston's

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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).

[66] We would reiterate that each fecundity adjustment builds upon the previous fecundity corrections described in this appendix. Thus, for example, 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.

[67] 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 in fecundity.

[68] 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 assumes that ovulation always occurs

estimates are used to calculate an initial conception probability as a function of the woman's age and the day in her cycle. As is discussed above, we 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) that the woman and her partner are 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.[69] For our purposes, however, failure rates must be defined somewhat differently. It is perhaps simplest to explain our approach mathematically. Assume that a woman's fecundity level is given by the constant $f$, and assume that she has intercourse $n$ times over a one-year period. 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 single-act failure

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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.

69 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 standard practice within the contraceptive efficacy literature by defining pregnancy rates in percentage terms.

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.

We calculate FamilyScape's contraceptive failure parameters using monthly data on contraceptive use and pregnancy rates among female 2006 – 2010 NSFG respondents who are at risk of pregnancy. As is discussed in Appendix II and in the main body of this paper, our calculations allow for variation by age and marital status in most methods' failure rates. However, we make the simplifying assumption that, within 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 monthly 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 monthly coital frequency among 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 $j$.[70] We then re-state Equation 6 as follows in order to solve for $c_{i,j}$:

[70] 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 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, our equations somewhat understate the true value of $P(Pregnant)_{i,j}$. However, the results

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

We perform separate calculations for each distinct combination of *i* and *j*. In other words, we develop demographically specific failure-rate estimates for each possible combination of female- and male-controlled methods. For example, we separately calculate dual-method failure rates for women who use a PPR and condoms and single-method failure rates for women who use a PPR and no male-controlled method. The only exception to this rule is sterilization, which we assume to completely eliminate the risk of pregnancy for any woman who is sterilized or whose partner is sterilized.[71]

We would also note that we model a "failure rate" for women in FamilyScape's "no female- or male-controlled method" contraceptive category. In other words, even for a woman in the model's "no method" category, we adjust downward her initial single-act conception probability as suggested by our fecundity equations. This decision was informed by a substantial body of evidence showing that many women who self-report as non-contraceptors actually rely on traditional family planning methods (e.g., withdrawal and fertility awareness).[72] This evidence may help to explain why Trussell (2011b) concludes that

of a series of back-of-the-envelope calculations suggest that our understatement of $P(Pregnant)_{i,j}$ has a minimal 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.

[71] In other words, we assume a 0% failure rate for women who are sterilized and for women whose partners are sterilized. As is documented in Table A8 below, real-world data suggest that annual pregnancy rates are well below one percent among both sterilized women and women with sterilized partners.

[72] For example, Jones et al. (2009), in their analysis of qualitative data, conclude that "some women and men who practice only withdrawal do not consider it a contraceptive method and may not report it on surveys" (p. 409). In a subsequent study, Jones et al. (2014) analyze data from a survey designed to measure dimensions of

the annual risk of pregnancy among current contraceptors who discontinue their methods is about 85%, even though the annual pregnancy rate is only about 40% among married women who wish to avoid pregnancy and who self-report as non-contraceptors.

Trussell speculates that this difference may be attributable to the fact that many non-contraceptors are selected for infrequent intercourse and/or for low fecundity. This consideration has implications for our simulations: when women in FamilyScape switch into and out of the "no method" category, we do not model any resulting changes in fecundity or coital frequency. We therefore implicitly assume that FamilyScape's "failure rate" for non-contracepting women reflects the effects of unreported use of traditional methods, rather than that it captures unusually low levels of fecundity or coital frequency among such women. We would also emphasize, however, that the model does in fact account for much of the covariance between method choice, fecundity, and coital frequency, since contraceptive use is simulated based in part on age (which governs fecundity within the simulation), annual sexual activity type, and within-month coital frequency type.

To summarize, then, we estimate demographically specific typical-use contraceptive failure rates for each contraceptive category (including the "no-method" category) save for categories that include sterilization, and our demographic disaggregations account for variation in a given method's failure rates according to both marital status and age.[73] In

withdrawal use that may not be captured by the NSFG. The authors find that the use of withdrawal is reported more than four times as frequently in their survey as in the NSFG. See also Jaccard (2009), Potts and Diggory (1983), and Sinia et al. (2006).

[73] In the nomenclature of population studies, "typical contraceptive use" encompasses both perfect and imperfect use of a given method. Some studies separately report typical-use and perfect-use pregnancy rates among contraceptive users. However, because FamilyScape 3.0 assigns a single contraceptive failure rate to all members of a contraceptive category who have a given set of demographic characteristics, typical-use rates are better suited to our needs.

order to maintain sufficient sample sizes for all of the demographic-contraceptive-method categories included in our analysis, we group women into two broad age categories (15 – 29 and 30 - 44) for the purposes of estimating $f_{i,j}$, $n_{i,j}$, and $P(Pregnant)_{i,j}$.[74] For the same reason, we allow our estimates of these three quantities to vary by marital status, but not by age, for LARC users.

We estimate $n_{i,j}$ using data on the monthly coital frequencies of women in the NSFG who fall into each demographic-contraceptive-method subgroup. Similarly, we produce demographically specific estimates of $f_{i,j}$ by: a) using our adjusted Royston equations to calculate a single fecundity estimate, averaged across all days in the menstrual cycle, for each woman in our NSFG sample; and b) using these estimates to calculate a mean fecundity level for each demographic-contraceptive-method group. We estimate $P(Pregnant)_{i,j}$ in two stages. First, we use the NSFG to estimate the monthly pregnancy rates of women falling into each subgroup.[75] And second, because abortions have been found to be substantially underreported in the NSFG (Jones and Kost, 2007), we correct our NSFG-based estimates of method-specific pregnancy rates for abortion underreporting. Our corrections rely on data taken from Jones et al (2002) and Jones and Jerman (2014).[76] Having developed

[74] We chose this age categorization because it allowed us to create two groups of relatively large size. In exploratory analyses, we found that other categorizations created age groupings that were so small in some cases as to produce unreliable estimates of the inputs for our fecundity calculations.

[75] 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 by contraceptive switching behavior. Contraceptive switching is instead modeled using a separate module that is detailed in Appendix II.

[76] Jones et al. (2002) use data from a survey of abortion patients to estimate the distribution of the most effective form of contraception used during the month of conception among women obtaining abortions. We apply this distribution to Jones and Jerman's (2014) tally of the total number of abortions in 2008 in order to approximate the number of abortions occurring to users of different methods. Because Jones and Jerman's abortion count is based on a survey of all known abortion providers, we assume that their estimate reflects the true number of abortions in the United States in 2008. Next, we use the NSFG to tabulate the annual number of self-reported abortions, disaggregated by the most effective method used during the conception month. For

demographically specific estimates of $n_{i,j}$, $f_{i,j}$, and $P(Pregnant)_{i,j}$ , we plug these quantities into Equation 7 in order to calculate a single-act contraceptive failure rate for each demographic-contraceptive-method subgroup.

