Published in final edited form as:

Stud Fam Plann. 2014 December ; 45(4): 429–441. doi:10.1111/j.1728-4465.2014.00006.x.

What is the Best Way to Reduce Unintended Pregnancies? A Micro Simulation of Contraceptive Switching, Discontinuation and Failure Patterns in France

Nadia Diamond-Smith^a, Caroline Moreau^{a,b}, and David Bishai^a

^aDepartment of Population, Family and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, 615 North Wolfe Street, Baltimore, MD 21205, USA

^bGender, sexual and reproductive health, CESP Centre for research in Epidemiology and Population Health, U1018, Inserm, F-94807, Kremlin Bicêtre, France

Abstract

Despite high rates of contraceptive use in France, over a third of pregnancies are unintended. We built a dynamic micro simulation model which applies data from the French COCON study on method switching, discontinuation, and failure rates to a hypothetical population of 20,000 women, followed for 5 years. We use the model to estimate the adjustment factor needed to make the survey data fit the demographic profile of France, by adjusting for underreporting of contraceptive non-use and abortions. We then test three behavior change scenarios which would aim to reduce unintended pregnancies: decreasing method failure, increasing time spent on effective methods, and increasing switching from less to more effective methods. Our model suggests that decreasing method failure is the most effective strategy for reducing unintended pregnancies, but all scenarios reduced unintended pregnancies by at least 25%. Dynamic micro simulations such as this may be useful for policy makers.

Keywords

contraception; unintended pregnancy; micro simulation modelling; contraceptive failures

Introduction

Contraceptive use is high in France where over 60% of women use a very effective method (IUD, pill, sterilization or implant) and less than 3% of women who need contraception are not using any method (Bajos et al. 2003; Bajos et al. 2004b). However, over a third of pregnancies in 2000 were reported to be unintended (Bajos et al. 2003). The COCON study

Corresponding author: Nadia Diamond Smith, Department of Population, Family and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, 615 North Wolfe Street, Baltimore, MD 21205, USA.

Authors Roles:

Nadia Diamond-Smith: Built the micro simulation model and wrote the paper

Caroline Moreau: Ran the data to get all necessary parameters, helped with concept, contributed to writing the paper and read all drafts

David Bishai: Oversaw the project, had the initial idea of using this data for micro simulation modeling, designed the architecture and parameterization of the model, contributed to interpreting the data, writing the paper and read all drafts

found that when asked the reason for unintended pregnancies, 46% of women cited incorrect or inconsistent contraceptive use, 19% did not know why they became pregnant despite using a method—a response assumed to partially reflect method failure, and 35% cited no contraceptive use (Goulard et al. 2006). Thirty percent of contraceptive failures were among women using very effective contraceptive methods (Goulard et al. 2006). Of the roughly one third of pregnancies reported to be unintended, 60% ended in an abortion (Bajos et al. 2004b).

Prior exercises connecting method mix to fertility have mostly been linear and static exercises in multiplying the percent of each method user times effectiveness rates. For example, the Futures Group has built the Proxdemo model in Excel that allows the user to input the proximate determinants of fertility developed by Bongaarts (proportion married, distribution of contraceptive methods, method effectiveness, abortion rates, duration of post-partum infecundability) (Bongaarts 1978) and then modify these parameters to see how much the TFR would change (The Futures Group 2014). Proxdemo is used by researchers and policy/decision makers to try to understand where to put their resources in an effort to reduce fertility, but it has limited ability to depict policies that alter time on method or switching probabilities.

Given the COCON findings that effectiveness varies with each woman's time on a method and that the method mix of individual women changes over the life course, we hypothesized that a dynamic model would offer a better fit to observed fertility outcomes and more specifically unintended fertility.

Micro simulation models are computer models that simulate the lives of hypothetical people by applying event probabilities based on findings from surveys or other data sources in the real world. Comprehensive explanations of how micro simulation models work can be found in Bracher et al. (2003) and Lutz (1997). In summary, in a micro simulation model, simulated individuals are followed over time, and they can experience events or change status, based on a set of probability distributions drawn from the literature (Bracher et al. 2003b; Lutz 1997). For example, in this model individuals can have a pregnancy, or change contraceptive methods. Micro-simulation models relax the assumption that state transition probabilities are constant over time and uniform across individuals making them more useful when one believes that individual's recent experiences change how they react. Micro simulation models naturally provide a statistical range around the predicted outcomes and this can be used like a confidence interval to predict the impact of different interventions and a level of uncertainty around the predictions. Like all simulation models they allow one to understand responses to policies that might be impossible or unethical to test in real populations.

Agent-based models are a specific type of micro simulation model in which the agents can interact with each other, in other words, the behavior of one individual can influence the behavior of others in the model (Macal and North 2010). Agent based models require more computational power, but may reflect real life processes better when agent to agent influences are an important part of the process. Peer influences in contraceptive decision-making are increasingly recognized, but quantification of the size of these peer influences

has been limited, and attempts to simulate agent interactions about contraceptive choice would rely heavily on assumptions about the size of peer effects. Since data on the size of peer effects on contraceptive choice is limited, our model does not include agent to agent interactions about contraceptive choices and is a micro simulation rather than an agent-based model.

