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PRACTICAL APPLICATION OF WEDDING RING IN AGENT-BASED DEMOGRAPHIC SIMULATION

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ABSTRACT

The applicability of Wedding Ring model to an agent-based demographic module is investigated. As interpretation of social simulation results requires in-depth understanding of phenomena from various angles in the spatio-temporal dimension, the agent-based modeling (ABM) approach in demographic and social studies gets popular. To provide with quantitative information about chronological dynamics, computational cost and influential networks for the implemented model, we first introduce the Wedding Ring model which captures empirical marriage patterns based on a micro-level hypothesis and its outputs which are directly affected by social interactions. Then, the key observations are examined at different points in time, population size, and distribution of social networks to check its desirability for representational details of ABMs. In conclusion, the presented model could be extended into a large-scale social laboratory with acceptable predictability and computation load to allow for investigating non-numerical characteristics while supporting traditional approaches in a complementary rather than competitive way.

1 INTRODUCTION

Advances in information technology and computer science have led to explosive applications of computational simulations in social science (Billari et al. 2003). Taking the capability of simulating systems which are basically hard to be conducted in real world (Borshchev and Filippov 2004), purposes of simulation experiments have become broader from prediction of upcoming events to understanding of bygone phenomena (Epstein 2008). Especially, with the strong needs to predict and understand dynamics of the real system, the simulation approach becomes an essential tool in both natural science and human systems which have complex features and exhibit emergence (Brailsford et al. 2011) although modeling methods and their target systems (or problems) become more complex (Sanchez and Wan 2015).

In the stream, the role of simulation in demography becomes more and more important in that the field is “rich in methods but poor in theories”(Van Bavel and Grow 2017). The traditional role of simulations in demography has been estimation based on the statistical analysis which simulates population as a macroscopic entity with empirical statistics. After that, more detailed methods have been applied such as microsimulation model (MSM) which has simulated population as microscopic entities to observe statistical outputs on multiple levels of detail. Unlike the macro-level approach, the common atomic unit in MSM is an individual who grows up, experiences events and changes states in his or her lifetime (Spielauer 2011). Recently, agent-based demographic simulations combined with other modeling frameworks have been emerging to overcome the limitations of observable features (e.g. interaction, geographic information and non-linearity) and data dependency in the existing methods (Silverman et al.

2011) which are closely related to linear analysis rather than incorporating the non-linearity of the emergent phenomena and underlying rules beyond superficial data. With the capability of adapting prescriptive rules, the ABM seems to bridge the gap between the data-based approach and the rather theoretical approach (Van Bavel and Grow 2017).

While one of the main roles of a simulation is predicting situations with uncertainties, one big limitation in social studies is that not enough data is available to prove the repeatability of any social phenomenon (O'Donoghue et al. 2014). For example, most phenomena and its corresponding factors do not have enough official data. Without additional investigation on a target problem, the usual option is associating the target problem with statistical indices from national statistical offices. In fact, the approach could be acceptable to a certain degree of detail, and over sixty nation-scale MSMs incorporating multiple social factors including demography, housing, tax and welfare had been developed to investigate potential problems and better political solutions for a target society using empirical statistics by 2013 (Li and O'Donoghue 2013).

By the same token, ABM has been applied as a demographic module to mimic detailed level of society models. One of the well-known and widely accepted modules in demographic simulation is 'Wedding Ring' model developed by Billari (2008) to reproduce empirical age patterns of marriage based on micro-level hypotheses. Thereafter, Wedding Ring has been combined with demographic and economic models to get the political implications for the welfare service (Žamac et al. 2010; Noble et al. 2012; Sajjad et al. 2016). With the demographic module and its derivatives, replacing sectional modules in large-scale MSMs with an agent-based approach has been considered in order to dig into a social phenomenon in the integrated form of multiple sectors (Morand et al. 2010; Li and O'Donoghue 2013).