**The Simulation of Pregnancy**

As is discussed above, a woman's single-act conception probability is calculated by taking the product of her (day-and-age-specific) natural fecundity level and the single-act failure rate of the contraceptive method that she is using. Each time that a woman has sex, her final conception probability is used to simulate the occurrence of pregnancy according to the approach outlined in Appendix I. In other words, at each act of intercourse, FamilyScape compares the woman's single-act conception probability with the result of a random draw from a uniform (0,1) distribution in order to determine whether or not a pregnancy occurs.

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each contraceptive category *j* (including the category corresponding to the use of no method), we then compute the following:

$$g_j = \frac{(P_j^{NSFG} - A_j^{NSFG}) + A_j^T}{P_j^{NSFG}},$$

where $g_j$ is the pregnancy inflation factor for users of method *j*; $P_j^{NSFG}$ is the (uncorrected) number of pregnancies occurring to users of method *j* as estimated using NSFG data; $A_j^{NSFG}$ is the (uncorrected) number of abortions occurring to users of method *j* as estimated using the NSFG; and $A_j^T$ is the "true" number of abortions occurring to users of method *j* as measured using data reported in Jones et al. (2002) and Jones and Jerman (2014). Note, then, that our estimates of $g_j$ are method-specific ratios of the abortion-undercount-corrected number of annual pregnancies to the uncorrected, NSFG-based count of pregnancies. We apply these ratios $(g_j)$ to our NSFG-derived monthly pregnancy rates in order to produce estimates of abortion-undercount-corrected, method-specific monthly pregnancy rates. Given that Jones et al. (2002) do not produce demographically disaggregated estimates of method-specific abortion counts, we are compelled to assume that the extent of abortion underreporting in the NSFG does not vary systematically between demographic groups within a given contraceptive category. And because Jones and her coauthors analyze data on contraceptive use among abortion patients in 2000 – 2001, we also implicitly assume that the distribution of abortions by method use did not change between this period and the 2006 – 2010 time frame to which FamilyScape is calibrated. We would prefer to have used more recent data and to have allowed our undercount estimates to vary demographically, but the Jones et al. (2002) paper is the most recent study to report estimates of the distribution of abortions by contraceptive method.

Validation of Method-Specific Pregnancy Rates

Having described the way in which FamilyScape models pregnancies, we now benchmark the model's simulated annual pregnancy rates among women who use various forms of contraception. The best available real-world estimates of method-specific pregnancy rates are reported by Trussell (2011a), who calculates the probability of experiencing a pregnancy during a year of typical use of a given method.[77] Trussell develops most of his estimates by allocating each at-risk person-month within his data to the contraceptive method that is the most effective form of contraception used by the woman in question during that month. He then uses these monthly data to estimate a woman's probability of experiencing a pregnancy if she were to use a given method over twelve consecutive months.

We calculate weighted averages of these method-specific pregnancy probabilities in order to produce estimates for broad contraceptive groupings that are comparable to FamilyScape's contraceptive categories. For example, we calculate a weighted average of the annual pregnancy probabilities associated with use of condoms and withdrawal in order to develop a real-world "Condom/Withdrawal" pregnancy-rate benchmark that is comparable to the estimate that we are able to produce with the microdata generated by FamilyScape. The weights used in these calculations reflect the relative shares of women who use each method included within a given contraceptive category. We employ contraceptive-use data reported in Jones et al. (2012) to develop these weights.

[77] Trussell (2011a) defines a person-month to be an "at-risk" month if the woman in question is sexually active, non-sterile, and not already pregnant during the month in question. We adopt the same restrictions in order to produce the simulated estimates reported in Table A8. In point of fact, Trussell's estimates reflect the probability of experiencing a pregnancy during the *first year* of use of a given method. We ignore this distinction because: a) data are not available on annual pregnancy probabilities over all years of method use; and b) once its switching module is activated, FamilyScape simulates women's contraceptive histories for a single year of analysis time.

We replicate Trussell's approach to produce estimates of FamilyScape's method-specific pregnancy rates. In other words, we calculate annual method-specific pregnancy rates using person-month data on women within the simulation who are at risk of pregnancy, we assign each at-risk person-month to a contraceptive category that corresponds to the most effective method that the woman used during the relevant month, and we use all available person-months assigned to a given method in order to calculate an annual continuous-use, typical-use pregnancy probability for women who rely on that method.[78] Because Trussell's estimates are not disaggregated by marital status (or by any other demographic characteristic), we report simulated method-specific pregnancy rates for all women, without respect to marital status.

Table A8 compares FamilyScape's simulated method-specific annual pregnancy probabilities to the comparable estimates reported by Trussell (2011a). Note that we report simulated and real-world estimates for women not using any contraception. Recall from a previous discussion in this appendix that there is wide variation in real-world estimates of risk of pregnancy among non-contraceptors. More specifically, Trussell (2011b) concludes that: a) women currently using reversible contraception would have about an 85% probability of becoming pregnant if they were to discontinue use of their methods but leave their behavior otherwise unchanged; and b) the annual pregnancy rate is about 40% among married women who are not using contraception but who do not wish to become pregnant. Thus, we report

[78] We consider sterilization to be the most effective contraceptive method, we assume that LARC methods are more effective than PPRs, and we assume that PPRs are in turn more effective than condoms. Thus, if a woman within the simulation is using both PPRs and a condom during a given month, the relevant person-month is assigned to the PPR category for the purposes of our calculations. Similarly, if a woman is using a PPR and her partner is sterilized, the relevant person-month is allocated to the male sterilization category, and so forth.

a range of 40% to 85% as the real-world benchmark for the “no-method” group.

For male and female sterilization, LARC, PPRs, and condoms, the simulated and real-world estimates reported in Table A8 are very similar to each other. The simulated annual pregnancy probability for women in the “no-method” group is close to the midpoint of the two real-world estimates for this category. In sum, FamilyScape closely approximates annual real-world, method-specific pregnancy probabilities.

**Table A8: Simulated and Real-World Estimates of the Proportion of Women Experiencing a Pregnancy Within a Year of Typical Contraceptive Use, by Contraceptive Method**

| | *Simulated Data* | *Real-World Data* |
|---|---|---|
| No Method | 66.7% | Between 40.0% and 85.0% |
| Condoms/Withdrawal | 20.2% | 19.0% |
| PPR | 9.6% | 9.7% |
| LARC | 3.1% | 2.7% |
| Male Sterilization | 0.0% | .15% |
| Female Sterilization | 0.0% | .5% |

*Notes: Real-world estimates were generated using data taken from Trussell (2011a) and Jones et al. (2012). Simulated results were generated using data from 100 one-year steady-state runs of the FamilyScape 3.0 model.*

**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. Ideally, these probabilities should vary by pregnant women's demographic characteristics. However, because of limitations in the relevant real-world data, this is somewhat of a challenging task. The relevant limitations of the pregnancy-outcomes data are twofold. First, no single dataset contains all of the information required 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 combining information from three or four different datasets. And 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.

