WORKING PAPER 336

MULTIREGIONAL MATHEMATICAL DEMOGRAPHY: THEMES AND ISSUES

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1. INTRODUCTION

The past twenty years or so have seen a small body of researchers, scattered in many different countries, working on a subject known as "multiregional mathematical demography". This involves the study of populations living in many regions through use of mathematical methods. Its roots lie partly in conventional mathematical demography, with its concern for people's life expectancies and the evolution of populations to stability, partly in a general interest among social scientists in the phenomenon of migration, and partly in the concern of local and central government planners for more accurate forecasts of regional populations.

What I wish to do in the paper is to review the themes that have characterized multiregional demography over the recent past and then to discuss in detail the important issues that arise out of the work. I shall refer to other papers in this session for examples of some of the points.

2. THEMES

2.1 THE DIFFERENT APPROACHES

Of late several separate approaches to multiregional mathematical demography can be seen to be converging. Perhaps three approaches can be identified.

(i) The first approach involved the development of the multiregional cohort survival model and its use as a projection tool (theory - Rogers, 1968; applications - Rogers, 1968; Compton, 1969; Joseph, 1975; McKay and Whitelaw, 1978; Liaw, 1978a, 1978b, 1980).

(ii) The connections to conventional demography were developed more strongly in the multiregional life table model which can be used to generate life, fertility and migration expectancies simultaneously by region of birth and region of residence (Rogers, 1975; Ledent, 1978, 1980; Willekens and Rogers, 1978). Projection, stability and zero growth analysis can also be carried out with this model. The marital status life table models of Schoen and Land (1979) were developed in parallel.

(iii) The multiregional accounts based model had its origin in national demographic accounts (Stone, 1971, 1975) which were given a spatial expression and provided with a model for estimation from partial information by Rees and Wilson (1977).

2.2 CONVERGENCE AND DIVERGENCE

Through a series of international seminars and collaborative research projects, some measure of agreement has been reached on the compatibility of these three approaches (Rees, 1979; Ledent and Rees, 1980; Rees and Willekens, 1981). Figure 1 shows the building blocks of a "multiregional mathematical demographic" analysis sytem. The analysis can begin at one of two points - with data on the transitions people make (migrations between regions between fixed start and finish points) or with data on the movements populations make (migrations between regions without reference to end time points). The data are assembled in accounts matrices that ensure consistency

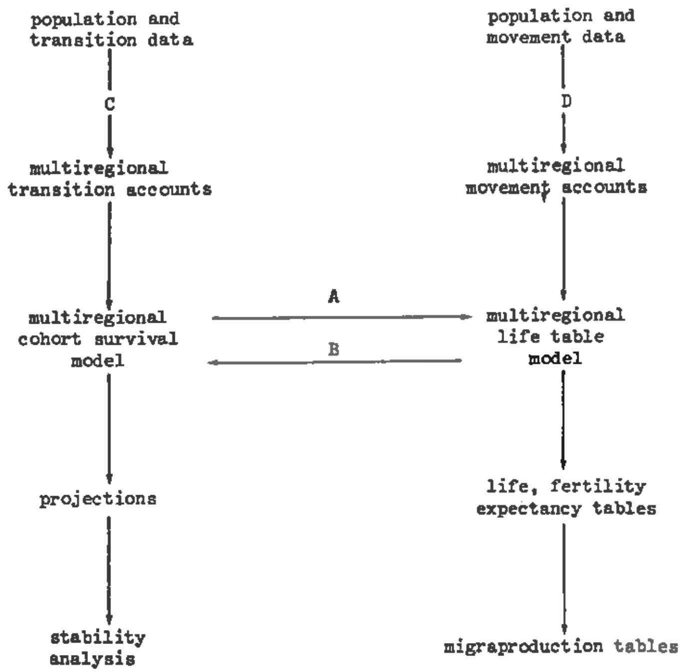


Figure 1. How the different approaches to multiregional mathematical demography have converged

of different inputs and complete specification of all relevant transitions or movements. Note that only methods for building transition accounts are well developed - the equivalent movement accounts are only implicit at the moment. From the accounts matrices, matrices of survivorship rates can be defined that are the essential ingredients of multiregional cohort survival models. From the movement data, survival probability matrices are defined that are used in the multiregional life table model. The approaches are connected at this level. Connection A involves methods of estimating or interpolating survival probabilities from survivorship rates. Connection B consists of the equations which define the survivorship rates from "life years lived" variables, reinterpreting them as stationary populations.

