

Simulating Demography – Dynamics of Fertility Using a Multi Agent Model

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Abstract — Many countries of the world have seen fertility rate declines. Sincere efforts have been made by the governments to change this trend. But still, countries like Korea & Japan are facing the problem of fertility rates well below the replacement fertility rates. Modeling and simulation offer a good way of understanding the dynamics of population. Of late, agent based modeling (ABM) has gained quite a lot of popularity in the field of simulation. We propose an actual population data fed agent based model whereby the agents in the simulation would take as input the actual census data and simulate the population fertility dynamics. Fertility rates are the main measures of population change. We will try and understand how fertility evolves by taking into various factors such as age, income, expenditure, social benefits; from the micro to macro level. The decisions of the agents, such as to get married and then have certain number of children, would be based on these factors. The fertility is predicted by accessing number of children a couple would have in the child bearing age. We hope to analyze and understand the effect of factors such as social benefits by this model.

Keywords — Agent Based Modeling, Demography, Fertility, Population Dynamics, Data Driven.

I. INTRODUCTION

Around the world different countries face different kind of problems regarding population growth. Some tackle the rapid growth and over population and others tackle slow population growth or even decline. Maintaining a healthy rate of population growth and right demographics is very important for a country. Countries experiencing slow growth of population or decline have increasingly large number of people in the dependent older population range. This exerts pressure on increasingly shrinking working population and the government resources supporting the dependent population. This decline in fertility is generally seen in the developed countries. Though this decline is thought to be temporary [1], some developed countries like Korea and Japan are still experiencing very low fertility rates. The current total fertility rate of Korea and Japan stand at 1.21 [2] & 1.42 respectively [3].

Various efforts have been made to revive this trend in these countries but the outcome of these efforts are not up to mark. So understanding dynamics of population growth and how

different factors effect population is very important. Agent Based Models gives us an opportunity to simulate this closely by helping us to analyze relation between behaviors at micro level to the macro level. We can study the emergence of global features from the bottom up, main idea being that interactions between the agents can produce the behaviors which are more/less than the aggregated sum of the individualistic behaviors [4].

The example use case in our simulation will be of Korea. Korea has been battling a low fertility rate for some time now. Various factors have been responsible for this decline. It has been postulated that increase in the rate of women participation rate in labor force and associated problems such as job insecurities, problems in maternity leave, childcare, is one of the main factors for this problem [5], [6]. Also there has been an increasing trend of late marriages in Korea. According to Korean Statistical Information Service (KOSIS) [2], the mean age of women at marriage has increased from 24.78 in 1990 to 29.81 in 2014. For men, it has increased from 27.79 to 32.42 for same time period. Due to development, people are valuing their career goals and stability over marriage and having children [5], [6]. The government is incentivizing families with children to boost the fertility rate. Some of the factors which impact fertility have been shown in Figure 1. Figure 2 shows total fertility rate (TFR) for same years. We can see that there is increase in female labor force participation, the increase in age at first marriage, decrease in marriage rate and decrease in total fertility rate. The data has been taken from Korean Statistical Information Service (KOSIS).

Taking various such influencing factors into account, we would apply ABM to understand the dynamics of fertility of the population [4], [7], [8]. ABM would help us to model the heterogeneous nature of the population as far as various contributing factors are concerned. To ensure the behavior of the ABM is not unrealistic, we would initialize the model with the actual census data of Korea. We would use probabilities for decision making by agents wherever necessary. The simulation would proceed by a mix of probabilities and interaction of agents driven by the statistical data. We would run simulation for various different years and compare the results obtained

with the actual data. This way we can compare and calibrate our model and use it for further evaluations.

The rest of the paper is organized as follows: Section II describes the model in detail, Section III discusses results and section IV includes conclusions and future work.