Despite these complications, we are able to use a subset of FamilyScape's standard demographic characteristics to produce disaggregated estimates of the probabilities that a simulated pregnancy will result in a live birth, an abortion, or a fetal loss. We take the following steps to achieve this objective:

- **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 disaggregated 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.

The next three subsections detail our procedures for collecting demographically specific pregnancy-outcomes data, as per the first step of the process described above. The subsequent two subsections describe the implementation of Steps 2 and 3. In the final subsection of this portion of the appendix, we compare simulated and real-world pregnancy-outcome distributions.

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

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 customized 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 2010.[79] 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 national-level data on induced abortion in the United States: the Guttmacher Institute's Abortion Provider Survey (APS) and the Centers for Disease

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

Control and Prevention's (CDC) Abortion Surveillance System.[80] The CDC has collected data on the incidence of abortion for 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 Guttmacher Institute directly surveys almost all known abortion providers.[81] As such, the APS tends to produce higher abortion counts than does the CDC's survey and is generally considered to be the more reliable of the two data sources in this regard.[82] We therefore use data from the Guttmacher Institute rather than from 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.[83] 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 and an overall count of abortions that is generated using 2008 Guttmacher data.

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[80] 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 specific to abortions that fall into the former category.

[81] 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 fielded underreporting surveys in order to determine the extent to which the APS may underestimate the incidence of abortion. The results of these surveys have shown: a) that the APS sample may exclude as many as half of the providers who perform fewer than 30 abortions per year; and b) that the actual annual number of abortions may therefore be three to four percent higher than is implied by the survey (Finer and Henshaw, 2003).

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

[83] 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.

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. 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. However, most publicly available tabulations of the CDC's demographic data are broken down by these characteristics separately but not simultaneously.[84] 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 their analysis. Thus, we eliminate education from our pregnancy-outcomes module, and we use Pazol et al.'s estimates to measure the covariance between age, race, and the incidence of abortion.[85]

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.

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

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 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.[86]

*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 loss. 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.[87] 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 considered the possibility of conducting independent analyses of the NSFG in order to produce demographically specific estimates of the incidence of fetal loss. However, we ultimately concluded that this option was impractical because: a) the number of pregnancies occurring to NSFG respondents in a single year is relatively small; b) fewer than a fifth of pregnancies result in fetal losses; and c) our simulation accounts for a number of different demographic characteristics. As a result, we were often compelled to estimate the frequency of fetal loss using data on an extremely small number of cases. Our estimates for many demographic subgroups were therefore

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

[87] Ventura et al. (2008).

either implausibly large or implausibly small and/or were highly inconsistent with the results of published analyses.[88]

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 the number of fetal losses to the number of 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 yields accurate 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, as discussed above, 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, but they do not account for marital status in their age-race disaggregation.[89] 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 A9 suggest that this is a reasonable assumption. The table shows estimates reported by Ventura et al. (2012) of fetal-loss ratios

[88] For additional discussion of these exploratory analyses, see Thomas and Monea (2009).
[89] See Ventura et al. (2012), Table 3.

that are disaggregated simultaneously by marital status and race.[90] These results suggest that there is little difference between the race-specific ratios of married and unmarried women.[91] 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 A9: 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: a) summing the numbers of live births, abortions, and fetal losses for each subgroup in order

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

[91] 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.

to estimate of the incidence of pregnancy; and b) using these estimates to produce, for each subgroup, the probabilities that a pregnancy will result in each of the three outcomes.

*Step #3: Assignment of Pregnancy-Outcome Probabilities*

In the third and final step of this process, we use the data described above to provide each woman in the simulation population with a set of live-birth, abortion, and fetal-loss probabilities based on her age, race and marital status. We then use linear regressions to model these pregnancy-outcome probabilities, estimating separate models for married and unmarried women.[92] All regressions control for the mother's age and race. The coefficients from these regression equations are used to assign final pregnancy-outcome probabilities to each woman within the simulation. Every time that a simulated pregnancy occurs, we use these probabilities to determine that pregnancy's outcome according to the procedure outlined in Appendix I.

Validation of Pregnancy-Outcome Distributions

Figure A8 compares simulated and real-world data on the shares of pregnancies to unmarried women that result in live births, induced abortions, and fetal losses. Figure A9 presents the same comparison for pregnancies to married women. For both groups, FamilyScape produces realistic pregnancy-outcome distributions.

[92] To be clear, then, the analytic samples for these regressions are comprised of individual women in FamilyScape's simulation population.

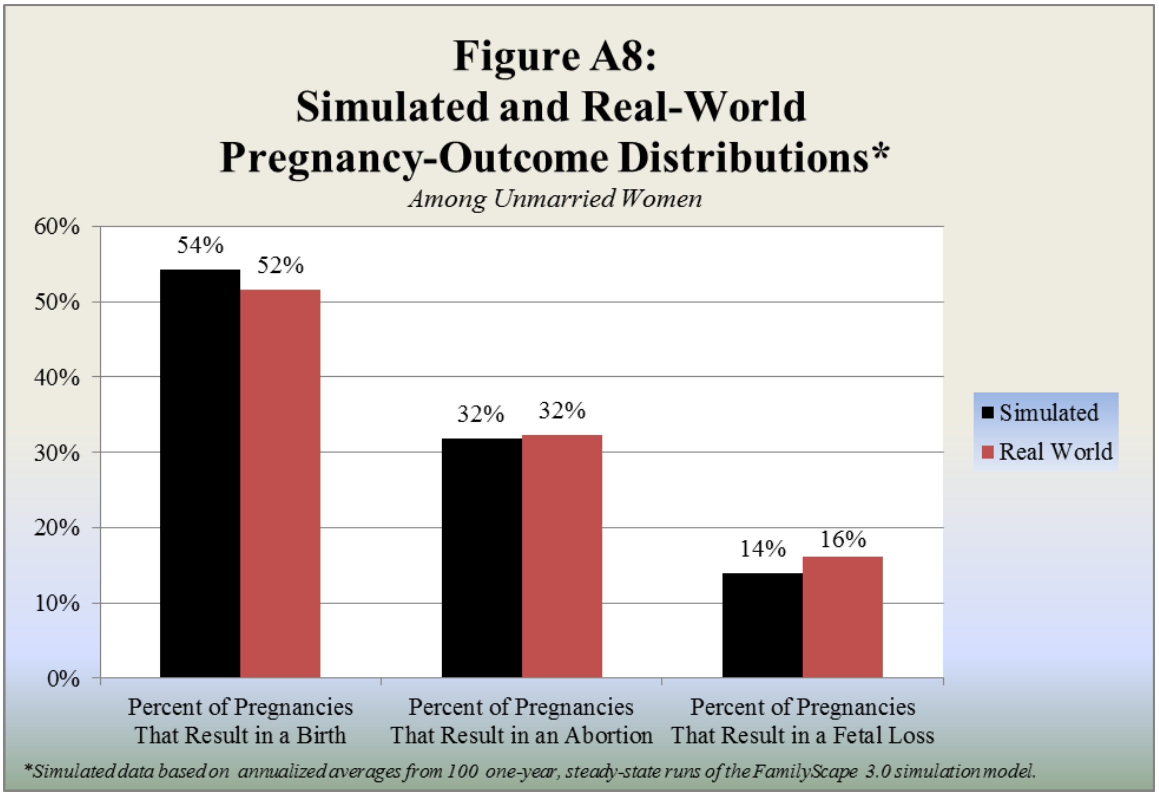
Figure A8:
Simulated and Real-World
Pregnancy-Outcome Distributions*
Among Unmarried Women
60%
50%
40%
30%
20%
10%
0%
54%
52%
32%
32%
14%
16%
Simulated
Real World
Percent of Pregnancies That Result in a Birth
Percent of Pregnancies That Result in an Abortion
Percent of Pregnancies That Result in a Fetal Loss
*Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.

