# Computer microsimulation and historical study of social structure: A comparative review of SOCSIM and CAMSIM

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**Resumen**

En los últimos 30 años, cada vez más está en uso la técnica de la microsimulación por ordenador para el análisis de la estructura social desde una perspectiva histórica. Este artículo empieza con el origen de la técnica y la labor pionera de Peter Laslett en el uso y la promoción de la microsimulación por ordenador en las investigaciones históricas. Luego, nos proporciona una introducción a dos sistemas de microsimulación demográfica: SOCSIM y CAMSIM. Concretamente, nos habla sobre sus principales diferencias. A continuación, se hace una reseña sobre aplicación de éstos dos sistemas para el estudio de sistemas familiares en el pasado, la estructura del parentesco y los cambios del mismo, la evaluación de los datos históricos y la investigación de otros temas teóricos y técnicos. Por último, resume las principales características de los estudios que utilizan la técnica de microsimulación por ordenador y reflexiona sobre sus limitaciones.

**Palabras clave:** microsimulación, SOCSIM, CAMSIM, sistemas familiares, estructura social

**Abstract**

Computer microsimulation has been increasingly used in the historical study of social structure in the last thirty years. This paper starts with its origin and Peter Laslett's pioneering activities of using and promoting computer microsimulation in historical research. Then it provides an introduction to two demographic microsimulation systems: SOCSIM and CAMSIM, their main differences in particular. Following that it reviews the application of the two systems to the study of past family systems, kinship structure and their changes, the eva-

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Fecha de recepción: diciembre, 2003. Fecha de aceptación: diciembre, 2004
Revista de Demografía Histórica, XXIV, II, 2006, segunda época, pp. 59-88

luation of historical data, and the investigation of other theoretical and technical issues. Finally, it summarizes the major characteristics of computer microsimulation studies and briefly discusses their limitations.

**Keywords**: microsimulation, SOCSIM, CAMSIM, family systems, social structure

**Résumé**

Dans les dernières 30 années, de plus en plus on utilise la technique de la microsimulation par ordinateur pour l´analyse de la structure sociale d´une perspective historique. Cet article commence avec l´origine de la technique et le travail pionnier de Peter Laslett dans l´utilisation et la promotion de la micro-simulation par ordinateur dans les recherches historiques. Ensuite, l´article proportionne une introduction à deux systèmes de micro-simulation démographiques: SOCSIM et CAMSIM. Plus concrètement, il nous parle de leurs principales différences. A continuation, il fait une référence sur l´application de ces deux systèmes pour l´étude de systèmes familiaux dans le passé, la structure de la parenté et ses changements, l´évaluation des données historiques et la recherche sur bien d´autres sujets théoriques et techniques. Finalement, l´article résume les principales caractéristiques des études qui utilisent la technique de la simulation par ordinateur et réfléchit sur ses limites.

**Mots clés**: micro-simulation, SOCSIM, CAMSIM, systèmes familiaux, structures sociales.

This paper, like others in the volume, is written in memory of Peter Laslett, a prominent historian of political thought and social structure, and my supervisor. It starts with Laslett's pioneering activities of using and promoting computer microsimulation in historical research. Then it provides an introduction to two major demographic microsimulation systems: SOCSIM and CAMSIM, which is followed by their applications. Finally it briefly discusses some related issues in the concluding section.

## 1. PETER LASLETT AND THE GENESIS OF COMPUTER MICROSIMULATION IN HISTORICAL INVESTIGATION OF SOCIAL STRUCTURE

Laslett was not only one of a few great scholars who significantly shaped the historical study of political thought and social structure in his century, but also one of a fewer number of distinguished historians who were so energetically engaged in using and promoting computer microsimulation in historical research. He pioneered the application of microsimulation to the study of past family systems and kinship structure, and was directly involved in the development of two of the most sophisticated and successful demographic simulation systems: SOCSIM and CAMSIM.

In the early 1960s, Laslett made an important discovery through his quantitative study of surviving census-type materials: households in pre-industrial England were simple in structure and consisted of mainly married couples or a single parent with unmarried children. The mean size of households was relatively small with marginally more than four persons. Large multi-generational households were rare. These findings shattered some widespread beliefs about the pre-modern English society and generated considerable research interest in Europe and other parts of the world. This led to the 1969 conference on household structure in Cambridge and the publication of *Household and Family in Past Time* in 1972.

Despite this great success, Laslett was aware of two challenges that faced him. First, his initial discovery was made in a few English communities. What was found there could be a genuine representation of household formation patterns in historical England, but it could also be an exception resulting from chance or random variation. To lay his conclusions on a solid foundation, the latter must be proved not to be the case. Second, the observed household structure or configuration of coresident kin could be affected by two major factors: demographic constraints and people's residential preference or social norms. The predominance of nuclear households recorded in the pre-industrial English communities could arise from the fact that people preferred to form households of this type, but it might also be a result of unfavorable demographic conditions such as low fertility, high mortality, late marriage and a low proportion marrying, which limited the type and number of surviving kin and in turn prohibited the formation of large extended households.[2] To establish that the large proportion of observed nuclear households indeed represented people's residential propensity or certain social norms, the impact of demographic influence must be measured and taken into account.

With the intention to tackle these issues, Laslett formed a team with two other prominent scholars, Eugene Hammel and Kenneth Wachter who were also intrigued by these questions. The formation of this team, consisting of a historical sociologist, a social anthropologist and a mathematical statistician, was rather unusual, but the trio were all extremely gifted researchers. At a meeting held in Cambridge in June 1971, they decided to start a research project 'to design a Monte Carlo simulation program with demographic events and household choices that could be varied to predict the proportions of complex households that would result from different combinations' (Wachter and Hammel 1986: 391).