While ABM has been widely used in various areas including science, medicine, security, environment and economy (Allan 2009), ABM has faced the critical challenge to the high computational time and cost. In general, ABM approaches incur higher computational loads due to the exponential increase of interactions among agents (e.g., a system of N entities has N(N-1)/2 interactions between two entities). Even the domino effect of interactions in processing ABM restricts simple parallel computing. Although some researchers have suggested alternatives including modeling abstractions (Shirazi et al. 2014) and distributed computing (Scheutz and Schermerhorn 2006) to speed up ABM, it is still true that ABM eventually requires a relatively higher computational loads and modeling complexity compared to MSMs. Sullivan et al. (2012) pointed out that the representational details of ABMs may not always be desirable and suggested heterogeneity, interaction effects, and extent of a target system as critical aspects to evaluate which phenomena make the ABM worth. The first criterion is heterogeneity of a phenomenon. For instance, if all agents are identical in both population and an agent's decision, an aggregate approach is simpler with the same results of ABM approach. Secondly, the effect of interactions means whether any considerable interaction in a system exists to give different outputs. If the interaction between entities are negligible, then a generalized payoff matrix is simpler with the same result of ABM. Thirdly, the extent of a system means size and organization of the system. Even if the target system has heterogeneity and strong interactions, ABM may not be better than the aggregate approach in case of a countless size of entities. For example, gas consists of countless particles and they directly interact while it is efficient to consider air as aggregated atmosphere, not numerous particles. Similarly, some intermediate level would be better than atomic level if the system is sufficiently organized like enterprises in business.

In this sense, this research aims at exploring an existing demographic module of the 'Wedding Ring' in terms of practical efficiency to assess the cost and capability of basic agent-based demographic model. The remainder of this paper is structured as follows: In Section 2, a brief review of the Wedding Ring model will be presented. Then, observations by chronological term, population size and social network are analyzed. Finally, Section 4 discusses the contribution and limitations of this research.

2 WEDDING RING MODEL

A demographic simulation replicates population dynamics by fertility, mortality and migrations. With the critical problem of ageing and low fertility which is a common phenomenon in advanced countries, a diversity of demographic modules have been growing based on sociological and psychological assumptions. It is natural in that population is a primary component in human system including society, urban system as well as economy and one phenomenon is the result of multiple sectors in a society. For example, demographic simulations taking low fertility and ageing typically have considered not only demographic but economic and sociological mechanism for better political implication (Zhang and Zhang 2005; Fent et al. 2013).

The Wedding Ring model developed by Billari (2008) is an agent-based model of marriage formation which aims to reproduce empirical marriage-at-age patterns based on micro-level hypotheses founded on existing evidence on social interaction. A central idea of the model is that an agent's willingness to marry depends on the share of married relevant others in his/her social network and the willingness directly affects the availability of potential partners. The only entity in this modeling approach is a human agent that exists randomly on a two-dimensional (2D) circle and does not move until the removal. All agents in the model are getting old and find their partner within a certain range given by the share of married relevant others. It has great implication that micro-level algorithm can replicate realistic shapes and dynamics, and a diversity of modified models have been developed such as Wedding Doughnut (Silverman et al. 2013) and Linked Lives (Noble et al. 2012). A few extended models have already shown its predictive capability, at least in the demographic sector, by reproducing empirical demographic reality (Bijak et al. 2013).

In fact, the marriage distribution of the Wedding Ring is anomalous to the distribution of first marriages for the virtual society, not similar to the common marriage pattern which government usually provides. Thus, it may have a little difference with the general marriage distribution in the peak point and decreasing rate after the peak point. The errors could be mitigated by adding mortality and divorce rate and adjusting the function of age influence. The empirical divorce rate seems to be more dependent on the its dropping pattern after the peak point. Even, it may cause increasing of marriage rate at older ages. In this research, we note that the purpose of the research is to investigate the applicability of an agent-based demographic module to a large-scale social model, rather than better predictability which has already been studied in other works, for the practical applicability of the Wedding Ring model in a large-scale agent-based demographic simulation.

