Population Dynamics Analysis for Policy Evaluation Using Micro-Level Population Dynamics

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Abstract— **Population dynamics describes the changes in size, distribution and age compositions of population. Modeling and simulation have been used by researchers and scientists to understand and analyze the population dynamics and to apply it for policy evaluation. In this paper we describe a population dynamics model based on the features of both the microsimulation and the agent-based modelling. We apply this model to simulate and analyze the Korean population dynamics using the Korean population data. The agents in this model derive their decisions and behaviors from the real data (microsimulation feature) and interact among themselves (agent based modeling feature) to proceed in the simulation and change their states such as their age, educational status, gender etc., along with simulation procedure. This model is used for the analysis of population dynamics by varying behaviors, interactions and social scenarios of the agents. The simulation results obtained through these virtual experiments enabled us to discover the factors that trigger population dynamics. This paper makes an attempt to filter out the main factors which can affect the Korean population dynamics. Furthermore, this paper shows that our approach can be used for the optimization and evaluation of the public policies with a pension policy example.**

Keywords - Microsimulation, Agent Based Modeling, Micro Level, Simualtion, Data Driven, Policy Evaluation

I. INTRODUCTION

The study of population dynamics is carried out in order to understand and predict the changes that occur in population over time. It is scientific study of population which focuses on the variation of size, distribution and age composition of population over the course of time. This paper is mainly concerned with the size and age structure of the population. The understanding of this phenomenon is rather difficult because it is not only related with the aggregate behavior of people, but also the individual level choices that people make according to their personal and social surroundings.

In general, the population over-growth is the main focus of the population related studies and analyses. However, recently, this field has received a special attention from the many countries of the world from a completely different perspective, i.e. the problem of low fertility and inadequate growth of population. It is important to note that while some countries like Niger have very high fertility rates (6.76 children per woman), others like Singapore (0.81), Korea (1.25), Japan (1.40) have low fertility rates [1]. The fertility rates are well below the sustainable rate of about 2.1 [2]. This signifies that population size cannot be maintained over time.

The problem of low fertility is generally related with developed countries of the world. With the development comes different preferences and life styles which are believed to be reason of low fertility [3]. Although one might think so, but it is a paradox to believe that lower population implies better facilities for fewer people rather than less facilities for many people. Many problems are related with low fertility rate. Lower fertility means that less number of children are being born and less number of people would grow up to be available as the work force. It is interesting to note that low fertility is generally related with the developed countries, where life expectancy of people has grown due to better health care services (the life expectancy of Korea is 82 years), and size of dependent population (population in age groups of 0 -14 years and above 65 years) is increasing as number of aged people are increasing. Median age of population in Japan is 46.5 years and that of Korea is 40.8 years. On the other hand, for India, which is a developing country, it is 27.3 years [1], [4]. This in turn means that governments have to invest more money to cater to the needs of increasing dependent population with pensions and other related facilities, with the decreasing work force. This could create a tremendous pressure on government and working population, which can lead to variety of social, welfare and economic issues. The Korean government is already spending 7% of its GDP on pensions as compared to USA, which is spending approximately 3% [5].

To tackle these problems and to revive the fertility rates, governments have undertaken many policies, but the outcomes of these efforts have not been up to the expectations. For instance, despite the changing policies related with maternity and childbirth, the current fertility rates of Korea and Japan are 1.25 and 1.40, respectively [1]. Huge sum of money has been spent and many policy changes have been implemented to give a positive push to the fertility rate. Since the expected targets have not been achieved, there is a need to test and evaluate such policies before they are implemented to optimize the results and expenditure.

Extensive research has been carried out and many different models have been prepared to analyze the population dynamics. Some popular examples of these models have been discussed in the related works in section II. But each of these models has certain drawbacks. These models are either microsimulation based or agent based, each having some drawbacks. For example, they do not take into account the micro-data for initialization for individual agents or don't use micro data for decision making, or don't use agent interaction for decision making. These models, albeit, depict the general notion of understanding for population dynamics, (such as impact of family welfare policies) and predict the future population structures, but they don't propose methods to arrive at desired numbers or structures of population.

