Low fertility in Tehran: An agent-based modeling approach[1]

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Abstract

Iran has experienced below-replacement fertility since 2000, and some provinces have reached very low fertility in recent years. Extensive studies have been carried out to explain low fertility using analytical tools which reveal the lack of a linear and monotonic relationship between low fertility and the factors affecting fertility. The availability of software and hardware facilities has made it possible to model such complex processes as low fertility containing non-monotonic and non-linear relationships. Agent-based modeling is considered as a powerful tool with the ability to model and predict the performance of complex systems along with the capability to employ various parameters in model building. In this paper, low fertility behavior for Tehran province as having very low fertility is simulated using agent-based modeling technique developed based on the Belief-Desire-Intention-BDI architecture. The simulations will predict such indicators as the number of births, number of pregnancies and abortions for the next 96 months. Considering the importance of economic variables on women's future fertility behavior, some related scenarios will also be simulated and evaluated based on the developed model. Our preliminary calibration results confirm the level of fertility during 2017-2019 published by the statistical center of Iran indicating the reliability of the predictions.

Keywords: Low fertility, agent-based modelling, simulation, Tehran.

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Extended abstract

Iran has experienced below-replacement fertility since 2000 (Abbasi-Shavazi *et al* 2009, McDonald *et al*, 2015). Extensive studies have been carried out to explain low fertility using analytical tools which reveal the lack of a linear and monotonic relationship between low fertility and the factors affecting fertility (Giulio *et al* 2013). The availability of software and hardware facilities has made it more and more possible to model such very complex processes as low fertility containing non-monotonic and non-linear relationships. To this end, 'agent-based modeling' is considered as a powerful tool with the ability to model and predict the performance of complex systems along with the capability to take into account various parameters in model building. In this paper, low fertility behavior as a function of different factors and parameters is simulated by agent-based modeling technique developed based on the Belief-Desire-Intention-BDI architecture. Considering the importance of economic variables on women's fertility behavior, some related scenarios will also be simulated and evaluated based on the developed model. The low fertility modeling process in carried out for Tehran province as the capital of Iran having a lower fertility rate (1.5 children per woman) than the national average (Statistics Center of Iran, 2016). The simulations will predict such indicators as the number of births, number of pregnancies (both wanted and unwanted) as well as abortion for the next 95 months as shown in the following sections. Our preliminary calibration results confirm the level of fertility during 2017-2019 published by the statistical center of Iran indicating the reliability of the predictions.

Data and methods

The main analysis is based on the sub-sample of data from the 2017 Iran Fertility Transition Survey (IFTS) conducted in five selected provinces of Iran (Abbasi Shavazi *et al*, 2019). The data collected from 1500 households in Tehran province including 798 ever-married women. The questionnaires were developed in the form of a general household questionnaire and a special questionnaire for ever-married women aged between 15 to 54.

Based on low-fertility theories as well as the relevant literature on low fertility, the process of extracting agents and introducing the attributes of the agents in the developed model are presented in the following section. Special attention will be made to economic scenarios and its impact on model outputs.

Agents and their extracted attributes

Household is defined as a multi-agent in the simulated model including two attributes of economic status of the household and the number of household members. *Female agent* attributes consisting the following 17 attributes were considered in the simulation model: age, duration of marriage, education, employment status, number of children, contraceptive use, gender equity within the family, degree of adherence to religion, influence of social media, attitudes toward government facilities, attitudes toward abortion, value of children, desired number of children, intellectual autonomy and decision to care for a child after pregnancy, social interaction and social pressure. All the household as well as female agent attributes have been extracted based on the IFTS questionnaires.

Government is defined as a single agent in the simulation model having two attributes: economic inflation and the impact of government facilities.

The following is a brief explanation of how the agents are formed and the way in which rules are extracted.

Rules and agent extraction methodology

To construct the agents, extract the computational rules, interactions among the agents, and finally initialization and generation of random agents, pre-processions are performed on the data using the CHIAD algorithm based on the decision tree. The generated rules are then coded and entered into AnyLogic software (version 8.74). Through written codes, each agent is called within the groups and its related variables and parameters are randomly set.