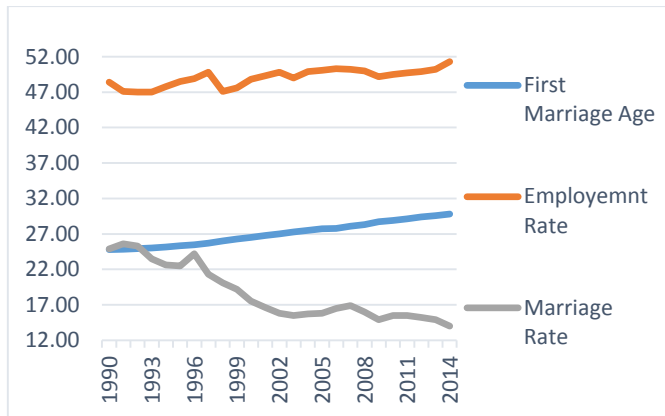


Figure 1. Age at First Marriage (in years), Employment Rate (in %), Marriage Rate for Women (in %) on the vertical axis

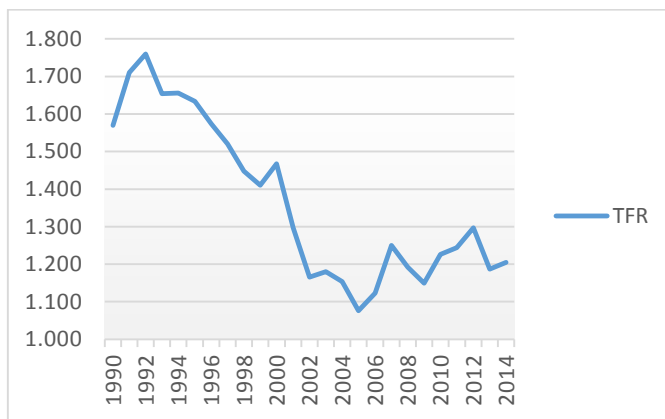


Figure 2. Total Fertility Rate (TFR)

II. MODEL DEVELOPMENT

In this we describe the model specification, the agents and the simulation procedure in detail.

A. Model Specification

Our proposed model is data fed agent based model. The agent based model is based on popular agent modelling technique Belief Desire Architecture System (BDI) [9], [10], [11]. The BDI model presents the working technique of a typical agent. Typical agent consists of beliefs – the knowledge an agent has of itself and that of other agents and the world. The desires are the possible goal states that an agent would want to achieve – which in this model could be getting married, having children, deciding no. of children etc. The intentions are those desires which are being pursued by an agent at a particular point of time. It is worth noting that intentions and desires are dynamic in nature. They change over time in accordance with the decision process of the agent. There is also a plan library

which has plans to execute the intentions and other activities of the agent. The advantage of using this architecture is that it provides the logical separation of the various activities of the agents and makes the understanding of whole process much simpler.

The tool used for modeling is Jason Multi Agent System. Jason is an interpreter for an extended version of AgentSpeak, which has been one of the most influential abstract languages based on the BDI architecture. Jason implements the operational semantics of that language, and provides a platform for the development of multi-agent systems, with many user-customizable features. Jason is available Open Source, and is distributed under GNU LGPL. Jason multi-agent system can be easily distributed over a network using SACI (Simple Agent Communication Infrastructure) or JADE (JAVA Agent Development Framework) and thus would support large number of agents, as required by our simulation [12].

B. Agents

The model contains two types of agents: male and female. Before starting the simulation, the agents are seeded with age and sex information from the Korean census data (the 50% agents are males and 50% females). The income and expenditure are also taken from census data. There are control variables for agents to have some desired no. of children. This is again based on the data from Korean context. 25% of the agents have desire for 1 child only, 60% have desire for two children and 15% agents have desire for 3 children [13]. The income of the agents is assigned based on education level [14].

C. Procedure

The simulation starts with agents wandering in virtual space and looking for suitable partners for marriage and then having children based on various factors. After an assigned period of time, the ‘time’ in the simulation increases (i.e., the next year would come) and agents grow old and other factors that depend on time (e.g. income, no. of children) change. The decision to get married depends on agents’ initial income and age. For two agents to get married, the age difference should be maximum 5 years.

