NEW METHODS OF DEMOGRAPHIC ANALYSIS*)

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Abstract: Unlike traditional demography that examines individual demographic processes in an isolated way, a new paradigm is appearing. It does not focus on the assessment of a certain phenomenon in its pure form, but on the entire life span consisting of demographic events and the time lived in a certain state. The event under observation largely depends on the previous experience and also influences the rest of an individual's life. In this connection, a number of new methodological techniques have been developed.

The methods used in demography evolved in the context of the advancement of demography as a science, in interaction with other scientific fields, and in connection with the new opportunities that were presented by data sources and computer technology. Clearly no method is entirely new, but rather draws on and furthers some previous method. In the 1980s, the increasingly widespread availability of computers triggered the emergence of new ideas and the advancement of more sophisticated methodological tools, which were also able to draw on better data sources. We begin this article by describing traditional demographic life tables and outline some of the new methods used in contemporary analysis. The text does not set out to present a systematic and exhaustive outline of existing methods but instead identifies some of the new ways of analysing demographic processes.

The life table: a basic tool of traditional demographic analysis

In Czech demography the 'life table' is the term used to describe every type of demographic table of quantified demographic processes that occur in time (the mortality table, the nuptiality table of singles, the table of marriage dissolution, the fertility table by parity, etc.). The life table is the basic methodological tool of traditional demographic analysis and it is still used today. The first life table is usually considered to be the mortality table that was created by *John Graunt* in 1662; this year is also regarded as the inception of demography as a science. The concept of a mortality table is based on describing a series of attritions in relation to age. As time passed the idea of the mortality table was mathematically developed and applied to other demographic (nuptiality, fertility, divorce rate, etc.) and non-demographic (life expectancy of cars or other equipment, etc.) processes.

The life table is based on the principle of an exposed population reduced by those people who experienced the event under observation. It is thus based on so-called decrement rule. The exposed population is defined solely on the basis of some initial event (for example, people born in the same calendar year, marriages concluded within the same year, births in a given birth-order) and all the individuals in it are exposed to the risk of undergoing the event

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under observation. We distinguish two types of life tables: single-decrement tables and multiple-decrement tables. The estimated values of the probability (risk) function of single-decrement table are based on the assumption that the individuals that did not undergo the studied event but left the exposed population for some other (intervening) reason than that of the observed phenomenon (so-called censored observation) would undergo the observed phenomenon in the same way (with the same intensity) as the others. Both phenomena, the observed and the intervening ones, are regarded as 'independent' and this type of analysis is called the study of a phenomenon in its 'pure' state (the phenomenon's probability is estimated as though the intervening events were absent). A multi-decrement table is based on the assumption that both phenomena, observed and intervening, are mutually incompatible and at the given time interval only one or the other of them can occur, so the probability of the observed event occurring and the probability of the intervening event(s) occurring are both estimated. Both types of demographic tables (single-decrement and multi-decrement) are well illustrated in nuptiality tables of singles, where in single-decrement tables it is assumed that those who have died would have had the same marriage rate as surviving singles, and so the nuptiality of singles whose death prevented them from ever marrying are still calculated into the estimate of the first marriage probability. The table population is reduced only by table marriages. In the case of multi-decrement tables (for example, double-decrement) at the given age interval the probability of first marriage is estimated along with the probability of dying single. Here the table population is reduced not just by table marriages but also by table deaths. The traditional methods of demographic analysis described in many textbooks are primarily linked to two names: *Louis Henry* (1972) and *Roland Pressat* (1961, 1983).

The basic paradigm of traditional demographic analysis is to define the studied population in such a way that it is as homogeneous as possible in its characteristics (so it is not just the initial event they have in common, for instance, their year of birth, but other characteristics too, such as being single and/or living in a particular region). In this way it is possible to ensure a solid comparison of individual population groups. The exposed population at the outset has a defined set of homogeneous characteristics, but these change somewhat over time, because selective departures of individuals from the exposed population can lead to a change in the structure of characteristics of this population. For example, in an analysis of mortality by age, as people grow older, (healthier) individuals with exceptional longevity account for a larger proportion of the surviving population, and they may have different average characteristics than the original (initial) population. Classic demographic methods are thus unable to capture this unobserved heterogeneity. Another hypothesis of traditional demography, one that is challenged today, is the hypothesis of independence. The occurrence (intensity) of the observed event (for example, the birth of a child) is not entirely independent of previous life experience. Also, the study of individual (isolated) phenomena in just their 'pure' form, independent of other phenomena occurring at the given interval, to some extent constitutes a problem. The assumption that those who, because of some other event, left the exposed population would behave in the same way as those who remained in the population is a debatable one, as both sub-populations can behave differently (those who die younger tend to be less likely to marry owing to their poorer health). In real life the principle of mutual exclusivity does not always apply either (i.e. it is not always true that only one event or another can occur), as is the case of mortality from a given cause (death by one cause rules out death by another). For example, entry into marriage and living in a cohabitation cannot be regarded as two incompatible events (i.e. in practice only one or the other occurs). In practice we know that an interaction between the two is possible, as many marriages take place after couples have cohabited. The 'shortcomings' of traditional demographic analysis can be summed up as follows: they overlook the problem of the heterogeneity of the population, previous experience, and the interaction of demographic phenomena, as they study individual processes in isolation (*Courgeau et al*. 1997). These problems of classic demography are to some extent addressed by differential analysis, which does define sub-groups as homogeneously as possible (by education, marital status, place of residence, and so on). However, the problem here is still the ever decreasing size of the population groups.

