New approaches and methodological innovations in the study of partnership and fertility behaviour

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The aim in this session is to situate the study of partnership and fertility behaviour in a broader research context than that adopted in the first two sessions of the conference. This broader perspective will enable us to introduce new approaches and methodological innovations from different viewpoints. The object here is not to give an exhaustive review of the various developments that have occurred in demographic methodology during the previous decade. Instead, attention will focus on three main fields associated with major methodological innovations or new approaches in demography.

In the first, partnership and fertility behaviour are considered as part of a more general life course, in which events occur in different fields such as education and employment careers, residential history, and so forth. These events are no longer treated as dependent characteristics that influence partnership and fertility behaviour, but as *interacting processes*. The life course in one such arena may influence the life course in another, and vice versa. As a result, partnership and fertility behaviours no longer occupy a central position in these studies, which instead extend over a very wide range of subjects. The new approaches developed to undertake such multi-state analyses have been responsible for important methodological innovations and have contributed to the emergence of a new paradigm in micro-demographic research.

Second, a macro-approach has been the impetus for the generalization of classical mathematical techniques to multi-state life-tables, where the different demographic events can be incorporated in life tables of increasing complexity. Partnership and fertility behaviour may be introduced with mortality and migration flows between observed areas, in a multi-regional model. However, use of transition intensities restricts the analysis to linear models that produce cycles in age structures and regional populations, which vanish as the system reaches the stable situation. Recent experimentation with more complex systems has led to the development of *non-linear models* capable of generating persistent oscillatory or erratic behaviour in certain areas of their parameter space. Here, then, is the basis for a shift in paradigm, with analysis of the predictable behaviour of linear models being replaced by investigation of the dynamics of non-linear models, which can display unpredictable equilibrium behaviour even when they are completely deterministic.

Third, demographers have in the past usually worked at a given level, either the individual level, as in the first of the fields described here, or an aggregate level as in the second. It has long been known, however, that results obtained using aggregate-level data can differ from those obtained using individual-level data. The task then is to understand why such discrepancies occur and to find ways to overcome this problem. This begins by recognising that an individual behaviour or process at the micro-level always occurs in a particular macro-level context. Each context presents a range of opportunities and restrictions for individual action that vary depending on the aggregate level at which it occurs. The *analysis of complex structures* can be used to identify the mechanisms responsible for these effects and to explain some of the discrepancies observed between individual and aggregate data. The analyst has the possibility of working simultaneously at different levels of aggregation, with the aim of explaining an individual behaviour or of understanding the working of the system at an aggregate level.

In what follows we review the methodological innovations associated with these new perspectives. This paper is concerned mainly with developments in the 1990s, though discussion of the changes involved sometimes requires reference to earlier periods.

I - Interacting processes

In the first two sessions of this Conference, partnership and fertility behaviour were considered as separate, independent processes. Under the classic paradigm in demography, each of these single phenomena is analysed as *independent* of the other, and as occurring in sub-populations, each of which is required to remain *homogeneous*. The intention is to isolate a process and to study its properties in the absence of other processes, in a "pure state" (Henry, 1959). In the real world, however, isolation is never feasible. This paradigm is at the origin of numerous problems. It is so restrictive as regards the events that can be studied that it effectively precludes entire sectors of demography, such as analysis of competing events and of interaction between events. (Courgeau and Lelièvre, 1996).

A new paradigm is required with which a more complete analysis of human behaviour can be achieved. Investigation should be focused not on homogeneous sub-populations but on a series of individual life courses involving a succession of different states. In contrast to the classical paradigm, the unit of analysis will no longer be a single phenomenon but the individual life history, considered as a complex stochastic process.

The new paradigm can be approached by the following postulate: throughout his or her life, an individual follows a complex trajectory, which at any given point in time is dependent on his previous itinerary to date, the information he has been able to accumulate in the past and the conditions prevailing in the society of which he is a member. Using this *life course paradigm* (Courgeau and Lelièvre, 1996, Willekens, 1999) the successive events occurring during one life history can be considered as a single behavioural process, without giving priority to partnership or fertility behaviour. This is the basis for multi-state event history analysis.