Initially, they intended 'to create in the computer a simulacrum' of some particular village populations. 'From the computer outputs, the cross-sectional household structure resulting from rules of post-marital household residence' would be examined (Wachter and Hammel 1986: 391). The computer simulation system, according to the plan, would be installed in both Berkeley and Cambridge. At the time, the project was thought to be 'a matter of months' (Wachter and Hammel 1986: 391). None of them foresaw the great difficulty and complexity in this simulation exercise, nor did they foresee 'a large project stretching over many years which would investigate a dozen salient problems in historical, anthropological, mathematical and contemporary demography' (Wachter and Hammel 1986: 395).

As the first of its kind, the study came across many unexpected difficulties in developing the simulation system, collecting input parameters and running the simulation under different computer environments. Despite the frustration, Laslett and his collaborators were determined to carry the project to the end. With the assistance of other researchers and computer programmers, they made impressive progress. A new computer microsimulation system named SOCSIM (Social Simulation) was developed in Berkeley under the leadership of

2 Here it is assumed that there is no migration or the impact of migration is small. Otherwise, it could also affect the number of kin available to each individual and the household structure.

Hammel who had already acquired some experience in simulation studies in the 1960s. The system was designed on the basis of Hammel and his colleagues' early work and particularly on the experience of POPSIM, another computer demographic simulation system developed by Daniel Horvitz and his team at the Research Triangle Institute in North Carolina. By 1973, SOCSIM had already generated some preliminary simulation results on the basis of selected historical English data (Hammel and others 1990; Wachter and Hammel 1986).

During the early years of the project, Laslett, Hammel and Wachter applied the simulation system to a number of research questions. Their results were reported at various conferences and research meetings, which eventually led to the publication of *Statistical Studies of Historical Social Structure* in 1978. This demanding work, as Richard Smith pointed out, 'was never popular among historians,' because of its 'hard going for those who were not of a mathematical and theoretical disposition'. But Laslett always regarded it 'as his most significant analytical achievement' (Smith 2001 and 2002: 5). As the first major statistical investigation of historical social structure, this study not only confirmed Laslett's early finding about the pre-modern English household formation system, but also brought computer microsimulation into the domain of historical research.

The publication of this work was not the end of Laslett's endeavor of using computer microsimulation in historical investigation. He made further effort in developing and promoting another computer microsimulation system CAMSIM (Cambridge Simulation) and used it, with the assistance of other researchers, in a number of important studies.

The development of CAMSIM is closely related to the research collaboration between Laslett and James Smith and Jim Oeppen, which can be traced back to 1975 when Laslett first met Smith at the University of Southern California and invited him to assist adapting SOCSIM to run on the computer at Cambridge. In the next few years, Smith visited Cambridge a number of times and worked on the project. According to the original plan, SOCSIM would be set up in both sides of the Atlantic, but this was not accomplished in England because of the incompatibility of the computer system at the time and other technical issues. However, during the process of converting and modifying the SOCSIM system, Smith, with the strong support from Laslett, designed another computer microsimulation system and named it CAMSIM.

The earliest version of the system was produced between 1980 and 1981, but the first major phase of its development took place during the period between 1982 and 1984 when Smith worked at the Cambridge Group for the History of Population and Social Structure as a visiting researcher. Since then Oeppen, another scholar at the Cambridge Group, has also been greatly involved in the development of CAMSIM. In comparison with SOCSIM, this system adopted a different modeling approach and was generally more efficient in simulating the kinship network for each individual. This was a considerable strength in the early 1980s, although it was achieved at cost, which will be further detailed in the next section when the two systems are compared.

CAMSIM was first used by Laslett in the study of past kinship networks and their historical changes, another important research agenda that he had in mind for some time. The simulation results were reported in *The significance of the past in the study of ageing*, a paper published in *Ageing and Society* in 1984. Laslett believed that 'a society cannot be understood unless we know its kinship system', but 'the study of kinship has not been easy for the historical sociologist to handle', which is largely due to the difficulty in gathering detailed evidence (Laslett 1986: 1-2). Therefore, conventional methods could make only limited contribution in improving our knowledge in this significant area. Through the use of computer microsimulation, Laslett demonstrated that the numbers and types of kin available to the elderly had changed notably in the English population over the last few centuries because of changing demographic conditions. The computer-aided historical comparison could considerably extend our perspectives in the study of ageing. Since the mid-1980s, Laslett authored or co-authored several papers discussing the CAMSIM simulation system and its implications. Questions addressed ranged from kin counts and kin sets in historical England, changes in kinship structure in contemporary Italy, to the impact of China's one child policy (Laslett 1986, 1988 and 1994; Laslett and others 1992).

In addition to utilizing SOCSIM and CAMSIM in his own work, Laslett played an extremely important part in promoting the use of computer microsimulation in historical research and in helping other scholars applying the method in their studies. I myself have been privileged and benefited greatly from having been able to study under Laslett's guidance and from having been consistently helped by Smith and Oeppen. It is the persistent effort of Laslett, Hammel, Wachter, Smith, Oeppen and many other researchers that has made SOCSIM and CAMSIM two of the most successful computer microsimulation systems in the historical investigation of social structure in the last thirty years.

## 2. TWO COMPUTER MICROSIMULATION SYSTEMS: SOCSIM AND CAMSIM

That SOCSIM and CAMSIM are selected and discussed in this paper is not only because the development of the two systems was closely related to Laslett's academic activities, but also because they are the most widely-used computer microsimulation systems ever-produced for the study of household composition and kinship structure. In addition, there is a further reason for making this decision.