The optimization of public policies designed by governments is extremely important for the welfare of people. But future policy design and evaluation is difficult as it is closely related to the population size and structure. Therefore, in order to design an effective policy and evaluate it, firstly the population characteristics at that point should be understood and predicted efficiently. After that the effectiveness and evaluation of the policy can be done by experimenting and estimating based on the virtual population.

Modeling and simulation are extensively used by scientists and researchers to simulate and understand population dynamics. Experimentation on actual population is a long, expensive and an unethical process. Microsimulation (MSM) and Agent Based Modeling (ABM) are two popular techniques being used for simulation and modeling. MSM is a classical technique, but ABM is comparatively newer. MSM models the individuals with micro-data from real population data (e.g. age at first marriage) and delivers the final output by adding up individual simulated outputs of individuals. ABM also considers and models each individual, but lays more emphasis on the interactions and feedbacks between the individuals in the virtual population. Both these techniques have similar features such as being bottom up, heterogeneous individuals in the virtual population, however, they have differences in defining the individual behaviors. MSMs define behaviors based on transition probabilities derived from micro data for different events; ABMs mostly have rule based behavioral definitions. Based on the features of both techniques, a hybrid system based on strong aspects of both these techniques can be built which would utilize the micro data as well as incorporate real life like rule based decision to yield better simulation results. Working on these lines, we have prepared a model to simulate population dynamics. The use case for the current work is Korean population. Korean census data has been used to initialize the data for simulation and to arrive at required transition probabilities and decision rules.

Based on the above discussion, and using the new hybrid model, we present the analysis of the population dynamics, focusing on the control, analysis and prediction from the micro level perspectives. For the current work, the Korean census data and social setting has been used for the model initialization. The results obtained depict that the education and divorce play a significant role in the future population size and structure. The proposed model is unique in terms of its usage of micro-data for initialization and decision making, use of Korean context to arrive at decision rules, use of hybrid technique based on MSM and ABM, usage of large data set (2% of Korean population or about 890,000 individuals) and an attempt to perform control, analysis and prediction from the individual level perspectives.

II. RELATED WORK

Population dynamics has been analyzed from both macro and micro perspectives. While the macro-level population dynamics predicts future changes of population from population behavioral patterns and its abstract properties, the micro-level analysis utilizes individuals' behavior and characteristics. Combination of these properties can generate unexpected phenomena that provide insights for solving the current problems.

Analysis on micro-level population dynamics have been conducted using various techniques, the most famous of these are: Microsimulation Model and Agent-Based Model. MSM was pioneered by Orcutt for evaluating socio-economic policies [6]. He identified and represented individual entities in the socio economic system with changing their behaviors as time evolved. MSM describes a target system at the individual-level, so the system dynamics are represented as the aggregation of individuals (i.e., bottom-up approach) [7]. Currently, many population dynamics models have been developed in many countries for estimating of the future population DYNASIM3 (USA), DYNACAN (Canada), MOSART (Norway), SESIM (Sweden), SAGE (UK), DYNAMOD (Australia), and DESTINIE (France).

ABM consists of autonomous agents (or individuals) that decide their actions based on their own conditions, environment where the agents are situated, and the interactions among the agents. The interaction is considered as a key factor since it enables us to analyze complex population dynamics by means of emergence [8]. Famous starting examples of ABMs are the segregation model proposed by Schelling [9], and John Conways Game of Life [10]. The agent based social simulation for population dynamics was initiated by Billari and Prskawetz [8]. Most of the previous works have been proposed in demographic contexts from the interaction perspectives, such as family formation [8], migration [11], residential mobility [12], household dynamics [13].