Conceptual framework

Nowadays, the study of computational agents having the ability to behave logically has attracted the attention of modelers. In this paper, the generation of the model and its subsequent simulation is based on an algorithm which results in the production of intelligent agents with decision-making capability. This agent affects the operation and is affected by the model. The algorithm used in the model derivation based on agent-based modeling in the literature is called BDI model (Rao and George, 1995; Singh *et al*. 2016; Adam and Gaudou, 2016; Caillou *et al*. 2017; Berndt *et al.* 2018). This modeling strategy is highly relevant for fertility decision making.

Decision making strategy in BDI

In the modeling procedure, female is modeled inside the household agent while the household is defined as a multi-agent. The attributes of household agent are divided into two parts, the first set of attributes named D is completely static and the assigned values to this part do not change during the implementation of the model. The second part denoted by B is a dynamic quantity and changes while the model is running. The sum of B multiplied by D results in intention denoted by I, which is essentially the intention to wanted fertility and leads to action with a specific probability. It should be noted that the output of the BDI calculations ultimately determines each woman's decision on her intention for wanted fertility in the simulation model.

Based on the interaction and behavior of the female agent with other agents, the outputs of the simulation model at any moment of the simulation for a 96- month (8 years) period are extracted dynamically as the following:

1) Cumulative frequency of children ever born; 2) number of wanted pregnancies; 3) number of unwanted pregnancies; 4) number of unwanted abortions; 5) number of wanted abortions; and finally 6) number of pregnancies. It should be mentioned that women's fertility behavior is observed in each age group separately and it is possible to analyse the differences in women's fertility behavior in various age groups

In order to verify the results, the model is calibrated and validated based on the available data obtained from (Statistics Center of Iran, 2019) and the outputs of the simulations. In the full version of this paper, the impact of economic situation on fertility is examined using a set of scenarios considering different economic variables (i.e. economic inflation and household income level).

Model calibration

In the modeling procedure an event named TFR is defined and applied. To calculate the TFR, first ASFR is calculated in each age group, then the summation of ASFR is derived and multiplied by 5. Finally, the generated number is divided by 1000 (UNESCAP, 2018).

TFR = (Sum of ASFR x 5) /1000

In this way the event, which is used for derivation of TFR for updating the parameters, is constructed. The mathematical calculations are carried out based on available data from the Statistics Center of Iran for Tehran province from 2017, 2018, 2019, respectively (Statistical Center of Iran, 2019). The TFR is calculated from tuning and calibration of the model based on the parameters named (un wanted pregnancy calibration, wanted pregnancy calibration, and recovery duration calibration). The results shown in Table 1 confirm that the TFR based on the Statistical Center of Iran and the simulated figures are almost identical.

Table 1. Comparison between real data and the results obtained from simulations

Years	**TFR based on Simulation Model**	**TFR based on Real World**
2017	1.66	**1.6**0
2018	1.50	**1.49**
2019	1.45	**1.44**

It should be noted that due to the probable nature of the model, the TFR results in Table 1 has been obtained after 100 times of simulation runs and averaging the results. After the model calibration, the outputs will be derived based on the proposed scenarios.

Simulation outputs

The following figures show the simulated outputs. The first output of the simulation model is cumulative frequency of children ever born for eight five-year age groups from 15 to 19 years to 50 to 54 years for Tehran province. The results are forecasted for 96 months (8 years) during 2017 to 2025, but note should be taken that the first 36 months (3 years) period of mode are assigned to model calibration.

As Figure 1 shows, from the 36th month of the simulation to the 96th month, the number of alive births for women will triple, increasing by 11 percent from 155 to 431 births. Women in age group 30-34 have the largest increase in the number of live births.

It should be mentioned that based on the ratio of married women in Tehran province for the production of random agents' scale of one to 1000 was used, and 2274 random agents were produced accordingly. The exact method of extracting random agents is given in detail in the full version of the paper.