Both SOCSIM and CAMSIM are computer microsimulation systems, in which all demographic events are simulated at the level of individuals rather than at the level of population or sub-population groups like that in a macrosimulation. They are capable of addressing not only the central tendency in people's demographic behavior, but also its intra-population variability at the individual level. Both SOCSIM and CAMSIM are stochastic models and all demographic events are executed randomly according to certain predetermined probabilities. This allows researchers to examine not only the deterministic aspect of the demographic process, but also the impact of chance. Furthermore, both systems have been designed and used largely in the study of demographic impact on kinship availability and household composition. Despite these similarities, however, SOCSIM and CAMSIM differ noticeably in their system designs, major assumptions, and simulated outcomes. The two systems stand side by side and serve as good examples in illustrating different computer microsimulation approaches, their strengths and limitations, and their different use in historical research.

SOCSIM and CAMSIM have been developed according to different designs. They use different approaches to simulate the population and demographic events. A SOCSIM simulation starts with an initial population, which is often generated by the system. Thµn it begins to execute demographic events such as marriage, childbearing and death that each individual may experience according to the probability that governs their occurrence as the simulation clock moves forward in time. From this point of view, the simulation is time driven. As the clock moves into a new month, all demographic events that are scheduled to take place in that month are executed. This process continues month by month till the ending time determined by the researcher. All simulated events and individuals are recorded by the system. Reference persons (sometimes called egos) can be identified at any time specified in the simulation. Information about them such as the type and number of their surviving kin and the structure of their households can be tabulated.

CAMSIM adopts a different simulation approach. It starts with simulating a reference person. This person is referred to as an ego and treated as the central figure in his or her kin set. Then the system simulates all demographic events that the ego may experience, such as marriage, childbearing and death. After the demographic history of the ego is constructed, the system uses a similar procedure to simulate his or her descending kin (if there is any) forward and ascending kin backward. The type and number of kin to be simulated are controlled by input parameters and can be altered according to the purpose of the investigation. When the simulation of the first ego and his or her kin set is completed, the system puts the records into storage and starts simulating the second ego and his or her kin set. This procedure can be further repeated until the required number of egos is met. Differing from SOCSIM, the CAMSIM simulation is not driven by time, but by events, although the time of each event, which is measured with respect to ego's date of birth, is recorded by the system.

The above discussion indicates that the outcomes simulated by the two systems are different. The population simulated by SOCSIM is similar to an actual population or a sample of such a population like that enumerated in a certain area or country at a particular time. The simulated individuals and households may or may not be related to one another. The population generated by CAMSIM is different. The simulated egos can be regarded as a sample of unrelated individuals drawn from a birth cohort. In the simulated population, ego's kin are related to one another by definition, but they do not link to any individual who belongs to the kin set of any other ego. If the simulated egos (or persons selected according to other criteria) are seen as lineage heads and their descendants as lineage members, then the simulated population can be regarded as a sample of unrelated lineages. Accordingly, it can be suggested that SOCSIM simulation adopts a 'population' approach, but CAMSIM simulation uses a 'genealogical' or 'egocentric' approach.

Because of the above differences, SOCSIM can take censuses in the simulated population at any time determined by the researcher, which is the same as an actual calendar date. Various period and cohort demographic rates can be calculated for the population on the basis of simulated demographic events. In contrast, in a CAMSIM simulation, the enumeration often takes place at various points in the life course of egos (or individuals selected according to other criteria). It usually computes cohort demographic rates for these egos (or specially selected individuals) at particular stages of their life courses rather than for different time periods.

The use of the egocentric approach gives CAMSIM a noticeable advantage in simulating complex kinship networks. This was particularly the case in the early 1980s when computing power was still rather limited. In a SOCSIM simulation, examining kinship structure for people with certain characteristics, widowers aged 70 and over for example, often requires simulating a large population. Enumerating all relatives connected through numerous types of relations, those remotely linked in particular, for simulated individuals is also difficult to accomplish. CAMSIM can generate egos with desired characteristics directly. The type of kin, even remotely related ones, can be easily simulated and recorded by the system. Despite that, however, the egocentric approach has a noticeable negative impact on the system development.

Because of its time driven simulation procedure, SOCSIM is able to change input demographic rates and other parameters while the simulation proceeds. For example, the fertility and mortality rates may increase or decrease as specified by the researcher. This is close to reality and makes the system very useful in simulating the impact of changing demographic conditions. In contrast, the current version of CAMSIM has been based on the assumption of demographic stability – input demographic and non-demographic parameters do not change over time. While this is a widely used assumption in demographic modeling and facilitates the implementation of the 'egocentric approach', it is less realistic. The use of this assumption and related procedures helps to avoid the complexities of program construction and at the same time enables a rather facile movement forward and backward in time when the kin set for an ego is simulated. But it makes it difficult, if not impossible, for the system to handle the influence of unstable demographic conditions.[3]

Another major difference between SOCSIM and CAMSIM is related to the way in which a spouse is selected or simulated when an individual is scheduled to marry. So far as this treatment is concerned, SOCSIM is regarded as a 'closed' model. When an individual is scheduled to marry, the system simulates the process of spouse selection and chooses a partner for that individual from the extant population. This is an important feature and makes the system very useful in simulating the impact of demographic conditions on the marriage market. When the simulated population is small, however, the limited number of qualified partners could restrict the proportion of married in the simulated population and lead to less realistic results. On the contrary, CAMSIM is an 'open' model. A spouse with certain characteristics is generated and added onto the existing population by the system when he or she is needed for a marriage. Adopting this strategy enables the right proportion of people to marry and ensures accurate distributions of age intervals between spouses, even when the simulated population is relatively small. But it excludes any possibility of examining the impact of the situation in the marriage market, which could be crucial in the study of a small population where intermarriage with other populations is rare. That the current version of CAMSIM does not provide information about the history of former marriages of egos' spouses is also related to this treatment. It is obvious that such information is important when levels of remarriage are high in the society.