Policy evaluation is conducted for checking the effects of the policies of respective ministries and for evaluating the policies in terms of necessity, efficiency, validity, etc. However, evaluating policies in the real-world is not feasible because of its massive costs. One solution that has been considered is the evaluation in the virtual society created from simulation. In this sense, due to the bottom-up approach of the micro-level population dynamics model, most of the micro-level population dynamics models have been developed for evaluating public policies [14].

There are many examples of the policy evaluation using simulation models. One example is Pensim2 developed by the

British Department for Work and Pensions [15]. Pensim2 is a micro-level simulation model, and used for estimating pension policies in UK. EuroMod is a simulation model for assessing tax policies in EU, and utilized for estimating the size of future population and tax policies for the estimated population [16]. Also, TRIM (Transfer Income Model) developed in USA is applied to analyzing potential impacts led by the changes of tax and health policies [17].

The MSM based models do not take into account the interaction of agents. Thus they lack the explanatory capacity and cannot support of emergence from the simulation, thereby missing some hidden patterns. These models cannot accommodate the incorrect results obtained by the sheer dependence on the empirical data. On the other hand, the ABM models either do not consider the micro-data for individual agents or use behavioral rules that are not derived from the micro-data (assumed analytically).

III. MICRO-LEVEL POPULATION DYNAMICS MODEL

As discussed in introduction of this paper, population dynamics is illustration and understanding of how population size and age structure vary over time. Demographers study the population dynamics and reasons for changes in the population. They study how the individual behaviors of people affect the changes in the populations. Various individual level activities are associated with the people that contribute to population dynamics. The size and age structure of the population is decided by activities such as matrimony, fertility, employment, mortality, which are undertaken by the individuals. Micro level population dynamics model tries to simulate the same for the virtual society and individuals.

Therefore, at this stage, our model takes into consideration activities such as matrimony, fertility, employment, education, mortality and migration. These activities affect size of population in several ways. For example, the fertility causes increase in the population size, mortality decreases the population size, migration may increase or decrease the population size and may cause density of population to increase or decrease (for a particular city or place). In addition, the matrimony or selection of partners for marriage causes the interaction to occur between the agents, the employment and education can be related with the activities such as fertility (may depend on income), or migration (due to place of work or education).

The segregation and implementation of these modules into the model helps in the better analysis of the results obtained. We can analyze the effect of activities such as matrimony and thereby, their effect on the population dynamics. E.g. what kind of effect can higher education have on the fertility of individuals. For the implementation of these modules, we require detailed micro level data for the individuals in the simulation. This data can be obtained from the government departments, which collect it for population statistics and future population estimates. Also, we need to define the behavioral rules of the individuals according to the Korean context. The use of ABM in our model enables the agents to interact with each other and enables the possibility of discovering an emergent behavior from the simulation. This hybrid use of microsimulation and agent based approach is thus a step towards improving the simulation by trying to make the individuals in the virtual population to 'behave' like actual world. Figure 1 represents the conceptual diagram of our proposed model.

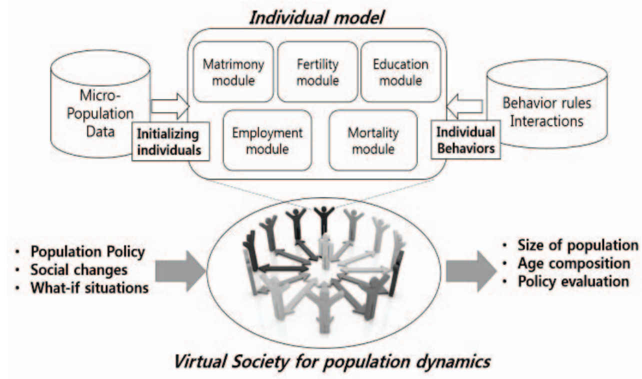

Figure 1. Conceptual Diagram of the Proposed Model

IV. KOREAN POPULATION ANALYSIS USING MICRO-LEVEL POPULATION MODEL

This section contains a short description of model developed. The model is a hybrid of agent based and microsimulation technologies. We have tried to exploit the best features of both the models that can us to yield better results.