Preliminary Results:

Figure 1: Predicting cumulative frequency of children ever born by age group during 2017 to 2025, Tehran province

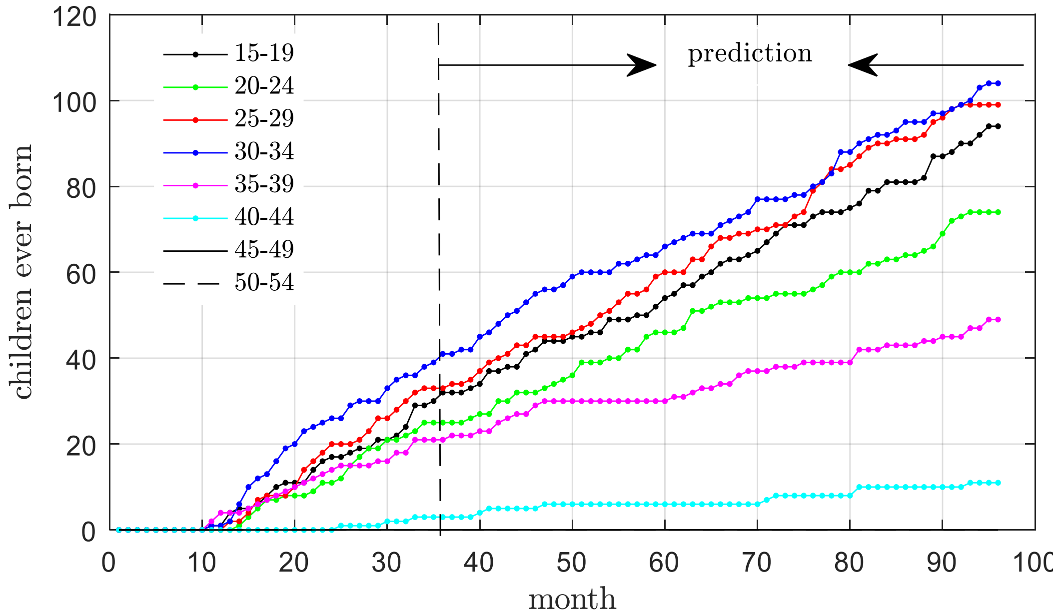


Figure 2: Predicting cumulative frequency of pregnancies by age group during 2017 to 2025, Tehran province

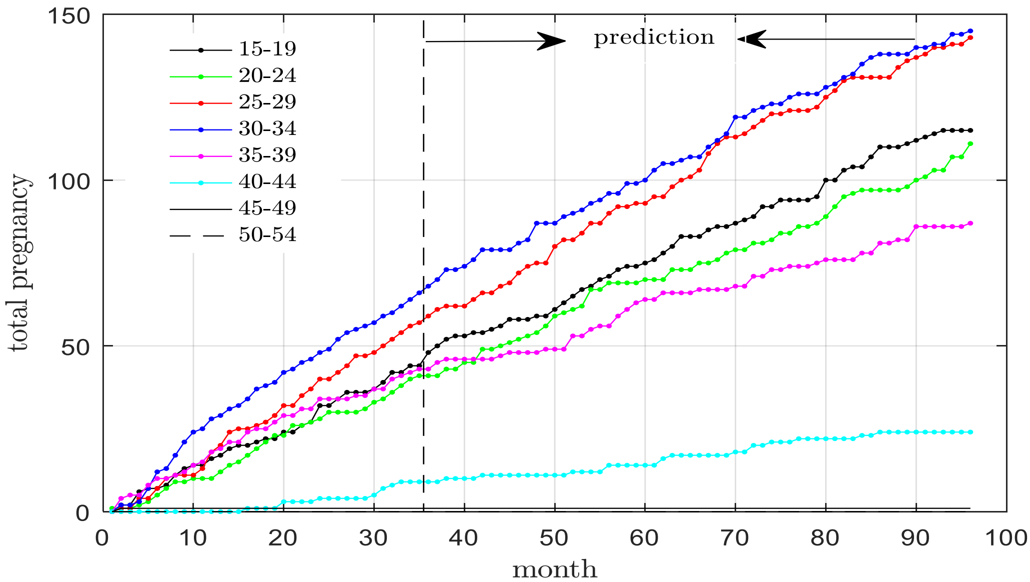


Figure 3: Predicting cumulative frequency of unwanted pregnancies by age group during 2017 to 2025, Tehran province

