<u>CHAPTER 22</u>*

MOBILITY AND SPATIAL HETEROGENEITY

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Introduction

Up to chapter 20 of this treatise, discussion has been concerned with the population of a country or region whose individual members possess the same patterns of behaviour, with the same levels of mortality and fertility and with equal propensities to exit or enter the population. This assumption of population homogeneity, taken with the condition of independence between demographic phenomena, forms the basic premise of the traditional analytical approach to demographic processes (Henry, 1959).

As was seen in chapter 21, the assumption of individuals' social and spatial homogeneity needs to be abandoned so that the heterogeneity of the populations under study can be included in the analysis. Later it will be seen that the assumption of independence between phenomena must also be abandoned (Chapter 23). We begin, however, by introducing individuals whose demographic behaviour is dependent on their region of residence, and we observe the changes in their spatial distribution over time, produced by their mobility. Analysis needs to consider behaviour patterns with respect to fertility, nuptiality and mortality for the territory under observation and the migration flows between its component regions.

I. Concepts of mobility

Demographers have traditionally treated the events that make up their field of study as being located primarily in time while completely ignoring their spatial aspect[1]. This oversight has long been a handicap to the analysis of mobility, whose very definition is impossible without reference to space. Also, the space in question is to be construed not as an immutable entity that is external to the population; rather as continuously produced and transformed through individual and collective activity, a contextual element being

* Translated from the French by Godfrey I. Rogers.

1 The revival of interest in this aspect is recent, thanks in particular to developments in multilevel analysis (Courgeau and Baccaïni, 1997, 1998).

fundamental to human groups and social institutions. And linking these different social spaces is mobility—by the migrants exchanged between them but also by all manner of spatial flows that vary continuously over time (tourism, cross-boundary commuting, professional travelling, and so forth).

We can see from this why a definition of mobility cannot be based on the multiplicity of flows that by their nature are transient and ever-changing. A clear definition can, however, be based on the social space in which this mobility occurs. In this case it can be said that the study of spatial mobility involves identifying the changes occurring over time in the relations between an individual or social group, and space (Courgeau, 1988). This space-focused definition expresses the basic principle behind the approach—individuals are constantly mobile, so the aim is to describe and analyse this mobility and its changes over time. This definition also avoids the search for a definitive and universally valid typology of migrations, which is nonexistent. Such a classification would in effect fix the phenomenon in a rigid framework that would be unable to accommodate either the appearance of new forms of mobility or the disappearance of existing forms. The advantage of the approach as proposed lies precisely in permitting analysis of these new forms of mobility, which can take completely unexpected forms[2].

However, the temporal dimension of mobility is also an important element and must be incorporated in analysis. It is particularly important for relating this mobility to other demographic or economic phenomena and for identifying the very close interdependencies that exist between the events in the individual's life course (Courgeau, 1985). Event history analysis (chapter 23) is an effective tool for illustrating these interactions.

A definition along the lines indicated also allows the various concepts of migration or spatial mobility used earlier to be integrated into a systematic analytical framework. We will show how these concepts can be defined in such a way that they combine to form a consistent and nested conceptual structure

1) Change of residence

The notion of residence was introduced to provide a relatively straightforward way of determining the position of each individual in a particular country. As used in demography, the term individual residence means the place where the person lives, in the sense of "domicile", denoting the place where a person is legally deemed to reside. The latter criterion must be sufficiently unambiguous for us to be able to attribute a single place of residence to each individual at a specified time. We will see later that definitional changes can hamper comparability over time, while definitional differences between countries are an obstacle to comparability in space.

Assuming these problems to have been resolved, at least for the members of a particular sub-population, we can say that migration "involves a change in usual place of residence. The place left by the migrant is the place of origin or place of departure; the place to which the migrant goes is the place of destination or place of arrival". If places

2 See in particular the new forms of mobility identified by Hervé Domenach and Michel Picouet (1987), and by Skeldon (1990), in the developing countries, and more generally by Wilbur Zelinsky (1971).

of origin and places of destination are equated with actual places of residence, all migratory moves will be included: this concept enables international comparisons to be made, on condition that place of residence is defined in the same way in all countries. Failing this, migration that occurs inside the regions that define the places will not be enumerated as such, thereby making comparison impossible, due to the differences in geographical divisions between different countries.

Also to be considered are the individuals and sub-populations for whom the concept of residence is either meaningless or problematic. A more detailed examination is required for these particular cases. Groups and individuals such as nomads and semi-nomads, sailors, and tramps, cannot be attributed a fixed place of residence, and so for them the concept of change of residence is irrelevant. These sub-populations must be clearly identified from the outset and alternative concepts employed.

In other cases it is defining a single place of residence that is problematic. For instance, should soldiers in garrisons, patients in hospitals, boarders in schools, and so on, be treated as residing at these locations or at their personal place of residence? Such cases call for the adoption of classificatory criteria which, though usually arbitrary, should if possible be kept constant over time so that comparisons can be made. This last condition is not always respected, creating discontinuities in statistical series. Thus in France until 1954 the usual place of residence of servicemen, school boarders, and so forth was where they lived on a more or less temporary basis. Since the 1962 census, for those who also possess a personal residence, it is this that is counted. By contrast, for prison inmates and individuals in communal accommodation (i.e. members of religious communities), the place of communal residence is used, whether or not they also have a personal residence.

Thus we can see that while the concept of residence is useful in census-type operations to determine the population of a particular place, it is less accurate when applied to the study of spatial heterogeneity, where movements of a more temporary nature are also important for an understanding of societal change. In these conditions new concepts have to be used.