3 EXPERIMENT

3.1 The Proposed Model and Its Chronological Verification

In this section, the agent-based simulation of the Wedding Ring module is presented and verified. Basically, all components of the presented simulation model in this section are implemented from the benchmarked reference (Billari et al. 2008) while the empirical data is replaced with Korean statistics (KOSIS, https://kosis.kr/). In the model, each agent on the 2D ring may try to find his or her spouse over age 15 and the acceptable scope for potential partners changes by the calculated social pressure. The detailed items of the developed model are listed in Table 1 and the letter constants in the benchmarked formula are replaced into the final assigned numbers in the literature. In Table 1, 'pom' in the formula of social pressure is the proportion of married people among relevant others and 'ai' is a function of age which has specific values from zero to one based on Marsden (1987) justifying that the size of social network varies with age.

The basic observations include marriage occurrence for both genders and 'pom' for single, couple and total agents at specific ages. In this research, we extended the observation details to classify outputs in chronological order especially for the initial steps which are directly affected by a starting situation because it might affect the applicability of the developed module for short-term implication (Note that the benchmarked reference observed 75 consecutive cohorts after 150 years of warm-up period). In fact, all outputs of the presented model converged on specific patterns since about the 150th step while the first decade has been showing considerable fluctuation in the simulation results. The equilibrium of the proportion of married neighbors by marital status is shown in Figure 1.

At first, the pattern of marital rates at specific ages starts with relatively high values at the initial step and gradually decreases as shown in Figure 2. The cause of the high values at the initial steps is that the original function of social pressure does not correctly replicate the given proportion of married agents by the input empirical pom. Thus, excessive number of single agents may find a qualified partner in the acceptable distance at the initial step in case of having relatively high social pressure by given pom. After the initial ten steps, the effect of the starting population on nuptiality decreases sharply and marital rates changes steadily as shown in Table 2. Table 2 lists the level of difference between the average nuptialities of two consecutive decades during the first fifty steps where 'Dx' stands for the x-th decade and the level of difference indicates the mean of absolute errors among all marriageable ages (e.g. sixteen to a hundred). The level of difference between D1 and D2 is larger by about three times than the others and the marriage-at-age has gradually converged to the equilibrium state after the first decade. Figure 3 depicts patterns for the initial 300 steps by five decades, where '1st' stands for the period from 1st step to 50th step and '2nd' stands for the next fifty steps. The chronological dynamics seems to be related to the social network as shown in Table 3 where 'Cx' stands for the x-th century. The increases in number of relevant others is caused by the indirect inheritance of the position from its mother agent (see Table 1) which generates population concentration in the long run. The current level of developed model is, if left as it is, inappropriate for short-term implication, additional processes fitting micro-level factors such as network and social position (e.g. IPF) as well as adjusting parameters in embedded functions need to be considered by reflecting targeted cases and their corresponding data.

Table 1: Detail Parameters in Wedding Ring Model.

Item	Value
Number of initial population	800
Position of initial population	random(0, 2π)
Maximum age (the age of death)	100
Number of people at a specific age	8
Social Pressure (SP)	$\frac{\exp\{7(pom-0.5)\}}{1+\exp\{7(pom-0.5)\}}+0.020688$
Maximum distance for relevant others (MDR)	random(0, 0.2π)
Average age gap for relevant others	random{-2, -1, 0, 1, 2}
Maximum distance for partner	0.225·SP·ai(age)
Maximum age gap for partner	25·SP·ai(age)
Position of newborn agents	(Mother's Position) ± 2·(Mother's MDR)
Couple/Single Distribution in initial population	Korean Statistics at 2000
Age Specific Fertility Distribution	Women in Korean Statistics at 2000
Sex Ratio (Men to Women)	0.5
Time-scale	Year

Table 2: The Mean Absolute Errors between Consecutive Decades in the First Fifty Steps.