Both micro simulation and agent-based models have been used in demography to understand factors related to pregnancy for many decades. Some of the early applications of these models studied demographic processes related to natality and reproduction, kinship networks and marriage patterns, and family planning policies. For a detailed discussion of past models see Lutz, 1997 and Wachter et al., 1997 (Barrett 1978; Lutz 1997; Wachter et al. 1997). Studies have used micro-simulation models to understand the dynamics of HIV, and how condom use might prevent the spread of the epidemic (Bracher et al. 2003b; Bracher et al. 2004; Bracher et al. 2003a). These types of models have also been used to assess mating and fertility in both human and non-human ecology. (Todd et al. 2005; An and Liu 2010)

More recently, micro-simulation models have been applied to understanding how marriage, divorce, migration, and geography in Malawi affect HIV rates, and how condom use might prevent the spread of HIV (Bracher et al. 2003b; Bracher et al. 2004; Bracher et al. 2003a). These authors primarily used data from a large survey collected in Malawi (the Malawi Diffusion and Ideational Change Project (MDICP)), but also used a variety of other data sources, including qualitative interview data, to build a micro simulation model to the complex interplay between demographic forces (such as marriage) and the spread and prevention of infections disease.

More closely related to contraceptive behaviors and related fertility outcomes, the “FamilyScope” model developed by the Brookings Institution (Thomas and Monea 2009) specifically focuses on modeling the associations between relationship formation, contraceptive use, sexual activity, and pregnancy outcomes by socio-economic demographic groups in the US. This model stratifies people’s use of contraceptive methods by different socio-economic groups, although contraceptive failure rates are applied uniformly across social groups, based on past literature..

Micro simulation models of reproductive health outcomes can also be used to project costs (Babigumira et al. 2012). This study created a hypothetical cohort of 15-year-old girls, and followed them over their lifetimes, applying data from the Uganda Demographic and Health Survey. Women could be in a state of not-sexually active, unintentionally not contracepting, intentionally not contracepting, using modern contraception, using traditional contraception, pregnant or dead. The cycle time was 9 months and the proportion using modern contraception was constant across all ages. They estimated the societal and governmental costs of various outcomes such as neonatal death, abortion, pregnancy averted, etc.

Other types of economic models which share characteristics with micro-simulation models do not integrate a time varying component, and have been used to test policy changes and interventions related to contraceptive use and unintended pregnancy. For example, Trussell

et al. (2013) used data from the National Survey of Family Growth in the United States to look at how increasing use of long acting reversible contraceptive methods (LARCs) could reduce unintended pregnancies (Trussell et al. 2013). This model tested various policy scenarios of increasing LARC use among different segments of the population, however the model did not depict dynamic method-switching among individuals.

In this paper, we build a dynamic micro simulation model and use it to examine outcomes of changes in contraceptive practices on unintended pregnancy rates in France. Our model focuses on risks of unintended pregnancies from contraceptive choice, switching and discontinuation in a French population. Compared to the FamilyScape model above, our aim is to focus on how contraceptive practices impact unintended pregnancy, and we do not include other fertility determinants such as union formation and frequency of intercourse. Compared to more static models that looked at the impact of behavior changes on unintended pregnancies, such as the Trussell et al. (2013) model discussed above, our model is able to follow women for a longer time period, and allows them to change methods, discontinue or fail, and has more details as to method mix. This type of modeling of the impact of behavior changes could be used to influence policies that targeted such behaviors.

We apply our model to examine fertility, abortions, and unintended births emerging from three scenarios: 1) Increase pill and condom effectiveness by 30%; 2) Increase time spent on the pill by 20%; 3) Increase the proportion of women who switched from the pill to a highly effective method by 50%.

Methodology

This micro simulation model was built using STATA11. First, a sample of hypothetical women was created with a uniform distribution of ages from 18–45. The hypothetical women were programmed to update their status each month for 5 years. The population was held constant so each woman having her 45th birthday was replaced by another woman having her 18th birthday. Mortality and migration rates were zero.

Our model's parameters are drawn from the French COCON study, a population based cohort study, gathered longitudinal data on the contraceptive behaviors of a random national sample of 2863 women aged 18 to 44 over a five year period (2000–2004) (Bajos et al. 2004a). Data was collected annually via telephone. This dataset provides detailed information on method switching, failure, and discontinuation patterns of French women, as well as their pregnancies, abortions, miscarriages, births and whether these pregnancies were intended or unintended.