2) Changes of dwelling unit

Given the impossibility of distinguishing clearly between temporary mobility and migration, one solution is to consider both forms of mobility simultaneously. The concept of dwelling or dwelling unit, defined as denoting housing accommodation appropriate for occupation by one household, appears preferable to that of residence, since even when parts of the population live in non-conventional housing—in tents or on boats, for example—the term dwelling unit is still comparable in meaning. This concept is much more flexible than that of residence and means that at any given time an individual can be associated with a specific dwelling. Nomadic or semi-nomadic populations can thus be tracked over time, since they are associated with a dwelling unit.

With the details of this concept made clear it is straightforward to define migration as a change of dwelling. Such a definition both extends and encompasses the concept of change of residence. Criteria can be selected, which vary between countries and over time, with which to decide whether a change of dwelling is in fact also a change of residence. The population registers for Hungary, for example, record both migratory and temporary moves and show the latter to be twice as numerous as the former.

The dwelling unit concept is becoming essential for a correct analysis of spatial mobility. The developing countries, in particular, are witnessing a rapid growth of temporary migratory movements with a preeminent role in economic and other areas of national life. But in the industrialized countries too, new spatial structures are now emerging in which temporary mobility has an increasingly important role.

A further advantage of this concept is its formal equivalence with the concept of migration. In both cases an individual is tracked over his or her lifetime and at each point in time is associated with a single location, which may be a place of residence or a dwelling unit. Both types of mobility can thus be approached using similar methods of analysis.

3) Change of life space

If the identification of an individual with a specific place at a specific time is to be satisfactory it must give an effective summary of the spatial area within which he or she interacts. While this was certainly the case in the past, notably for much of the rural population, the space in which individuals nowadays lead their lives is expanding greatly. Substituting the place of residence or dwelling unit for this space is no longer satisfactory and the definition must be enlarged to include a new dimension.

This dimension is provided by the life space concept, which encompasses all the places with which individuals interact at any given time. Included in this space, as well as the places they actually visit or stay in, are those to which they are relationally linked. To facilitate quantitative analysis, however, this space has to be limited to a smaller number of places that can be precisely defined.

In an initial simplified form, life space is the individual's spatial work-residence pattern. The commuting journeys thus defined can be studied in relation to the migratory moves made by individuals. It is interesting to note that while at certain times in the life course this may be two distinct places, as when people are economically active and do not work at home, it is one and the same place when people work at home or are retired. This new concept thus corresponds to a space whose dimensions can vary over time.

Other forms of life space could include holiday homes or the places of residence of an individual's family and friends. On condition that these different places and the individuals associated with them are specified sufficiently carefully, the life space can be made more complex yet remain quantifiable.

From a formal perspective the life space concept differs significantly from the two previous concepts. It involves monitoring along spatial and temporal dimensions not one but a varying number of locations. A spread or extension may occur through the addition of new points of spatial attachment. An example of this is when individuals start employment yet retain all their existing points of attachment. Conversely, elimination of some existing points causes the life space to contract or shrink. This is frequently what is observed when a person retires. When some existing points are lost but new ones acquired we could speak of a shift in the life space, such as accompanies a change of workplace, for example. Finally, this shift could become a transplantation, in the case that contact is broken with all former points. This results in a complete change in the person's spatial implantation and the occupation of a new territory.

Collection and analysis of information on these life space changes requires innovative survey designs and new methods of measurement and investigation. Though still in its early stages this work is rich in potential for future research.

II. Measurement issues

The concepts of mobility are thus much more numerous and complex than those associated with other demographic phenomena, and they also imply use of sharply contrasted measurement procedures. Each of these measurement procedures is in addition associated with a specific type of data source that must be reviewed at the same time.

1) Migratory moves, registers and surveys

The first approach considers all the migratory moves undertaken by an individual in the population being studied. Individuals are counted as many times as they move. Working from this standpoint, therefore, what is being counted is a number of events, whether these be changes of residence or of dwelling. This is the measure used in population registers or in prospective and retrospective surveys, already mentioned in chapters 13 and 14.

The most satisfactory method for completeness of coverage is certainly that of population registers, when they are well-maintained. Migratory moves are then recorded as and when they take place. Unfortunately, only a few countries, mainly in northern and eastern Europe, operate and maintain correctly such a system of continuous registration. Furthermore, they are not especially reliable for measuring international migration, compared with migratory movements within national boundaries. They record only a limited amount of personal information, such as civil status, nationality and occupation, which is unsuitable as a basis for very detailed analysis, compared with information collected by surveys. As operated in some countries, however, the registers record changes both of residence and of dwelling (Hungary and Poland, for example) and in some cases even changes in the life space, as measured by residence, dwelling and work place (Denmark), thus allowing a more detailed measurement of population mobility.

Prospective surveys record moves as they occur and yield high quality information when carried out in good conditions. Unfortunately, well-nigh insurmountable problems arise with data collection when following up such a sample in the national territory and, to an even greater extent, abroad, since the sample is likely to become biased as a result of selective loss of individuals. People who have been through a difficult experience, or who have made a migratory move without leaving an address at their place of origin, for example, form special sub-samples of the population; they will either refuse to be re-interviewed for the survey, or will be impossible to trace for the follow-up. Also, the long interval between initiating a survey and analysing the results, leads many investigators to prefer retrospective surveys. It is true that a good quality analysis requires a long observation period, of at least ten years and often longer.

Usually, therefore, investigators opt instead for a retrospective survey in which a sample of individuals are questioned on their past mobility. By selecting cohorts of a fairly advanced age at the time of the survey, information is obtained that relates to much of their lifetime. With this procedure the problem of sample attrition does not arise since all individuals are questioned on a single occasion. In addition, the investigator conducting the survey is able to analyse the results immediately, since the totality of retrospective information is collected. On the other hand, there can be serious memory recall problems given that individuals are required to remember events that may have occurred long ago and to date them as accurately as possible.