ABM and MSM have been extensively used for modeling the micro level population dynamics modeling. MSM mainly focuses on heterogeneity of the individuals in the population whereas the ABM focuses on the interactions and emergence. There are various characteristics of the MSM and ABM which are similar, such as heterogeneous individuals, being bottom up approach, and micro level modeling of individuals. On the other hand there are some features such as interactions (absent in MSM and prominent in ABM), the objectives (projections in MSM and explanation in ABM), the state change process for an individual (stochastic in MSM and rule based in ABM) which are different form each other [18]. By analyzing these properties, we prepared a model which takes MSM part in defining the individuals, their micro characteristics such as age, gender, marital status etc. and ABM part which mainly focuses on interaction among the individuals for the matrimony related activities.

The virtual population in the model consists of agents which represent individuals. Agents in simulation is a self-contained, modular and uniquely identifiable individual. It is autonomous in nature and has a state that varies over time. It is social as it interacts with other agents for making decisions related to matrimony. The attributes of agents can be static or dynamic in nature. Static attributes are the ones that don't change with the simulation, viz. identifier, gender, birth year, birth region etc. dynamic attributes are those which evolve or change with the simulation, such as age, employment type, spouse, living region etc.

The agents not only have these attributes, but also have behaviors. The agent behaviors are the activities that are related to population dynamics. Some examples of these behaviors include mortality, health, education, economy, matrimony, fertility and migration. These behaviors are interconnected with each other for an agent. For instance, for an agent, the level of education attainment decides kind of job he is doing, the kind of job could decide the living region of the agent. The transition probabilities and deterministic rules are derived in accordance with micro population data. These behaviors of the agents evolve based on set criterion and by means of interaction with other agents.

To handle large number of agents and associated complexity, the model framework makes use of many-core based distributed execution environment. To maintain a reasonable execution time with large no. of agents, the model has been developed using C and C++ language rather than other popular languages like Java. The main components of framework include simulation framework, large scale distributed and parallel computing platform and user interface. A user can design the simulation model using model designer in the web user interface (UI). The model architecture is generated in .xml files whereas the model code is then generated in the .c and .h files. The framework does not require user to have expertise in the distributed or parallel computing. The simulation system consist of multi nodes simulation system which contains 2 nodes having two 5 core CPUs running on Intel Xeon E5-2650 V2 2.6 GHz, 64 GB DDR3 FBDIMM. The average time taken per step of simulation using 5 cores is 3.575 seconds. The details of the implementation of this framework are out of scope of this paper and will be covered in different paper.

The data used for the analysis in our model is Korean population data. The source of this data is Korean Statistical Information Service (KOSIS) and Statistics Korea (KOSTAT). KOSIS provides detailed data regarding the population census containing a wide variety of fields with specific data regarding individuals. We have filtered out required data from this data dump available. Data from specific fields like age, region, employment, education, family information etc. are chosen and are used in the model initialization. For experimentation purposes we are currently using about 2% of the micro population data. This is equivalent to about 890,000 individualistic data being utilized in the model. Using this large data set for initializing the heterogeneous agents in our model, we hope to discover emergent behaviors from the collective population.

Simulation starts by micro data seeded agents wandering in the virtual space, and looking for suitable partners and getting married. The simulation proceeds and as time passes by, the dynamic attributes and the behaviors of the agents evolve. By means of measuring various attributes of the virtual population, such as no of births, education levels, employment status, we can analyze population behavior as well as predict the future population structure. We vary agents rule set for decisions and change various conditions in model's virtual population to make analysis and observations.