The technique of proportional hazards models, introduced by Cox (1972), provided the basis for many demographic applications of event history analysis in the early 1980s. However, most of the models developed at this time took the form of single-spell models (or else examined sequences of similar events, such as successive births) using very restrictive assumptions and leading to the separate analysis of fertility, migration, and so on. These models introduced the effect of different individual characteristics.

Although some models during the 1980's did consider the interaction between different processes (Courgeau and Lelièvre, 1986, Courgeau, 1987), it was not until the 1990's that such an approach became widely accepted (Keilman, 1993; van Wissen and Dikstra, 1999; Lawless and Fong 1999). The models employed correspond to two different approaches.

The causal model

The first way interdependent processes were introduced was to consider one of the processes as dependent. The occurrences of the other processes are then treated as binary time-dependent covariates whose values become equal to one after their occurrence (Gill, 1992; Blossfeld and Rohwer, 1995). The assumption is made here that the current rate of the dependent process depends on the past history of the other processes but is taken into account up to the current interval.

This approach leads to different causal models, one for each studied process depending on the occurrence of the others. The likelihood for all these processes can be factorised into a product of the likelihoods for the separate models. This is made possible by the fact that a change in one of these processes, at any specific point in time, *t*, may depend on the history of all the processes up to, but not including t. This assumption of conditional independence can be used in different models, which may introduce more complex groups, as will be seen later (Lelièvre *et al*., 1997). Let us show how this can be modelled.

Let us suppose, to take a simple example, that the main process has a failure time T_1 while the only other one has the failure time T_2, and that there are several time independent covariates given in a vector Z_i, for individual *i*. Under a proportional hazards model, this causal approach leads to the following formulation of the hazard rate for the occurrence of the first process at time *t*:

$$h_{i,1}(t|\ Z_i, u_2) = h_1(t)\,exp([1 - H_0(t - u_2)]\beta_1 Z_i + H_0(t - u_2)[\beta_0 + \beta_2 Z_i]) \qquad [1]$$

where $H_0(t-u)$ is a Heaviside function, equal to 0 if $t \le u$, or 1 if $t > u$, where u_2 is the time of occurrence of the second process, $\beta_0, \beta_1, \beta_2$ are parameters to be estimated. In this case the baseline hazard will be multiplied by $exp(\beta_1 Z_i)$ if the second process has not yet occurred, and by $exp(\beta_0 + \beta_2 Z_i)$ when it has occurred. It can be seen that the influence of the second process on the first one will be to multiply the baseline hazard by a constant, and to change the multiplicative effect of the time independent covariates.

It is simultaneously possible to modelize the transition rate for the second process, with the first process being treated as a time dependent covariate. From formula [1], we will obtain a symmetrical formulation for such a transition rate.

This approach enables an easy generalization of the Cox model and its related statistical procedures to multi-state models in demography, under the assumption of independent censoring

(Gill, 1992). The other underlying hypothesis for this model is that the hazard rate for the first process is affected only by the occurrence of the second process, not by its timing.

Such a model can be further generalized to include a large number of time dependent covariates, corresponding to the occurrence of different processes, while each of these processes may be considered in a separate equation.

The interaction model

Instead of analysing one of the interdependent processes in terms of its dependence on the other processes, this model focuses on the system of interdependent processes as a whole. It involves defining a new joint state space, based on the various state spaces of the coupled processes, and then proceeding as in the case of a single dependent process. If we have n processes, then the system will have 2^n different hazard rates to estimate. Some of these combinations may not be possible, of course, and must be excluded.

Let us consider the same example as in the previous section. We will now have four hazard rates to estimate (2^2) instead of two (Courgeau and Lelièvre, 1986, 1989, 1992; Hougaard, 1999a). For the first process we can define two kind of rates based on whether the second process has or has not previously occurred. Let us call 0 the initial state for every individual who has not experienced any of the considered processes. The rate for the first process occurring to individual, *i*, who has not yet experienced the second process, may be written:

$$h_{i,01}(t \mid Z_i) = h_{01}(t)\exp(\beta_1 Z_i) \qquad [2]$$

For the individuals who have already experienced the second process at time u_2, the rate for the first process which has not occurred before this time, may be written:

$$h_{i,21}(t \mid Z_i, u_2) = h_{21}(t, u_2)\exp(\beta_2 Z_i) \qquad [3]$$

where, contrary to [1], the baseline hazard may now be defined as a function of t and u_2.