At the start of the program, current pregnancy and contraceptive use status were initialized according to age to be consistent with data from France for 2000 (Bajos et al. 2004b). All pregnant women were initialized with a random a date of last menstrual period. Non-pregnant women were initialized to be in one of eleven states: no partner/not exposed, partner and no contraception, condom, oral contraception, other hormonal methods (patch or ring), Intra Uterine Devices (IUD), withdrawal, spermicide, sterilization, fertility awareness methods, or trying to get pregnant. Women were initialized on a contraception method based

on age-specific contraceptive rates from COCON (Bajos et al. 2003)(Bajos et al. 2003)(Bajos et al. 2003)(Bajos et al. 2003)(Bajos et al. 2003). There were initialized to have a prior tenure on their method that was consistent with COCON data. Women who were sterilized stayed sterilized until the model ended or they aged out of the model by turning 45. Each woman who turned 45 was automatically replaced by an 18 year old who was assigned a family planning or pregnancy state representative of 18 year olds in the COCON study.

At each month, each woman experienced a probability of switching to any one of the other states, which differed by method type and length of time on that method. Switches from a method directly to pregnancy counted as an “unintended pregnancy” (method failure). Likewise, women who became pregnant as the result of an unmet need for contraception (36%) were considered as having an “unintended pregnancy”. The majority of women who became pregnant after a period of “trying to get pregnant” were counted as “intended pregnancy”, although 12% of these pregnancies were classified as unintended, based on the classification of women in of the COCON study.

Women who became pregnant followed the pregnancy algorithm seen in Fig. 1. At each month of pregnancy a random variable determined if she continued with the pregnancy, miscarried, or aborted the pregnancy. Age specific rates of induced abortion from France and pregnancy loss (miscarriage, ectopic pregnancy and stillbirth) from European data were applied (Vilain 2011; Anderson et al. 2000) (Table I). Abortion rates were only applied to unintended pregnancies. Women who gave birth were given a 3-month non-susceptible period, and women who miscarried or aborted were fecund in the following month. After pregnancy, women were re-initialized onto a contraceptive method as per the post-pregnancy contraceptive distribution in the COCON study.

Method specific discontinuation and failure rates by duration of use were based on data from the French COCON study (Moreau et al. 2009; Moreau et al. 2007). In addition, Table II shows an example of the pattern of switching from the pill to another state among women who discontinued the pill. Similar switch rates by time of use for all other methods parameterized the model for every possible switch for each time period. Switching rates were quite high in the first few months of use of barrier or natural methods (Moreau et al. 2009). The initial model was based purely on data from the COCON study. An adjusted model changed the initial model based on assumptions about areas of poor reporting in COCON, so as to better replicate the reproductive behavior of the French population.

We tested the impact on unintended pregnancy of various potential reproductive behavior change scenarios. We conceptualize these as ways of understanding the effect that large shifts in behavior would have on unintended pregnancies, and therefore modeled rather large changes in contraceptive practice. While the magnitude of the changes modeled in the different scenarios is somewhat arbitrary, the goal was to change the model parameters systematically to see how this affected our outcome of interest. Behavior Change Scenario 1 increased pill and condom effectiveness by 30%. Behavior Change Scenario 2 increased the amount of time people stayed on the pill by 20%. Behavior Change Scenario 3 altered switching patterns by increasing by 50% the proportion of women who switched from the

pill to a highly effective method (the IUD in this case) and reduced the number of women switching to “no method”, holding constant the mean duration of use. For each behavior change scenario we computed the effect on unintended pregnancy rates in each of 1000 iterations in a population of 20,000 over a 5 year period.

Before conducting the behavior change scenarios, we ran a series of simulations to determine how many women (agents) were needed in the model before the outcome stabilized (This was tested on the adjusted model). These simulations served as a way to test the validity of the model by verifying that the model produced roughly similar outcomes at various sample sizes. Starting with 100,000 women followed for 10 years (which took over 24 hours on a super computer), we compared the standard deviation of the TFR to the sample size to determine where the model stabilized (Fig 2). The model stabilized around 10,000 women for 10 years. Since the COCON data was collected over a 5 year period, we ran all remaining models on a sample of 20,000 women for 5 years (giving us the same amount of data as 10,000 women for 10 years).

Finally, we compared our model for Behavior Change Scenario 1 to the Proxdemo model developed by the Futures Group (The Futures Group 2014) to assess the added value from the more complex model developed in this paper compared to a linear model. The basic code in STATA 11 is posted in an online appendix for replication purposes.

Results

With the baseline settings on method mix and method failure by age and duration on method taken directly from COCON, the model underestimated observed fertility (TFR) in COCON. Therefore, we adjusted the model parameterization to address several sources of potential underreporting. We hypothesized that under-reporting was expected to be most prevalent surrounding abortions, the amount of time spent in the state of wanting and trying to have a child, and on transitory periods of contraceptive non use. Underreporting of abortions would lead to lower estimates of probability of pregnancy, because those pregnancies that ended in abortion would not be counted as pregnancies. Underreporting of time spent in the state of wanting and trying to have a child would lower the time that women spent more at risk of having a pregnancy, and therefore lower over all pregnancies. Finally, underreporting of transition periods would also lessen the time women were at higher risk of a pregnancy, again, leading to an estimated fewer pregnancies than actually occurred. Had we assumed different sources of underreporting, and thereby adjusted different parameters in the model, the adjusted model may have had a higher or lower TFR. The parameters discussed above were the most likely sources of underreporting, given past findings from surveys on contraceptive and pregnancy related behavior.