In this paper we present the analysis of the Korean population vis-à-vis its size and structure. As already discussed in the previous sections, the lower fertility causes the working population to decrease and dependent population to increase. In this paper, we focus on the working population in the range of 15 - 65 years age group and dependent population in age group of above 65 years. The choice of the sizes of these groups is based on the fact that the government should be aiming comparatively more towards increasing the working population. The working population is determined by the number of people in the 0 – 14 age group, which means that more working population would come from more people in 0 – 14 age group, which in turn would come from increased fertility [19]. In addition, we attempted to estimate the pension amount required based on the future population structure.

To pursue the desired analysis, a wide variety of test cases were designed and the simulations were run for each one of them. While designing the test cases we not only consider the factors which may affect the size of population, but also tried to take the Korean social context into consideration and only design test cases that are plausible in the Korean context. Four main factors were considered and varied for the analysis: matrimony, employment, education and divorce rate. We varied matrimony rules for partner selection which is mainly handled by interaction among the agents. The employment and education were considered as they are closely related with the partner selection and economic condition of the agents, which are further related with the fertility. The divorce rate was considered as has been on rise in Korea. It has increased 88% in last 24 years [3]. Since in Korean context, cohabitation is negligible, we figured out that divorce rate should be an important factor as far as fertility is concerned. We compared our test observations against the normal predictions made by not changing any of above shortlisted factors (which served as our control). For designing these test cases, we varied a number of factors, described as follows:

A. *Matrimony*

1) *Age:*
   - *a)* Random
   - *b)* Male could be up to 5 years elder than female.
   - *c)* Female could be up to 3 years elder than male
2) *Education Level:*
   - *a)* Random
   - *b)* Could differ up to 2 levels

This rule implies that for choosing partner, male and female agents would take these rules into. The implication of this setting is to bring about effect of Korean social context into simulation. The education in simulation is defined in six different levels. Our test case implies that a Ph.D. graduate can marry a person which has at least attended high school.

B. *Education of all agents in simulation*

- *a)* No change
- *b)* Increase by 15%
- *c)* Decrease by 15%

Higher education is serious matter in Korean context. Almost 85 % of high school graduates go for college. Bachelor's degree is held by 65% of Korean students in age of

25-34, against the OECD average of 39% [20]. Higher education, especially for women, is also considered as one of reasons for lower fertility [21]. We figured that experimenting with education field could be beneficial. We experimented with no change in education attainment, and also increased and decreased the education attainment of people in general by 15%. This increase or decrease would be distributed over the entire agent population.

C. *Divorce rate*

a) No change

b) Increase by 30%

c) Decrease by 30%

South Korea's divorce rate has been surging. It has increased by about 88% in the last 24 years (1990 – 2014 data) [3]. Since cohabitation is negligible in Korean society and children born out of wedlock are quite low (about 2%) [3]. We figured that change in divorce rate may bring about some change in the fertility and hence the population size. We varied divorce rate by increasing and decreasing it by 30% and also keeping it unchanged.

D. *Employment Rate:*

a) No change

b) Increase up to 15%

c) Decrease up to 15%

It is also postulated that employment rate also affects the fertility choices, especially by women participation in the work force [21]. Higher participation in the work force may imply less time for family and consequently less attention towards having children. We varied employment rate by increasing and decreasing it by 15% and keeping it unchanged.

By combining the various test scenarios, as described above, 162 test cases were prepared and simulation was run for each of these cases. Each simulation (each test case) was run for 10 times. Each simulation was run for 100 years. In total this resulted in 162,000 iterations. Further, in the simulation outputs, we grouped the data according to age and years. A typical test case output had 4040 rows of information. This resulted in evaluation of about 6.5 million rows of data for our analysis.

V. RESULTS AND ANALYSIS.

We evaluated our results based on the population numbers in the working age (15 – 65 years) group, 0-14 years age group, 25 -54 years age group, 54 - 65 age group and above 65 years of age group. For the best case (with the largest population), the number varied from 892,024 to 980,896 and in the worst case (with the least population) the number went up to 955, 132 from 892,024; before the numbers started decreasing.