This model is identical to the previous one only if we suppose that this function is independent from u_2 and proportional to the first baseline hazard. In this case we can write:

$$h_{21}(t, u_2) = h_{01}(t)\exp(\beta_0) \qquad [4]$$

and this relationship leads to a synthetic formulation of formulae [2] and [3], which is formula [1].

In another situation we can suppose that this function may be written:

$$h_{21}(t, u_2) = h_{21}(t - u_2) \qquad \text{for } t \geq u_2 \qquad [5]$$

which leads to a semi-Markov model, in which the baseline hazard depends not on age but on duration of stay in the second state (Courgeau, 1995). Other situations may lead to more complex models, which are no longer Markovian (Hougaard, 1999a).

The two other hazard rates, for the second process occurring before or after the first one, are symmetrical to the previous rates [2] and [3].

When there are no intervening covariates and when the baseline hazards are independent of u , it is possible to distinguish various interesting forms of dependencies between the two studied processes. We can see how the previous occurrence of a phenomenon may influence the future probability of occurrence of another one. If this influence is one sided, then we can conclude for a unilateral or local dependence (Schweder, 1970): one process will have an influence on the other, while the reverse is not verified. If this influence operates in both directions, then we can speak of reciprocal dependence. The last case, when there is total independence between the two events, is very rarely encountered.

As can easily be shown, this approach yields more precise and detailed results than the previous one, and allows the introduction of different interacting processes. For it to be efficient, however, very large samples of individuals are needed so as to obtain large numbers of interacting events for analysis. Also, the methods for analysing multiple times are not yet adequately handled and require further research (Andersen *et al.*, 1992).

Some other issues

Much of the discussion so far has been presented in terms of proportional hazard models, in which the different characteristics affect an individual's rate in a multiplicative way. This hypothesis has to be verified by using a non-parametric approach, for example, and many techniques have been developed to examine how covariates should be measured and whether their effects are constant or not. When the Cox regression model is found to be inadequate to modelize the observed interactions between the processes, an alternative has to be used. Various models, such as an accelerated failure time model, have been proposed to get a better fit to the data.

Another important theoretical issue raised by use of the Cox model concerns unobserved heterogeneity caused by omission of important covariates. In fact, while using a linear normal model, it can be shown that when the unknown covariates are independent of the known covariates, the regression parameters are unchanged. This is no longer the case with the Cox model. However, a technique has been developed to study how omitting characteristics affects the estimated parameters of the observed ones (Bretagnole and Huber-Carol, 1988). When the omitted characteristic is independent of the observed ones, this omission has no effect on the sign of the estimated parameters, but it does result in a reduction of their absolute values. This means that if the effect of a characteristic was significant when other independent ones were omitted, introducing them in the model will only reinforce the effect of the first characteristic. On the other hand, some characteristics that apparently had no significant effect may acquire a pronounced significance when characteristics initially unobserved are introduced. In contrast, when an accelerated failure time model is used, it can be shown that there is no change in the regression part of the model (Hougaard, 1999b).

Another problem arises when the sources of longitudinal data, such as the OPCS longitudinal study, the INSEE Demographic Panel Survey (EDP) or the geographic and wealth mobility survey in 19th and 20th century France, contain fragmentary demographic information (Courgeau and Najim, 1995). For example, the family history of individuals may be fully documented via vital registration data, while their migration or occupational history may be known only as regards their place of residence or occupation at the time of a census or family event. In this case all we know is that a move has occurred between two censuses or family events. The usual methods of event history analysis are unable to handle such interval-censored data. If the assumptions are made that no more than one of the events studied (say, migration) can occur between two observation times, and that the events defining the individual's spatial or social position are independent of the geographical or occupational mobility we want to measure, a valid estimation of the probabilities of moving then exists, and proportional hazards models can be calculated. However, in order to estimate interaction between two processes (family formation and mobility, for example) one or both of the previous assumptions have to be discarded. Much work remains to be done in this field.