In order to calibrate the model to replicate COCON's fertility we prepared Model B which imposed an increase on the proportion of women aged 20–39 at initialization who were in the state of trying to become pregnant by 1% point (and took these women out of the state of “no partner/not exposed”). The adjusted model also increased the probability of pregnancy for those trying to get pregnant so as to make the 1 year cumulative pregnancy rate equal to 85%, based on estimates published in the literature (Trussell 2011), compared to about 77%

in the COCON model. The adjusted model successfully reproduced a Total Fertility Rate of 1.27 which was very close to COCON's TFR. COCON's TFR is lower than the official TFR for France of 1.8, however, suggesting that the COCON population that was followed up over time was not exactly representative of the reproductive age female population of France.

All Behavior Change Scenarios were made in reference to the adjusted model (Table III). Behavior Change Scenario 1 (increased pill and condom effectiveness by 30%,) reduced unintended pregnancy rates by about 7% points (to 36% of pregnancies being unintended). The TFR declined slightly in this model as well. Behavior change Scenario 2 (reduced pill discontinuation rates by 20%, extending the amount of time spent on the method) reduced unintended pregnancy rates by only 1.2% point (to 38% of pregnancies being unintended). Behavior change Scenario 2 reduced TFR to about 1.0. In the final model, Behavior Change Scenario 3 (increased the proportion of women switching from the pill to the IUD, and reduced the proportion switching from the pill to no method), unintended pregnancy rate fell to an average of 38% (a decline of about 1.4%) and TFR actually increased slightly.

To offer a comparison of how the micro simulation results would differ from a simple linear model, we input the basic parameters of COCON into Proxdemo model. These included the method distribution for the population as a whole (not by age group or by duration on method), the proportion of women using a method (78.2%), the proportion of women who do not state "no partner" (90%), the method effectiveness found in COCON, the non-susceptible period used in our model (3 months), the total abortion rate for the population (15/1000) the percent sterile found in COCON (1.4%) and the TFR found in the first model (1.27). We then applied Behavior Change Scenario 1, where we increased pill and condom effectiveness by 30%, to the Proxdemo model.

Micro simulation results differed substantially from what would be obtained with the Proxdemo linear model. When Proxdemo simulated Behavior Change Scenario 1 with all of the COCON parameters the TFR dropped to 0.81 (by about 35%) compared to the 7% drop predicted by our simulation. There is no way to determine what percent of pregnancies are intended versus unintended pregnancies using Proxdemo, so we cannot compare those outputs to our own model. We were unable to test Behavior Change Scenarios 2 or 3 on Proxdemo because those simulations looked at switching rates and time on methods, neither of which can be modeled in Proxdemo.

Discussion

Based on parameters from a national survey of French women, we used a dynamic simulation model to compare the potential impact of three family planning strategies to reduce unintended pregnancies. We found that increasing method effectiveness of user dependent methods that are currently used seemed more effective in reducing unwanted fertility than acting on method switching patterns. Thus, behavior change model 1 was associated with a 7% point reduction in unintended pregnancy rates while behavior change scenarios 2 and 3 only reduced unintended pregnancy rates by 1.5% point. These different models were meant to provide a test of the relationships between contraceptive behaviors

and unintended pregnancy rates in a dynamic system. Some of these behavior change scenarios have policy or programmatic relevance, discussed below. The exact magnitude of behavior changes in the model is bound to vary due to local contextual factors. In this initial model our goal was simply to understand how the model works and the relationship between the various components. Future models that specifically aim to test possible interventions and policies should focus on various levels of behavior change.

Policy and programmatic relevance

Increasing current method effectiveness is a challenging goal. Few studies have identified strategies to increase effectiveness of user dependent methods. Thinking about Behavior Change Scenario 1 (increasing pill and condom effectiveness), empowering women to make an informed choice which best suits their needs may be a first step towards improving adherence to contraceptive regimen. This was suggested in a study among French pill users, showing women were less likely to use the pill consistently when they felt they had not been fully involved in the choice of their method (Moreau et al. 2006). Other interventions, such as receiving or provided with daily reminders to take their pill (via phone calls, text messaging or emails, or reminder cards) have also shown marginal benefits (Lachowsky and Levy-Toledano 2002), although not consistently (Hou et al. 2010). A significant proportion of failures come from the use of barrier or natural methods, even though a minority of women uses these methods. In France it is estimated that 35% of abortions result from pregnancies due to barrier or natural method failures (Moreau et al. 2010). In this case, increasing effectiveness involves partner negotiation and the use of backup options such as emergency contraception to reduce the risk of pregnancy after exposure. However no study has shown a population effect of making Emergency Contraception more widely available (Raymond et al. 2007).