Items	D1 vs. D2	D2 vs. D3	D3 vs. D4	D4 vs. D5
MAE	0.43%	0.11%	0.19%	0.13%

Table 3: The Increasing Rates of NOR and Nuptiality in the Five Centuries

Items	C2 to C1	C3 to C2	C4 to C3	C5 to C4
NOR	1.22	1.18	1.10	1.05
Nuptiality	1.18	1.15	1.08	1.02

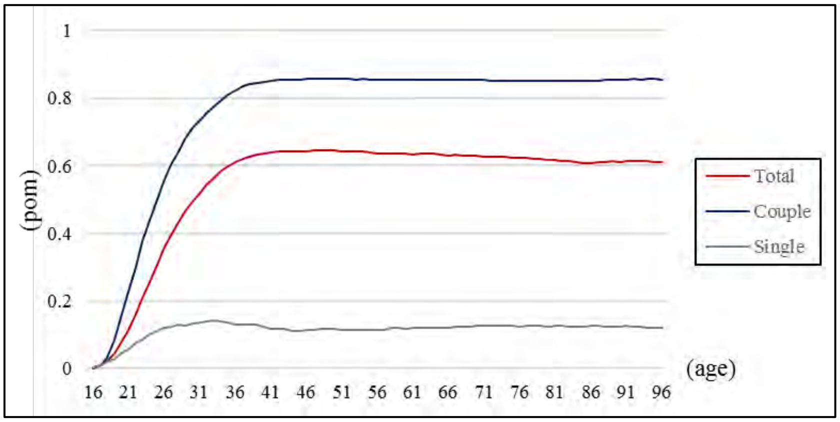

Figure 1: The equilibrium of pom by agents in the different marital states.

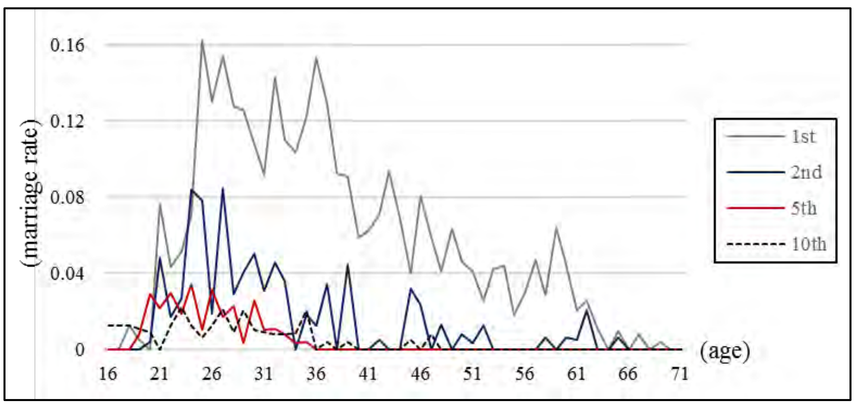

Figure 2: The dynamics of marriage-at-age in the first decade.

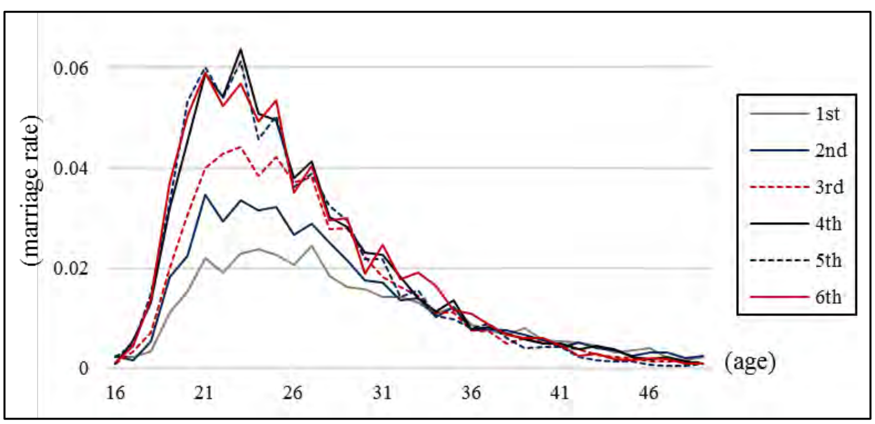

Figure 3: The distribution of marriage-at-age in the 300 steps.

3.2 Population Sizes

The number of agents is typically considered as a salient factor in modeling complex systems because the size of the population could affect key observations in the system. Nation-scale social models equipped with microscopic analysis have emerged to root out thorough details on an atomic level and minimize any omissions in the actual system. However, an increase in population size demands an exponential increase in computation load while typical methods to decrease computing processes (e.g. blocking) may cause different results in complex systems. Thus, the affordability of population size involving its corresponding computational load is one important factor to consider a component module for large-scale social models.