Recent work has explored the variation in results for the same regional system of interest that issues from choices in the analysis sequence. Work by Ledent and Rees (1980) suggests that "major" theoretical choices in life table construction such as the function to represent "life years lived" (linear, cubic, exponential, or interpolative-iterative) or such as the nature of the model used to construct the transition accounts (forecast or backcast, unconstrained or constrained) are relatively unimportant. What appears to have a critical influence on results is choice of migration concept and period of measurement, and the way in which the system of regions is closed, and the availability of place-of-birth classified migration data.

2.3 THE COMPARATIVE MIGRATION AND SETTLEMENT STUDY

These models have been applied in a wide variety of situations in the Comparative Migration and Settlement Study at IIASA (Rogers, Willekens and Ledent, 1982). Firstly, a series of 17 national case studies have been completed using the same methodology to study regional population dynamics using multiregional methods (see Rees and Willekens, 1981 for a list). Secondly, a series of papers are in preparation that compare results in the different countries (Rees and Willekens, 1981; Termote, 1981; Rogers and Castro, 1981; Liaw, 1981).

The case studies document for a set of developed North American, European and Asian nations the way in life expectancies vary across regions within countries, the way in which life expectancies by region of birth incorporating the effect of migration have much lower variance than conventionally measured life expectancies, how regional birth cohorts are likely to spend their lives across all the regions within their nation, how the children to be born under current fertility conditions to regional birth cohorts are likely to be distributed across regions, and how many interregional migrations persons are likely to make over their lifetimes. Regional populations are projected under the influence of a set of interacting regions and the results compared with more spatially confined models. In most national case studies the stable regional and age structures are computed and compared with the situation currently obtaining. Finally, the set of 17 country studies provide a unique and readily accessible data base (published as Appendices in each national report) for further study.

The case studies do not provide ideal material for exact comparative analysis (for reasons discussed in detail in Rees and Willekens, 1981) but a great deal can be learnt, nevertheless, about regional differentials in mortality indicators (e.g. Termote, 1981), about the nature of regional and interregional migration by age schedules (Rogers and Castro, 1981), or about the degree to which the regional population system is currently close to or far away from stable equilibrium (Liaw, 1981).

2.4 ESTIMATION METHODS

Putting together the information system for multiregional population/analysis is not an easy task. The paper by Doeve (1982) concentrates on this problem for a less developed country, drawing on the mainstream of demographic methods for useful techniques.

The model proposed by Frey (1982) has, as one of its motivations, the need to tailor the level of decomposition of the regional system to the data series likely to be available.

The input of data to the models via explicit or implicit accounts requires a good deal of estimation work. Willekens has developed this work applying entropy maximizing, information-theoretic and contingency table techniques (Willekens, 1977; Willekens, Por and Raquillet, 1981; Willekens, 1981) to the problem of estimating migration flow arrays classified by region of origin, region of destination and age. The methods employed crop up in a large number of disciplines - Willekens has integrated the various techniques. Although much progress has been made in developing general estimation methods, much of the work must, of necessity, be specific to the particular system being studied.

2.5 NEW TYPES OF SPATIAL SYSTEM AND MULTIREGIONAL MODEL

The regional systems used in the Comparative Migration and Settlement study were fairly aggregate, designed to cover the whole of the country, and their selection somewhat dependent on the availability of published migration data. Frey (1982) suggests that more interesting spatial shifts are going on within and between metropolitan areas in the U.S.A., and Rees and Stillwell (1982) report on the construction of a multiregional information system for metropolitan counties and standard region remainders, designed to capture the metropolitan-non-metropolitan population shifts currently in full spate in the UK. Problems in obtaining suitable data for these more spatially disaggregated systems are tackled by model re-design by Frey (1982), and by estimation method development by Rees and Stillwell (1982).