1) *Best Case:*

The conditions in the best case from the largest population number and structure perspective are:

a) the female was up to 3 years elder than male agent

b) the education of male and female partners for marriage was random,

c) the divorce rate was 30% less,

d) education of people in general was 15% less

e) employment was 15% less

This test case not only delivered the best results in terms of highest population, but also the best numbers in number of people in the working age. Further, this case featured fourth highest number of people in 0 -14 years age category, which is in conformance of fact that more number of people in this group implies that more number of people would grow up and be available as work force.

2) *Worst Case*

The conditions in the best case from the largest population number and structure perspective are:

a) the male was up to 5 years elder than male agent,

b) the education of male and female partners for marriage was random,

c) the divorce rate was 30% more,

d) education of people in general was 15% more

e) employment was 15% less

This test case had not only the least population but also least population in the working age. It had least number of people in the 0 -14 years age category which reaffirms that the number of people in 0 -14 years age group have a direct impact on the number of working people available. The best and worst case overall population, working population and aged population can be visualized in the Figure 2.

One interesting thing worth noticing here is the point at which best and worst case scenarios start to differ substantially in the graph. If we compare the graphs a) and b), this occurs much later over course of time. This implies that in spite of the fact that the overall population in the best case is higher, the best case doesn't increase the number of aged people, which is good characteristic of population structure setting.

To have a deeper look at test cases and in order to analyze a trend among the best and worst cases, we analyzed the twenty worst and best cases. The summary of this analysis is presented in the Tables 1 & Table 2, for best and worst case respectively. In this table we represent case numbers and their respective settings of deciding factors. By examining this table it can argued that there are relations between divorce rate and general education levels, with the population numbers.

By analyzing the data in Table 1, it can be stated that the population tends to increase (which in turn implies greater fertility) with decrease in divorce rate and decrease in the people going in for higher education.

From the Table 2, it can be argued that when divorce rate and education attainment are increased, the population tends to decrease, which implies that fertility declines with increase in these factors. It is interesting to note that in spite of the fact that the education or divorce rate is decreased, and / or not changed, one of these factors with an increased value is contributing to the decline in population or fertility.

We also made an attempt to estimate the pension requirements for the best and worst case scenarios which are shown in Figure 3. For the pension total budget, the amount can be related with graph of total aged people (as shown in Figure 2c). This means for the best case, even though the population is higher, the number of aged people is less in number, which further implies that no. of working population is higher. However, we need to subject this analysis of the pension budget to further details to draw some conclusions

Figure 2. a) This graph represents the best and worst case population over years; b) This graph represents the working popualtion numbers; c) This graph represents aged popualtion numbers. (For these graphs, the y-axis respresents popualtion numbers, and x-axis respresents years).

We are currently in process of implementing these details. We plan to set measures to compare and evaluate the total budget and pension per person to evaluate the pension policy.

3) Discussion:

Many interesting conclusions can be drawn from results obtained during the simulation. Simulation results seems to imply that higher education directly affects the fertility. Korea spends large amounts of money in the education field. It spends about 8% of its GDP in education against the OECD average of 6%. The private expenditure share in Korea is also highest, especially at the tertiary level [20]. This signifies that a lot of attention and resources are invested on the education by population. Higher education has a positive relation with respect to better jobs and earings [20], [22] and therefore, the preferences of individuals seems to shift from family towards education and professional life. The decrease in this trend can imply more attention towards family life. Secondly, as already discussed, the divorce rate in Korea has grown by about 200% since 1990, and couples are increasingly having unhappy marriages mainly due to stress in professional life, and lack of time for time for each other [4], [23]. Simulation results show that decrease in the divorce rate impacts the population numbers in a positive way. Decrease in divorce rate could imply less stress in domestic life and consequently more chances of a better attention towards family life.

