Modeling Empowerment, Intention, and Fertility Impacts of a New Contraceptive Technology: A Case Study Using Depo-Medroxyprogesterone Acetate Subcutaneous in Kenya

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Abstract
Contraceptive technologies not only affect fertility but also influence women's empowerment. Depo-Medroxyprogesterone Acetate Subcutaneous (DMPA-SC), designed for self-injection, aims to improve access to contraception by reducing dependency on healthcare providers. The study enhances the Family Planning Simulator (FPsim), an agent-based model, to simulate contraceptive use and empowerment outcomes. Data from the Kenya Performance Monitoring for Action (PMA) survey, which includes information on fertility intentions and empowerment metrics, were used to parameterize the model. Empowerment is measured through economic and social indicators such as decision-making autonomy and labor force participation. The study models various scenarios for scaling up both 3-month and 6-month DMPA-SC and projects their impacts on modern contraceptive prevalence rates (mCPR) and women's empowerment. These findings provide insights into how improved access to contraception can influence both fertility outcomes and broader socio-economic empowerment in low-resource settings.

Keywords: contraception, empowerment, modeling, DMPA-SC

1. Background

Contraception plays a crucial role in women's health and overall wellbeing. It is essential to accommodate women's needs to support their reproductive decisions. Enhancing the contraceptive landscape often involves evaluating new contraceptive technologies' impact, usually by projecting the potential increase in users and corresponding reduction in pregnancies. However, in addition to direct fertility impact, new contraceptive technologies are also developed to impact women’s empowerment, autonomy, and overall wellbeing. Researchers and policymakers should no longer evaluate new contraceptive technologies without considering women’s desires, preferences, and intentions. With models that better capture if women can fulfill their preferences for, if and when they access and use safe contraception, we can better understand the true potential uptake and impact of new technologies.

Depo-Medroxyprogesterone Acetate Subcutaneous (DMPA-SC) was developed and introduced with the intention of reaching women who had limited access to contraception(1). The design of this contraceptive, which allows for self-injection, aimed to empower women by reducing their need for frequent visits to clinics, addressing issues related to distance, availability of healthcare providers, and time constraints(2,3). The self-injectable nature of DMPA-SC also aimed to increase women’s autonomy over their reproductive health, as it offers discretion and convenience(4). Since not all these impacts can be directly measured in trials, we can model changes in contraceptive use and pregnancy rates after introduction, along with effects on contraceptive intentions and empowerment outcomes.

In this study, we aim to model the contraceptive, fertility, and empowerment impacts of introducing DMPA-SC in Kenya. We update an existing agent-based model, FPsim, with enhancements that address these two related evolutions in the current family planning research landscape: centering women’s intentions and preferences; and considering the broader impact of family planning on women’s empowerment.

2. Methods

2.1 Model Structure

The Family Planning Simulator (FPsim) is an open-source agent-based model that can be calibrated for various contexts, with initial implementations in Senegal and ongoing development for Kenya and Ethiopia(5). Agent-based models (ABMs) are rule-based computational models, in which researchers can simulate cohorts of individual agents and run hypothetical simulated scenarios. Agents are faced with decisions and events throughout their life course, most of which are decided probabilistically. In FPsim, each woman begins with her own individual underlying biological fecundity. She can then experience sexual debut, sexual activity, contraceptive choice, conception, abortion, miscarriage,