A theme of recent applied work has been resolution of the conflict between a desire to model the behaviour of the populations of a large number of areas and the inevitable sparseness of any data arrays when the number of classes is very large. Methods of aggregation and decomposition have been explored by Rogers (1976); most researchers faced by the practical problems of projecting populations finely disaggregated by age have adopted other strategies (Gilje and Campbell, 1973; Masser, 1976; Martin, Voorhees and Bates, 1981), treating the propensity to out-migrate in fine age detail and the selection of destination region with a coarse or completely aggregate age classification. The work of Rogers, Raquillet and Castro (1978) on model migration schedules has been applied to local area migration profiles in the Martin, Voorhees and Bates model (see also Bates and Bracken, 1982 and Bracken and Bates, 1982).

The published description of the model does not give the detailed model equations, so what follows is my interpretation of what the authors have done. Although the aim of the model is to deliver net migration forecasts to the client department for input to the Office of Population Censuses and Surveys sub-national projection model, the model is essentially the migration component of a multiregional cohort survival model. The equation for forecasting migration is

$$M_x^{ij} = \hat{m}_x^J \sum_x GMR^i \ \hat{m}_x^I \ P(j| \ i, X)$$

where age x is contained in aggregate group X, origin area i is a member of origin group I, destination j is a member of destination group J, where M_x^{ij} is the migration flow from area i to area j for persons in a single year of age x at the start of the year; $\hat{m}_x^J$ and $\hat{m}_x^I$ are predicted in- and out-migration rates for a single year of age x, scaled to unity, derived from model migration schedules for groups J and I respectively. There were 12 groups of in-migration profiles and 12 of out-migration schedules, derived from a classificatory analysis of a set of 108 pairs of profiles. The migration schedules are fitted to the Rogers, Raquillet and Castro (1978) model function in rearranged form (see Bates and Bracken, 1982). GMR^i is the gross out-migration rate for area i which is computed as the sum over all ages of the total migration rates for each region. Finally, the P(j| i, X) term is the probability that a migrant from area i in age group X at the start of the year will select destination j. Substitution of a gravity model for these destination choice probabilities was considered, but rejected as of insufficient accuracy compared to the use of the full observed historical matrix. The same conclusions had been arrived at earlier by Stillwell (1979, 1980).

2.6 OTHER KINDS OF "REGION"

Multiregional population models can be applied to other systems. If we classify population by marital status we can explore the likely life histories of people through the never married, married, divorced and widowed states as Espenshade (1982) does, and discover the number of marriages, divorces and widowhoods we are likely to experience. Multiregional population methods have also been used to follow the experience of the labour force through employment, unemployment, and inactivity (Willekens, 1980), and similar work has been carried out in manpower studies, and in educational research (Stone, 1975). It might also be instinctive to construct a "multiregional" cohort survival model for Welsh only speakers, Bilingual Welsh and English speakers and English only speakers in Wales in order to disentangle the influence of migration from that of failure of parents to transmit the language on the survival of Welsh as a language.

3. ISSUES

In any field of interest there are issues about which investigators are puzzled, uncertain or about which they hold differing views. Some of these issues are discussed in this third section of the paper.

3.1 THE NATURE OF MIGRATION

The most fundamental of the issues concerns the nature of the migration process. Understanding why people migrate is not the issue for multiregional mathematical demography - migration modelling is really a separate field with its own themes and issues. The issue here is that researchers understand fully what is being measured by the census, survey, registration or indirect methods employed, and use this information carefully in the population models involved.

For current purposes attention is confined to migration flows between areas (or within) measured directly since these are the lifeblood of multiregional models. A number of researchers (Courgeau, 1973; Rees, 1977; Ledent, 1980; Courgeau, 1980; Long and Boertlein, 1981) have explicitly considered the different types of migration measure, though undoubtedly earlier workers were aware of the distinctions. Courgeau (1980) recognizes three types of direct migration measure in Chapter II of his book:

(i) migrations (moves, movement)

(ii) migrants (movers, transitions)

(iii) "les derniers migrations ou derniers migrants" (migrations or migrants classified by last place of residence)

The first migration measure counts all changes of region in a time interval, but without reference to initial state or final state in that period. The second migration measure counts all changes between initial and final states in a time interval without reference to intermediate migrations. The first measure is a count of events; the second a count of persons. The third type of migration measure derives from the census question

"What was your last place of usual residence?"