In addition to those discussed above, there are some other differences between SOCSIM and CAMSIM, for example, the way in which fertility and childbearing are simulated by them. SOCSIM uses age- and parity-specific fertility rates. CAMSIM uses parity progression ratios and birth-interval and sterility distributions. Those who are interested in these and other details about the two systems are recommended to consult the references listed at the end of the paper. Understanding these differences, those addressed in this section in par-

3 James Smith, the designer of CAMSIM, has undertaken some experiments using the system to simulate the impact of changing demographic rates in a single simulation run. However, the current version of CAMSIM is still constructed and run under the stable population assumption.

ticular, and their implications is crucial in correctly interpreting SOC-SIM and CAMSIM simulation results that are reported in this paper and elsewhere.

## 3. THE USE OF COMPUTER MICROSIMULATION IN HISTORICAL RESEARCH

During the last thirty years, SOCSIM and CAMSIM have been used in a large number of studies. Their applications will be discussed in this section under four sub-headings.

### 3.1. Kinship availability in the past and its change over time

Scholars have long recognized the importance of investigating past kinship structure and its changes, but their efforts have been encumbered largely by the lack of evidence. As pointed out by Smith, 'in principle, kin counts can be obtained by empirical enumeration using genealogical, survey, or census methods. But in practice, it is often difficult or impossible to obtain kin counts by these methods. All of these problems are compounded when we want kin counts for the past where genealogical and census data are even more sparse and surveys cannot be used' (Smith 1987: 249). For this reason, researchers could never be confident that all or even the majority of kin links could have been recovered by conventional methods.

The number and type of kin (those linked through biological ties or marriage) available to each individual, however, are determined by marriage patterns and levels of mortality and fertility prevailing before and during his or her lifetime. Hence, if we have good knowledge about demographic conditions that exist in a population, the change of the population and the kinship availability in the population can be simulated. Computer simulation systems like SOCSIM and CAMSIM could generate detailed records of a person's kinsfolk and provide extremely important information for our understanding of past kinship systems.

In the early 1980s, Eugene Hammel, Kenneth Wachter, and Chad McDaniel simulated kinship availability among the white population of the United States in 1950 and 2000 (Hammel and others 1981). This is one of the early studies in which SOCSIM was used in the investigation of changing kinship structure. Under the demographic conditions observed in the twentieth century and two fertility scenarios (one high and the other low), Hammel and his colleagues examined the kinship universe for the simulated population in the two periods specified in the study. They recorded numbers of living grandparents, parents, siblings, spouses, children, and grandchildren for all individuals at various stages of their life courses. A major objective of this research was to find out the kinship universe of those aged 70 and over, and the position of the middle generation in a three generational kinship group.

Their results showed that under the given demographic conditions, the aged in 2000 would be in a better position than the aged in 1950 'with respect to the potential sources of social and material support'. They are likely to have a greater number of surviving spouses, siblings, and children. However, 'as the time advances beyond 2000, the position of the aged may deteriorate' (Hammel and others 1981: 30-31). Under the high fertility assumption, the position of the middle-aged in 2000 would be about the same as they were in 1950, but it may become worse by 2050 if the high fertility is maintained. Under the low fertility scenario, their position would be more favorable in 2000 when the number of their dependents would be smaller.

Designed particularly for the study of the availability of kin, CAMSIM has been used in such investigations from the start. Based on the comprehensive study of English population history conducted at the Cambridge Group for the History of Population and Social Structure, Smith and Oeppen collected fairly detailed demographic rates for the period from mid-16th century to mid-18th century. This gave them a unique opportunity to examine the change in kinship composition over this long period.

Smith and Oeppen 'modeled kin sets for three samples of 1,000 male egos, each representing birth cohorts subject to demographic conditions similar to those prevailing in English birth cohorts of 1550, 1650 and 1750, respectively' (Smith and Oeppen, 1993: 292). Because of CAMSIM's efficiency in simulating kinship structure, they were able to provide detailed information of many types of kin that was extremely difficult to obtain using conventional methods. For example, in addition to the types of kin examined by Hammel and his colleagues as discussed above, Smith and Oeppen's study also included great grandparents, great grandchildren, uncles and aunts, nephews and nieces, and first cousins.

The estimated life expectancy for the 1550 birth cohort was 36 years. Their fertility was moderate and the gross reproduction rate was 2.3. Mean age at first marriage was 26 for males and 24 for females. In contrast, the 1650 birth cohort experienced higher mortality and lower fertility. Their mean age at first marriage also increased by two years. The life expectancy was about 39 years for the 1750 birth cohort. While their age at first marriage was similar to the 1550 birth cohort, their fertility level was somewhat higher. These led to considerable differences in the number of surviving kin available to the three birth cohorts. As indicated by the simulation results, for example, the mean number of surviving children for those born in 1650 was noticeably lower in comparison with other two birth cohorts. The difference in numbers of surviving first cousins was even greater. 'A male in his younger twenties on average had about 15 surviving first cousins in the sixteenth century, about 17 in the eighteenth century, but only about 11 (25 to 40 per cent fewer) in the intervening century' (Smith and Oeppen, 1993: 292). While simulation results like these were 'stylized and subject to the qualifications applicable to' the system, they provided useful background information 'for broader discussions of the social, economic, and political aspects of kinship in the past' (Smith and Oeppen, 1993: 298-299).

Both SOCSIM and CAMSIM have been used in the examination of changes in kinship networks in China and their impact on state and family support to the elderly. While scholars used different simulation systems with different assumptions (SOCSIM was used by Hammel and others 1991; Yang 1992; Lin 1994 and 1995, and CAMSIM by Smith 1991; Zhao 1994a and 1998), their results and conclusions were broadly similar. Under the high mortality and moderate marital fertility that existed in the past, the number of surviving siblings and children available to each individual was not very high. Due to the considerable improvement in mortality and high fertility of 1950s and 1960s, the number of surviving kin in the population showed a great increase. However, this situation did not last for very long because of China's unprecedented fertility decline, which was largely driven by its nationwide family planning campaign.