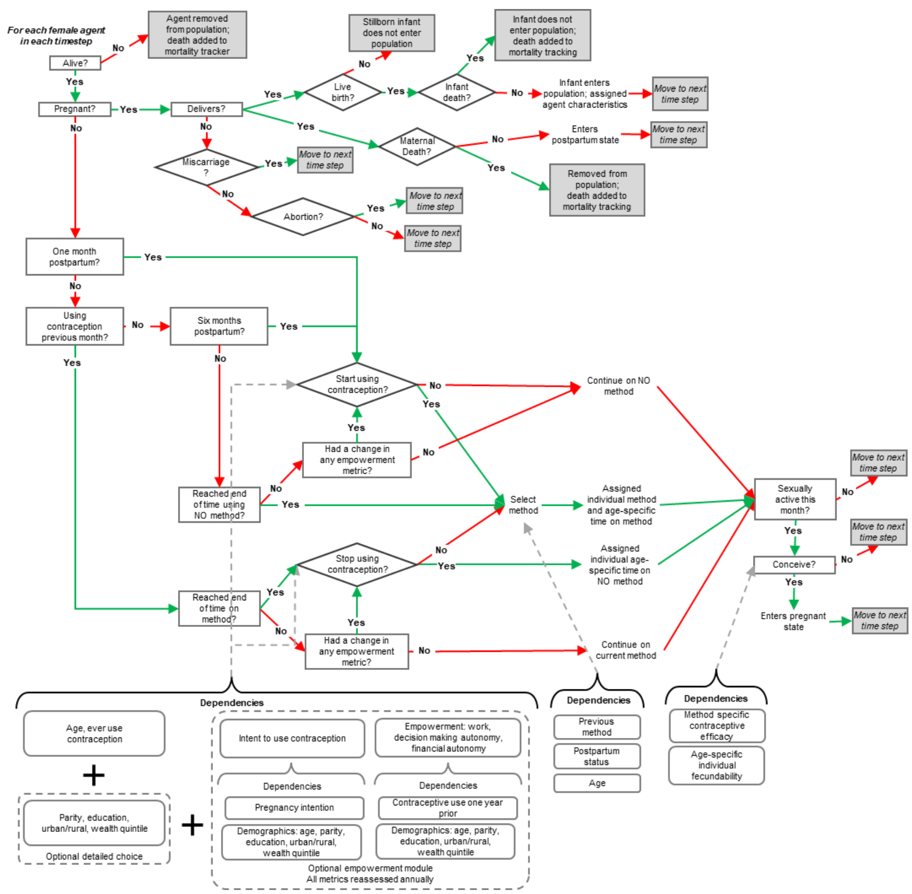

Figure 1. Decision map displaying contraception and pregnancy-related events in FPsim. Reading from the top, each agent in each timestep is checked for live status, and if alive, is checked for pregnancy status. If pregnant, the agent enters the pregnancy and childbirth module. If not, she continues on by checking if she is postpartum and if she was previously using contraception. She then walks through a series of decisions to determine if she will start or stop using contraception. If she is sexually active, she is eligible for conception.

stillbirth, a live birth, infant mortality, and/or maternal mortality. Agents encounter these events with different probabilities based on data from the context, and for most events, broken down into age and time period (Figure 1).

2.2 Data sources

FPsim leverages multiple sources of data. The key data source for this analysis and for the enhancements described in this study is the Kenya Performance Monitoring for Action (PMA) data(6). PMA is a nationally representative survey completed annually. Survey participants are women aged 15 to 49 who are asked about their background, birth histories, family planning methods, fertility preferences, community norms, aspirations, intentions, empowerment, and more. The survey is based on a multi-stage cluster design with urban-rural counties as strata. Households are randomly sampled within each representative geographical cluster. Beginning in 2019, PMA implemented a panel design embedded within the cross-sectional surveys, allowing for longitudinal analysis. We used three years of longitudinal data from 2019, 2020, and 2021. For regression models described below that required data from two timepoints, we combined data from 2019 to 2020 and 2020 to 2021.