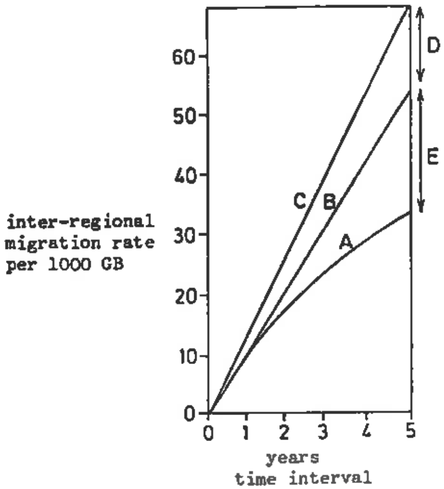
This yields information on "transitions" with a fixed end state but with a starting state indefinite in time. Courgeau demonstrates that the measure needs very careful handling, and cannot be used directly in multiregional models.

Most multiregional population model applications have used either moves or transitions (see Rees and Willekens, 1981), though applications in Japan and Mexico may have employed statistics derived using the third measure.

For the second and third types of migration measure there is an additional distinction depending on the length of time interval of measurement. It is now well known that the n-year migrant count is always less than n times the one-year count. Long and Boertlein (1981) explore the relationship between migration rate and length of period in detail. Figure 2 sketches the empirical differences involved for interregional migration in the UK. There is a difference, D, between using one year movement data and one year transition data. This difference is largely ignored in the Long and Boertlein (1981) discussion although from statistics presented on migration in England and Wales by Ogilvy (1980) we can deduce that for every inter-regional transition over a one-year period there were 1.22 inter-regional moves. The difference, E, is between 5 times the number of one-year transitions and the number of 5-year transitions. It is this difference which so concerned Ledent and Rees (1980) in their exploration of choices in life table construction. These differences in mobility levels derived from the different measures have a considerable impact on any results closely associated with migration such as lifetime spent in regions other than that of birth.

What migration processes underlie these differences? A number of explanations can be put forward, none of which have been definitively tested but all of which could be if the necessary set of longitudinal life histories for a set of regions were available.

Assume we are attempting to estimate the transition probabilities for persons aged 15 over 5 years to age 20 for a three region system. The first subtable of Table 1 shows the structure of the 3 x 3 matrix involved and defines the regions. We have two alternative one-year matrices - the first based on movement data and the second on transition data. The first two alternative estimates use this



A - n year transitions

B - n times one year transitions

C - n times one year moves (1.22 moves per transition)

D - moves less 5 times 1 year transitions

E - 5 times 1 year transitions less 5 year transitions

1 year moves: 1/4/71 - 31/3/72 1 year transitions: 25-26/4/70 - 25-26/4/71
5 year transitions: 25-26/4/66 - 25-26/4/71

Figure 2. The dependence of migration levels on type of measure and period of measurement: a sketch of GB interregional migration rates

Table 1. Alternative estimates of transition probabilities

General structure

Age 15 From \ To		Age 20: 1	2	3
East Anglia	1	p_{11}	p_{12}	p_{12}
South East	2	p_{21}	p_{22}	p_{23}
Rest of Britain	3	p_{31}	p_{32}	p_{33}

Source: estimated from data in Kitsul and Philipov (1981), p. 2 and p. 24. All probabilities have been made conditional on survival.