These recall problems were tested empirically with a retrospective survey conducted in Belgium, a country which also possesses a population register (Poulain et al., 1991, 1992). Although the retrospectively collected information is of significantly poorer quality for migration compared with other demographic phenomena (marriage or birth of children), we were able to verify that the material errors in the retrospective collection did not generate large errors in the longitudinal analysis (chapter 13) or event history analysis (chapter 23) of these moves (Courgeau, 1991a, 1992). It seems that the errors introduce a random noise in the exact dating of events but do not create bias in the analysis results. Memory would thus appear to be reliable on the points that are crucial for the analysis.

Another source of bias in these surveys is the fact that interviewing is restricted to individuals who have survived up to the survey and who have not emigrated abroad definitively. The assumption has to be made that, for as long as they are in the territory being studied, their migration behaviour is the same as those present at the time of the survey. The hypothesis is made that the sample is non-informative (Hoem, 1985) with respect to the behaviour we wish to study. The validity of this hypothesis can be tested for countries which possess population registers. This verification has been undertaken for the study of other demographic phenomena (Lyberg, 1983), and the hypothesis does seem to be supported, but we are not aware of any studies that have attempted it for migratory movements.

Surveys, finally, provide information suitable for the study of life spaces, ranging from the simplest to the most complex. They allow us to show the changes that occur over the lifetimes of individuals and to relate these to their personal characteristics and to the characteristics of the socio-spatial environment in which their lives are led.

2) Migrants, latest migration and censuses

Exhaustive measurement of migration activity in the census, even if limited to the inter-censal period, is impractical for reasons of cost. Consequently we have to make do with less detailed information, derived from just one or two questions, to provide a general view of population mobility.

If we compare the places of residence of individuals at the beginning and end of the period we obtain the number of migrants, when these two places are different. The focus in this approach is the individual, ignoring any intervening moves that may have occurred in the period, and comparing only the origin and destination points. The period considered is usually of one or five years, producing annual or five-year rates respectively for use in analysis. In some countries, such as France, the migration question in the census concerns the inter-censal period. The reason for this is that knowing the populations of a region at two successive censuses, and knowing also its natural increase over the period, and the number of internal and international immigrants, and finally the number of internal emigrants, the level of international emigration can be deduced. Unfortunately this estimation by comparison of two successive censuses usually generates a very large error term that makes the method unreliable (Baccaïni, 1999).

The "place of birth" question asked in most censuses can be used to measure what are known as life-time migrants i.e. whose place of birth was in a different administrative unit to their current residence. Their number is a useful general indicator of migration activity in countries with very low levels of mobility but is of limited interest for most modern countries where individuals undertake a great many migratory moves over their lifetime.

Another approach is to ask only about individuals' last residential migration and previous place of residence. With this we measure the number of latest migrations or more exactly the number of migrants by latest migration. In contrast to the single question on migrants, measurement of latest migrations precludes two analytical possibilities. First, whereas the number of migrants can be measured on any of a country's territorial sub-divisions, by asking for the previous address in as much detail as possible the latest migrations in effect impose a particular migration-defining division. Reconstituting the numbers of migrants that would be observed using different sub-divisions is thus impossible. Let us assume, for example, the latest migrations are measured between departments. If we wish to estimate the most recent migrations between communes, those whose most recent move was inside a department and who had previously made an interregional migration, will not be captured. Conversely, if we wish to estimate the most recent interregional migrants, those whose previous move was between departments in the same region will not be identified either. An additional drawback is that the most recent migration, the date of which will vary between individuals, cannot be used to make population projections with migration, as this requires the numbers to be measured over fixed one- or five-year periods.

For these reasons the questions on the latest migration, though often still included in censuses, should not be used. Measurement of migrants avoids these disadvantages and is to be strongly recommended.

III. Mobility over time

In traditional longitudinal analysis of age-specific all orders migration, the rates are calculated in exactly the same way as the age-specific emigration rates discussed in chapters 13 and 14. These rates are seldom used, since they are not amenable to a simple modelling of migration flows. If, on the other hand, mobility is analysed by order of move and by duration of residence, we obtain rates and probabilities that are much less volatile and easier to apply in modelling attempts. Modelling with a small number of parameters is in fact essential in the case of migration activity, given the complexity of the phenomenon and the large number of flows to be introduced, especially when working with a division into regions.

Let us see first of all how these rates and probabilities can be estimated, before applying them in the modelling process and comparing the numbers of migrants and migratory moves obtained with the various measurement methods.

1) Mobility by order of move and duration of residence

We proceed for first migrations in the same way as for first births. Data from retrospective surveys are unlike data drawn from prospective surveys and population registers in that they do not include deaths. If we denote $M_x^{i,1}$ the number of first migratory moves observed between ages x and $(x + 1)$ in the birth cohort i, and $P_x^{i,0}$ the non-mover population of age x, the migration probability mg of rank order 1 is written, when working with retrospective data:

$$mg_x^{i,1} = \frac{M_x^{i,1}}{P_x^{i,0}}$$

When working with prospective data the mortality of non-movers between ages x and $(x + 1)$, $D_x^{i,0}$, has to be introduced, which gives the following migration probability:

$$mg_x^{i,1} = \frac{M_x^{i,1}}{P_x^{i,0} - 0.5D_x^{i,0}}$$

For higher than first-order migrations, numerous studies have established that it is much better to work on the duration of residence between successive moves rather than on the age of the individual. This is because with the latter the populations at risk obtained for the young ages are very small, resulting in rates or probabilities with substantial variance that are liable to lead to completely wrong estimations if used for distributions or survival functions. Such problems are avoided if we work on duration of residence, and the much more uniform curves that result can be used for a simple modelling of successive migrations.