Traditionally, the study of demographic issues has relied, with some exceptions, on aggregate data, and the methods used evolved in the context of available data sources. Most often data were derived from standard vital statistics records and censuses. As soon as one type of aggregate data was chosen, it was used for the entire analytical problem, because that enabled the use of the same class of methods and thus ensured the compatibility of the results (*Courgeau et al*. 1998). The values of classic demographic indicators, rates, and probabilities were compared between different populations and groups. The differentiation of demographic indicators by the defined sub-groups was also presented in relation to other characteristics which were assumed capable of influencing demographic parameters. For example, the higher intensity of emigration out of a given region was explained by the high rate of unemployment in that region. However, the findings based on these relations between indicators calculated from aggregate data can be distorted. This type of error is called an 'ecological fallacy'. A higher rate of unemployment need not mean that it is the unemployed who are emigrating from the given region (the probability of emigrating can be the same or the opposite for unemployed and employed). That a correlation between phenomena measured at the aggregate level need not be the same as it is in a calculation based on individual measurements is a problem that was first identified by the American statistician *W. Robinson* (1950), who, based on data from the 1930 census in the United States, showed that the correlation coefficient between the fact of being black and the fact of being illiterate was 0.95 at the aggregate level (the correlation between the proportion of blacks and the proportion of illiterate in individual states), while the correlation coefficient calculated on the basis of individual records was 0.2. This study clearly demonstrated that results obtained at the aggregate level cannot be automatically projected into individual behaviour. When the within-group variability of a given variable is greater than its between-group variability it is possible to arrive at erroneous conclusions.

The new paradigm of demographic analysis

An understanding of these problems led to the spread and popularisation of analysis based on measurements for individuals and not just on aggregate data. This approach also constituted support for and the advancement of sample surveys that specifically relate to the life course (the 'life line') of an individual, that is, they capture the sequence of events that an individual goes through in life, also recording the individual's personal characteristics and how they may change over time. The development of sample surveying in demography and with it the formation of new data sources then also led to a boom of new methods. The focal point of interest became not the event (an isolated phenomenon) but individual biography, i.e. a person's individual record. Thanks to these new opportunities for research a new paradigm of demographic study was also born (*Courgeau et al*. 1997). Unlike traditional methods, the new paradigm has the following distinct principles: it is no longer the evaluation of an isolated phenomenon in its pure form that is at the centre of interest, but rather the reality of how the given (observed) event influences the rest of an individual's life. For example, to what extent does marriage influence the subsequent professional career or migration or the birth of a child? In what way do the specific characteristics of an individual influence his/her behaviour, how do these characteristics change during his/her life, and how do his/her decisions change? This type of analysis is more demanding, because it studies the life course (life line), which is complicated. An event that occurs at a given time interval is also dependent on previous life events/experiences (traditional demography was based on the hypothesis that demographic phenomena are independent of each other) and on the social conditions in which the life course of the individual had taken shape up until the time of the observed event. The new paradigm involves identifying the relationships between the complex individual behaviour of an individual, which is dependent on time, and the characteristics of that individual. But the characteristics of an individual may be constant (place of birth) or variable over time (employment, education, etc.). The analysis is based on the interaction of various demographic phenomena in the observed populations, which is not homogeneous in terms of its characteristics.