Atomic fallacy

A potential problem for event history analysis concerns the tendency to consider individual behaviour as being influenced only by individual characteristics. The danger here is of committing the *atomic error,* that is, of ignoring the context in which human behaviour occurs. In reality, of course, individual behaviour is influenced by context, and it seems fallacious to consider individuals in isolation from the constraints imposed by the society and milieu in which they live. We will see later how contextual and multilevel analysis can be used to solve this problem.

II - Non linear models

Macro-level approaches in demography were until recently usually associated with the use of linear models. However, the hypotheses, which underlie such models, are remote from real world conditions and recent efforts have been directed to develop more realistic models.

Multi-state non linear tables

For more than 300 years, classical mathematical techniques have been used in demography to produce life tables. Important generalizations of these methods in the late-1960s and 1970s led to the development of non-hierarchical tables. With these it is possible to accommodate different forms of decrement from an initial state, chain together a series of tables, include re-entrants into states and differentiate interstate moves by both origin and destination (Land and Rogers, 1982).

Mathematical models can be built to describe transitions between the different states, leading to time-continuous Markov chain models. Such models consider an individual life course as the result of a stochastic process occurring in a given state space. This process is said to satisfy the Markov property if its future state depends solely on its present state, that is, if none of the states previously occupied have any effect on the present probability of moving to another state. However, the process is not stationary, as this probability may be dependent on the time at which the step is being made.

Such hypotheses lead to linear or quasi-linear models, which are the basis for population projections. For example multi-state projections using regional fertility rates, regional mortality rates and out-migration rates from each of these regional sub-populations, produce a stable regional distribution in the future.

However, such assumptions are very restrictive and are a crude approximation of many demographic processes. One way of analysing non-Markovian processes is to expand the state space so that the process in the new space is Markovian. But such an extension causes inflation in the data necessary for estimating large numbers of transition intensities, beyond the capacity of the usual data sets. In fact for further advances to be made it appears that non-linear models must be employed.

If it is accepted that a given behaviour is linked to the entire past life history of the individual, we can see that it is necessary to develop non-Markovian processes. A fertility behaviour may depend on feedback mechanisms of the kind proposed by Lee (1974). Contrary to linear stable population models, which produce cycles that vanish as the system reaches the stable situation, such non-linear models generate persistent oscillating behaviours when these mechanisms are strong enough. Only recently, however, has the link been established between non-linear models and unpredictable behaviour of the studied processes (Bonneuil, 1994a).

In the multi-state tables such non-linearities may arise for a variety of possible reasons. For example, the fertility behaviour of an individual who migrates may change according to the area of destination, but this change is not necessarily instantaneous and may be influenced by a memory of the previous states in which he had lived. Similarly, migration from high mortality areas, such as Northern France or Brittany, to low mortality areas like Paris or Southern France, will not free an individual from his past history, such as a period spent working in a coal mine, or a past alcoholic behaviour. Mortality will be linked to this past history.

The classical model, as indicated earlier, used fertility, mortality and out-migration rates. However, such out-migration rates do not take into account the attractiveness of destination areas. A more realistic model will use a migration parameter, between regions i and j in some time interval (t_0, t_1), defined as $M_{i,j} / (P_i(t_0).P_j(t_1))$. Here $M_{i,j}$ is the number of migrants between areas i and j during the particular interval, $P_i(t_0)$ denotes the population of the region of origin at the beginning of the interval, and $P_j(t_1)$ the population of the region of destination at the end of the interval. The resulting model is non linear and no longer leads to a stable regional distribution in the future: sustained cycles may appear, certain sub-populations may disappear, and chaotic behaviour may even occur (Courgeau, 1995). For chaotic behaviour to occur, however, the migration parameter may reach values that are unlikely to be encountered in usual populations.

For the analysis of partnership formation, the interacting regions used for migration are replaced by interacting individuals. Two-dimensional marriage rates include in their denominator an expression of the time both spouses were exposed to the risk of partnership formation, or of the numbers of males and females not yet in partnership. This two-sex problem has also been examined using non-linear models with cycles (Chung, 1994).