In the case of migration of order n, we denote $M_t^{i,n}$ the number of migrations of order n occurring in an interval between t and $(t + 1)$ of the previous migration in cohort i, $P_t^{i,n-1}$ the population of individuals who have made $(n-1)$ migrations and not yet made the next order migration, and $O_t^{i,n-1}$ the losses from observation affecting this population. The latter have to be included because we are working on the duration of residence since the last migration. The migration probability for rank order n is then written, if we have retrospective data:

$$mg_t^{i,n} = \frac{M_t^{i,n}}{P_t^{i,n-1} - 0.5O_t^{i,n-1}}$$

If we have prospective data, we need to introduce the deaths in the population of individuals having made a migratory move of rank order *(n–*1*)* at time *t*, $D_t^{i,n-1}$:

$$mg_t^{i,n} = \frac{M_t^{i,n}}{P_t^{i,n-1} - 0.5O_t^{i,n-1} - 0.5D_t^{i,n-1}}$$

The analysis can be further developed by calculating the probabilities by duration of residence and age at previous migration. To do this we obviously need to be able to work on large numbers or combine ages to form age groups.

For illustrative purposes let us examine migrations by the Norwegian 1948 birth cohort, followed from age 15[3].

Figure 1a shows that first-order migration is clearly differentiated from higher-order migrations.

[3] We would like to thank the Norwegian statistical services for allowing us to use the data files produced from their population registers and censuses.

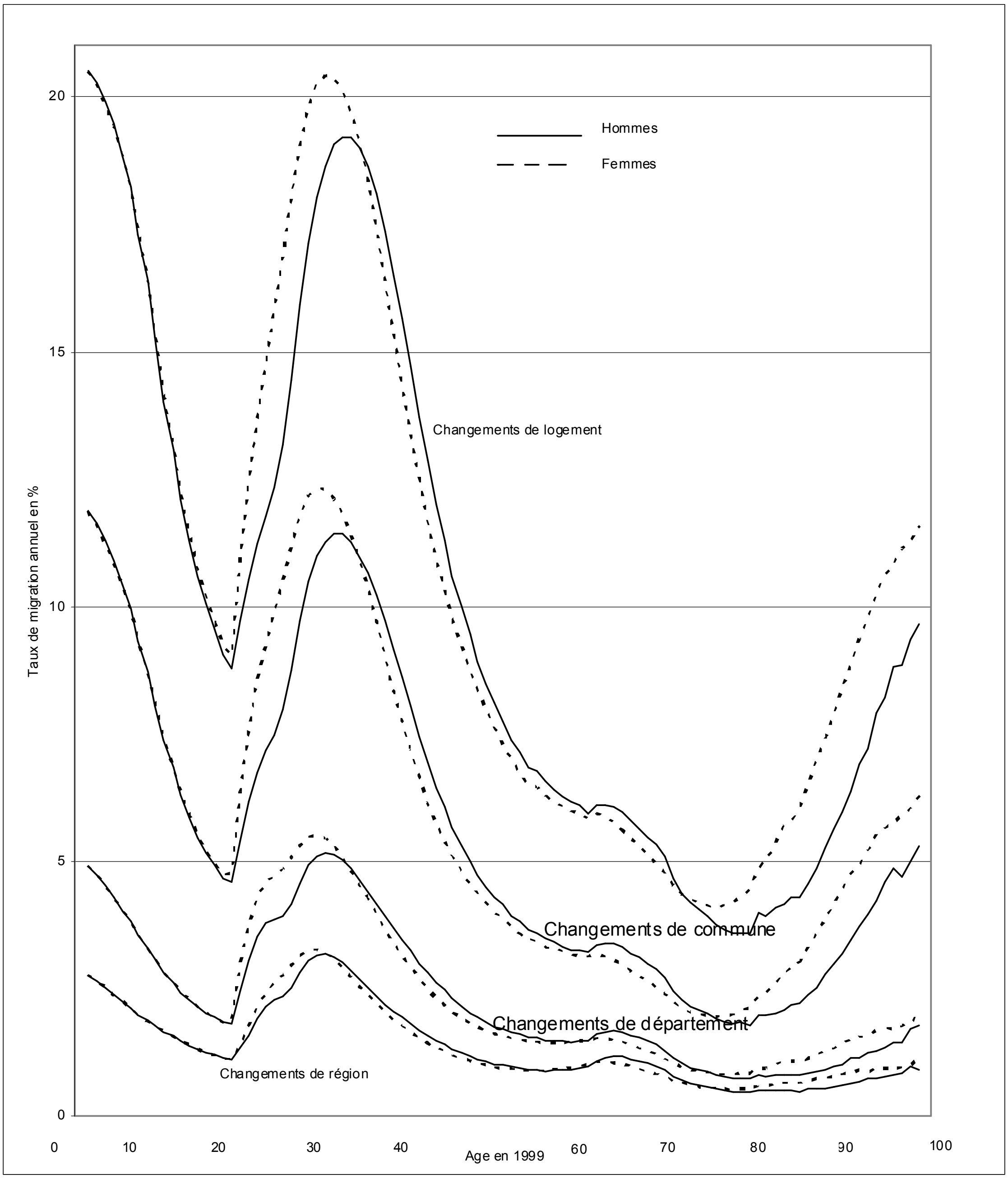

Figure 1. Migrations in the Norwegian 1948 birth cohort
Source: Population Register of Norway

The migration probabilities for rank order 1 rise to a maximum at age 23 whereupon they fall rapidly. In contrast, the migration probabilities for higher-order moves are all very similar and follow the same pattern of a continuous sharp fall without reaching a maximum. It can also be noted that, at least for durations up to six years, the probabilities are higher the lower the migration rank order, though the differences are never great. If the age group in which the previous migration was made is also introduced, we obtain for rank orders of move 2, 3, and 4 the results in Figures 1b, 1c, 1d. These show clearly that these probabilities depend on the age at the previous migration—the younger the age at this migration the higher the probabilities—but they are now almost independent of the order of move being considered. These results show that migrations of orders higher than one can be modelled using a small number of parameters.