2.3 Contraceptive and fertility intention

In the model, each woman has two new attributes that reflect her preferences: intent to use contraception in the next 12 months (contraceptive intent), and desire for a pregnancy in the next 12 months (fertility intent). Whether an agent expresses fertility intent is based on an age-specific probability calculated from PMA data, determined by the woman's age. Having contraceptive intent is assigned based on a survey-weighted generalized linear model (GLM) with a quasi-binomial family. The predictors in the model are contraceptive intent in the previous year, age, parity, education, urban/rural, wealth quintile, and fertility intent (equation (eq) 1).

$$logit(p(contraceptive.intent))_{yr=t} = \beta_0 + \beta_1 * age + \beta_2 * urban + \beta_3 * wealth + \beta_4 * education + \beta_5 * parity + \beta_6 * contraceptive.intent_{yr=t-1} + \beta_7 * fertility.intent \quad \textbf{Eq. 1}$$

2.4 Empowerment attributes

To define the process of empowerment, we referenced the Can-Act-Resist Framework(7) which operationalizes this process through a series of questions that identify key measures and indicators: Do you want to engage in a particular behavior? (choice and aspiration); Can you engage in the behavior? (CAN); Have you engaged in the behavior? (ACT); What happened as a consequence of this action? (consequences); and if there was backlash, did you continue to engage in the behavior? (RESIST). We consider both economic empowerment and social empowerment that may be associated with contraceptive utilization. Economic empowerment is defined as a woman's ability to succeed and advance economically and her power to make and act on economic decisions. This includes factors such as labor force participation, education, autonomy and household decision-making power, and financial literacy and inclusion. Social empowerment is defined as the process in which individuals or social groups acquire the skills necessary for taking control of their own lives. This includes such factors as freedom of movement, voice agency, freedom from violence / harassment, and socioemotional. Unfortunately, the existing data is limited for many of these components, and predominantly collects information about *economic* empowerment, thus our analysis focuses more heavily on this aspect.

We included several empowerment metrics into the model (Table 1). These included survey questions measuring components of work, decision making autonomy, and financial autonomy. We also included two aggregate scale metrics, for household decision making and financial autonomy, based on a confirmatory factor analysis on the PMA data(8). While we recognize that empowerment encompasses more than just the factors listed above, we are restricted by the indicators available in the PMA dataset.

Table 1. Empowerment metrics included in the model. Source PMA data.

Empowerment Metric	Survey question
Individual metrics	
Paid work	Aside from your own housework, have you done any work in the last 12 months? AND Are you paid in cash or kind for this work or are you not paid at all?
Sexual autonomy	I am able to decide when to have sex.
Decision autonomy: her wages	Who usually makes decisions about how your earnings will be used?
Decision autonomy: partner's wages	Who usually makes decisions about how your husband/partner's earnings will be used?
Decision autonomy: major	Who usually makes decisions about making large household purchases?
Decision autonomy: daily	Who usually makes decisions about making household purchases for daily needs?
Decision autonomy: clothes	Who usually makes decisions about buying clothes for yourself?
Decision autonomy: health	Who usually makes decisions about getting medical treatment for yourself?
Savings	Do you currently have any savings for the future, such as a bank account, savings group, or cash?

Financial info	Do you know where to go for financial information or advice?
Financial goals	Do you have financial goals toward which you are working?
Composite metrics	
HH decision making	Scale for household decision making based on factor loadings from confirmatory factor analysis(8)
Financial autonomy	Scale for financial autonomy decision making based on factor loadings from confirmatory factor analysis(8)

Each woman is assigned a value for each metric annually. With the exception of the aggregate metrics, these values are based on survey-weighted GLMs with a quasi-binomial family. The predictors in the models are whether she was using contraception the previous year, the value of that empowerment metric the previous year, age, parity, education, urban/rural, and wealth quintile (eq. 2).

$$logit(p(empowerment))_{yr=t} = \beta_0 + \beta_1 * age + \beta_2 * urban + \beta_3 * wealth + \beta_4 * education + \beta_5 * parity + \beta_6 * contraceptive.use_{yr=t-1} + \beta_7 * empowerment_{yr=t-1} \quad \textbf{Eq. 2}$$

2.5 Contraceptive use

We implemented contraceptive use as a three-step process in the model: 1) decide if a woman is using contraception, 2) if so, which method she will use, and 3) for that method, how long she will use it.