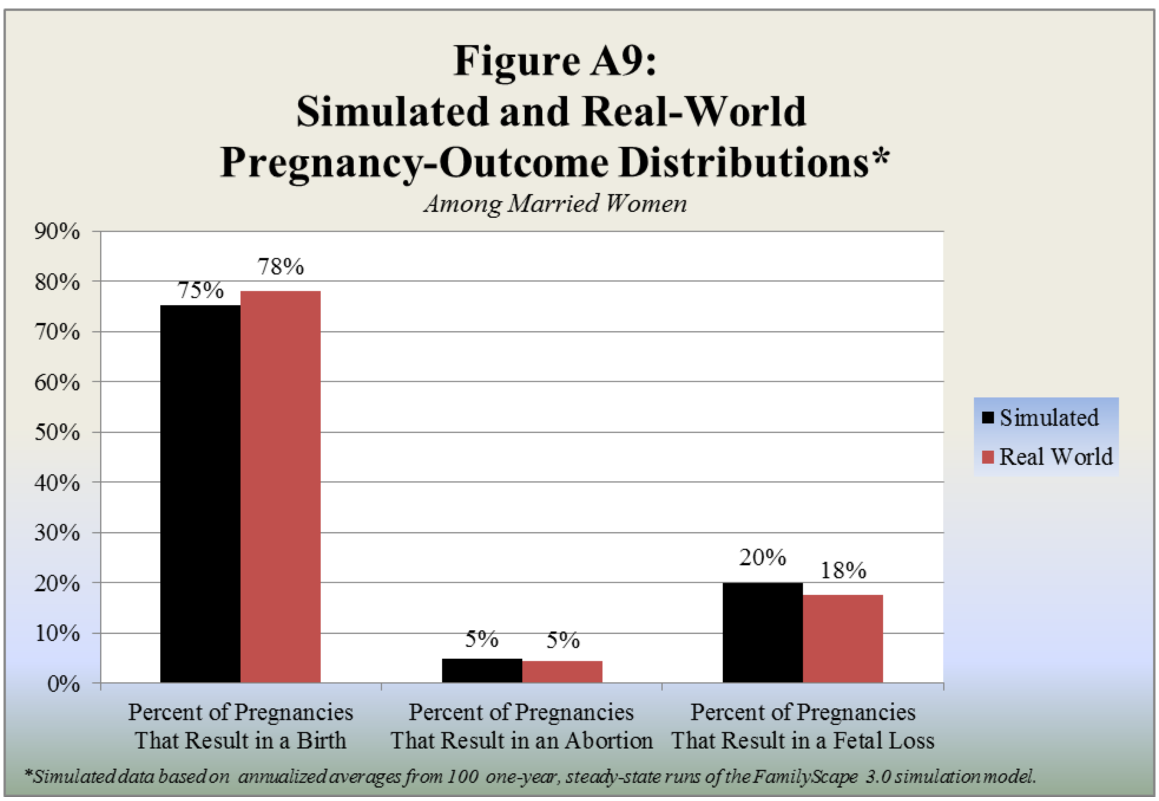
Figure A9:
Simulated and Real-World
Pregnancy-Outcome Distributions*
Among Married Women
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
75%
78%
5%
5%
20%
18%
Simulated
Real World
Percent of Pregnancies That Result in a Birth
Percent of Pregnancies That Result in an Abortion
Percent of Pregnancies That Result in a Fetal Loss
*Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.

**Gestation Periods**

When FamilyScape assigns an outcome for a newly simulated pregnancy, a gestation period is also assigned to that pregnancy. A woman within the simulation is unable to become pregnant again for the duration of her 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.[93]

Given that women are also 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 interval 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 16 weeks, and that the average period of post-pregnancy infertility after an abortion or a fetal loss lasts for about three weeks.[94] Once it is determined that a pregnancy will result in a live birth, a random draw is therefore taken from a uniform (357,385) distribution in order to specify the combined length of the woman's gestation and post-pregnancy infertility periods.

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[93] Information on gestation periods for live births was taken from Martin et al. (2013). 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). 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).

[94] For additional information on postpartum infertility, see National Center for Chronic Disease Prevention and Health Promotion (2015), Hatcher et al. (2004), and Pinto and Palloni (1996); for additional information on post-abortion infertility, see Curtis et al. (2010) and World Health Organization (2007); and, for additional information on infertility after a fetal loss, see MD Health (2015) and MedicineNet (2015).

For abortions and miscarriages, equivalent draws are taken from uniform (35,111) and (49,91) distributions, respectively.[95]

**Validation of Key Simulation Results**

We now turn to what is perhaps the most critical test of FamilyScape's architecture: a comparison of simulated and real-world pregnancy, birth, and abortion rates. We begin by describing our methods for calculating the demographically specific real-world benchmarks with which FamilyScape's simulated results are compared. We then assess the model's capacity to match these benchmarks.

Pregnancy and Pregnancy-Outcome Benchmarks

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 develop 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 the 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

[95] 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 (16*7) = 112 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 + 112 = 357 and whose upper bound is 273 + 112 = 385.

not disaggregate their age-and-marital-status cross-tabulations by race and Ventura et al. do not disaggregate their age-and-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 characteristic). 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.[96]

[96] Later in this section, we discuss the fact that the model is less accurate in simulating pregnancies for women over the age of 40 than for younger women. We ultimately conclude that outcomes for women over 40 should be eliminated when results are reported from FamilyScape's policy simulations. We arrived at this decision after having made 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 (2012) 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 older 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 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.