ALTERNATIVE DATA

One year matrix based on moves

.957	.023	.020
.002	.980	.018
.001	.012	.987

Estimates based on ratios of moves to transitions derived from Ogilvy (1980)

One year matrix based on transitions

.966	.019	.016
.002	.983	.015
.001	.010	.989

ALTERNATIVE ESTIMATES

Five year matrix based on 5 × one year (based on moves) migration rates

.785	.115	.100
.010	.900	.090
.005	.060	.935

Five year matrix based on 5 × one year (based on transitions) migration rates

.825	.095	.080
.010	.915	.075
.005	.050	.945

Five year matrix based on conventional equation

.842	.084	.074
.010	.920	.069
.005	.047	.947

Five year matrix based on fifth power of one year matrix (based on transitions)

.840	.086	.075
.010	[illegible]	.047
[illegible]	.048	[illegible]

data in a primitive way - multiplication of the migration (off-diagonal) rates by five. The difference between using movement or transition data is quite marked. Our estimates of the five year probabilities are reduced if we use the conventional estimating equation (equation (1) in Kitsul and Philipov, 1981 or "option 3" in Willekens and Rogers, 1978). Simply raising the one year transition based matrix to the power five gives very similar results. If we had raised the diagonal terms of the one year matrix along to the fifth power, we would obtain probabilities of staying of .839, .918, and .945 for the three regions. Yet the transition probabilities based on observed five year migrant tables are:

.895	.057	.047
.008	.950	.043
.003	.032	.965

What lessons do we learn from these alternative estimates? Firstly, if we use movers data we are liable to exaggerate the amount of inter-regional transfer occurring over 5 years. Secondly, a comparison of the diagonal terms raised to the fifth power and those of the matrix indicate that there is little return migration produced by the conventional or powered estimate. Thirdly, the large differences between the best estimates based on one year data and the observed five year probabilities must represent return migration well above that predicted in the normal Markov based model.

Kitsul and Philipov (1981) show that a model involving high- and low-intensity movers is needed to link the one and five year matrices. Ledent (1981, Table 3) shows that these two groups can be identified by place of birth: the transition probabilities for return migration streams are ten times greater than those for non-return migration streams!

I think we can suggest a couple of hypotheses about the importance of return migration.

(i) The greater the temporal interval (time scale) involved, the more important will be the process of return migration. Evidence for this is in the shape of the n-year migration rate curve shown in Figure 1 of Long and Boertlein (1981).

(ii) The greater the migration distances or spatial scale of the regional units involved, the more important will be the return migration process.

This second hypothesis is put forward for the following reasons. The principal motivation for return migration is the desire to return to "old haunts", to return to the regional or national culture or milieu from whence the migrant came. This milieu is a fairly dispersed concept, however, and is not normally associated with particular residences which in any case are not available to return to. It is rare for a permanent migrant to return to exactly the same home or job. Hence if we looked at residential mobility statistics we should expect to find very little return migration, although repeat migration would be very important, of course. On the other hand, at the international level return migration is likely to be very important. In Rees (1977) a simple multiplicative model fitted the distribution of the population of heads of household living in Great Britain by number of moves over a five year time interval and the number of five year migrants fairly well. Residential mobility was involved here. However, the multiplicative model failed to predict 5 year out-migration rates from 1 year at the regional scale. Another piece of evidence is for international migration to and from the UK. Table 2 shows a classification of immigration and emigration by citizenship and we see that a large proportion of the migrants were returnees.

Table 2. Immigration and emigration, UK, 1980

Source: Office of Population Censuses and Surveys (1981) from International Passenger Survey statistics.
Figures in 1000's.
UK = United Kingdom RW = Rest of World

		UK citizens		Non-UK citizens		All citizens		% return migrants	
	To	UK	RW	UK	RW	UK	RW	UK	RW
From	UK	-	150	-	79	-	229		34
	RW	67	-	107	-	174	-	39	-

What have been the responses to these conceptual problems?

The major response has been to do nothing. This usually occurred in situations in which only one migration measure was available. Where alternatives were available, the response has been varied. Ledent and Rees (1980) recommend use of five year transition data in preference to one year transition data in preference to one year movement data in constructing life tables and population projections. Long and Frey (1982) on the other hand choose to use special tabulations of one year migration rates from the Current Population Survey of the US in preference to the readily available five year migration rates. The UK Census Office dropped the 1971 practice of both a one and a five year question asked of a 10% sample of the population in favour of a 100% response one year question in the 1981 Census, despite vigorous protests from the author and others.