2.5.1 Probability of using contraception

The probability of using contraception is first assessed at the time of her sexual debut. It is then reassessed if she has a change in the status of one of her empowerment metrics, or if she reached the end of her time on a method (described in further detail below). Additionally, the probability of contraception is assessed at 1 month postpartum, and, if she does not start using a method then, again at 6 months postpartum.

Contraceptive use is determined with a survey-weighted GLM with a quasi-binomial family. Each of the empowerment metrics listed in Table 1, as well as intent to use contraception and five demographic metrics (age, parity, urban/rural, education, and wealth) were all considered for covariates, as well as the interactions between each of these. Variables were selected for inclusion using a Lasso regression model using *glmnet*(9) in R version 4.3.2 with a binomial family. Ten-fold cross-validation was used to identify the optimal regularization parameter.

2.5.2 Method choice

If a woman does begin to use contraception, she selects which method to use based on data from the contraceptive calendar in the 2022 Kenya Demographic and Health Survey (DHS)(10). For 1-month postpartum, 6-months postpartum, and not postpartum, we produced age and previous method stratified method mix probabilities, which are used to select the method.

2.5.3 Time on method

Once a method is selected, or a woman decides not to use a method, she is assigned a time on that method, or a time on no method, as relevant. These times are based on accelerated failure time models using the contraceptive calendar data from the 2022 Kenya DHS. For each woman in the data, we identified the first time she switched a method from one month to the next and counted how many months she continued to use that method. We then fit accelerated failure time models for each method adjusted for age group, compared several distributions: exponential, Weibull, log-logistic, log-normal, Gompertz, and gamma, and selected the distribution with the lowest AIC.

2.6 Calibration

Calibration of agent-based models to data is a crucial step to produce results that inform public health policy(11). Because the model incorporates many free parameters that rely on theoretical assumptions where data are scarce, the process of calibration involved adjustment of these free parameters within a plausible bound. The FPsim calibration to a Kenya-like setting included key fertility and family planning calibration targets as well as age-specific distributions of education and paid work.

2.7 Intervention Scenarios

We modeled the implementation of both 3-month and 6-month DMPA-SC. First, we modeled a baseline scenario without DMPA-SC in which we assumed annual growth in modern contraceptive prevalence rate (mCPR) of 2%, with no new products introduced. Then, we model a scale up of 3-month DMPA-SC from 1.5% at introduction to 5% by 2040 in women under age 20. Next, we modeled a scale up of 6-month DMPA-SC from 1% in 2030 up to 5% by 2040 in women under age 20. We assumed 26% of women on 3-month DMPA-SC and 20% of women on traditional methods will switch to 6-month DMPA-SC(12). Finally, we modeled a combined DMPA-SC scenario with both 3-month and 6-months scenarios implemented.

3. Expected Results

Our first set of results will include validation of each of the regression equations, predictive power, and contribution of each explanatory variable to the overall result. We will then demonstrate calibration results, comparing modeled results to data for each calibration target. Preliminary calibration results are shown in Figure 2.

Key results will include a projection for each of the intervention scenarios over time, including uncertainty. We will project mCPR as well as each of the empowerment metrics. For example, we have projected mCPR for each of the intervention scenarios using a previous version of the model prior to the updates described in the methods section. These results will be updated, but we preliminarily find that scaling up the 3-month product accelerates adoption of the 6-month product due to switching behaviors (Figure 3).