Behavior Change Scenario 2 (reducing rates of discontinuation from the pill) might be targeted by programs that provide more counseling to women about expected (“normal”) side effects, which otherwise might cause women to discontinue. Also, increasing access to birth control pills over the counter (in settings where this is not already the norm) or giving women larger packs of pills (for example, 6 months at a time) might increase women’s ability to continue the method without as many barriers (although this is already the case in France).

Many past programs have targeted increasing uptake of long acting reversible contraception (LARC), such as was modeled in Behavior Change Scenario 3. Programs encouraging women to adopt LARC such as the IUD or the implant are recognized as the most cost-effective strategy to reduce unintended pregnancies (Trussell et al. 2009). The contraceptive CHOICE project in Saint Louis is the most compelling example of the way such programs may improve reproductive outcomes. By providing evidenced based information on LARC methods and no-cost contraception, the intervention resulted in 67% of women choosing LARC over other options (Secura et al. 2010) and a subsequent reduction in abortion rates, repeat abortions, and teenage birth rates. Continuation rates of LARC methods are also substantially higher than for other methods of contraception, reducing contraceptive gaps and the likelihood of switching to less effective methods (Vaughan et al. 2008; Moreau et al.

2009). LARC uptake in our simulated model did not result in greater reduction in unintended pregnancies as compared to other strategies such as improving effectiveness of less effective methods or prolonging duration of use.

From a methodological perspective, our model showed that the reported contraceptive method mix and use efficacy in a survey imply fertility rates that are lower than the actual fertility rates. We conjecture that this was due to women underreporting the time spent in the “wanting to become pregnant” and “no method” state. Since using contraception is the norm in France, women might be reluctant to report spending time exposed to sex but not using a method, especially in the context of responding to a survey conducted by the French National Health and Medical Research Institute. Second, women underreport abortions (by as much as 50%) (Moreau et al. 2004), and therefore are likely to omit reporting a method failure if the pregnancy is terminated, especially when the pregnancy is due to the use of less effective methods or incorrect use on their part. This was made evident in the US context (Fu et al. 1999) which shows the same proportion of abortion underreporting in population based surveys (Jones and Kost 2007).

When we adjusted the model slightly to take into account underreporting of exposure to unprotected sex, we were able to replicate the TFR found in the COCON study more closely. The COCON TFR was lower than the TFR for Mainland France during this time period. The substantial attrition rate of the COCON survey during the 4 years of follow up (Razafindratsima and Kishimba 2004), mostly due to women who could not be reached for follow-up interviews rather than refusal to participate may have introduced sample selection bias related to fertility as couples who expand their families are more likely to move than others.

Limitations

The lack of information related to age specific switching and discontinuation rates in our model is likely to have reduced the variation in pregnancy rates across age groups. Unlike the US data (Kost et al. 2008), French estimates of failure rates vary little by age group, in the case of the pill or the IUD (Moreau et al. 2007). While the data indicate higher condom failure rates among women 20 to 35 as compared to younger women, the imprecision of these estimates prevents integrating this information in the models (Moreau et al. 2007). Future research should incorporate age specific rates of switching and discontinuation, rather than rates based solely on time spent on each method.

A limitation of the model is that it does not take the parity of the woman into account in assigning her a baseline method, switching or discontinuation rates, or pregnancy outcome risk (abortion or live birth). This may affect the validity of our results as prescribing practices in France restrict IUDs almost exclusively to women with children (Bajos et al. 2004a). We do account for age when assigning risk of abortion, miscarriage and live birth. Subsequent models should allow for differences by parity.

Our dynamic modeling of contraceptive behaviors allows a comprehensive forecast of different family planning policies on total and most importantly on unintended fertility at the population level. As most societies are experiencing declining TFRS and rising

contraceptive prevalence rates for a mix of methods, differences in method effectiveness, time on method and switching patterns will become more important in evaluating policy impact on unintended pregnancy rates rather than overall fertility rates. Consequently more refined prediction models are warranted to assess the impact of method duration and method switching on fertility outcomes. The flip side of a more refined model such as this is the need for a great deal of detailed data. More applications of this model to other contexts is required to ensure that the burden of collecting such detailed data is justified by the types of nuanced information that these models are able to produce.