Common to these approaches is a shift in paradigm away from an analysis of the predictable behaviour of linear models, to the investigation of the dynamics of non-linear models which may exhibit chaotic behaviour even when they are completely deterministic (Keilman, 1993). Such behaviour is unpredictable in the sense that very small variations in the initial values or in the parameters can produce sharply contrasting subsequent changes.

However, this shift to chaotic behaviour occurs only when some parameter values have surpassed so-called bifurcation points. It is questionable whether these bifurcation points can in fact be attained in actual populations. Blanchet (1997) has demonstrated the need for caution and shown the problematic character of attempts to build models, which establish the intrinsically chaotic nature of demographic dynamics. In addition, a careful balance must be struck over possible tendencies to detect chaos whenever explanation and understanding fail. Chaos and stochastic processes may be considered as different approaches to analyse behaviour. The models, which lead to chaotic behaviour, far from being stochastic, are entirely deterministic, being merely the latest attempts to reduce the apparent disorder of the real world to simpler macro-laws.

Viability Theory

Let us now try to observe what happens when a random component is introduced into such models. This can be done by means of *viability theory*, which is concerned with the evolution of non-linear macro systems in the absence of any determinism. Developed by Aubin (1990), this theory has received many applications in the fields of demography and economics (Bonneuil, 1997). Its basic premiss is that a complex social organization can be described by simple regularities, which have the capacity to generate durable social forms. Let us consider its main features in more detail.

First, the states of the studied system have to be defined in terms of the various characteristics that summarize its existence, such as fertility, income, household size, consumption, and so forth. These characteristics are time dependent, but they must attain certain thresholds for the system to exist. Such conditions are thus at the origin of state constraints, such as an income threshold for an individual to live or a size threshold for a household to exist. To ensure its survival, the system can adopt a number of possible actions, such as a change in fertility or a change in consumption. These actions are called 'controls' and can be situated between certain values. A change in consumption, for example, is characterized by a degree of inertia and is limited to a closed interval.

Once these conditions have been defined, the evolution of the system can be formalized, with the derivatives over time of its characteristics being specified by known equations, such as a predator-prey relationship. From among the whole set of initial states and trajectories the viable ones can be identified. Viability depends on finding a trajectory departing from this state which will always stay within the constrained set of states. More interesting, however, is to transform this problem, which is a global one in the state space, into a local one at time t : from a given state occupied at this time what are the possible choices which will ensure the survival of the system? No attempt is made therefore to predict a determinist evolution of the system, merely to identify a set of possibilities with which the system can be maintained.

Contrary to the traditional emphasis on the study of asymptotic equilibrium in linear models, this new approach involves delineating the set of possible evolutions and actions that ensure the survival of the system at any time. It cannot provide a precise forecast of the future for a particular system, since no single trajectory is preferable to any other among the viable ones; but it does allow selection of a set of attitudes which at any given time is able to keep the system in existence forever.

When studying temporal fluctuations in fertility, for example, the notion of demographic cycles can be replaced by viability theory. Thus in order to maintain a particular standard of life, households have the possibility of modifying either their fertility or their lifestyle (Bonneuil, 1994b). When the viability constraints for the standard of living are reached, as happened during the Second World War, considerations of economic viability lead to a choice between reproduction and consumption and may result in sharp jumps in fertility.

Ecological fallacy

Multi-state linear or non-linear tables can be extended in order to identify the relations which exist between the rates corresponding to the phenomenon being studied in each sub-population, and the average values of different characteristics also calculated for each sub-population. An analysis of the fertility rates in different regions, for example, would seek to link them to the out-migration rates, for example, or unemployment rates, found in these regions. Such an analysis can be said to make possible an examination of the effect that the groups being studied have on their own demographic behaviour. In this case the aggregated characteristics are interpreted as being a set of constraints that each sub-population imposes on its members and which influence their behaviour.

An analysis conducted on these lines might, for example, reveal a positive association between the rate of unemployment in a region and its fertility rate. There is a real danger of concluding from this result that individuals who are unemployed have a higher fertility, whereas all that is in fact known is that a high rate of unemployment is accompanied by a high rate of fertility, regardless of whether the individual involved is economically active, unemployed or inactive. This mistake is an example of what is known as the *ecological fallacy*, which occurs when inferences about individual behaviour are based on aggregated measures.