As for the future of the family support system, it is true that the extraordinary fall in fertility will considerably alter the current ratio between the old people and their children. In comparison with the present situation, the availability of children (for old people) will decrease markedly in the future. But because of the improvement in mortality, the chance of children dying before their parents has reduced drastically. This considerably offsets the negative effect of fertility decline by ensuring that the majority of the elderly could have at least one surviving child. Indeed, if China's present mortality regime and marriage patterns and replacement level fertility are maintained in the near future, the proportion of old people having no surviving children may still be lower than that in the past. However, if China's fertility continues to fall, then China will face a serious challenge in providing adequate support to the elderly.

In addition to those mentioned above, the two simulation systems have also been used in the examination of kinship availability in Ancient Rome, Victorian England, 20th century America and Spain, and 21st century Italy and America (Laslett and others 1992; Reeves 1987; Reher 1997; Saller 1994; Wachter 1995 and 1997; Zhao 1996). These studies are not detailed here because of their broad similarity with those discussed above.

### 3.2. Household formation and composition in past times

SOCSIM and CAMSIM provide a great aid to the investigation of household formation and composition. They have been used in a number of such studies (Hammel 1989; Hammel and Wachter 1977; Wachter and others 1978; Zhao 1994b and 2000) and the following discussion will concentrate on two of them.

The initial objective of designing SOCSIM, as mentioned earlier, was to study household composition in historical England and to test the hypothesis that the observed low proportion of stem family households was a result of social norms rather than an outcome of unfavorable demographic conditions (Wachter and others 1978). To implement the study, Wachter, Hammel and Laslett set up 15 scenarios, which were characterized by different combinations of demographic regimes and household formation systems. The demographic rates specified in these scenarios attempted to cover a range of demographic situations in England in the 1600s and 1700s. The three sets of selected stem family household formation rules were summarized as follows. The first was labeled as primonuptial, where first marrying children brought spouses into the household to co-reside. This rule was designed to maximize the number of stem family households. The second was called ultimonuptial, where last marrying heirs brought spouses into the household to co-reside. This would minimize the proportion of households with a stem family structure in comparison with the other two specified household formation systems. The third rule was named as primoreal. It modified the extreme characters of the above two in line with certain features that were thought to be more realistic for historical communities.

Having set up these experimental conditions, Wachter and his collaborators created a starting population, which was later used in all simulation runs. Then, the demographic rates and household allocation rules specified in each of the 15 scenarios were fed into the computer, and the simulation was executed for 150 years under the given conditions. Finally, all simulated households were recorded and their structure was analyzed. For each scenario, a total of 64 replications were carried out. The input parameters used in the 64 runs were exactly the same except for random numbers, which led to random variations in the simulation results. Altogether, 960 (15 times 64) simulation runs were conducted. Although numbers of people and households involved in each simulation run were relatively small, the total numbers of simulated population and households were far greater than those dealt with in most historical studies.

This study provided some interesting results. The 15 different scenarios led to noticeable variations in proportions of households by kin-composition. However, under the conditions specified in the study, behavior rules or social norms were more potent determinants of the formation of stem or complex family households than demographic rates. In comparison with those found in some historical English communities, the overall levels of simulated stem or complex family households were rather high. Even the ultimonuptial household formation rules produced average proportions of stem or complex family households exceeding the 15 per cent mark which was greater than that found in most historical English communities. According to these results, 'any resort to demography for the sake of reconciling a theory of stem-family formation behavior with such low observed levels of occurring complex households appears unjustifiable' (Wachter and others, 1978: 46).

CAMSIM was designed primarily for the examination of kinship and could not be easily used in the study of household composition in a particular population, but it offered a useful tool for the investigation of residential experience of individuals or a birth cohort.[4] In a paper published in 2000, Zhongwei Zhao applied this system to the examination of residential patterns that people might experience in historical China (Zhao 2000).

This study concentrated on two questions. First, under demographic conditions similar to those existing in China in the past and under joint family household formation rules similar to those suggested by John Hajnal (1984), how many people could possibly live in joint or multiple family households at different stages of their life course? Second, under these specified conditions, how long could a person possibly spend in a household with a joint or multiple family structures during his or her lifetime? The study was conducted in three steps. First, CAMSIM was used to simulate 3,000 male egos and their kin sets under the demographic conditions close to those existing in China over the last few centuries. This resulted in the creation of a model population of about 12 million. Then, the simulated egos and their relatives were grouped into households on the basis of certain household allocation rules.[5] Finally, these data were analyzed according to kin-composition of the household.

A noticeable feature of this study is that it investigated not only the demographic impact on the formation of large multi-generation households, but also the relationship between individuals' lifetime residential experiences and their residential patterns at a particular point in life courses.

The study showed that demographic conditions had a strong impact on the formation of large multi-generation households in the past. The simulation enforced a set of household allocation rules that are generally in favor of the formation of large multi-generation families, and all egos lived in such households whenever it was demographically possible. However, under the given demographic conditions, egos aged 20 and over on average spent about half of their lifetimes in households with

4 As has been mentioned earlier, because of its particular design, egos simulated by CAMSIM can be seen as a sample of unrelated individuals of a birth cohort, which differs considerably from an empirical population observed in an area at a particular time. Moreover, in a CAMSIM simulation, residential experience is usually examined from the perspective of each ego rather than from each household.

5 For detailed discussion regarding these demographic rates and household allocation rules, please see Zhao (2000).

only one or two generations. Between 75 and 95 per cent of them lived in such households at some stage of their life courses. Similarly, some 90 per cent of those surviving to age 50 and over experienced life in simple households. The number of years that the egos resided in households with a simple structure was in fact longer than that spent in joint family households. The notions that the traditional Chinese household was characterized by four generations living together (Tang and Xie 1993) and that households with five generations might have reached more than five per cent (Eastman 1988) simply have no demographic foundation.