Nevertheless, even analyses based on data on individuals that describe sequences of life events and the characteristics of individuals can still suffer from another type of error: 'atomic error'. What this signifies is that a study based on data on individuals disregards the contexts (surroundings, society, institutions) in which life events take place. The data on individuals that are usually acquired record in great detail the context of the family (parents, siblings). For this reason analyses are evolving towards multilevel modelling, which combines individual analysis with contextual analysis, which can then be described using aggregate data. Multilevel modelling draws on hierarchically structured data (individual, household, region), wherein individuals can belong to more than one group. The parameters at the micro-level are a function of the contextual variables at the higher levels. This approach eliminates both types of error, ecological fallacy and atomic error. Multilevel modelling is also regarded as the connecting link between micro- and macro-analysis (*Courgeau et al*. 1998). However, even micro-level modelling is not an absolute solution and like every method it also has certain limitations. The drawbacks to this approach lie mainly with the task of correctly defining the context. The problem is whether the context is real or whether it just reflects the average of individuals' characteristics (*Hank* 2002). In the latter case we speak of 'contextual fallacy'. A correctly defined context expresses the rate of influence of the environment (peers, elders, etc.) on an individual's decisions, the degree of social control, available infrastructure (e.g. decisions about whether or not to have a child can also depend on the availability of preschool facilities or after-school care) etc.

Sometimes demographic processes do not proceed sequentially, and instead many of them can occur simultaneously and are therefore correlated. For example, marital fertility is correlated with the formation and the end of a union (a woman is simultaneously exposed to the risk of conception and the end of a partnership). The trajectories of the two processes (dissolution of a marriage/union and marital fertility) interact. Unions that are less stable usually have fewer children than those unions that consciously or unconsciously are not heading towards divorce. Remarriages also often lead to the birth of another child, and therefore women who marry more than once usually have more children. In this regard a new class of models emerged for multiple simultaneous processes (multi-process modelling), which have a multi-dimensional risk function (*Lillard* 1993; *Leone et al*. 2007). Because these are very specific models, it was necessary to develop special software for them, which is today freely available on the web (aML) and is intended for multilevel and multi-process modelling.

Event history analysis

There is a series of methods used to analyse the history of events that were originally developed out of traditional life tables and their defining principle was gradually elaborated in the context of new findings and new technological possibilities. This gave rise to the creation of a series of new and more complex models based on the concept of regression analysis. The methods were developed independently within the framework of various scientific fields, and therefore they are referred to with different terms: in epidemiology it is survival analysis, in the technological sciences it is failure time analysis or reliability analysis. It is also possible to find other terms: life-time models, transition-rate models, response-time models, event history models, duration models, or hazard models (*Vermunt-Moors*).

Event history analysis involves studying the qualitative changes (events) that occur at a certain time point (*Allison* 1984). This is different from those tasks in which the focal point is to examine continuous quantitative changes. The event/change signifies an important turning point between what was before and what is after. Because these changes occur at certain time points, in order to study them and their explanatory variables/factors it is necessary to use longitudinal data (event history data). To this end the data on individuals (or a collective) that are used cover what in demography is called the 'life line', i.e. events, the period of time that has elapsed between individual events, and the characteristics of the studied units. The characteristics (explanatory variables) can be constant over time (place of birth) or they can change (income). The purpose of analysing an event is thus to explain why some individuals are exposed to a higher risk of undergoing the studied event than others are. Unlike the data used in classic multidimensional statistical problems, there are two basic problems with the data used in event history analysis, and they were mentioned in the first section of this paper. The data may be censored (not everyone undergoes the studied event: for example, not everyone marries; or the datum is no longer available owing to the occurrence of another competing event than the studied one: for example, the death of an individual in the case of nuptiality analyses). The second problem is that the data may contain explanatory variables that change over time (income). The models may vary according to whether the period before the event is continuous or discrete, whether the studied event can be recurring (births) or not (birth in a given birth order), and whether the event is singular (wedding) or has mutually exclusive variants (e.g. death from one causes rules out death from another). Special regression models that were developed for this kind of problem are based on the idea (equation) of explaining the risk of undergoing the observed event at a particular time interval (explained variable) with the aid of certain characteristics (explanatory variables). This is the context in which we should understand the subtitle of the classic work by *P. Allison* (1984) 'Regression for Longitudinal Event Data'. Regression moreover makes it possible to include not just explanatory variables but also a random element that can deal with the problem of unobserved heterogeneity.