In this study, the aforementioned outputs in the last subsection are observed to check for changes in different population sizes. To deal with different population sizes, we have corrected minor parts of the original model which are related to maximum spatial distance for relevant others and potential partners. Although population size increases, the number of agents in the corresponding boundary is the same in the corrected model. In other words, the number of relevant others and potential partners will not change with the different population sizes. To maintain the average number of social interactions for an agent, a new coefficient of $\frac{8}{N}$ is multiplied by the maximum distance for relevant others and potential partners where N means the number of people at a specific age (Table 4). For example, if N is equal to eight in the original conditions, the maximum distances will be exactly same in the original case while the distances will be half in N of 16. The observations of marriage distribution and proportion of married neighbors have no distinguishable effect by most population sizes as shown in Figure 4 which depicts the marriage-at-age patterns from 151th steps to 300th steps. However, the marriage-at-age pattern for N of 8 is lower than the others at young ages and the designed heredity of social position seems to affect the social network of relevant others differently by the population size.

Table 4: Parameter Adjustment to Changes of Population Sizes.

Item	Value
Number of initial population	100·N
Number of people at a specific age	N
Maximum distance for relevant others	random(0, 0.2π) $\cdot \frac{8}{N}$
Maximum distance for searching partner	180SP$\cdot \frac{1}{100N}$ ·ai(age)
Maximum distance between mom and baby	2·random(0, 0.2π)

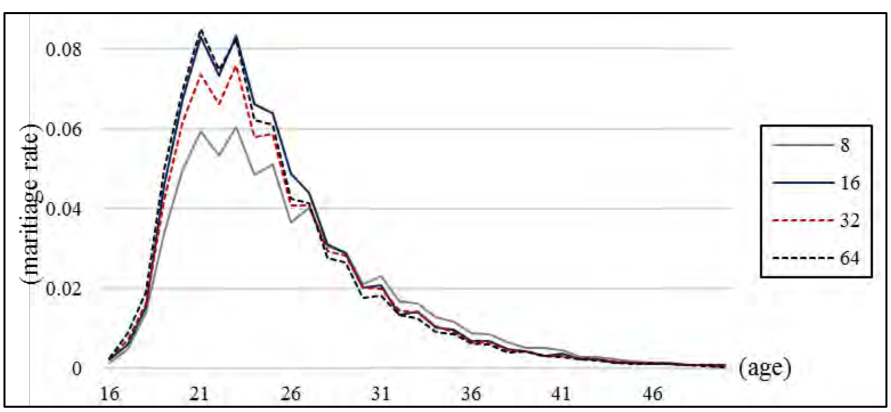

Figure 4: The distribution of marriage-at-age after 150 steps of different population sizes.

Both modeling and simulating in the developed system have been developed on Anylogic 7.1 which is a java-based platform. All simulation outputs in this section are collected for twenty replications on the same computing system to average out results. System specification including processor, system type and memory information is listed in Table 5.

Table 5: The Specification of Simulation System.

Items	Specifications
Processors	i7-3770 @3.40 GHz
System type	64bit OS
Maximum available RAM in software	8GB
Simulation Platform	Anylogic 7.1 University

The mean computation time in the benchmark population size is less than one second per run on the normal computer system. The highest computational load occurs during finding qualified partners among all agents and it will exponentially increase as population size becomes bigger. The averages and standard deviations of computation time in different population sizes are illustrated as shown in Figure 5. As the initial population size gets two times greater, the computation time increases by four times.