The study also demonstrated that even if a set of residential rules that encourage the formation of large multi-generation families was followed universally and many people resided in large families at some stages of their life courses, they could not live in such families all the time. Under the input demographic and non-demographic conditions, the overwhelming majority of the egos experienced changes in their household structure. On average, only about one-third of their lifetimes were spent in joint family households. For these reasons, the proportion of people living in joint family households may not be very high in cross-sectional data collected at a particular time. It is not surprising to find that a considerable number of households were simple in structure in Chinese history when the large multi-generation family household was widely regarded as the ideal.

### 3.3. Evaluation of historical data

In a stochastic demographic simulation like the one carried out using SOCSIM or CAMSIM, the occurrence of all demographic events and the time of their occurrence are determined primarily by input demographic parameters. The only other factor that could affect them is the random variation. Since every member of the population and every demographic event experienced by them are all recorded by the system, the simulated demographic data do not suffer from any kind of under-registration or selective biases like those frequently observed from empirical data. Moreover, because of its experimental nature, the simulation study could effectively control and measure the impact of certain demographic or non-demographic factors through changing one or a group of input parameters. Similarly, by manipulating the simulated population or sub-groups of the population, researchers could also examine the influence of various types of selection and under-registration. These advantages make computer microsimulation very useful in the evaluation of historical data.

One of such examples is Hammel and Wachter's assessment of 1698 Slavonian census (Hammel and Wachter 1996a and 1996b). The 1698 Slavonian census is widely regarded as 'one of the most important and controversial censuses of early modern Europe', and 'a foundation for the understanding of the social and demographic history' of the region (Hammel and Wachter, 1996a: 146-147). Yet, this census suffered considerably from under-registration problems. Children under age 15 were largely omitted from the enumeration. In addition, certain household members were excluded: for example, no woman was listed as a wife and the number of women in comparison to men was very small. These problems made the census data extremely difficult to use.

To overcome the difficulty, Hammel and Wachter used computer microsimulation to evaluate the census data and to estimate the population. Their study was conducted in the following steps. On the basis of historical and ethnographical studies undertaken by themselves and other scholars, they first selected demographic rates and household formation rules that were believed to be close to those existing in the studied population. Then they used SOCSIM to simulate a model population under each specified scenario, which was characterized by different demographic conditions and different census counting procedures. Each simulation, which had the same starting population, was run for 150 years and resulted in a terminal population with detailed records of every household and its members. Thereafter, through the comparison of the simulated household members who qualified by age and kin type for being included in the census with those actually listed by the 1698 census, they selected the 'preferred simulation run' whose outcomes most closely matched the census results (Hammel and Wachter 1996b: 300). Finally, they computed a ratio of the total simulated household members to those who qualified for being recorded in the census. On the basis of these results, they estimated the size of the population, the mean size of households, the distribution of households by size, and the distribution of household members by their relationship to the household head.

These simulation results and the estimates made on the basis of these results should not be seen as uncovered historical reality. But as Hammel and Wachter suggested, they provided us with some important references and allowed 'the historical scholar to move more surely in interpretation of the past' (Hammel and Wachter 1996b: 323).

Computer microsimulation has also been used in the evaluation of genealogical data and the investigation of their potential biases (Oeppen 1999; Zhao 1994b and 2001). Social historians have long been interested in using genealogies in their research. In comparison with some other types of population data, people recorded in genealogies usually have common ancestry and are connected to one another through kinship. They are less restricted by residence. These materials, therefore, can be very useful in the study of population genetics, heterogeneity, and social and geographic mobility of the family and lineage. Furthermore, some genealogies recorded details of family or lineage members extending over many generations, thereby providing researchers with a rare, possibly unique, opportunity to investigate long-term demographic patterns.

However, genealogies often suffer from various types of under-registration, such as missing dates of birth and death, the exclusion of females, and the omission of those who died young and those who brought disgrace upon the family. In addition to these problems, genealogical materials have another bias that is difficult to measure. Many genealogies were initially compiled a long time ago, and records of late generations were added onto the genealogies gradually. Most available genealogies are records of lineages that had survived to the time when the genealogies were collected. From this point of view, they are records of surviving lineages. One reason, among many, why some lineages avoided extinction is that they experienced more favorable demographic conditions: higher fertility, lower mortality, and probably a higher proportion of members marrying. Because many lineages are patrilineages extending through the male line, the sex ratio in such surviving lineages may also tend to be higher than in the general population.

Using CAMSIM, Zhao (2001) generated a model population consisting of 3,000 male egos, their spouses, and their descendants of nine generations. A total of 16 million people were simulated altogether. The demographic conditions experienced by the population were broadly similar to those observed in China in the last few centuries. The 3,000 simulated male egos were operationally defined as patriarchs and their descendants were treated as their lineage members. Then Zhao defined and selected two types of lineages. The first was referred to as surviving patrilineages. These lineages included members related through only the male line and extended to the ninth generation. They were similar to those recorded in surviving Chinese genealogies. The second consisted of the male founders and members of all lineages including those related through the female line (excluding those who married into the lineages). These selected lineage members can be regarded approximately as a collection of 'clustered' samples drawn from a population that has experienced the same demographic conditions. Finally, by comparing demographic rates recorded in the surviving patrilineages with those observed in all lineage members, Zhao examined the following questions: What types of biases could be found in the genealogies of surviving patrilineages, and if they were used, to what extent would these biases affect our understanding of past demographic regimes in the total population?