Since we have assigned income to agents on basis of education, the education level of marrying agents should not differ by more than 1. As available in the census data, we have three education levels (0 – high school, 1 - college 2 - university). The agents after getting married, check their surplus income and decide to have certain no. of children if surplus income is enough to raise a child. Surplus income is obtained by subtracting consumption expenditure and non-consumption expenditure (income tax etc.) from total income. The couples having children have government assistance added to their surplus income, and cost of raising child would be subtracted from surplus income. Thus their decision to have subsequent children could be affected based on government assistance. The values for income, consumption expenditure, non-consumption expenditure, income based on education level are taken from KOSIS [2] and Statistics Korea (KOSTAT) [15]. The values for amount of government assistance are taken from OECD statistics [16]. The rough cost of having a child for a year has

been taken from a Korean Ministry of Health and Welfare report, which is around 15 million KRW [17].

The education level and income level of the agents evolve over time. Each agent would have a target education level (0, 1, and 2) and would continue to update education till age of 35. If target education level is achieved before that, the agent stops pursuing for further education. Agents with constant education level also update their income level as time passes by. The growth rate of income would depend on the education level an agent has. The data regarding education and income has been taken from Service (KOSIS) [2].

The population in the simulation changes over time. The agents 'die' when they reach the age equal to life expectancy of Korea (different for male and female agents). The married agents bear children, which like real life, grow old and contribute to the population growth when they get married and this process goes on. Whenever a couple has a child, there would be biological time difference between subsequent children. This varies randomly from 2-5 years for different agents. The maximum number of children a couple can have are equal to desired number of children variable (varies from 1-3). Rough fertility related activities are shown in Figure 3.

The married couple in our model have children only while the female agents are in age group of 16-45. Additionally, the age of first marriage these days is 32.4 for males and 29.8 for females. Further, age of females at first, second and third birth is respectively 30.97, 32.81 & 34.65 years. The values for age at marriage and birth are taken from Korean Statistical Information Service (KOSIS) [2]. The female age at first child from year 1993 to 2014; the trends of average income per month for education levels high school, junior college, and college and university or higher, for males aged 25-29, from years 1990 to 2010, is shown in Figure 4 [2]. We are using these trends and data in our simulation.

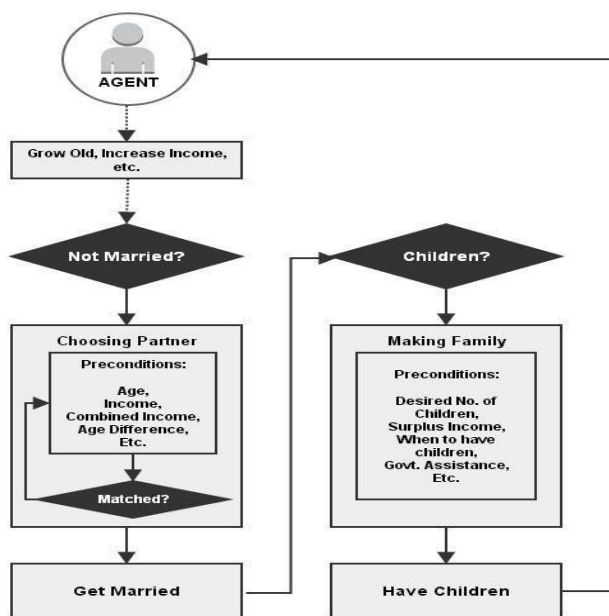


Figure 3. Fertility Related Activities of an Agent in the Simulation

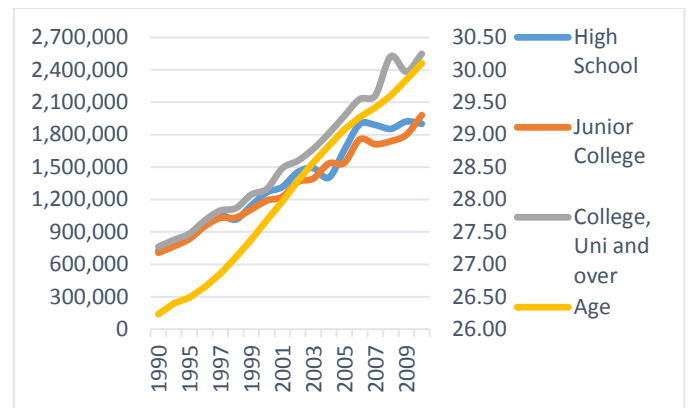


Figure 4. Growth of Income (in KRW) on left vertical axis. Variation of age at first childbirth over the years (in years) on right vertical axis. Horizontal axis represents years