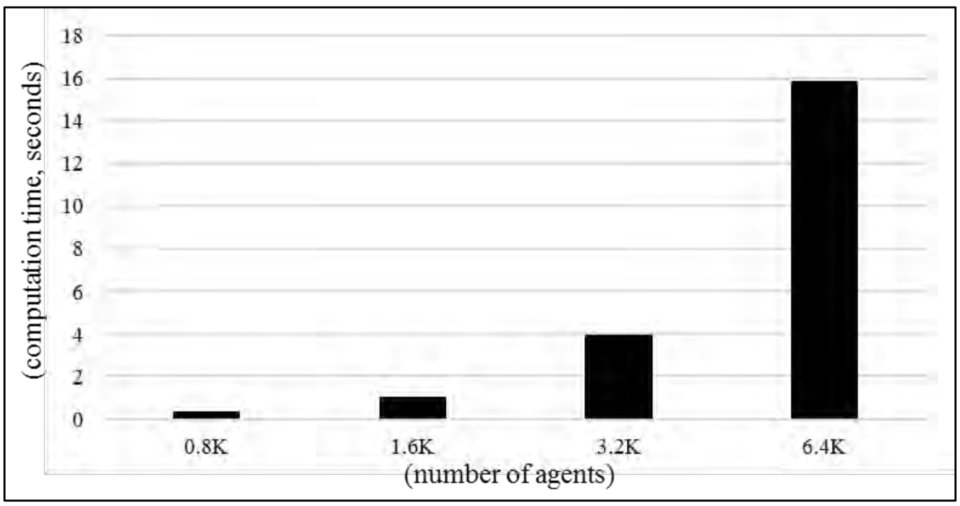

Figure 5: The average computation times by different population sizes.

3.3 Network Types

Network analysis on a certain system has been increasingly spotlighted both in physical and social sciences (Borgatti et al. 2009). In social science, the structure and size of a network among components are key factors which could yield totally different social phenomena. In fact, social networks and mechanisms are strongly related to the quantum and tempo of fertility and the model investigated in this research is one of models reflecting this trend in demographic fields (Bernardi and Klärner 2014). Moreover, one big strength of the agent-based framework is the capability to adapt multiple assumed scenarios with a network analysis, which is hard to replace in other modeling solutions. To take a closer look at social characteristics for which a partial agent-based approach or full-fledged ABM should be considered, this section presents a network analysis of different sizes and distributions of relevant others.

To fully control the network size of all agents, we changed the searching method of relevant others based on the distribution of NOR. The original range-based search may not strictly assign the number of relevant others from the selected distribution to all agents and, moreover, the average number of relevant others increases. An agent in the experiment of this subsection will be linked to a certain number of neighbor agents which is randomly selected from a given distribution while the original range-based search takes all people in the maximum range as relevant others. The number of agents at a specific age is fixed to sixteen for all experiments in this subsection. The simulated output is averaged out from 20 replications and 100 consecutive years since the 401th step from the beginning of simulation to see the equilibrium states of each scenario.

We tested with three different types of distributions including ‘Uniform’, ‘SymTriangle’ and ‘BisTriangle’ which take the same average of eight. ‘Uniform’ distribution means that the number of relevant others of agents in this option are uniformly distributed from zero to sixteen. The NOR of agents in the ‘SymTriangle’ is distributed on a symmetrical triangle function in which the minimum and the maximum is same with those of ‘Uniform’ distribution. Thirdly, ‘BisTriangle’ means fully biased triangle which has a peak point at zero number of relevant others and the maximum value is kept to be near 20 to set the average of the distribution to eight. Three distributions by numbers of relevant others in the simulated society are shown in Figure 6 and the marriage-at-age patterns by each distribution are shown in Figure 7. The different distributions of NOR give different outputs in terms of the marital quantum while they are little significant in the peak age and pattern in case of taking the same average. Meanwhile, the peak age is moved up compared to the original result and has become closer to the empirical observations. Although the additional experiment is necessary to capture the fundamental mechanism, we can suggest that the distribution of NOR is one of important factors to affect the quantum and timing of marriages at least in the case that proportion of married neighbors affects one’s marital decision.