The study showed that under the demographic conditions specified in the simulation, the chance of a man having his own patrilineage extended into future generations was rather low. For those lucky enough to have male children, the chance of having their patrilineages descended to at least generation nine was only about 35 per cent. The study also suggested that in comparison with those recorded in all lineages, demographic rates conducive to population growth were more likely to be found in surviving patrilineages. This was particularly the case in the first few generations after a patrilineage was started by a patriarch, where less severe mortality, a greater proportion marrying, a larger mean number of children, especially of sons, a higher sex ratio, and faster inter-generational population growth were recorded.[6] However, these differences diminished quickly and became hardly noticeable after the patrilineage extended to generation four or five. According to these results, surviving patrilineal genealogies are potentially biased data sources when used in the investigation of the demographic history of the whole population. But, because the selective biases are largely observed in the first four or five generations after the start of a patrilineage, excluding these records from the genealogical data could effectively eradicate, or at least considerably reduce, the influence of these biases. Demographic rates obtained from these materials (assuming they are not affected by other types of under-reg-

6 Other demographic factors, such as having the first son at a young age, might have also played a part in helping to extend the patrilineal family line, but their role was insignificant under the demographic conditions specified in the simulation.

istration problems) could then come very close to the average demographic experience of the entire population.

### 3.4. The use of SOCSIM and CAMSIM in other research areas

In addition to their applications described in preceding sub-sections, SOCSIM and CAMSIM have been used in other research areas (Hammel 1976 and 1990; Hammel and Mason 1993; Hammel and others 1979 and 1980; McDaniel and Hammel 1984; Wachter 1980; Oeppen unpublished manuscripts). Simulation studies of the following theoretical and methodological issues are such examples.

Cultural regulations of sexuality have been observed in many populations. Some taboos of incest and the practice of exogamy may be traced back to their early history. One of the interesting research questions relating to such regulations and practice is their demographic disadvantage (of course, there are also advantages). This is referred to 'the demographic cost incurred through the restriction of available mates by the regulation of sexual relations. Individuals barred from certain choices of mates may have longer average waiting times until marriage, and the group to which they belong may lose some of its potential fertility' (Hammel and others 1980: 210). This could have a devastating impact on the survival of small tribe populations.

Using SOCSIM, Hammel, McDaniel and Wachter investigated this question (Hammel and others 1980). They conducted 1,600 simulation runs under 12 scenarios, which were characterized by different size of the starting population (three different sizes) and the incest level (four different levels). They simulated nearly stationary populations. In doing so the same fertility rates were used for both married and unmarried women. The total births were then divided into two groups: births to the normal marriage that was regulated by the level of incest and those to unmarried women. The proportion of the second group out of the total births was defined as 'the alternative fertility proportion', which was regarded as 'the amount of fertility these populations would have to realize outside the normal marriage if their stationarity were to be maintained' (Hammel and others 1980: 211). It was used as an indication of the pressure for social or demographic change.

Their simulation results showed that under the experimental conditions, the impact of incest prohibitions as measured by the alternative fertility proportion was directly related to the size of the population and the level of taboo. When the population was relatively large, a few hundreds for example, the demographic disadvantage of incest taboos was nearly negligible. A strong prohibition against marriages of second cousins or closer relatives would lead to as much as five per cent of alternative fertility. But if the population was relatively small and with only a few dozens, the demographic cost of incest prohibition rose considerably. The proportion of alternative fertility could increase to nearly 60 per cent if marriages involving second cousins or nearer relatives were not accepted. When the population size was small or moderate, the impact of different levels of incest taboos was clear. Under the given conditions, the most stringent taboo (prohibition of marriage involving second cousins and closer kin) had much stronger demographic influence than the least stringent taboo (prohibition of marriages involving nuclear family members).

These simulation results provided useful references for the study of the impact of incest taboos on the growth of small isolated populations. However, as Hammel and his colleagues pointed out, the demographic impact of any such taboo should not be 'assessed outside the general socio-demographic and ecological context within which the tabu is implemented. Sexual prohibitions are a few among many factors – the underlying biological rates, mechanisms for alternative fertility, fluctuations in demographic rates – that determine the population growth rate' (Hammel and others 1980: 231).

SOCSIM was also used by Wachter, McDaniel and Hammel in their evaluation and development of kin-based measures for population growth (Wachter 1980; McDaniel and Hammel 1984). Because members of a population are not only grouped by age and sex, but also linked through kinship relation, demographers are interested in the development of some kin-based rather than age-based measures. These measures could be very useful in some populations where people are found to have better knowledge about their relatives than about their ages. In the late 1970s, Noreen Goldman proposed a formula using a ratio of counts of youngest sisters to oldest sisters to estimate the intrinsic natural population growth rate (Goldman 1978). This formula and its variants are 'based on stable population assumptions, rest on facts about mean values, whereas the natural applications concentrate in situations where random variability about mean value may be impressive' (Wachter 1980: 103).

Wachter, using SOCSIM, evaluated the performance of Goldman's formula (Wachter 1980). The experimental nature of the simulation study allowed him to repeat each of the four designed simulations many times. He then counted younger and older sisters and compared them to the population growth rate recorded in each simulation, and through which examined the impact of random variations. His study suggested that Goldman's formula represented an important step in using kin-based measure to estimate population growth rate, but the method was vulnerable 'when stable population assumptions are modified to allow for random variability such as would be encountered with field work on small populations' (Wachter 1980: 103).

On the basis of this evaluation, McDaniel and Hammel undertook further simulation studies and developed another kin-based method for estimating the population growth rate (McDaniel and Hammel 1984). In comparison with Goldman's formula, their new measure is simpler, because it 'works *solely* from counts of those living who are the *youngest* or *oldest* in their completed sibsets. These counts are entirely independent of actual ages of respondents' siblings' and 'less subject to reporting bias' (McDaniel and Hammel 1984: 41). Their evaluation of this and the other measure showed that this sibset bounds based measure has a smaller sampling variance. It 'is a more powerful kin-based measure for *r* than the sisters of sisters measure given by Goldman' and it has 'greater potential utility in actual field studies than the other' (McDaniel and Hammel 1984: 50).