III -Analysis of complex structures

Although the conceptual origins of the analysis of complex structures can be traced back to the mid-1950s, it was only during the 1980s that efficient and practicable computational strategies were developed. These often developed as theoretical elaborations of questions, which had earlier been the subject of considerable debate in sociology (Lazarsfeld and Menzel, 1961), and produced statistical estimations used mainly in normal linear models.

As was noted earlier, the study of micro-processes can lead to an atomic error, while the study of macro processes can lead to an ecological error. The best solution to these problems may thus be to incorporate both individual-level and ecological measures in the same analysis. This approach might include different measures of the same factor. For example, each subject would be characterized by his or her own exposure level as well as the average exposure level for all members of the group to which he or she belongs. The aim here is to explain a behaviour, which is still treated as individual, while working simultaneously on different levels of aggregation. The risk of ecological fallacy is thus eliminated, since the aggregated characteristics are used to measure a construction that is different from its equivalent at the individual level. It is introduced not as a substitute but as a characteristic of the sub-population, which will influence the behaviour of an individual member. Meanwhile the atomic fallacy is also avoided by the correct inclusion in the analysis of the context in which the individual lives.

Contextual and multilevel analysis

Various methods have been developed for including both individual-level and ecological measures in the same analysis.

The first method, often called *contextual analysis*, is a simple extension of conventional modelling techniques such as logistic regression or event history analysis. The model seeks to fit the data at the individual level and includes both individual and ecological predictors.

In such models, the characteristic to be analysed is always considered at the individual level: kin network size (regression model); being married or not (logistic model); age at marriage (event history model). The explanatory characteristics can be more diverse. The first step is to introduce individual characteristics. Next, characteristics for a given aggregation level are introduced. These might be the percentages or averages of individuals having these characteristics, such as percentages of married individuals in each area. More complex analytical procedures can also be employed. For example, in addition to average income, it is possible to introduce the correlation between income and matrimonial status.

Other characteristics are more global and concern the observed units in their entirety, as for example the number of hospital beds in an area. These do not correspond to any individual characteristic, but they can be aggregated at larger levels. Thus the number of hospital beds in a larger region is the sum of the number of beds in each area of this region. Finally, other collective characteristics are well defined for a given level of aggregation, but cannot be aggregated at larger levels. The political orientation of a commune, as defined by the party of affiliation of its mayor, for example, cannot be aggregated with those of the neighbouring communes, which may cover a broad spectrum.

Such a contextual model may consider the interaction between migration and marriage, for example, by means of a simple logit model (Baccaïni and Courgeau, 1996). Let us write the probability that the characteristic to be estimated, $y_{i,j}$, for individual i living in area j is equal to one, is expressed in relation to the explanatory individual variable, $x_{i,j}$, and the aggregated one, $x_{.,j}$, by a logit model:

$$P(y_{i,j} = 1 | x_{i,j}, x_{.,j}) = [1 + exp(-[a_0 + a_1 x_{i,j} + a_2 x_{.,j}])]^{-1} \quad [6]$$

Applied to young Norwegians, this appears to indicate that married men have a higher probability of migration from their region of origin, than unmarried men. However, when the percentage of married men increases in a region, the probability of migrating decreases for both married and unmarried men. Such a result highlights the dangers of inferring individual results from results obtained at a more aggregated level: the presence of a large number of young married men in a region results in a lower probability of migrating for all the categories of population. But this does not mean that married men have a lower probability of emigration than unmarried men; the exact opposite is in fact observed.

A serious limitation of contextual analysis is that outcomes for individuals within regions are treated as independent. In practice, the outcome for an individual in one region often depends on the outcomes for other individuals living in that region. Ignoring such within-region dependence generally results in estimated variances of contextual effects that are biased downward, making confidence intervals too narrow. One response to this problem of within-region dependence, is to introduce random effects into the contextual model.