Of course, no model replicates reality perfectly, and there are some outcomes of this model that are unexpected. For example, in Behavior Change Scenario 3, TFR actually increased by two one hundredths (from about 1.27 to 1.29). This is surprising, especially since this behavior change model moved women switching off the pill to LARC methods, which would be expected to be an effective method for reducing fertility and unintended pregnancy. However, it is important to consider how many women are actually at risk of being impacted by each of our Behavior Change Scenarios. Behavior Change Scenario 1 could impact all women on pills or condoms at any point, which is 588,758 woman months of time. Behavior Change Scenarios 2 could impact all women on pills for a short duration (say, less than 5 years), which is 45,316 woman months of time. Behavior Change Scenario 3 can only impact women switching from the pill, which is 13,431 women months of time. Behavior Change Scenario 2 and 3 affect a much smaller number of women, limiting both of their abilities to make a big impact on unintended pregnancies. This highlights the fact that policies that impact the largest number of users will have the most impact on outcomes.

Comparison to past models

Predictions of population effects of family planning policies are currently mostly based on linear models, such as the Proxdemo model. The Proxdemo model does not account for age specific patterns of contraception use (method mix) nor does it account for significant changes in failure rates and contraceptive switch patterns over time. More importantly the Proxdemo model predicts total fertility rather than unintended fertility. The model presented in this paper adds many layers of dynamic behavior options (contraceptive switching, discontinuation, failure, by age and by duration on method), allowing for a more nuanced understanding of fertility and unintended pregnancy. A direct comparison of behavior change scenario 1 using the Proxdemo linear model showed that the change in TFR was larger in Proxdemo than in our model, when both were applied to a 30% increase across the board in method effectiveness. We believe that our estimate is more realistic because it accounts for age-specific differences in method mix where women in their 30s facing highest risks of 2nd and 3rd pregnancies are choosing more effective methods with ceiling effects that limit the fertility impact of a 30% rise in effectiveness.

Of course, it is possible that our model would behave differently, especially compared to Proxdemo, if information from a higher fertility, low contraceptive prevalence context were applied. In such a setting, small differences in risk by age and time on method might be overshadowed by the impact of unmet need and pregnancy rates over all. In the future, contraceptive calendar information available from the Demographic and Health Surveys

could be integrated to inform strategic planning for family planning policies and programs. This could also help test whether micro simulation models such as this one provide more or better information than lineal models. Micro simulation models are complex to build, and time and computationally intensive. Therefore, testing whether they do indeed provide additional insight is important before expanding their use, especially in resource poor settings that might not have access to large computer systems to run these types of models.

Our model adds to the small current body of the use of micro simulation modeling of fertility outcomes by focusing on the complex relationship between women's contraceptive use, switching and discontinuation by time spent on each method as a means of understanding unintended pregnancies. The FamilyScape model, most comparable to our simulation, is focused on the distribution of unintended pregnancies in the population, whereas this model concentrates on the complex nature of contraceptive behavior itself. That a country like France, with very high rates of contraceptive use, still has more than a 30% unintended pregnancy rate is surprising and unsettling. This model can help us disentangle what key points in a woman's contraceptive lifecycle put her most at risk, and what types of contraceptive practice changes might be most useful in reducing unintended pregnancies.

Conclusion

This type of micro-simulation modeling may have great potential for use in reproductive health research, allowing for a better understanding of the implications of method switching and discontinuation on unintended pregnancy in the context of rapid changes in fertility expectations and contraceptive prevalence. More research in other contexts, is needed, especially relating to what additional information this type of modeling provides and how it can be applied to interventions and policies. Other competing sexual health outcomes could also be examined, such as the risk of sexually transmitted infections relative to the risk of unintended pregnancies in high-risk populations. There is a wealth of possibility for the use of such models in demographic and public health research, and this exercise has offered one small illustration of the potential of micro simulation models to model fertility behavior.

Acknowledgments

The authors would like to thank the Population Center and the Bloomberg School of Public Health at Johns Hopkins University.

References

- An, Li; Liu, Jianguo. Long-term effects of family planning and other determinants of fertility on population and environment: agent-based modeling evidence from Wolong Nature Reserve, China. *Population and Environment*. 2010; 31(6):427–459.
- Anderson, Anne-Marie Nybo; Wohlfahrt, Jan; Christens, Peter; Olsen, Jørn; Melbye, Mads. Maternal Age and Fetal Loss: population Based Register Linkage Study. *British Medical Journal*. 2000; 320(1708)
- Babigumira, Joseph B., et al. Potential Cost-Effectiveness of Universal Access to Modern Contraceptives in Uganda. *PLoS ONE*. 2012; 7(2)
- Bajos, Nathalie; Leridon, Henri; Goulard, Helene; Oustry, Pascale; Job-Spira, Nadine. The COCON Group. Contraception: from accessibility to efficiency. *Human Reproduction*. 2003; 18(5):994–999. [PubMed: 12721175]