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 can easily be disaggregated simultaneously 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 estimate 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.[97]

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 by the United States Census Bureau (2012), which were themselves derived from the Annual Social and Economic Supplement to the 2008 Current Population Survey.[98]

Validation of Pregnancy, Birth, and Abortion Rates

Table A10 presents detailed simulated and real-world pregnancy and pregnancy-outcome estimates. The table reports annual rates of pregnancy, birth, and abortion per 1,000

[97] For reasons discussed in our explanation of Step #1c above, this would seem to be a sensible assumption.
[98] Zolna and Lindberg (2012) use the same approach to generate population denominators for their analysis.

women. Estimates are disaggregated by marital status and age. The top panel of the table displays averaged results from 100 runs of the model. The bottom panel presents real-world pregnancy and pregnancy-outcome benchmarks from 2008 as measured using the data described above. The greyed rows at the bottom of each panel report aggregate pregnancy, birth, and abortion rates among married and unmarried women.

Aggregate simulated pregnancy and birth rates for unmarried women are within about 2% of their real-world targets, and the simulated unmarried abortion rate is within about 4% of its corresponding benchmark. Among married women, the simulated pregnancy rate is within about 3% of its target, and simulated and real-world birth rates are nearly identical. The simulated rate of abortion among married women is, in proportional terms, somewhat further away from its real-world benchmark, but this difference is small in absolute terms (.7 abortions per 1,000 married women) because the married abortion rate is so low. On the whole, then, these results demonstrate that FamilyScape is able to replicate with considerable precision a number of important aggregate real-world benchmarks among both married and unmarried women.

| Table A10: Comparison of Simulated and Real-World Fertility 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 | 78.3 | 215.5 | 79.5 | 19.0 | 45.5 | 19.3 | 45.7 | 126.5 | 46.4 |
| 20-29 | 140.2 | 225.9 | 166.4 | 45.1 | 13.5 | 35.4 | 77.7 | 174.2 | 107.3 |
| 30-39 | 84.0 | 113.9 | 102.8 | 34.1 | 3.8 | 15.1 | 37.6 | 83.6 | 66.5 |
| *All* | *107.6* | *152.9* | *124.3* | *34.3* | *7.3* | *24.3* | *58.4* | *114.9* | *79.2* |
| **Real-World Data** | | | | | | | | | |
| 15-19 | 67.7 | 234.9 | 72.5 | 19.2 | 0.7 | 18.7 | 37.0 | 194.3 | 41.5 |
| 20-29 | 146.1 | 209.9 | 168.2 | 47.8 | 9.2 | 34.4 | 77.6 | 170.8 | 109.9 |
| 30-39 | 102.1 | 113.6 | 110.0 | 36.2 | 5.5 | 15.2 | 44.8 | 84.7 | 72.2 |
| *All* | *110.1* | *147.6* | *125.6* | *35.6* | *6.6* | *23.6* | *56.8* | *115.1* | *81.0* |

*Notes: Real-world data were derived using estimates reported in 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 here. Simulated results were generated using data from 100 one-year steady-state runs of the FamilyScape 3.0 model.*

Many of FamilyScape's demographically disaggregated estimates are also well-matched to their real-world equivalents. Among unmarried women in their twenties, for example, the simulated rates of pregnancy, birth, and abortion are all quite close to their targets. For other subgroups, however, the model's simulated results are further removed from their corresponding benchmarks. This dynamic is the most pronounced for comparatively small groups (e.g., married teenagers and unmarried women in their thirties) and for outcomes that occur with very low frequency within a given subpopulation (in particular, abortions to married women).[99] This general result is to be expected, given that the demands placed upon the relevant data become increasingly difficult to meet for increasingly small groups and/or or for outcomes that are increasingly rare. It is, however, noteworthy that the model's simlated teen pregnancy rate (79.5 pregnancies per 1,000 teenaged girls) is not far off from its real-world benchmark (72.5 pregnancies per 1,000 teens).

[99] Among the members of FamilyScape's simulation population aged 15 – 39, women between the ages of 30 and 39 constitute a smaller share (23%) of the unmarried population than do women in any other age group, while teenagers constitute the smallest share (1%) of married women. Conversely, the groups for which FamilyScape performs especially well tend to be comparatively large. For example, women in their twenties represent the largest age group (45%) within the unmarried population, and women in their thirties comprise the largest share (65%) of the married population. As is discussed above, the model produces realistic results for unmarried women in their twenties. The same is generally true for married women in their thirties.

We have also found that the model over-simulates pregnancies to a noticeably greater degree among women in their forties than among women under 40. This suggests that, even after we have implemented our fertility adjustments, the age-based decline in fecundity within FamilyScape may be too gradual for this group, as we hypothesized in Appendix III. Thus, and since the literature is particularly sparse with respect to the shape of the age-fecundity profile for women over 40, we have chosen not to include results for this age range when we report findings from FamilyScape's policy simulations. Hence the fact that Table A10 here and Figures 6 and 7 in the main body of this paper focus only on pregnancies and pregnancy outcomes among women aged 15 to 39.

Taken as a whole, these results suggest that it is more appropriate to use FamilyScape to perform policy simulations targeted on broad groups (teenagers and unmarried women, for example) than to target narrowly defined demographic subpopulations. For these larger groups, FamilyScape's simulated fertility outcomes are sufficiently realistic to allow for credible and informative policy analyses.

## Appendix IV: Newborn Child Outcomes

This fourth 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 interwoven throughout the simulation modules that have already been explicated in the previous three appendices. For example, Appendix II explains the ways in which we differentiate between married and unmarried women in the simulation of sexual activity and contraceptive use. These dynamics represent two of the most important proximate causes of pregnancy, which in turn is a necessary prerequisite for childbearing. Appendix III then describes our methods for simulating the occurrence of pregnancy and childbearing (among other pregnancy outcomes) among married and unmarried women. Thus, the prior sections of this paper collectively serve as an overview of our approach to modeling family structure, 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.

We do, however, describe here FamilyScape's poverty-simulation module. This component of the model is parameterized based on the results of regression models that were estimated using data from the March 2009 CPS, which contains income data for calendar year 2008.[100] Because we are interested in modeling 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

[100] Given that most of FamilyScape's parameters were developed via analysis of NSFG data, and for the sake of consistency, we previously considered the possibility of using the pregnancy file of the NSFG rather than the CPS to estimate 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).

the child, information for the relevant demographic controls is taken from the mother. Thus, we regress infants' poverty statuses on their mothers' demographic characteristics.[101] More specifically, these regressions control for the mother's age, education level, and race.[102] Separate models are estimated for children born to married and unmarried mothers.

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 demographic characteristics. A poverty status is then assigned to the child according to the approach outlined in Appendix I. Figure A10 compares the simulated poverty rates of children born to unmarried and married mothers with their real-world equivalents. For both groups, FamilyScape 3.0 approximates real-world newborn child poverty rates relatively well.

[101] 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-Walt et al. (2013).

[102] These regressions were weighted using the mother and child's family weight. We do not include controls for SES because the necessary data are not available in the CPS.