This refinement results in *multilevel models* (Goldstein, 1995; Courgeau and Baccaïni, 1997), which are also called mixed-effects or hierarchical models. Reconsidering model [6], this approach can now be formalized in the following model:

$$P(y_{i,j}=1 \mid x_{i,j}, x_{.,j}) = p_{i,j} = [1+exp(-[a_0+u_{0j}+(a_1+u_{1j})x_{i,j}+a_2 x_{.,j}])]^{-1} \qquad [7]$$

where u_{0j} and u_{1j} are random variables, of expectation zero. It follows that the answers are distributed according to a binomial distribution of parameter $p_{i,j}$:

$$y_{i,j} \approx B(p_{i,j}, 1) \qquad [8]$$

In this case we have the following conditional variance: $var(y_{i,j} \mid p_{i,j}) = p_{i,j}(1-p_{i,j})$. The model then becomes a non-linear one: $y_{i,j} = p_{i,j} + e_{i,j} z_{i,j}$ where $z_{i,j} = \sqrt{p_{i,j}(1-p_{i,j})}$ and where the variance of $e_{i,j}$ is equal to unity. This is the level 1 variance, and we shall work essentially on the level 2 variances and covariances:

$$var(u_{0j}) = \sigma^2_{u0} \qquad var(u_{1j}) = \sigma^2_{u1} \qquad cov(u_{0j}, u_{1j}) = \sigma_{u01} \qquad [9]$$

Different estimation procedures have been proposed to estimate these parameters, their variances and covariances. Methods include those based on Bayes estimators (Wong and Mason, 1985), on non-linear model estimation (Goldstein, 1991), and on 'bootstrap' procedures (Laird and Louis, 1987).

For the previous example, a multilevel model does not change the estimated parameters, which remain entirely significant. The random effects, while not null, do not appear to be significant, thus inviting the conclusion that the aggregate characteristic explains the major differences between regions.

Rather than use individual characteristics and their aggregate counterparts, as in the previous example, it may be interesting to introduce structural and contextual characteristics, which have no equivalent at the individual level. A good example of this approach is found in the study of interethnic marriages of Moroccan men in Belgium (Lievens, 1998) where district-level variables are introduced. A logit model is again employed, in this case to explain the probability of being married to a western European partner versus a partner of the same ethnic group.

An individual level analysis is first undertaken with the primary purpose of explaining the probability of an interethnic marriage using individual characteristics. The basic hypothesis is that the minority group members who are the most assimilated to the dominant culture (longer periods of stay, higher levels of education, etc.), have the highest probability of being married to a partner from the majority group. This hypothesis is well verified in the present case. The introduction of a district-level variation does not modify the effect of individual level characteristics but reveals a very large variance between districts. Thus for the highest residual, the odds of being married to a Western European are 3.17 times larger than the overall probability, while for the lowest one they are 2.16 times lower.

District-level variables, such as ethnic or socio-economic heterogeneity, the degree to which positions on different dimensions are correlated ('consolidation'), etc., are then introduced to see if they have an impact and do not even outweigh the individual effects. From this it emerges that although these characteristics do play an important role in interethnic marriages they do not modify the existing effects of individual characteristics. Their introduction explains almost all of the district-level variance, which ceases to be significant, as in the previous example.

The conclusion from this example is that the two different theoretical approaches, individual versus macro-structural, can indeed be combined in a multilevel approach, yielding valuable additional insights and illustrating the interplay between these two analytical viewpoints.

Towards a multilevel event history analysis

Multilevel analysis has so far involved introducing space or social space into the study of a static characteristic by means of a regression or a logit model. The next step is to introduce time into the analysis, thus making possible a multilevel event history analysis.

Individuals are to be observed throughout their life. They may move from one area to another in which different behavioural patterns are observed, and some of their characteristics may change at given times (they marry, change occupation, etc.). Equally, the characteristics of the regions in which they live can be expected to change over time (increase in the percentage of married people, increase or decrease of regional unemployment, etc.).