The models used in event analysis can essentially be divided into three large groups: a) non-parametric, b) semi-parametric, and c) parametric. Non-parametric models are actually simple models used in classic demography (life tables), and when necessary are further specified by other variables (the principle of differential demographic analysis). In these models the hazard function is empirical (calculated from the distribution of data) and no assumptions are made about the type of the probability distribution on which the survival times are based, just as specifications about sub-populations and groups are based on empirical data. It is possible to test the differences in the table functions of two or more sub-populations, usually by using non-parametric tests. In standard computer programs these types of problems are referred to as Life tables (SPSS: Survival/life tables; SAS: LIFETEST) or Kaplan-Meier (SPSS: Survival/Kaplan-Meier; SAS LIFETEST). In semi-parametric models the hazard function is also calculated from empirical data (assumptions are not made about its type in relation to time). The explanatory variables have to meet certain preconditions. A typical example of a semi-parametric model used on demographic problems is the Cox proportional hazards regression. This means that, for instance, the mortality risk of singles is a multiple of the mortality risk of married people (it is proportional). In the Cox regression model the explanatory variables can be constant or variable over time and numerical or nominal. Cox regression forms part of a number of statistical packages: for example, SPSS: Survival/Cox regression; Cox regression/ Time-Dependent Covariate, or the SAS PHREG. The third group of models are parametric models, which are based on certain assumptions that relating to the type of the probability distribution of survival time and to the explanatory variables. The most frequently models are the exponential, gamma, the Weibull or the Gompertz function (SAS: LIFEREG).

As the preceding discussion indicates, more complex models for event history analysis emphasise the differentiation of risk in the context of time and the explanatory variables, while in classic life tables the focal point is the distribution of time (life duration). Another direction in which the idea of life tables can be developed and extended is multi-state demography, the objective of which is to capture the distribution of states and the average time spent in individual states. This method is based on the theory of Markov processes, which are based on the assumption that the probability of a change in state (the occurrence of a given event) is not dependent on the course of preceding states.

Multistate demography

In life people move from one state to another at specific time intervals – going from the state of being single to that of being married, from the state of being married to that of being divorced, and sometimes they get married again. Traditional decrement life tables fail to capture the dynamics of this change of states (in this case marital status), as they are essentially single-state (a change in state/event can only happen once). Often these simple, traditional demographic models are based on the assumption of a closed population. The main shortcoming in the traditional approach is that no reverse flow is possible, which is particularly a problem for the construction of tables of the economic activity of women using the so-called Sullivan method (i.e. by multiplying the stationary population Lx by the share of economically active women), as that state changes several times in life owing to maternity. Similarly, people may move several times, or move back to the same region. Only one state is final/irreversible (absorbing), and that is to be dead. In this respect multistate demography opened up new opportunities because it allows for both increment and decrement life tables. This allows an individual to be included back in the table population by (re-)undergoing the same event. Multi-state life tables then led to the development of multi-state projections. Most studies of this type were done in the 1970s and 1980s (*Rogers* 1975, 1995; *Hoem et al.* 1976). In the Czech Republic the problem of reverse flows with regard to economic activity has been dealt with by *Roubíček* (1970) and a summary of methods was prepared by *Koschin* (1992).

Multistate life tables represent a dynamically integrated system. They can share one radix (at the outset everyone is single or economically inactive) or to be multiradix (being born in the city, the countryside, or in various regions). From a structural perspective they can be divided into two types according to whether we are observing demographic changes by states at their defined start (e.g. we observe separately the attrition of regional populations defined by place of birth, i.e. before moving to another region, we divide the given table population into indigenous and those from (an)other region(s)), or whether we are interested in the behaviour of a table population in a given state and at a given time interval regardless of some phenomenon in the past, by place of residence (e.g. the table population of a given region is reduced by emigrants and increased by immigrants regardless of what region they are from). In both cases the 'incoming' population adopts the demographic behaviour of the indigenous population. Alongside calculating the intensities (risks) of transition, these tables also show the amount of time spent in individual states. For example, it is possible to calculate how long the given population spends in a state of being single, married, divorced, and widowed. Multistate tables have been applied, for instance, in the analysis of regional mortality (multi-regional life tables), they have been used in the study of the dynamics of economic activity (working life tables), or to calculate the amount of time spent in various different family states or in cohabitation, and they can also be applied to children according to the state of their parents. They can be applied to the problem of changes in health status, and so on. In connection with household analyses and projections, special software (LIPRO) was developed that can generally be used to calculate multistate tables and projections.