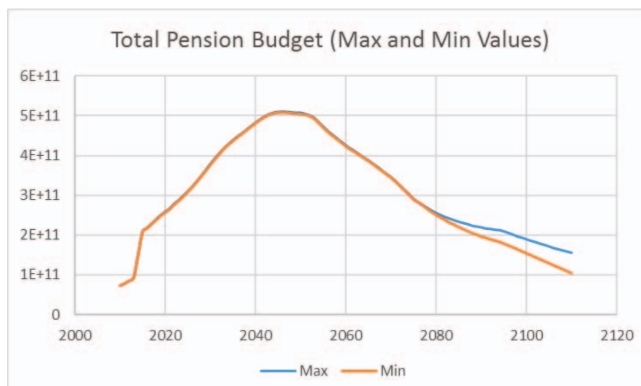

Figure 3. Total Pension Budget Over the time. For this graph, y-axis respresents total budget in korean won, and x-axis respresents years.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we implement the population dynamics model which is a hybrid system of MSM and ABM, and possesses advantages of both these modelling techniques. Further, we used this model to run variety of test cases (162 cases) to analyze their impact on the population dynamics. In this paper, we mainly focused on population size and structure and attempted to estimate future pension budget for government. The results indicate that the reduction in divorce rate and education attainment could have a positive impact on the population size and a favorable structure. However this analysis is in the initial stages and this paper stands in the middle of our research. Future work will include a rigorous analysis of the results obtained, by using more test cases and taking into account more deciding factors and quantifying the effect of various factors. Based on these results, we plan to analyze the pension policy for future years. We also plan to perform control analysis after the detailed analysis and prediction.

TABLE I. SUMMARY OF CASES WITH HIGHEST POPULATION NUMBERS (BEST CASES)

S. No.	Case No.	M / F (Elder in Age)	Education Level Diff	Divorce Rate (Less or More by 30%)	Education (Less or More by 15%)	Employment (Less or More by 15%)
1	108	F	Random	Less	Less	Less
2	80	M	2 Levels	Less	Less	More
3	134	F	1 Level	Less	Less	More
4	81	M	2 Levels	Less	Less	Less
5	106	F	Random	Less	Less	No Change
6	53	M	1 Level	Less	Less	More
7	54	M	1 Level	Less	Less	Less
8	160	F	2 Levels	Less	Less	No Change
9	52	M	1 Level	Less	Less	No Change
10	79	M	2 Levels	Less	Less	No Change
11	133	F	1 Level	Less	Less	No Change
12	135	F	1 Level	Less	Less	Less
13	162	F	2 Levels	Less	Less	Less
14	161	F	2 Levels	Less	Less	More
15	107	F	Random	Less	Less	More
16	35	M	1 Level	No Change	Less	More
17	63	M	2 Levels	No Change	Less	No Change
18	62	M	2 Levels	No Change	Less	More
19	117	F	1 Level	No change	Less	Less
20	142	F	2 Levels	No Change	Less	No Change

TABLE II. SUMMARY OF CASES WITH LOWEST POPULATION NUMBERS (WORST CASES)

S. No.	Case No.	M / F (Elder in Age)	Education Level Diff	Divorce Rate (Less or More by 30%)	Education (Less or More by 15%)	Employment (Less or More by 15%)
1	15	M	Random	More	More	Less
2	14	M	Random	More	More	More
3	13	M	Random	More	More	No Change
4	6	M	Random	No Change	More	Less
5	5	M	Random	No Change	More	More
6	4	M	Random	No Change	More	No Change
7	12	M	Random	More	No Change	Less
8	11	M	Random	More	No Change	More
9	10	M	Random	More	No Change	No Change
10	24	M	Random	Less	More	Less
11	150	F	2 Levels	More	More	Less
12	23	M	Random	Less	More	More
13	123	F	1 Level	More	More	Less
14	148	F	2 Levels	More	More	No Change
15	122	F	2 Levels	More	More	More
16	149	F	2 Levels	More	More	More
17	95	F	Random	More	No Change	Less
18	22	M	Random	Less	More	No Change
19	94	F	Random	More	More	No Change
20	40	M	1 Level	More	More	No Change

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References

[1] CIA World Factbook. Available: https://www.cia.gov, [April 2016].