The arguments in favour one measure over another, given both or all are available, will depend on analysis purpose. For example, if population projections year by year are demanded then clearly one year transition data must be used. For "abridged" life table construction five year transition data have the advantage of matching time period and age interval exactly with no ambiguity in data-model fit. However, it is likely that life spent outside the region of origin is underestimated when 5 year transitions are used because of the return migrations just as the one year transition data used in a five year model exaggerates life spent outside region of origin. In a situation where all sets of data derive from samples there is much to be said for using the longer interval migration data which will yield large and more reliable sample sizes. Some researchers also argue in favour of the use of five year migrant data on the grounds that short term chronic migrants are omitted from the analysis. On the other hand if one is interested in working out lifetime mobility rates (migraproduction rates) then these chronic moves need to be represented and use of shorter intervals is indicated. If censuses are taken every five years in a country it makes good sense to ask five year questions to link the census points, as in Canada and Australia. However, I am not fully convinced by any of these arguments and the debate remains open.

Several researchers have offered empirical ratios to link the different migration measures and to enable the researcher to convert from one to the other. Table 3 shows some ratios for the US computed by Long and Boertlein (1981) for inter-county migration together with the equivalent ratios for residential mobility in Great Britain.

Table 3. Empirical ratios for converting between one and five year migration

US migration 1970-75 (1975-80) from Long and Boertlein (1981)

		Numerator time interval 1 year	5 years		
Denominator time interval	1 year	1.0	3.16 (2.93)	Scale:	inter-county migration
	5 years	.32 (.34)	1.0		

GB migration data 1966-71 and 1970-71 from Office of Population Censuses and Surveys (1978)

		Numerator time interval 1 year	5 years		
Denominator time interval	1 year	1.0	2.96	Scale:	residential mobility
	5 years	.34	1.0		

Others have shown the considerable effect that controlling for much return migration by introducing place-of-birth as a classification into multiregional models has (Ledent, 1981; Philipov and Rogers, 1981). Kitsul and Philipov (1981) construct a chronic mover-stagnant mover model to link one year and five year migration using British data. Of course, neither this model nor the empirical ratios are of much use unless one has both one and five year data for calibration of the model or computation of the ratios in the first place. However, these researchers are to be thanked for developing techniques uniquely suited to the UK situation and they will enable me to recover from the Registrar General's deletion of the 5 year question in the 1981 Census.

3.2 PROBLEMS OF OPERATIONAL APPLICATION

Many important issues are raised when multiregional models leave the nursery of two-, three- or four-region systems and enter the planning world of twenty-, thirty-, forty- or a hundred-region systems. Two problems occur. Firstly, can bhe general computer programs for multiregional population analysis (Willekens and Rogers, 1978 - SPA; Rees, 1981b - ABM) handle the expanded arrays generated in these many region systems? Secondly, do the arrays become too sparse (ie. have to many zero entries or small number entries)?

The answer to the first question is as yet unknown because the programs haven't been used with very large systems, but current versions on the University of Leeds Amdahl VM470 computer comfortably cater for up to 20 regions (without special storage allocation). I have confidence that the programs could be modified to deal with larger systems should this be required. However, with large systems the array sparseness forces researchers to adopt decoupled or aggregated models. The method of dealing with sparseness is to separate the out-migration process from the destination selection process, as in the GLC model (Gilje and Campbell, 1973; Congdon, Hollis and Strachan, 1981) or in the DoE England and Wales model (Martin, Voorheesand Bates, 1981). Both decoupled models are rather specific to the systems being studied and the associated computer programs non-transferable. It would therefore be valuable for general work on this problem to be done and incorporated in the general, transferable programs.