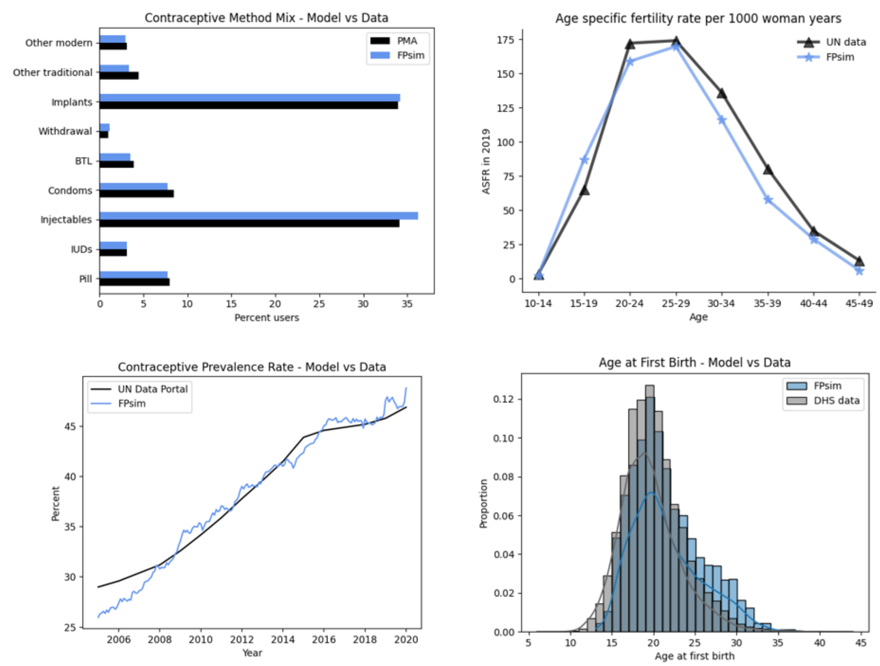

Figure 2. Preliminary calibration results comparing contraceptive method mix, age-specific fertility rate, contraceptive prevalence rate, and age at first birth from FPsim model results (blue) to data from the Kenya DHS (black).

4. Discussion

By incorporating intentions and empowerment metrics, this analysis provides a more comprehensive framework for simulating the multifaceted effects of contraception. Simulation of individual intentions and empowerment outcomes allows for a more accurate prediction of how new technologies, such as DMPA-SC, influence women's overall well-being, particularly in low-resource settings like Kenya. While these advancements are significant, the model also has limitations. The reliance on survey data from Kenya’s PMA dataset, although robust, may not capture all the factors affecting contraceptive use and empowerment across diverse populations. Further, the current model’s focus on economic empowerment overlooks important aspects of social empowerment, which could provide a fuller understanding of how contraceptive access impacts women's lives. Additionally, testing and validating the model across contexts will be critical to enhance its generalizability and applicability. Nonetheless, the innovations outlined in this study mark a meaningful step forward in designing more holistic and person-centered family planning policies and programs.

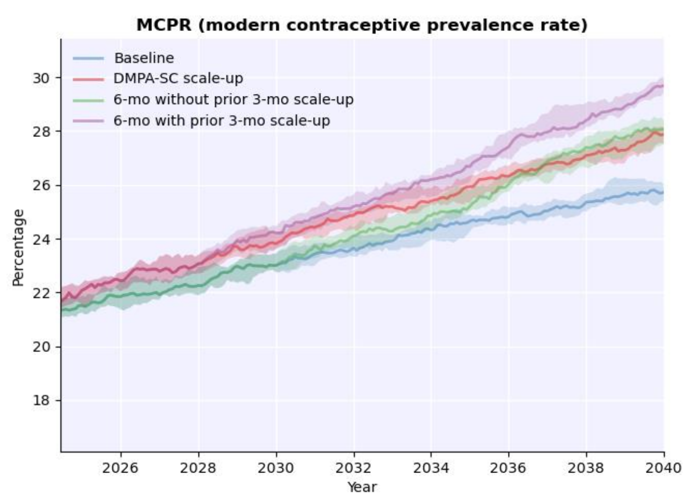

Figure 3. Preliminary results projecting modern contraceptive prevalence rate (mCPR) for the four intervention scenarios.

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