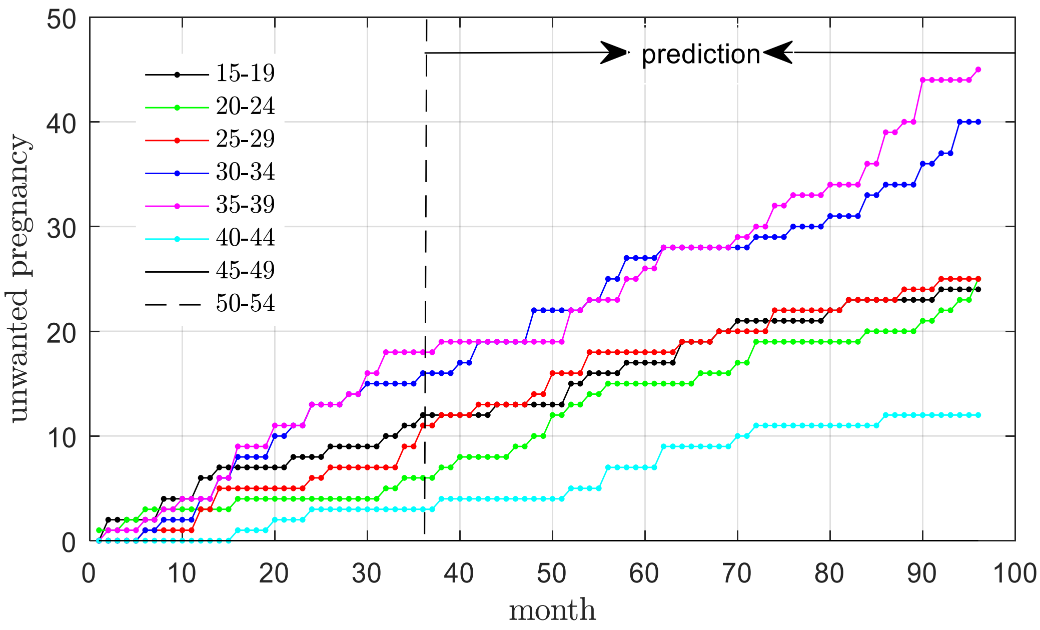


Figure 4: Predicting cumulative frequency of wanted pregnancies by age group during 2017 to 2025, Tehran province

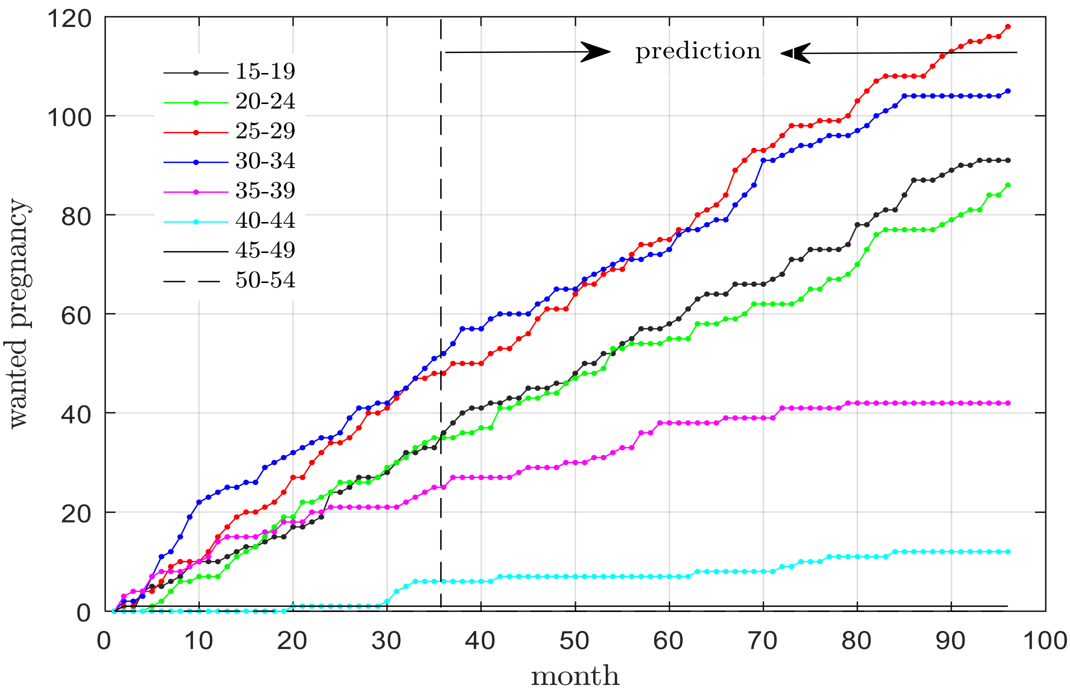


Figure 5: Predicting cumulative frequency of wanted abortions by age group during 2017 to 2025, Tehran province