2) Time-dependent models

These sets of migration probabilities by order of move and duration of residence can be conveniently summarized by means of simple models. The various migration models encountered in the literature cannot be discussed in detail here and we will simply consider the most commonly used.

The oldest and most widely-used formal model is certainly the so-called "*mover-stayer*" model (Blumen *et al.*, 1955). Its basic hypothesis is that only a fraction of a population that has made a previous migration is at risk of making a subsequent move. The first step in the modelling procedure is to disaggregate the population that has made a migration of order $(n-1)$ into a sub-population that will make no further move and, on the other hand, a sub-population that will move again. For this second sub-population the hypothesis is then made that the probability of making a new move is independent of the duration between the move of order n and move of order $(n-1)$. If we assume that the proportion of potential migrants is K, the proportion of stayers at time t may be written as:

$$S(t) = (1 - K) + K\,exp(-\mu t)$$

where μ is the instantaneous migration hazard in the population of potential migrants. We verify that when $t \to \infty$ the proportion of stayers tends to $(1-K)$, as predicted by the model. The curve representing the hazard rates of order higher than 1 does indeed have the same form as the curves in Figure 1.

The relatively constant scale of these parameters can be confirmed by working on the sample of women in the INED "Triple Biography" (3B) survey from which respondents under age 50 have been excluded. Table 1 gives the parameter estimate values of K for migrations of successive orders and involving changes of dwelling, commune or department. The proportions of potential migrants for any given type of migration are seen to be virtually independent of migration rank order. However, this constant declines slightly as we proceed from changes of dwelling to changes of commune and to changes of department.

Table 1. Probability of a subsequent residential migration in France, for successive migrations and different types of move

Change of	Individuals age 50 or over (%)					Numbers observed
	$K2$	$K3$	$K4$	$K5$	$K6$	
Dwelling	0.89	0.86	0.87	0.91	0.84	1,954
Commune	0.77	0.75	0.76	0.76	0.74	1,610
Department	0.72	0.64	0.70	0.71	0.67	1,028

Source: INED, “3B” survey

Let us now consider changes of dwelling and see how parameters K and μ vary as a function of age at the previous migration and of the order of move. The results appear in Table 2.

Table 2. Parameters K and μ for changes of dwelling of successive orders, pre-1931 birth cohort, France

Mean age at move of order (n-1)	K_2	μ_2	Number observed	K_3	μ_3	Number observed	K_4	μ_4	Number observed
17.5 years	0.91	0.19	820	0.92	0.20	309	0.91	0.18	113
22.5 years	0.78	0.16	563	0.84	0.18	420	0.87	0.17	242
27.5 years	0.67	0.15	114	0.70	0.16	222	0.80	0.16	192
Source: INED, "3B" survey									

This shows a slight decline in parameters K and μ as mean age at the previous migration rises. On the other hand, for a given age at the previous migration, these two parameters are only slightly dependent on order of move. This result is very similar to what we determined by empirical observation for the Norwegian migrations.

Modelling of successive migrations is also possible using the *Gompertz* model. This model postulates that the variation in the instantaneous hazard rate is proportional to the population at risk at a particular point in time. Under these conditions the proportion of stayers is written:

$$S(t) = (1 - K)^{1-exp(-\mu t)}$$

where K again represents the proportion of individuals who will migrate, and μ is a parameter expressing this relationship between hazard rate change and population at risk (for more details see Courgeau and Lelièvre, 1989, 1992, 2001). When $t \to \infty$, we verify that the proportion of stayers tends to $(1 - K)$ as predicted by the model.

A comparative assessment of these two main models with several others was conducted by Ralph Ginsberg (1979) using data from the Population Register for Norway. From this it emerged that the fit obtained with these two types of model was on the whole equally good for all the flows under consideration (by age, marital status, income, region of origin, etc., representing a total of 308 different flows) and considerably better than that obtained with the other distributional models (exponential, Weibull, log-normal, etc.). However, the Gompertz model is more flexible, since it allows for both increasing and decreasing hazards, and can thus accommodate cases in which the flows follow distributions that are non-monotonic decreasing.

3) Migrants and migrations

We are now in a position to model the differences between measurements of migrations derived from population registers or surveys and census-based measurements of migratory flows. Such modelling is necessary because census data are often only available over periods of varying length, while for making comparisons across time and across countries it is preferable to work with results relating to flows and to annual migration rates.

The model we present here is in a simplified form, and while it can be made more realistic by adopting more complex hypotheses, this does not fundamentally modify the theoretical argument or the results.

The first assumption made by the model is that the instantaneous migration probability, p in the total population is time invariant. This hypothesis can be considered to be valid for a short period of time though it may well not hold over longer periods. Thus for the United States the probability remained at around 0.19 from the end of the Second World War to the start of the 1970s, whereupon it fell slightly to 0.17 in subsequent years. This shows that the hypothesis is satisfied for this country, and the same is true for many other countries (Long and Boertlein, 1976). The second assumption is that a mover-stayer model adequately describes the migrations observed in the country. As noted, this hypothesis is often verified correctly. In addition, parameters K and μ are assumed not to change as a function of order of move or of age at previous migration. It was seen that this hypothesis is not fully verified for migration in France and Norway, but it can serve as a satisfactory first approximation of behaviour. For ease of calculation the assumption is also made that the population does not change during the interval under consideration: it is equal to P.