To check the effect of different sizes of relevant others, we simulated homogeneous population by fixing the number of relevant others for all existing agents. In the virtual society, all agents have the same number of relevant others while the maximum distance between newborn baby and its mother agents is same with the original setting regardless of the fixed number of relevant others to take similar dynamics of population concentration. All relevant others of an agent in the fixed NOR setting have the same age while agents in the other settings distribute its neighbors over five consecutive ages centered at the assigned mean of age gap. Figure 8 and Figure 9 show the marriage and proportion of married relevant others at fixed NOR of 0, 1, 2, 4, 8 and 16. In homogeneous social networks, the equilibrium states are quite different in terms of both quantum and timing of nuptialities though the output in most inputs of NOR shows notable erratic pattern. In fact, the heterogeneous population consists of agents in homogeneous population and it suggests that higher marriage rates of ‘SymTriangle’ option in Figure 7 is caused by less number of agents having zero and one relevant other. Notwithstanding these limited experiments, it is suggested that the size of NOR is also significant factor for marital decision in the developed situation and the political support for alleviating severe absence of social interactions is expected to be more efficient for increasing the quantum of marriages and moving up the timing of the wedding event.

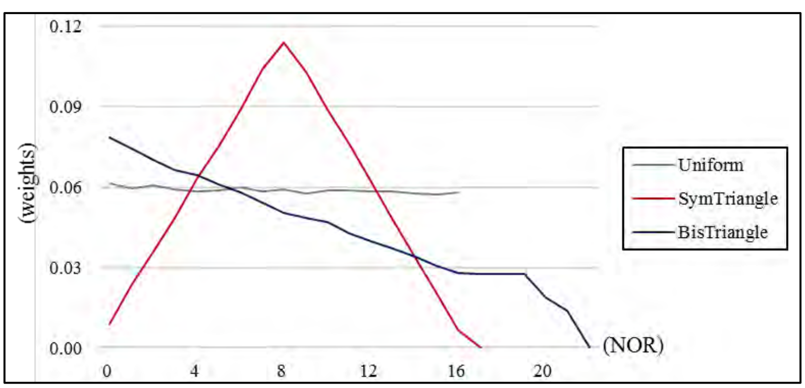

Figure 6: Simulated distribution types of NOR.

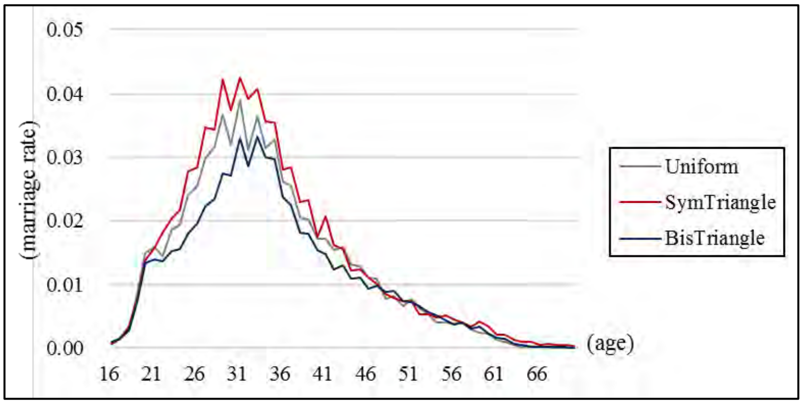

Figure 7: Marriage-at-age pattern in different distributions of NOR.

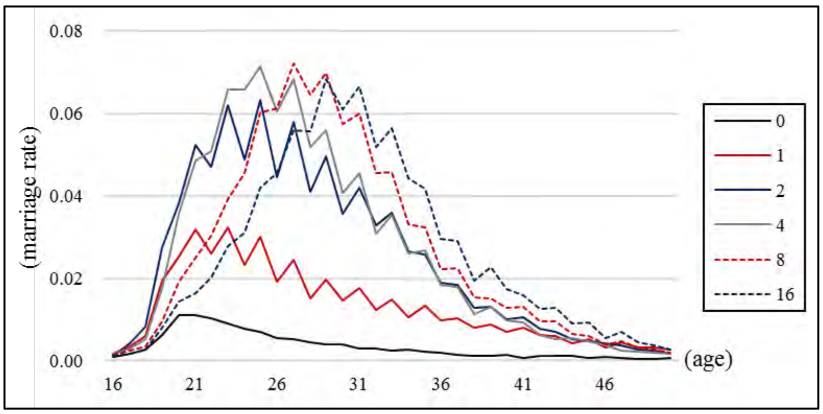

Figure 8: Marriage-at-age in different number of relevant others.