The shift to many region systems in the GLC and DoE-England and Wales models was occasioned by the need of planners to project the population of large numbers of local government areas. The output of the models is used in the planning process but has yet to be analysed for content and pattern. This would be valuable because the richness of geographical pattern and spatial process increase as the number of units into which a national territory is divided is increased. Geographers, in particular, have worked with systems of city regions or with local authority areas but usually with all age and sex detail omitted. It is at this scale that the 1981 UK Census has revealed

"... the counter-urbanisation trends, which are also evident in other countries, are strong and can be expected to continue."
(Census Division, Office of Population Censuses and Surveys, 1981, p. 29)

I have taken up this challenge, as best as the migration statistics allow (Rees and Stillwell, 1982). The multiregional population models will use a 20 region system consisting of the metropolitan counties and their equivalent, region remainders and non-metropolitan regions. This is already proving a very interesting system to work with. Preliminary estimates suggest that about 66% of the variance in population change rates among the set of 20 areas is associated with a metropolitan-non-metropolitan split (decrease/increase), some 1% with a North/South split (less growth/more growth) and some 12% with within class differences. The net migration flows (net 1966-71 inter-regional transitions) between the areas reveal a clear hierarchical pattern that produces an ordered set of net migration maps (see Figure 5 in Rees and Stillwell, 1982).

Other further problem encountered in the operational application of multiregional mathematical demography is that of updating the migration information. In countries with registration systems that yield annual movement data this is no problem, but where reliance has to be placed on periodic censuses what does the researcherdo for years in between the censuses? The solution generally adopted is to use any continuous surveys that incorporate geographical migration questions (such as the Current Population Survey of the US Bureau of the Census) or to use partial or surrogate registers such as the National Health Service Central Register in the UK which records changes of Family Practitioner Area by patients. The time series of survey or register movement rates or counts will generally not be available in the detail customarily provided by the census, and there is also the problem of concept difference between sources. In the former case the solution is to adopt some form of probability chain model to update the census rates and in the latter case the time series should be converted into index numbers for migration level adjustment and into locational probabilities for adjusting the spatial pattern rather than to adopt matrix adjustment (RAS) methods.

3.3 INCORPORATING EXTERNAL MIGRATION INTO MULTIREGIONAL MODELS

External migration flows currently play a role in only some of the multiregional models set out in Figure 1. They are an essential part of multiregional transition accounts and can be entered in a variety of ways into multiregional cohort survival models. Net external migration rates may be added to the stayer-survival rates; or net external flows may be added after the internal region operations have been carried out; or emigration may be modelled using emigration rates and immigration treated as a flow input or both immigration and emigration may be modelled using admission and transmission rates; or the external zone may be incorporated explicitly as an internal region. Alexander (1981) has explored the consequences of some of these choices for the achievement of population stability or stationarity using an adapted version of a native-non-native population model proposed by Rogers (1980). One interesting conclusion of the analysis was that if the rate of population change in a country is negative and there is a fixed quota of net immigrants, eventually the population of the country will achieve stationarity at the point when domestic losses are exactly counterbalanced by gains from abroad.

3.4 CONNECTING TO NON-DEMOGRAPHIC SYSTEMS

Most economic-demographic or general urban models have a fairly simple demographic structure that deals with migration to and from study zones or study system in fairly "bundled" terms rather than in a multiregional fashion. The demographic component is kept simple in order to focus on some other subsystem or process. However, I would have thought that there was a good case for reversing the strategy: that is, attaching simple economic and housing models to more complex multiregional demographic ones. National economic forecasts are often available to provide leading economic indicators and Ogilvy (1979) has shown the level of migration activity to be closely associated with national macroeconomic indicators such as the unemployment rate, per capita income, house prices and the rate of housebuilding. Regional economic activity could be modelled through shift-share analysis of employment and redundancies and links forged with migration through gravity models.

This may sound rather like an "ad hoc" recipe for integrated economic-demographic model-building, but I think more ambitious schemes based on inter-regional input-output models and the like have little chance of being made operational.

3.5 THE NEGLECTED STUDY OF HOUSEHOLDS

We have in our models neglected the study of the household at the regional scale, except to forecast their numbers and size as part of a projection exercise using headship rates. Rectification is needed.

4. CONCLUSIONS

The field of multiregional mathematical demography has made substantial progress over the past decade and a half, fuelled by a desire to understand the processes underlying spatial population change. The processes have turned out to be a good deal more complex and interesting than at first thought, when conventional projection, life table and accounting methods were first converted to deal with interacting regions. So there are plenty of challenges - conceptual, theoretical and applied - to be met before the empirical results of multiregional mathematical demography follow the methodology into the corpus of social science knowledge.

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