- Bajos, Nathalie; Leridon, Henri; Job-Spira, Nadine. La contraception et le recours à l'avortement en France dans les années 2000: présentation et premiers résultats de l'enquête Cocon : introduction au dossier. *Population and Development Review*. 2004a; 59(3-4):409-418.
- Bajos, Nathalie; Moreau, Caroline; Leridon, Henri; Ferrand, Michèle. Why has the number of abortions not declined in France in the past 30 years? *Population and Societies*. 2004b; 407
- Barrett, John C. Effects Of Various Factors On Selection For Family Planning Status And Natural Fecundability: A Simulation Study. *Demography*. 1978; 15(1):87-98. [PubMed: 631401]
- Bongaarts, John. A Framework for Analyzing the Proximate Determinants of Fertility. *Population and Development Review*. 1978; 4(1)
- Bracher, Michael; Santow, Gigi; Watkins, Susan Cotts. A Microsimulation Study of the Effects of Divorce and Remarriage on Lifetime Risks of HIV/AIDS in Rural Malawi. *PARC Working Paper Series, WPS 03-01*. 2003a.
- Bracher, Michael; Santow, Gigi; Watkins, Susan Cotts. Assessing the Potential of Condom Use to Prevent the Spread of HIV: A Microsimulation Study. *Studies in Family Planning*. 2004; 35(1): 48-64. [PubMed: 15067788]
- Bracher, Michael; Watkins, Susan; Santow, Gigi. "Moving" and Marrying. *Demographic Research*. 2003b; (Special 1):207-246.
- Fu, Haishan; Darroch, Jacqueline E.; Haas, Taylor; Ranjit, Nalini. Contraceptive failure rates: new estimates from the 1995 National Survey of Family Growth. *Family Planning Perspectives*. 1999; 31(2):56-63. [PubMed: 10224543]
- Goulard, Helene; Moreau, Caroline; Gilbert, Fabien; Job-Spira, Nadine; Bajos, Nathalie. The Cocon Group. Contraceptive failures and determinants of emergency contraception use. *Contraception*. 2006; 74:208-213. [PubMed: 16904413]
- Hou, Melody Y.; Hurwitz, Shelley; Kavanagh, Erin; Fortin, Jennifer; Goldberg, Alisa B. Using Daily Text-Message Reminders to Improve Adherence With Oral Contraceptives: A Randomized Controlled Trial. *Obstetrics & Gynecology*. 2010; 116(3):633-640. [PubMed: 20733446]
- Jones, Rachel K.; Kost, Kathryn. Underreporting of induced and spontaneous abortion in the United States: an analysis of the 2002 National Survey of Family Growth. *Studies in Family Planning*. 2007; 38(3):187-197. [PubMed: 17933292]
- Kost, Kathryn; Singh, Susheela; Vaughan, Barbara; Trussell, James; Bankole, Akinrinola. Estimates of contraceptive failure from the 2002 National Survey of Family Growth. *Contraception*. 2008; 77:10-21. [PubMed: 18082661]
- Lachowsky M, Levy-Toledano R. Improving compliance in oral contraception: 'the reminder card'. *Eur J Contracept Reprod Health Care*. 2002; 7(4):210-215. [PubMed: 12648292]
- Lutz, Wolfgang. FAMSIM-Austria: feasibility study for a dynamic microsimulation model for projections and the evaluation of family policies based on the European Family and Fertility Survey. Vienna, Austria: Österreichisches Institut für Familienforschung; 1997.
- Macal, Charles M.; North, Michael J. Tutorial on agent-based modelling and simulation. *Journal of Simulation*. 2010; 4(3):151-162.
- Moreau, Caroline; Bajos, Nathalie; Bouyer, Jean. The COCON group. Questions comprehension and Recall: The Reporting of Induced Abortions in Quantitative Surveys on the General Population. *Population-E – English edition*. 2004; 59(3-4):439-454.
- Moreau, Caroline; Bouyer, Jean; Bajos, Nathalie; Rodríguez, German; Trussell, Jame. Frequency of discontinuation of contraceptive use: Results from a French population based cohort. *Human Reproduction*. 2009; 24(6):1387-1392. [PubMed: 19252195]
- Moreau, Caroline; Bouyer, Jean; Gilbert, Fabien; Bajos, Nathalie. Cocon group. Social, demographic and situational factors associated with inconsistent use of oral contraceptives. *Perspect Sex Reprod Health*. 2006; 38(4):190-196. [PubMed: 17162311]
- Moreau, Caroline; Trussell, James; Desfreres, J.; Bajos, Nathalie. Patterns of contraceptive use before and after an abortion: results from a nationally representative survey of women undergoing an abortion in France. *Contraception*. 2010; 82(4):337-344. [PubMed: 20851227]
- Moreau, Caroline; Trussell, James; Rodriguez, German; Bajos, Nathalie; Bouyer, Jean. Contraceptive failure rates in France: results from a population-based survey. *Human Reproduction*. 2007; 22(9): 2422-2427. [PubMed: 17599942]