Over a very short interval $(\theta, \theta + d\theta)$ this population will make $Ppd\theta$ migrations. Under the mover-stayer model, only a proportion of these movers will go on to make a new migration: $PpKd\theta$. Let us consider the distribution over time of these additional moves. During the time interval $(t, t+dt)$ these new migrations will satisfy the following formula:

$$\frac{d[M_n(t)]}{PpKd\theta - M_n(t)} = \mu dt$$

where $M_n(t)$ represents these new migrations occurring between θ and t. Integrating between θ and t, we obtain this number:

$$M_n(t) = PpKd\theta[1 - exp(-\mu\{\ t - \theta\ \})]$$

By varying θ, between an initial time ($\theta = 0$) and a final time ($\theta = t$) we will have counted all the new migrations that occur in this period:

$$\int_{\theta=0}^{\theta=t} PpK[1 - exp(-\mu\{\ t - \theta\ \})]d\theta = PpK[t - \frac{1}{\mu}(1 - exp\{-\mu t\ \}]$$

Lastly, if there are no return migrations, by calculating the difference between the total migrations that will be recorded during the period ($M(t) = Ppt$) and these multiple migrations, we obtain the number of migrants that would be given by a census at time t in the place of residence at the initial time:

$$m(t) = Pp[(1-K)t + \frac{K}{\mu}(1 - exp\{-\mu t\ \})]$$

Introduction of a geographical division into units such as communes and departments, for example, means that return migrations also have to be included. If we assume that these return migrations $r(t)$ form a constant proportion of the migrations of order higher than 1 that occur in a year, this hypothesis is written:

$$r(t) = l\sum_{i=2}^{\infty} m_i(t)$$

where $m_i(t)$ represents the migrations of order i that occur during the year t. This hypothesis is verified for France (Courgeau, 1973a, 1979) and allows us to write the number of migrants as:

$$m(t) = Pp[(1 - K(1+l))t + \frac{K(1+l)}{\mu}(1 - exp\{-\mu t\})]$$

Applying this model to the data for the United States and France produces the parameter estimates reported in Table 3.

Table 3. Parameter estimates of the migrants-migrations model, United States and France

Coefficients	Change of dwelling		Change of county
	United States (1960-1970)	France (1968-1970)	United States (1960-1970)
μ	0.490	0.180	0.520
p	0.183	0.104	0.075
K(1+*l*)	0.810	0.780	0.770
Source: Courgeau, 1982; Long and Boertlein, 1981.			

With these parameter estimates we can compare the main characteristics of migrations in the two countries. We note first that the instantaneous migration hazard p in the United States is almost twice what it is in France (0.183 compared with 0.104). This greater mobility is not associated with a smaller proportion of non-movers, since in both the United States and France approximately 80% of individuals who have made a residential migration subsequently make another one. The essential difference, however, is the time that elapses before these new migrations occur. In the United States, nearly half the population at risk make this new migration in the year following the previous migration, compared with less than one-fifth in France.

A comparison can also be made between changes of dwelling and changes of county in the United States. These are characterized primarily by a much lower rate of inter-county mobility, whereas this time the proportions of non-movers and the interval between moves are very similar in each case. It must be noted, however, that the data do not enable us to distinguish authentic non-movers ($1–K$) from return migrants l, since we can only estimate a coefficient that measures non-movers corrected for returns, $1–K(1+l)$. For changes of dwelling the estimated parameter obviously relates only to non-movers, since moves back to a previous dwelling are negligible.

Figure 2 displays the curves observed for migrants, compared with the curves estimated by the model, for changes of dwelling and of county in the United States.

Figure 2. Proportions (%) of estimated and observed migrants and average number of migrations, United States

We note first the near perfect match between the curves showing observed and estimated data. The corresponding migrations show the large size of the differences between migrants and migrations, of approximately one-to-two, after five years.

This model can of course be made more realistic by introducing a variation over time in the probability of moving and dependencies between parameters K or μ and age at the previous migration. This involves no fundamental change to the formulas employed.

IV. Mobility, space and spatial models

The next step in the analysis is to incorporate the spatial context in which these migrations occur. We define a territorial division into r regions between which flows of migrations or of migrants are observed. Let us begin by looking at the different rates and indices that can be defined to describe these flows.

1) Interregional mobility rates

Let us consider the totality of inflows and outflows affecting a particular region. The most favourable situation is when the analyst has data from population register or survey sources. For region i, we have already defined the annual age-specific emigration rates,

x, e_x^i, and the rates for age groups of n years ${}_n e_x^i$ (see chapter 13). We also explained that age-specific immigration rates are harder to define, since the population at risk is no longer that of region i but of the rest of the world. In this case the preferred solution is to use the same denominator as for the emigration rate, though by so doing we no longer have a conventional demographic rate.

The situation is more complex when census data are available for migrant numbers over a duration of n years. Calculation of a corresponding annual rate is now made impossible by the multiple moves and return migrations that occur during this period (Courgeau, 1973a, 1979). Thus all we can calculate is a *probability of emigrating* over n years, or *proportion of migrants,* by dividing this age-specific number by the population of individuals surviving at the census and who resided there at the start of period P_x^i:

$$ {}_n\varepsilon_x^i = \frac{{}_n\mathcal{E}_x^i}{P_x^i} $$

In this case too the proportion of immigrants will use the same denominator, even though this term no longer represents the population at risk.