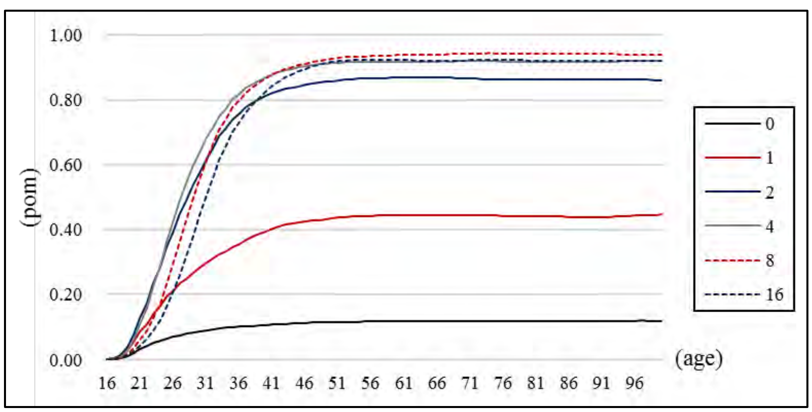

Figure 9: Proportion of married neighbors in different number of relevant others.

4 DISCUSSION AND CONCLUSION

This research aims to provide practical information on applying the Wedding Ring model as a demographic module to understand a complex phenomenon with respect to multiple sectors of a society. There have been seminal works to extend the Wedding Ring model for multiple reasons such as bridging MSM and ABM frameworks in demographic studies, reproducing the empirical demographic reality (Bijak et al. 2013) and capturing the social specialty in the real world for better political implementation (Noble et al. 2012). Moreover, the application of an agent-based demographic module is expected to become necessary to understand multi-disciplinary problems of a society in that the module directly affects the quantitative aspect of the core entity. In the presented work, we have observed the chronological dynamics of marriage distribution, computational costs in augmented population sizes and influential network of the agent-based model which are major considerations when compared to other modelling approaches.

In general, the implemented demographic model has a quite stable output in the long run and seems to be easily replaced with other traditional models with lower computational loads and better predictability when simulating stable social behaviors, notwithstanding the selected inputs and observations. However, the capability to replicate non-linearity and uncertainty with the assumed rules and scenarios may be difficult to assess directly by using traditional statistical methods. In addition, dynamic indices with less available data such as social networks have been typically observed in modern society while the characteristics of social networks could change the simulation results as tested in the designed experiment. In such cases, agent-based models provide a virtual laboratory to investigate broader scenarios while keeping a certain level of uncertainty and predictability under control. The presented module could be extended for a large-scale social laboratory with admissible predictability and affordable computation load to allow for exploring, modelling, and analyzing non-numerical characteristics while supporting traditional approaches in a complementary rather than competitive way.

A shortcoming of the current study is that the developed model takes a stepwise approach where all events occur simultaneously in the designed order and restrict unpredictable heterogeneity in the real world. These restrictions could be supplemented by increasing the resolution of simulation steps like pseudo-continuous settings while it must require higher computational load. Another limitation of the experiment is that it took the minimum analysis of social network implying the influence of neighbors on the marital behavior rather than finding out the underlying mechanism or adjusting key characteristics for practical applications with empirical cases. Better specified impacts of different informal networks could be suggested by further analysis based on traditional network theory considering small-world and scale-free properties such as Song et al. (2015).

Although previous works adopting the Wedding Ring model for reproducing the empirical data and complexity have been reported, it is still important to test a similar model in another stand point such as applying for South Korea undergoing considerable changes in the social indices with the world-top level ageing and economic growth. In fact, most demographic researches have been studied in a quite stable context and the final step to check applicability of an agent-based demographic module will be whether or not the model can reproduce the empirical values. In this reason, extreme cases could provide with a good testing ground for applying the agent-based module to explore the interdisciplinary aspects with demographic study. In the future, further integration agent-based demographic module with different social sectors such as economy and welfare services could benefit preparing for the upcoming ageing society. Eventually, a comprehensive study in dynamic context and its political implications can support decision-making under various underlying rules and uncertainties in a complex society.

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