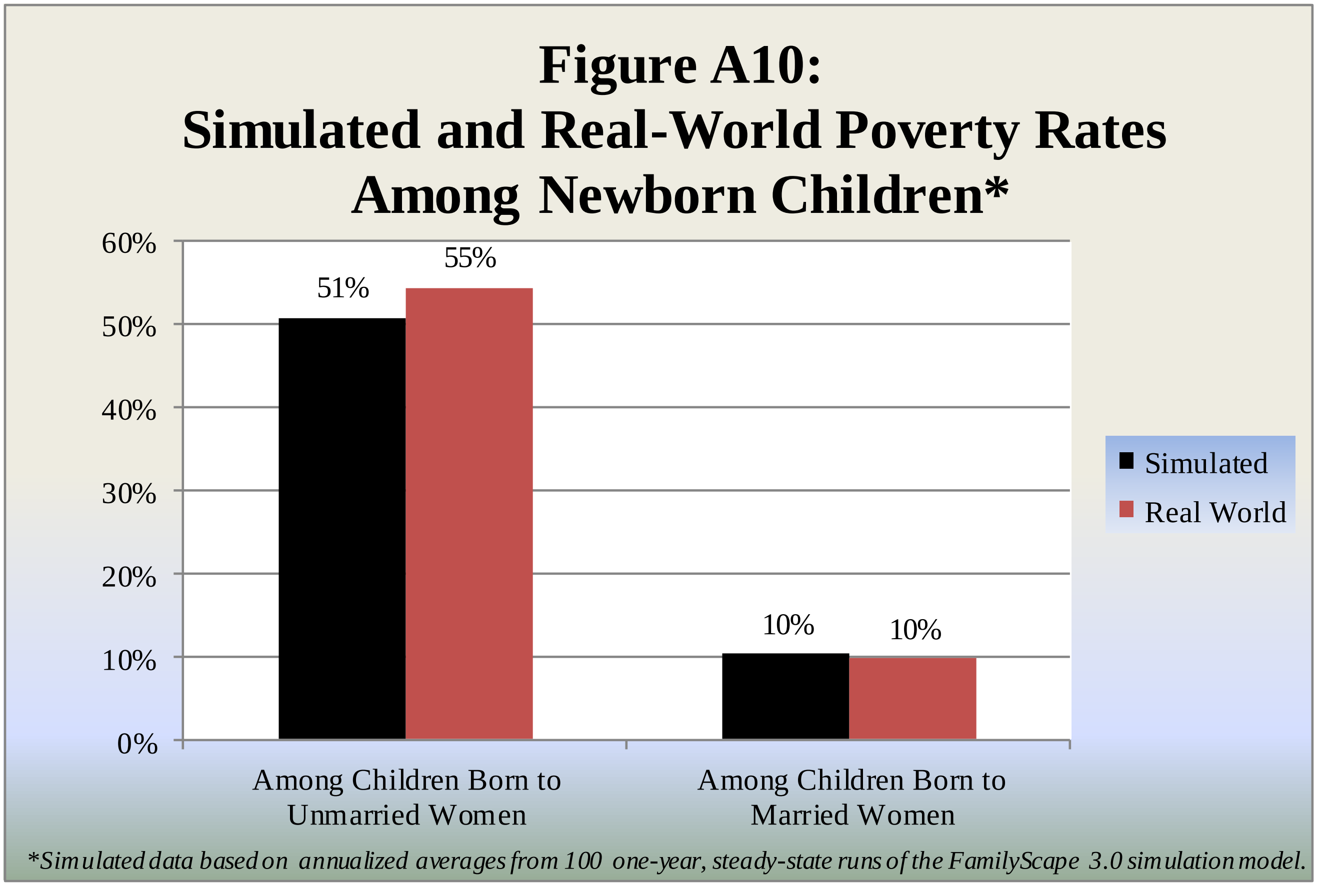
Figure A10:
Simulated and Real-World Poverty Rates
Among Newborn Children*
60%
50%
40%
30%
20%
10%
0%
51%
55%
10%
10%
Among Children Born to Unmarried Women
Among Children Born to Married Women
Simulated
Real World
*Simulated data based on annualized averages from 100 one-year, steady-state runs of the FamilyScape 3.0 simulation model.

## Works Cited

Abdalla, Hossam, Gilbert Burton, Angela Kirkland, Mark Johnson, Terence Leonard, Alan Brooks, and John Studd. "Age, Pregnancy and Miscarriage: Uterine versus Ovarian Factors." *Human Reproduction* 8 (1993): 1512 – 1517.

Anderson, Sarah and Aviva Must. "Interpreting the Continued Decline in the Average Age at Menarche: Results from Two Nationally Representative Surveys of U.S. Girls Studied 10 Years Apart." *Journal of Pediatrics* 147 (2005): 753 – 760.

Barrett, John C. and John Marshall. "The Risk of Conception on Different Days of the Menstrual Cycle." *Population Studies* 23 (1969): 455 – 461.

Bongaarts, John. "The Proximate Determinants of Natural Marital Fertility." In Rudolfo A. Bulatao and Ronald D. Lee (eds.), *Determinants of Fertility in Developing Countries, Volume I.* New York, N.Y.: Academic Press, 1983.

Bornstein, Marc H., Chun-Shin Hahn, Joan T.D. Suwalsky, and O. Maurice Haynes. "The Hollingshead Four-Factor Index of Social Status and the Socioeconomic Index of Occupations." In Marc H. Bornstein and Robert H. Bradley (eds.), *Socioeconomic Status, Parenting, and Child Development*. Mahwah, NJ: Lawrence Erlbaum Associates, 2003.

Brown, Stephen. "Miscarriage and its Associations." *Seminars in Reproductive Medicine* 26 (2008): 391 – 400.

Citro Constance F. and Eric A. Hanushek. *The Uses of Microsimulation Modeling, Volume 1: Review and Recommendations*. Washington, D.C.: National Academy Press, 1991.

Colombo, Bernardo and Guido Masarotto. "Daily Fecundability: First Results from a New Data Base." *Demographic Research* 3 (2000): 5.

Curtis, Carolyn, Douglas Huber, and Tamarah Moss-Knight. "Postabortion Family Planning: Addressing the Cycle of Repeat Unintended Pregnancy and Abortion." *International Perspectives on Sexual and Reproductive Health* 36 (2010): 44 – 48.

DeNavas-Walt, Carmen, Bernadette D. Proctor, and Jessica C. Smith. *Income, Poverty, and Health Insurance Coverage in the United States: 2012*. United States Census Bureau Report #P60-245 (2013).

Dixon, Garret W., James J. Schlesselman, Howard W. Ory, Richard P. Blye. "Ethinyl Estradiol and Conjugated Estrogens as Postcoital Contraceptives." *Journal of the American Medical Association* 244 (1980): 1336 – 1339.

Dunson, David, Bernardo Colombo, and Donna Baird. "Changes with Age in the Level and Duration of Fertility in the Menstrual Cycle." *Human Reproduction* 17 (2002): 1399 – 1403.

Everett, Christopher. "Incidence and Outcome of Bleeding Before the 20th Week of Pregnancy: Prospective Study from General Practice." *British Medical Journal* 315 (1997): 32 – 34.