Obtaining information on all these changes calls for a new kind of sample survey that will introduce characteristics measured at different aggregation levels and allow the links between individual behaviour and social structures to be identified. The aim must be to "set up systems of observation that are representative of diversified and hierarchical social contexts, by combining in a system of integrated multilevel indicators the contributions of ecological analysis, individual sociological surveys and contextual analysis" (Loriaux, 1987). Although the WFS has encouraged collection and analysis of community data (Casterline, 1987), the data are generally collected at the time of the survey, whereas what is needed is a continuous record. More recently, DHS surveys undertaken at different times in the same African country using the same sampling unit are an encouraging development even if the contextual characteristics collected are of limited interest for fertility studies (Schoumaker, 1999). One possible solution to this problem is to use data from different sources but measured in the same area so as to observe over time individuals and the areas where they live.

On the other hand, analytical techniques already exist for calculating a partial likelihood, which is the ratio of the hazard of the individual who experiences the event at a given time, to the sum of the hazard rates of the remaining population exposed to the risk. The product of these likelihoods, calculated for each time an event occurs, can be maximized by introducing several aggregation levels

(Goldstein, 1995). However, these results have yet to be generalized to more general multi-state models.

Also, at a given aggregation level an individual may move to another area during his stay in the population submitted to the risk. This can be shown by considering the study of fertility in different regions of a country. It is clear that some individuals can be expected to change residence between these regions during their reproductive period. They must therefore be linked to a new region each time they move, and the effect of the contextual characteristics of these regions will influence their fertility behaviour. A Markov hypothesis can be made that the behaviour of an individual depends only on the region in which he is at present and that when he arrives in a new region he immediately forget the constraints of the regions previously inhabited. Yet this hypothesis is scarcely plausible. The conditions need to be made less rigid. A solution is to test the speed of adaptation to conditions in the new region, if this is what is observed, or the conditions of selection of migrants in the region of origin, if the second hypothesis is confirmed (Courgeau, 1987).

In this way we are led to non-Markov models of demographic behaviour, whose complexity has to be added to the consideration of multiple aggregation levels.

The social structure of some of the groups under examination also needs to be considered. This has been shown to be necessary in the case of small groups, such as the family or the household. A full treatment of their social structure may require taking into account the interactions, which occur, between the members of the group and the changes over time in their interactions (Lelièvre *et al.*, 1997). The hypothesis of conditional independence may also be adopted for these models, thereby allowing models of 'shocks' to be incorporated into the analysis of behaviour changes induced by events occurring to other members of the group.

V - Concluding remarks

The preceding account has focused on the three main areas in which major innovations in demographic methodology have taken place: multi-state event history models, non-linear macro system theories and multilevel models. Developments have of course also occurred in other fields, which we will mention briefly here.

Methods originating elsewhere in the social sciences, and applied in substantially unmodified form, have yielded a number of new advances in demography. A case in point is the application of statistical methods originally developed for the analysis of textual data to the study of itineraries and event histories: these amount to a ‘corruption’ of textual statistics in that the words which are analysed are artificial. These methods are suited to the analysis of complex trajectories that are difficult to formalize with event history techniques (Courgeau and Guerin, 1998). Another example concerns the procedures developed in geostatistics under the name of universal kriging, which have been used for the analysis of the spatial diffusion of demographic phenomena (Bocquet-Appel and Jakobi, 1997).

Although some innovations in the field of household dynamics have been touched upon, particularly in the discussion of multilevel models, we have ignored other, more general models of household formation and dissolution. In our opinion this field was characterized by little progress in the 1990s and is in need of an entirely new theoretical approach (Murphy, 1996). In a similar fashion, the problems raised by microsimulation models lie not in the implementation of the simulation itself, but in the theoretical bases underlying these models.

Last but not least, we have quite deliberately excluded from discussion the study of the fertility transition and its relationship with mortality and mobility transitions in a long term perspective. The changes in this field were significant less in terms of new methodological developments than for combining perspectives and contributions from the other social sciences (Friedlander *et al.*, 1999; Burch, 1999): *economics*, with the 'new home economy', *human geography*, with the 'innovation-diffusion approach', *sociology*, with the 'adaptation approach', *ecology*, with 'evolutionary theory', *psychology*, with 'decision theory', and so on.

These new approaches and methodological innovations need to be situated in a more general reflection on the interrelationship between the social sciences and on their epistemological bases, as a prelude to the elaboration of new conceptual frameworks for explanation.

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