If we consider now the flows between two regions, two types of rates can be calculated. The first relates the number of migrations or migrants only to the average population of the area of origin, considered to be at risk. Thus the rate of emigration from i to j at age x can be written:

$$ e_x^{ij} = \frac{E_x^{ij}}{0.5(P_x^i + P_{x+1}^i)} $$

The second type of rate includes in addition the population of the area of destination. Numerous empirical studies have established that the flow depends as much on the population of the destination area as on that of the origin area (Courgeau, 1970; Poulain, 1981). We are then able to define an *index of migration intensity* between two regions, i and j, in the period (t, $t+n$), for migrants of age x at the start of the period, over n years:

$$ mg_x^{ij} = \frac{\mathcal{E}_x^{ij}}{P_x^i \, P_{x+n}^j} $$

This index can be interpreted as the probability that two individuals alive at the end of the period and selected at random, one from the population living in i at the start of the period, the other from the population living in j at the end of the period, will be identical (Courgeau, 1980). The effect on the migrants of the origin and destination populations is thus eliminated. It can be demonstrated that when two or more regions are combined, as origins or destinations, the intensity index is a mean, weighted by the products of the populations, of the intensity indices for each pairing. It follows that when the indices between each pairing are equal, the index for their combination will always take this shared value.

2) Spatial models

For a country divided into r regions and a population containing y age groups, $yr(r-1)$ indices must be calculated in order to characterize all the flows affecting the individuals. It is not hard to see the advantage of condensing this information into a smaller number of summary indices with which to characterize mobility in the country in question. This can be done by means of explanatory models in which interregional distance—in its spatial though also more sociological conceptualization—is introduced as a variable. This distance is known to be a deterrent to migration, a phenomenon related to the sharp reduction in relational networks that occurs as the distance between individuals increases. In the discussion below we present only the most commonly used model. (For a more comprehensive review of the other types of model in use see Courgeau, 1980).

Let us suppose that the distance between two regions i and j is d^{ij} and that the index of migration intensity between these two regions is mg_x^{ij}. A Pareto-type distribution can then be fitted to the set of flows observed:

$$mg_x^{ij} = \frac{k}{(d^{ij})^n}$$

where parameters k and n are estimated from the data. These models give a generally good account of the migration flows and yield coefficients of determination of between 0.8 and 0.9 (Poulain, 1981).

This kind of model can be used to describe the distribution of migrants across various divisions of the territory. Using different spatial units and running the model with different exponents, we have given a theoretical demonstration (Courgeau, 1973b) that there is a simple relation expressing the migration rate observed as a function of the number of units in the division used, r, which is in turn equal to the ratio between the total population of the country and that of an average unit:

$$mg_r = K \log r = K(\log P - \log P_r)$$

Empirical verification of this law is straightforward for countries for which migration rates by various territorial divisions are available. Table 4 presents the results observed in Holland and France.Table 4. Relation between migration rate and average population of a spatial unit, Holland and France.

Territorial division	Annual migration rate (%)	Number of spatial units	Parameter K
Holland (1982)			
Dwelling	10.59	5,310,945	0.0159
Municipality	3.90	774	0.0156
Economic region	3.30	129	0.0165
Corop region	2.23	40	0.0151
Province	1.54	12	0.0160
France (1968-1975)			
Dwelling	10.37	17,744,985	0.0143
Commune	6.44	36,394	0.0142
Department	3.09	95	0.0156
Region	1.90	22	0.0142
Sources: Courgeau *et al.*, 1989; Courgeau, 1980.			

The annual migration rates in France were estimated using the migrants-migrations model presented above and are therefore fully comparable with the rates observed using the Dutch Population Register. The model is found to give a good fit for both Dutch and French data. The curves showing the percentages of migrants as a function of the logarithm of the average population of a spatial unit form straight lines almost parallel to each other (constant parameter *K*): consequently, if a measure of residential migration was not available, very good estimates could be made based on the other types of migrations.

This means that in the countries for which we possess no general measure of residential migration but only measures of mobility between various types of territorial units, a residential migration rate can be estimated that is suitable for comparison with other countries. The divisions for which data are available can also be used to check the validity of the model to ensure comparability. These models have been used to compare population mobility in the European countries (Rees and Kupiszewski, 1999).

V. Multistate models

We again consider a country divided into r regions. The objective is to represent the probabilities of the various demographic events in matrix form, which we can use to project from the age-specific regional population at time *t* to that at time (*t*+1). This representation is much more complex than that considered in chapter 20, which allowed only for mortality and fertility in a single population. Moreover, the matrices depend heavily on the hypotheses made about the migrations. In what follows we consider only the two main hypotheses.

1) Priority to emigration rates

For ease of exposition we will limit ourselves to a female population. Let us suppose that for each region $i(i = 1, \dots r)$ we know the survival probability between the age groups x and $x+1$, p_x^i, and the number of girls born between t and t+1 to a woman of age x at t, f_x^i. For the migration we work here on the probability of migrating from region i to region j, ε_x^{ij}. This probability will thus be calculated in relation to the population of the area of origin, like the proportions of emigrants presented earlier. To simplify the calculations we consider the female population, by year of age up to the limit age l and we assume that only one event can occur in the course of a single year[4]. Under these conditions we can project the population of age x of region i at t, $P_x^i(t)$, to its population of age $(x+1)$ at $(t+1)$:

[4] More realistic assumptions can easily be made, though presentation of the results then becomes more complex (Rogers, 1995).