Finer, Lawrence B. and Stanley K. Henshaw. "Abortion Incidence and Services in the United States in 2000." *Perspectives on Sexual and Reproductive Health* 35 (2003): 6 – 15.

Fu, Haishan, Jacqueline Darroch, Taylor Haas and Nalini Ranjit. "Contraceptive Failure Rates: New Estimates from the 1995 National Survey of Family Growth." *Family Planning Perspectives* 31 (1999): 56 – 63.

Gamble, Sonya B., Lilo T. Strauss, Wilda Y. Parker, Douglas A. Cook, Suzanne B. Zane, and Saeed Hamdan. *Abortion Surveillance – United States, 2005*. Morbidity and Mortality Weekly Report #57-SS13 (2008).

The Guttmacher Institute. *In Brief: Facts on Induced Abortions in the United States*, http://www.guttmacher.org/pubs/fb_induced_abortion.html (2008).

The Guttmacher Institute. *Issues in Brief: The Limitations of U.S. Statistics on Abortion*, http://www.guttmacher.org/pubs/ib14.html (1997).

Harding, Ann. *Challenges and Opportunities of Dynamic Microsimulation Modelling*. University of Canberra National Centre for Social and Economic Modelling Working Paper (2007).

Hatcher, Robert A., James Trussell, Felicia Stewart, Anita L. Nelson, Willard Cates Jr., Felicia Guest, and Deborah Kowal. *Contraceptive Technology: 18th Revised Edition*. New York: Arden Media Inc., 2004.

Henshaw, Stanley K. and Kathryn Kost. *Trends in the Characteristics of Women Obtaining Abortions, 1974 to 2004*. New York: Guttmacher Institute, 2008.

Jaccard, James. *Unlocking the Contraception Conundrum: Reducing Unplanned Pregnancies in Emerging Adulthood*. Washington, D.C.: The National Campaign to Prevent Teen and Unplanned Pregnancy, 2009.

Jones, Jo, William Mosher, and Kimberly Daniels. *Current Contraceptive Use in the United States, 2006 – 2010, and Changes in Patterns of Use Since 1995*. National Center for Health Statistics Report #60 (2012).

Jones, Rachel, Jaqueline Darroch, and Stanley K. Henshaw. "Contraceptive Use among Women Having Abortions in 2000 – 2001." *Perspectives on Sexual and Reproductive Health* 34 (2002): 294 – 303.

Jones, Rachel, Julie Fennell, Jenny Higgins, and Kelly Blanchard. "Better than Nothing or Savvy Risk-Reduction Practice?: The Importance of Withdrawal." *Contraception* 79 (2009): 407 – 410.

Jones, Rachel, and Jenna Jerman. "Abortion Incidence and Service Availability in the United States." *Perspectives on Sexual and Reproductive Health* 46 (2014): 3 – 14.

Jones, Rachel, Laura Lindberg, and Jenny Higgins. "Pull and Pray or Extra Protection?: Contraceptive Strategies Involving Withdrawal among US Adult Women." *Contraception* 90 (2014): 416 – 421.

Jones, Rachel and Kathryn Kooistra. "Abortion Incidence and Access to Services in the United States, 2008." *Perspectives on Sexual and Reproductive Health* 43 (2011): 41 – 50.

Jones, Rachel K. and Kathryn Kost. "Underreporting of Induced and Spontaneous Abortion in the United States: An Analysis of the 2002 National Survey of Family Growth." *Studies in Family Planning* 38 (2007): 187 – 197.

Jones, Rachel K., Mia Zolna, Stanley K. Henshaw, and Lawrence B. Finder. "Abortion in the United States: Incidence and Access to Services, 2005." *Perspectives on Sexual and Reproductive Health* 40 (2008): 6 – 16.

Lass, Amir, Carolyn Croucher, Suzanne Duffy, Karin Dawson, Raul Margara, and Robert Winston. "One Thousand Initiated Cycles of In Vitro Fertilization in Women ≥ 40 Years of Age." *Fertility and Sterility* 70 (1998): 1030 – 1034.

Leridon, Henri. "Can Assisted Reproduction Technology Compensate for the Natural Decline in Fertility with Age? A Model Assessment." *Human Reproduction* 19 (2004): 1548 – 1553.

MacDorman, Marian F., Munson, Martha L., and Kimeyer, Sharon. *Fetal and Perinatal Mortality, United States, 2004*. National Vital Statistics Report #56-3 (2007).

Martin, Joyce A., Brady E. Hamilton, Michelle J.K. Osterman, Sally C. Curtin, and T.J. Matthews. *Births: Final Data for 2012*. National Vital Statistics Report #62-9 (2013).

McDonald, John, Alessandro Rosina, Ester Rizzi, and Bernardo Colombo. "Age and Fertility: Can Women Wait Until their Early Thirties to Try for a First Birth?" *Journal of Biosocial Science* 43 (2011): 685 – 700.

MD Health. *Fertility after Miscarriage*, http://www.md-health.com/Fertility-After-Miscarriage.html (accessed February 18, 2015).

MedicineNet. *Pregnancy after Miscarriage*, http://www.medicinenet.com/pregnancy_after_miscarriage_trying_again/views.htm (accessed February 18, 2015).

Menken, Jane, James Trussell, and Ulla Larsen. "Age and Infertility." *Science* 233 (1986): 1389 – 1393.

Merz, Joachim. *Microsimulation: A Survey of Methods and Applications for Analyzing Economic and Social Policy*. Forschungsinstitut Freie Berufe Discussion Paper #9 (1994).

Mitton, Lavinia, Holly Sutherland, and Melvyn Weeks. "Introduction." In Lavinia Mitton, Holly Sutherland, and Melvyn Weeks (eds.), *Microsimulation Modelling for Policy Analysis: Challenges and Innovations*. Cambridge, United Kingdom: Cambridge University Press, 2000.

Moreau, Caroline, James Trussell, Germàn Rodriguez, Nathalie Bajos, and Jean Bouyer. "Contraceptive Failure Rates in France: Results from a Population-Based Survey." *Human Reproduction* 22 (2007): 2422 – 2427.

National Center for Chronic Disease Prevention and Health Promotion. *Breastfeeding Report Card, United States, 2014*, http://www.cdc.gov/breastfeeding/pdf/2014breastfeedingreportcard.pdf (accessed February 18, 2015).

National Center for Health Statistics. *National Marriage and Divorce Rate Trends*, http://www.cdc.gov/nchs/nvss/marriage_divorce_tables.htm (accessed January 28, 2015).

National Center for Health Statistics. *VitalStats Births*, http://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm (accessed December 7, 2012).

National Center for Health Statistics. *Public-Use Data File Documentation: 2006 – 2010 National Survey of Family Growth, User's Guide*. Hyattsville, MD: Centers for Disease Control and Prevention, 2011.

Nybo Anderson, Anne-Marie, Jan Wohlfahrt, Peter Christens, Jorn Olsen, and Mads Melbye. "Maternal Age and Fetal Loss: Population Based Register Linkage Study." *British Medical Journal* 320 (2000): 1708 – 1712.