- Raymond, Elizabeth G.; Trussell, James; Polis, Chelsea B. Population effect of increased access to emergency contraceptive pills: a systematic review. *Obstet Gynecol.* 2007; 109:181–188. [PubMed: 17197603]
- Razafindratsima, Nicolas; Kishimba, Ngoy. Attrition in the COCON Cohort Between 2000 and 2002. *Population (English Edition).* 2004; 59:357–385.
- Secura, Gina M.; Allsworth, Jenifer E.; Madden, Tessa; Mullersman, Jennifer L.; Peipert, Jeffrey F. The Contraceptive CHOICE Project: reducing barriers to long-acting reversible contraception. *American Journal of Obstetrics & Gynecology.* 2010; 203(2):115.e111–115.e117. [PubMed: 20541171]
- The Futures Group. Proximate Determinants of Fertility Demonstration. 2014
- Thomas, Adam; Monea, Emily. Brookings Working Paper. Center on Children and Families at Brookings; 2009. *Familyscape: A Simulation Model Of Family Formation.*
- Todd, Peter M.; Billari, Francesco C.; Simão, Jorge. Aggregate Age-At-Marriage Patterns From Individual Mate-Search Heuristics. *Demography.* 2005; 42(3):559–574. [PubMed: 16235613]
- Trussell, James. Contraceptive failure in the United States. *Contraception.* 2011; 83:397–404. [PubMed: 21477680]
- Trussell, James; Henry, Nathaniel; Hassan, Fareen; Prezioso, Alexander; Law, Amy; Filonenko, Anna. Burden of unintended pregnancy in the United States: potential savings with increased use of long-acting reversible contraception. *Contraception.* 2013; 87(2):154–161. [PubMed: 22959904]
- Trussell, James; Lalla, Anjana M.; Doan, Quan V.; Reyes, Eileen; Pinto, Lionel; Gricar, Joseph. Cost effectiveness of contraceptives in the United States. *Contraception.* 2009; 79:5–14. [PubMed: 19041435]
- Vaughan, Barbara; Trussell, James; Kost, Kathryn; Singh, Susheela; Jones, Rachel K. Discontinuation and resumption of contraceptive use: results from the 2002 National Survey of Family Growth. *Contraception.* 2008; 78(4):271–283. [PubMed: 18847574]
- Vilain, Annick. Les interruptions volontaires de grossesse en 2008 et 2009” Direction de la recherche, des études, de l’évaluation et des statistiques. Directorate of Research, Studies, Evaluation and Statistics (DREES). 2011; 765
- Wachter, Kenneth W.; Blackwell, Debra; Hammel, Eugene A. Testing the Validity of Kinship Microsimulation. *Mathematical and Computer Modelling.* 1997; 26(6):89–104.

Green boxes=States

Blue boxes/arrows=Transition Pathways

Figure 1.
Diagram of Model States and Transition Pathways

Fig 2.
Testing for necessary sample size to stabilize results

Table I

Fertility, Abortion and Pregnancy Loss Rates

Age Group (years)	Pregnancy Loss (Miscarriages, Ectopic Pregnancy and Stillbirths) (Anderson et al. 2000)	Induced Abortions (Vilain 2011)
<19	6%	2%
20–24	8%	3%
25–29	10%	2%
30–34	12%	2%
35–39	15%	1%
40–44	18%	1%
>45	30%	0%

Table II

Monthly Probability of Switching Rates for the Pill, baseline model: Of those who switch from the pill to something else in each time period, what method do they switch to? (Bajos et al. 2004a)

	Pill <6 months	Pill 6–12 months	Pill 1–2 years	Pill 2–3 years	Pill over 3 years
No method	16.5%	14.2%	10.4%	14.1%	11.5%
IUD	19.6%	19.9%	7.0%	11.5%	8.2%
Condom	18.6%	20.8%	22.5%	26.5%	15.8%
Withdrawal	4.0%	2.0%	4.5%	4.4%	2.3%
Fertility Awareness	1.7%	0.0%	1.5%	0.3%	1.2%
Spermicides	0.6%	0.5%	0.1%	2.5%	0.6%
Long acting hormonal	4.4%	6.5%	3.3%	0.5%	3.8%
Sterilization	1.2%	1.0%	0.1%	0.1%	2.3%
Pregnant	4.8%	4.1%	8.1%	7.1%	5.9%
Trying to become pregnant	18.2%	21.8%	35.7%	24.5%	37.6%
No partner	10.4%	9.2%	6.7%	8.5%	10.6%

Table III

Total Fertility Rate, percent of pregnancies intended and unintended in the Adjusted Model and Behavior Change Scenarios 1,2 and 3

	Adjusted Model	Behavior Change Scenario 1	Behavior Change Scenario 2	Behavior Change Scenario 3
TFR	1.270	1.225	0.996	1.289
Intended pregnancies %	61%	64%	62%	62%
Unintended pregnancies %	39%	36%	38%	38%
% Change in unintended pregnancies		6.93%	1.17%	1.37%

Final Adjusted Model

Scenario 1—reduce failure rates for pill and condom users by 30%

Scenario 2—reduce switching from the pill by 20% per time period

Scenario 3—increase switching to more effective methods, 50% more women switching from the pill now switch to the IUD rather than no method.