Like SOCSIM, CAMSIM has also been used in wider research areas. For example, Oeppen has used the system to examine experience of sharing lifetimes and of death in the past and present populations, and the welfare of widows in rural northern Europe over the period between 1700 and 1900 (Oeppen unpublished manuscripts). These studies are not detailed here because they have not yet been formally published and because of the restriction of space.

## 4. CONCLUDING REMARKS

While this paper is about computer microsimulation and its applications in the historical investigation of social structure, it is not intended to review all or most of the microsimulation systems that have been developed in the study of social history and demography. For the same reason, simulation systems developed and used by researchers of other disciplines, economics for example, have not been examined here. Discussion of many other computer simulation systems and related theoretical and methodological issues can be found in the books *Family History: Methods and their Applications*, edited by Bongaarts, Burch and Wachter (1987), and *Improving Information for Social Policy Decisions: The Uses of Microsimulation Modelling* edited by Citro and Hanushek and a number of articles by De Vos and Palloni (1989), Merz (1991), Van Imhoff and Post (1998), Spielauer and Vencatasawmy (2001) and O'Donoghue (2001). Readers who are interested in these issues are advised to consult these and other listed references.

The evidence presented in the last section clearly demonstrated that computer microsimulation has played an important role in the historical study of social structure in the last thirty years. In comparison with those conventionally used in the field, it as a new research method has a number of noticeable strengths.

Computer simulation helps to extend and improve our imagination and analytical ability. Most of the questions addressed in the previous section are not new. For example, the importance of examining past kinship structure and demographic constraints on household formation was mentioned many years ago. Scholars actually did some calculations to assess such impact.[7] However, most of their results were based on simple estimates, and these questions had not been successfully tackled until the method of computer microsimulation was developed. This, in addition to the lack of data, is largely due to the fact that the process involved in such analyses is too complicated for the conventional method to handle. This has been overcome through the use of computer microsimulation. As we have already seen, what the simulation study has told us is not what we already know but what we do not know or do not know well.

Strictly speaking, history and social events can never repeat themselves. Probably there are no two historical events or social phenomena that are exactly the same. This makes it difficult to develop and test social theories, and leads to some uncertainty in historical and social research. As in natural sciences, computer microsimulation helps to cre-

7 In the late 1960s, for example, Glass and Wrigley constructed simple models to estimate the effect of demographic conditions on the frequency of three-generation families. See Glass (1966) and Wrigley (1969).

ate a highly controllable experimental environment. Because of this nature, it allows researchers to test their theory under the same or controlled conditions, and to recreate the 'world' according to their perception of it.

In a real society, kinship structure, household composition or other social phenomena in which we are interested are often affected by a large number of factors. These factors usually work together and their influence is difficult to disentangle. This is a challenge that we face frequently in empirical research, especially in interpreting its results. Through the use of computer microsimulation, factors that are considered theoretically important can be specified and manipulated. This helps to make the impact of these factors readily measurable, the hypothesis easily testable and the research outcome more interpretable. Accordingly, conclusions can be reached on a more reliable base.

In an empirical study, it is also difficult to unravel the impact of chance or random variations, especially when the study is conducted on the basis of a small number of non-randomly selected samples. Therefore, making generalizations from small case studies is often a risk because the randomly occurred extreme could be mistaken for the average. Stochastic computer microsimulation provides an answer to this problem. In modeling people's social demographic behavior or events of other kinds, computer microsimulation is effective in measuring the central tendency, variability and the relationship between them. Although results of computer simulation are obtained under experimental conditions, they could be used as important references for the interpretation of empirical findings.

These strengths, along with those discussed in the early sections have made SOCSIM and CAMSIM valuable tools for historical research. Nonetheless, a number of areas need to be further promoted in the future development of SOCSIM and CAMSIM. During the last three decades, a considerable amount of work has been spent in developing the two systems and their applications, and this has indeed led to a great success. But, criticism has been directed to the use of SOCSIM and CAMSIM from the start and some scholars have been skeptical about the credibility of their results (Fitch 1980 and Ruggles 1993). One of most effective ways to convince people that the two systems are reliable is to provide systematic validation results. While the system designers and other researchers have made some effort to validate the systems against empirical data (Wachter and others 1997; Oeppen

1998), further work is needed. Another area that may be important for the future development of the two simulation systems is the further incorporation of the feedback or impact of non-demographic factors on the demographic behavior into the simulation process. For example, people's marriage or fertility behavior may be affected by their position in the family or household composition. Similarly, the nature and characteristics of the sexual union could also affect people's fertility behavior and its outcome. Building these mechanisms into the systems will make them more sophisticated, more realistic and more useful.

Another point which needs to emphasize is that computer microsimulation differs from conventional historical research by nature. In a real world, observed population changes or other social phenomena are affected by a large number of interrelated factors. But, a computer simulation can take into account only those factors that have been specified in the simulation system. Its results are conditioned by the simulation process and input parameters. These results could not tell us what has actually happened in a real world, but rather the implications of the theory and assumptions that are embedded, both explicitly and implicitly, in the process of simulation. As Wachter once pointed out 'the word simulation itself connotes the making of a likeness. But the pursuit of realism through simulation is in fact a chimera'; what we could simulate 'is not a likeness of operation of the world but a likeness of some set of our own ideas concerning the operation of the world' (Wachter 1987: 215).

During the last thirty years, considerable effort has been made in pursuing computer microsimulation studies. In addition to SOCSIM and CAMSIM, many other socio-demographic simulation systems have been developed. Most of these systems are rather sophisticated and the simulation has in general become more realistic. However, factors that can be taken into account in the simulation system are still limited in comparison with those working in a real society. The construction of the simulation system and the assumptions built into the system are also be affected by researchers' own views about the operation of the process to be simulated. Hence, the simulated outcomes are different from and should not be mistaken for reality. Despite these limitations, computer microsimulation has become an important aid in historical social science and simulation results like those discussed in this paper have offered valuable insights into past social structure.

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