[2] J. Craig "Replacement level fertility and future population growth," Population Trends 78, pp. 20-22,1993.

[3] M. Myrskyla, Hans-Peter Kohler, and F. Billari, "Advances in development reverse fertility declines," Nature 460, pp. 741-743, August 2009.

[4] Korean Statistical Information Service. Available: http://kosis.kr/eng, [April 2016].

[5] OECD , "Pensions at a Glance 2015: OECD and G20 indicators," OECD Publishing, Paris, 2015.

[6] G. H. Orcutt, "A new type of socio-economic system. The review of economics and statistics," pp. 116-123, 1957.

[7] N. Gilbert and K. Troitzsch, "Simulation for the social scientist," McGraw-Hill Education (UK), 2005.

[8] F. C. Billari, F. Ongaro, and A. Prskawetz, "Agent-Based Computational Demography: Using Simulation to Improve Our Understanding of Demographic Behaviour," chapter Intro-duction: Agent-Based Computational Demography, Physica-Verlag HD, Heidelberg, , pp. 1-17. 2003.

[9] T. C. Schelling, "Dynamic models of segregation†," Journal of mathematical sociology, 1(2), pp. 143-186, 1971.

[10] J. Conway, "The game of life," Scientic American, 223(4):4, 1970.

[11] F. Heiland, "Agent-Based Computational Demography: Using Simulation to Improve Our Understanding of Demographic Behaviour," chapter: The Collapse of the BerlinWall: Simulating State Level East to West German Migration Patterns, Physica-Verlag HD, Heidelberg, pp. 73-96, 2003.

[12] I. Benenson, I. Orner, and E. Hatna, "Agent-based modeling of householders migration behavior and its consequences," Agent-Based Computational Demography, pp. 97-115, 2003.

[13] N. Geard, J. M. McCaw, A. Dorin, K. B. Korb and J. McVernon, "Synthetic population dynamics: A model of household demography," Journal of Articial Societies and Social Simulation, 16(1):8, 2013.

[14] C. O'Donoghue, "Microsimulation and public policy," Ann Harding (Ed.), Journal of Articial Societies and Social Simulation, 1, 1998.

[15] E. Carl, H. Reed and A. Shephard, "An assessment of PenSim2" No. 04/21. IFS Working Papers, Institute for Fiscal Studies (IFS), 2004.

[16] H. Sutherland, "EUROMOD: An integrated European benefit-tax model. (No. EM9/01)," EUROMOD Working Paper Series, 2001.

[17] L. Giannarelli, "An Analyst's Guide to TRIM2: The Transfer Income Model, Version 2," The Urban Insitute, 1992.

[18] K. Singh, M. Sajjad, and Chang-Won Ahn. "Towards full scale population dynamics modelling with an agent based and micro-simulation based framework." Advanced Communication Technology (ICACT), 2015 17th International Conference on. IEEE, pp. 495-501, 2015.

[19] A. Prskawetz, et al. "The effects of age structure on economic growth: An application of probabilistic forecasting to India." International Journal of Forecasting, 23(4), pp. 587-602, 2007.

[20] OECD, "Education at a Glance 2014: Country Notes – OECD," Available: http://www.oecd.org/edu/Korea-EAG2014-Country-Note.pdf, 2014.

[21] B. Kye, "Delay in first marriage and first childbearing in Korea: Trends in educational differentials," California Center for Population Research, 2008.

[22] S. Baum, J. Ma, and K Payea., "Education pays 2013," The College Board, 2013.

[23] Marriage rate declines in South Korea: Avaialble: http://www.koreaobserver.com/number-of-marriages-drops-last-year-28213/, [April 2016].