III.RESULTS

Initial agent population in our simulation is 10,000 (5000 male, 5000 female agents). In order to compare, we are taking data from 1990, 1995, 2000, 2005 and 2010. Basically, we initialize our model with the 1990 data and observe the trends in the simulation. Then we compare it with the actual census data. Our work is in progress and initial results obtained so far are satisfactory. However, we are not in a position to publish these results, as at the time of writing this paper, we are experimenting with the model by different inputs of data and trying to explore model with more depth. We are pursuing multiple cases for cross-checking our model to establish the working of our model. Once this analysis is complete, we would be able to publish these results. We are mainly interested in seeing how the population changes as the time goes by. We have calibrated this model with the census data to validate the working of this model. The screenshot of Jason is shown in Figure 5 on next page. We can use this model to find various kind of other demographic trends such as marriage rate, birth rate etc., but for the initial working we are observing how the population evolves. The time step for each year is about 15 seconds, since interaction of large number of agents, all the dynamic processes, and decision making takes time. The simulation would run for 200 years, or if agent population is finished. Thus, if population survives 200 years, simulation runs for about 50 minutes.

IV.CONCLUSIONS

This paper presents a model to study the dynamics of demography with use case of Korea. In general, a modeler can initialize the simulation with country specific data for country contextual studies. We take into account the properties of agents such as age, income, education, government support in process of getting married to bearing certain number of children. We use agent based model which help us to study and understand the emergent non-linear behavior of the population dynamics, by taking into account the micro (or individual) level decisions of various agents. Further, we used Korean census data in our model to remove the possibility of using, or obtaining unrealistic values of various parameters used.

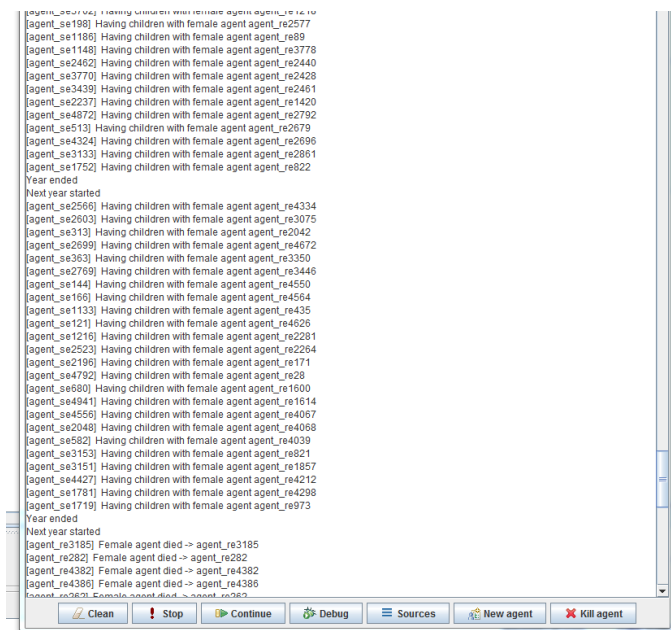


Figure 5. Screenshot of Jason Simulation

Thus we have accommodated the heterogeneity of the population dynamics in our model. We are exploring different facets of our model and we are pursuing sensitivity analysis. We are hopeful that this model could be used by various organizations for their respective needs. For the future work, we are working on increasing number of agents in the simulation as well as trying to decrease the simulation time for various runs. Also, we would more cases and more modules such as migration, to study the emergent behavior of population. We hope to use our model for understanding and then for prediction of population dynamics.

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