Decomposition methods

Decomposition methods are about breaking down the value of the difference between two indicators into specific underlying elements. These techniques have been used in demography since the 1980s (*Vaupel et al*. 2003). The principle of decomposition is that the difference in value between two indicators is divided – broken down – into several effects or components. The difference between two indicators can be a difference of time, countries, sex, and so on. The earliest decomposition methods were linked to standardisation ideas and *E. Kitagawa* (1955) wrote the pioneering work on this subject. In her work the difference between two crude rates was broken down into three components (the effect of the change of structure, the effect of the change in intensity, and the interaction between the two effects). This theme was elaborated further in a work by *Das Gupta* (1978, 1993). The second of these two publications especially constitutes a summary handbook of different types of decomposition, with model examples and their relevant Fortran programs. Another example of decomposition involves methods of decomposition of the difference between two life tables, usually the difference between two life expectancies at birth. This method of decomposition is based on calculating the contribution of individual age groups to the overall difference between two life expectancies at birth. Independently of each other the same approach was proposed by *Andrejev* (1982) and *Pressat* (1985). J. Pollard (1982, 1988) also proposed a method of decomposition of the difference between two life expectancies at birth, using two dimensions – one based on age and one based on cause of death. *Arriaga* (1984) took this problem to a deeper level and defined so-called temporary life expectancy as the average number of years lived at a given age interval and proposed a decomposition with three components: the direct effect (measuring the change in mortality intensity in the given age interval), the indirect effect (measuring the change in the number of additional years as a result of the change in mortality, i.e. the change in mortality and the change in survivors). A summary study of decomposition differences between two life expectancies at birth is found in a publication by *Ponnapillo* (2005). The significance of the change in the infant mortality rate for life expectancy is examined in a historical look at the Czech Lands presented in the publication by *Rychtaříková* (1980).

Decomposition techniques were used abundantly in the 1980s and 1990s in demographic practice, particularly in the analysis of mortality by age and eventually in combination with causes of death. Use of these methods experienced a boom recently, when decomposition methods were applied in wider practice to other demographic processes, for example, fertility (*Andrejev et al*. 2002). A new element of the decomposition of mortality is the addition of another process – the quality of the state of health measured as life expectancy in a certain health state category (health expectancy). The difference between two life expectancies at birth is then broken down into that part stemming from the difference in health state and that part that relates to different mortality. Another step is then the addition of another dimension – mortality causes and morbidity causes (*Nusselder et al*. 2004).

Age-Period-Cohort Models

APC (age-period-cohort) models are a typically demographic group of models that represent the three axes of the Lexis diagram (*Wilmoth* 2006). The central idea is the decomposition of the variability of demographic intensity indicators into three dimensions: age (generally duration), calendar time (period), and cohorts (the period of the initial event). A particular age, period, and cohort do not in themselves express causal effects, but are just proxies of specific social and biological conditions/situations. The effect of wars or epidemics can in a given period have a direct impact on the mortality rate of the population (period effect), but it can also, in the case of the child population, select resistant individuals (cohort effect) who will live longer when they are older. Nevertheless, it is possible also to consider the opposite effect of wars and similar calamities, where hardship in early childhood can damage a child's health, so that later on the mortality rate of that sub-population may, conversely, be higher. The cohort effect is also documented in *Easterlin's* well-know theory based on conditions in the United States, where less numerous birth cohorts allegedly had better labour market conditions, which led to their full employment and easy opportunities for starting a family, while the post-war baby-boomer generation, growing up in relative surplus and with great aspirations, had a difficult situation in the labour market and therefore more complicated conditions for having children.

Even though at a theoretical level APC models look like an interesting tool of demographic analysis, they have prompted discussions relating not just to their theoretical framework but also and especially to their mathematical identification. The problem is estimating the model's parameters, where the explained variable is the intensity indicator (usually in some transformed form, most often a logit) and the explanatory variables are age, period, cohort, and there are only two independent variables, because period = cohort + age.

Conclusion

This article outlined just some of the latest methods in demography, but like the references to literature the outline itself is not exhaustive. There are of course all sorts of other models that pick up and elaborate on the older ones. For example, the stable population model was expanded by the concept of quasi– and semi-stable population (*Pichat* 1994), model life tables or models of fertility and nuptiality have been advanced and are summarily described in a UN publication (*Indirect Techniques* 1983). The translation equations expressing the relationship between cross-sectional and cohort indicators remain today the subject of discussion (*Calot* 1992; *Bongaarts et al*. 1998; *Keilman* 2006).

Demographic study does not limit itself just to methods developed for the specific needs of its field, but instead it successfully applies other techniques used in related fields. These include, for instance, other types of regression models, factor analysis, correspondence analysis, or cluster analysis. We can even find publications devoted to causal modelling (*Wunsch* 1988) or qualitative research (interdisciplinary method based on a large amount of information on a small number of individuals and used to create a holistic picture of the problem under investigation). These trends to some degree are connected to the widening thematic focus of demography and its increasing interdisciplinary nature, which engenders not just interaction between scientific fields but also methods. New methods introduce and open up previously unimagined possibilities, and this is also made possible by ever better and richer data bases and more powerful computers. On the other hand, more complicated methods and approaches make bigger demands on their being employed correctly.

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