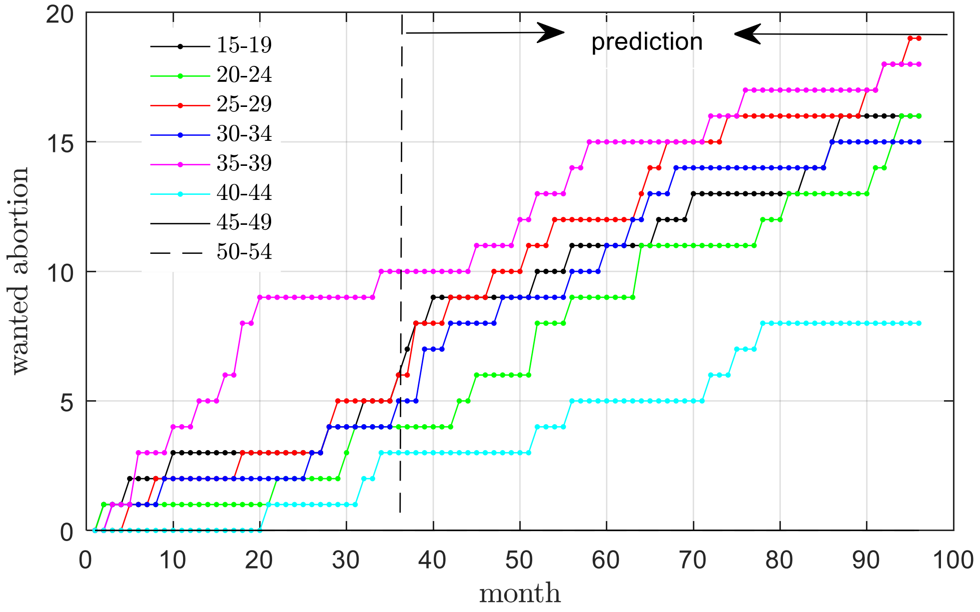
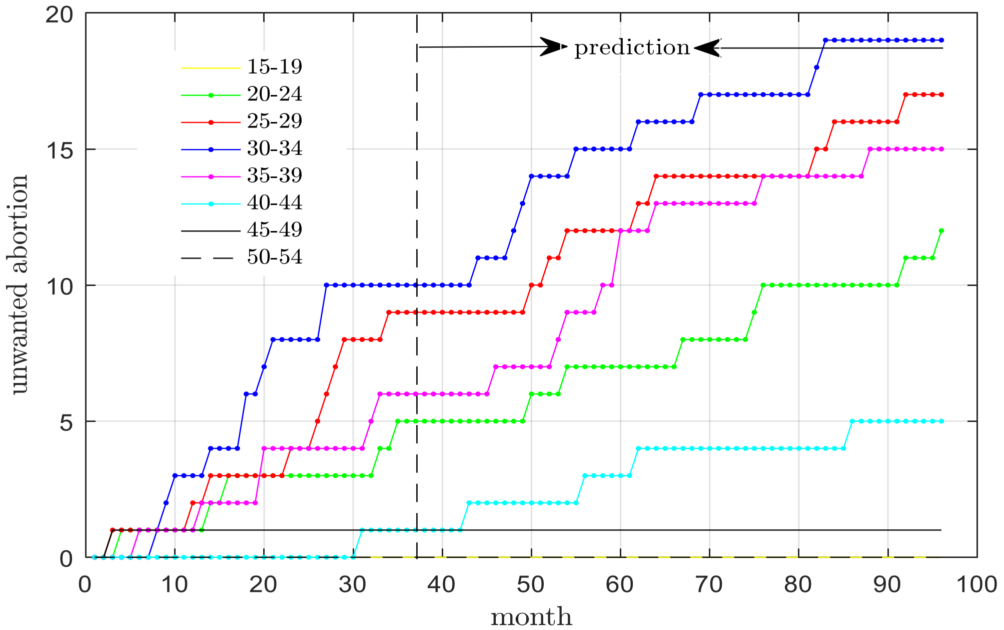


Figure 6: Predicting cumulative frequency of wanted abortions by age group during 2017 to 2025, Tehran province



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