$$P_{x+1}^{i}(t+1)=P_{x}^{i}(t)\left[p_{x}^{i}-\sum_{j\neq i}\varepsilon_{x}^{ij}\right]+\sum_{j\neq i}\varepsilon_{x}^{ji}P_{x}^{j}(t)$$

For the births in the course of the year we can write:

$$P_{0}^{i}(t+1)=\sum_{x=15}^{49}f_{x}^{i}P_{x}^{i}(t)$$

The set of probabilities can be represented in matrix form, M, while the age-specific populations of the regions are represented by a vector of $r(l+1)$ elements, $P(t)$ and $P(t+1)$, between which the following relation is verified:

$$P(t+1)=MP(t)$$

This relation can be used to project the initial population, by making the assumption that matrix M remains constant over time, for example, or changes according to certain rules. We can show that when matrix M does not change, the population will tend towards a stable population structure. The first real element in this matrix tells us if the overall population will increase or decrease. The stable population structure will be reached in two stages: at the end of the first the populations of each region become stable; at the end of the second stability is reached in the regional age structure (Rogers, 1995).

It remains to estimate the probabilities, based on the annual emigration and mortality rates. At age x, for example, we will write the following matrix of the annual rates of emigration, e_{x}^{ij} and mortality $\left(q_{x}^{i}\right)$

$$\mathrm{M}'(x)=\begin{bmatrix}\left(q_{x}^{1}+\sum_{j\neq 1}e_{x}^{1j}\right) & -e_{x}^{21} & \cdots & -e_{x}^{n1}\\ -e_{x}^{12} & \left(q_{x}^{2}+\sum_{j\neq 2}e_{x}^{2j}\right) & \cdots & -e_{x}^{n2}\\ \vdots & \vdots & \ddots & \vdots\\ -e_{x}^{1n} & -e_{x}^{2n} & \cdots & \left(q_{x}^{n}+\sum_{j\neq n}e_{x}^{nj}\right)\end{bmatrix}$$

It can be shown that the matrix of survival and emigration probabilities can be written:

$$M(x)=\left[I+\frac{1}{2}M'(x)\right]^{-1}\left[I-\frac{1}{2}M'(x)\right]$$

where I is the unity matrix, whose diagonal terms are equal to 1, and all the others zero (Willekens and Rogers, 1978; Rees, 1986). It is of course possible to work on five-year periods and age groups.

2) Priority to migration intensities

The previous solution is not very satisfactory, in that it is based on emigration rates, while as was seen earlier, many studies have confirmed that relations between two regions are better represented by indices of intensity. So if we now let mg_{x}^{ij} be the migration intensity between i and j, the previous relation between populations at t and $t + 1$, can be rewritten in the following form:

$$P_{x+1}^{i}(t+1) = P_{x}^{i}(t) \left[p_{x}^{i} - \sum_{j \neq i} mg_{x}^{ij} \ P_{x+1}^{j}(t+1) \right] + P_{x+1}^{i}(t+1) \sum_{j \neq i} mg_{x}^{ji} \ P_{x}^{j}(t)$$

So as to identify the populations for estimation more easily, this system of equations can be written in the form:

$$\mathrm{P}_{x+1}^{i}(t+1) \left[1 - \sum_{j \neq i} mg_{x}^{ji} \ \mathrm{P}_{x}^{j}(t) \right] + \mathrm{P}_{x}^{i}(t) \sum_{j \neq i} mg_{x}^{ij} \ \mathrm{P}_{x+1}^{j}(t+1) = p_{x}^{i} \ \mathrm{P}_{x}^{i}(t)$$

We see in this case therefore that these equations can still be represented in matrix form, but that this matrix will depend on the populations at time t:

$$M[\ P(t)]\ \ P(t+1) = P(t)$$

If matrix $M\left[P(t)\right]$ possesses an inverse, we can write:

$$P\ (t+1) = (\mathrm{M}\,[\mathrm{P(t)}])^{-1}\ \mathrm{P}\,(t)$$

We still have a relation with which to project from $P(t)$ to $P(t+1)$, but it is no longer a linear relation. If for example this nonlinear relation is used to project the initial populations under the assumption that the migration intensity values remain constant over time, we no longer obtain a stable population (Courgeau, 1991b; Keilman, 1993). Instead, some populations may disappear, while others may follow a sustained cyclical or even "chaotic" course, albeit one that is fully specified since the model contains no random variable.

Conclusion

We have seen that measurement and analysis of population mobility is extremely complex. The phenomenon must be considered in its temporal as well as spatial dimensions if all its aspects are to be grasped. The demographic analysis of migrations has developed new methods to improve our understanding of these flows, while making use of techniques originating in economics and human geography (Courgeau, 1976).

As part of this, linear regression methods can be used to explain the aggregated flows with respect to the characteristics of the origin and destination areas. This involves a generalization of spatial models, in particular that of Pareto, by introducing physical and social distance but also variables such as the effect of unemployment, the percentage of old people, and more generally the economic, social and political attributes of the regions of origin and destination (Puig, 1981).

An alternative approach to migration involves working at the individual level and explaining migration behaviour by means either of logistic models, which do not introduce time, or event history models, which do (chapter 23). Differences in migration behaviour are explained here with reference to characteristics related to the occupation, family, etc. of the individuals, in order to identify the personal motivations in these migrations and the effect of time on the process (Courgeau, 1985).

Lastly, there is an approach which attempts a synthesis of the two previous strategies by means of multilevel models (chapter 24). These seek to explain individual characteristics by introducing personal but also aggregated characteristics, and differentiate the behaviours with regard to the regions under examination. These models are a rich analytical tool for the study of migrations, situating the individuals under consideration in a multi-dimensional context that is both geographical and social.

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