Pazol, Karen, Suzanne Zane, Wilda Parker, Laura Hall, Cynthia Berg, and Douglas Cook. *Abortion Surveillance – United States, 2008*. Centers for Disease Control and Prevention Morbidity and Mortality Weekly Report #60-SS15 (2011).

Physicians for Reproductive Choice and Health. *An Overview of Abortion in the United States*, http://www.guttmacher.org/presentations/abort_slides.pdf (accessed November 28, 2012).

Pinto, Guido and Alberto Palloni. *Effects of Lactation on Post-Partum Amenorrhea: Re-Estimation Using INCAP Data*. University of Wisconsin-Madison Center for Demography and Ecology Working Paper #96-17 (1996).

Potts, Malcolm and Peter Diggory. *Textbook of Contraceptive Practice, Second Edition*. New York, NY: Cambridge University Press, 1983.

Royston, Patrick. "Basal Body Temperature, Ovulation and the Risk of Conception, with Special Reference to the Lifetimes of Sperm and Egg." *Biometrics* 38 (1982): 397 – 406.

Saul, Rebekah. "Abortion Reporting in the United States: An Examination of the Federal-State Partnership." *Family Planning Perspectives* 30 (1998): 244 – 247.

Sawhill, Isabel, Quentin Karpilow, Jennifer Manlove, and Adam Thomas. *The Role of Contraception in Preventing Abortion, Nonmarital Childbearing, and Child Poverty*. Manuscript included in the Online Paper Collection for the Fall 2013 Research Conference of the Association for Public Policy Analysis and Management, 2013.

Sawhill, Isabel, Adam Thomas, and Emily Monea. "An Ounce of Prevention: Policy Prescriptions to Reduce the Prevalence of Fragile Families." *Future of Children* 21 (2010): 133 – 155.

Schwartz, Daniel and Marie-Jeanne Mayaux. "Female Fecundity as a Function of Age: Results of Artificial Insemination in 2193 Nulliparous Women with Azoospermic Husbands." *New England Journal of Medicine* 306 (1982): 404 – 406.

Sinai, Irit, Rebecka Lundgren, Marcos Arévalo, and Victoria Jennings. "Fertility Awareness-Based Methods of Family Planning: Predictors of Correct Use." *International Family Planning Perspectives* 32 (2006): 94 – 100.

Spira, Alfred. "The Decline of Fecundity with Age." *Maturitas* 1 (1988): 15 – 22.

Teruya, Yoko, Shigeru Kamiyama, Makoto Hirakawa, Kie Yamashiro, and Koji Kanazawa. "Accelerated Decline in Pregnancy Rate after In Vitro Fertilization and Embryo Transfer in 35-41-year-old Women: 15 Years' Experience in the Okinawa Islands, Japan." *Reproductive Medicine and Biology* 5 (2006): 51 – 57.

Thomas, Adam. "The Role of Mass Media Campaigns in Preventing Unintended Pregnancy." *Journal of Media and Communication Studies* 6 (2014): 23 – 27.

Thomas, Adam. *Policy Solutions for Preventing Unplanned Pregnancies*. Brookings Center on Children and Families Policy Brief #47 (2012a).

Thomas, Adam. "Three Strategies to Prevent Unintended Pregnancy." *Journal of Policy Analysis and Management 3*1 (2012b): 280 – 311.

Thomas, Adam. "Unintended Pregnancy and Public Policy." *Notre Dame Journal of Law, Ethics, and Public Policy 26* (2012c): 501 – 532.

Thomas, Adam, Quentin Karpilow, and Alex Gold. *FamilyScape 2.0: An Architectural Overview*. Brookings Institution Center on Children and Families Working Paper (2013).

Thomas, Adam and Emily Monea. *FamilyScape: A Simulation Model of Family Formation*. Brookings Institution Center on Children and Families Working Paper (2009).

Treloar, Alan E. "Menarche, Menopause, and Intervening Fecundability." *Human Biology* 46 (1974): 89 – 107.

Trussell, James. "Contraceptive Efficacy." In Robert A Hatcher, James Trussell, Anita L. Nelson, Willard Cates Jr., Deborah Kowal, and Michael Policar (eds.), *Contraceptive Technology: Twentieth Revised Edition*. New York: Arden Media Inc., 2011a.

Trussell, James. "Contraceptive Failure in the United States." *Contraception* 83 (2011b): 397 – 404.

Trussell, James, Barbara Vaughan, and Joseph Stanford. "Are All Contraceptive Failures Unintended Pregnancies? Evidence from the 1995 National Survey of Family Growth." *Family Planning Perspectives* 31 (1999): 246 – 247.

United States Census Bureau. *Table A1. America's Families and Living Arrangements: 2008,* http://www.census.gov/population/www/socdemo/hh-fam/cps2008.html (accessed November 28, 2012).

Ventura, Stephanie J., Joyce C. Abma, William Mosher, and Stanley K. Henshaw. *Estimated Pregnancy Rates by Outcome for the United States, 1990-2004*. National Vital Statistics Report #56-15 (2008).

Ventura, Stephanie J., Sally C. Curtin, Joyce C. Abma, and Stanley K. Henshaw. *Estimated Pregnancy Rates and Rates of Pregnancy Outcomes for the United States, 1990-2008*. National Vital Statistics Report #60-7 (2012).

Vollman, Rudolf. "Assessment of the Fertile and Sterile Phases of the Menstrual Cycle." *International Review of Natural Family Planning* 1 (1977): 40 – 47.

Weinstein, Maxine, James Wood, Michael Stoto and Daniel Greenfield. "Components of Age-Specific Fecundability." *Population Studies* 44 (1990): 447 – 467.

Wilcox, Allen J., Clarice R. Weinberg, and Donna D. Baird. "Timing of Sexual Intercourse in Relation to Ovulation." *The New England Journal of Medicine* 333 (1995): 1514 – 1521.

Wilcox, Allen J., Clarence R. Weinberg, John F. O'Connor, Donna D. Baird, John P. Schlatterer, Robert E. Canfield, E. Glenn Armstrong, and Bruce C. Nisula. "Incidence of Early Loss of Pregnancy." *New England Journal of Medicine* 319 (1988): 189 – 194.

Wood, James. "Fecundity and Natural Fertility in Humans." *Oxford Review of Reproductive Biology* 11 (1989): 61 – 109.

Wood, James and Maxine Weinstein. "A Model of Age-Specific Fecundability." *Population Studies* 42 (1988): 85 – 113.

World Health Organization. *Family Planning: A Global Handbook for Providers*. Baltimore, MD: Johns Hopkins Bloomberg School of Public Health, 2007.

Zolna, Mia and Laura Lindberg. *Unintended Pregnancy: Incidence and Outcomes among Young Adult Unmarried Women in the United States, 2001 and 2008*. New York: Guttmacher Institute, 2012.