KEY ISSUES IN SUBNATIONAL PROJECTION MODELS

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ABSTRACT

The paper presents the issues that must be addressed by the designers of population projection models at subnational scales. Projection aims must be made clear. The system of interest must be comprehensively identified and the model designed to supply population forecasts for that system. The design is a compromise between desire for fine detail in projection outputs and the supply of reliable data for the consequent large number of model variables. Attention must be devoted to the development of a consistent database and to the design of assumptions for driving the projections. Outputs must be specified in as flexible a form as possible, in suitable media. No ideal choice set is offered for the many design decisions that must be made, but careful consideration of each issue should lead to the development of an effective and usable projection model.

ACKNOWLEDGMENTS

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1. INTRODUCTION

The principal aim of this paper is to review the design decisions faced when a population projection task is undertaken. The constructor of subnational projections is faced with a number of crucial design decisions which will affect the projections produced. Some issues are well understood while others are addressed rather rarely. These issues are as follows: the aims of the projection (taken up in section 2), the design of the system of interest (section 3), the design of the projection model (section 4), the development of the benchmark database (section 5), the development of the input assumptions (section 6) and the design of the outputs (section 7).

The paper discusses each of these issues, drawing on recent work by on subnational projections at several different scales: (a) for a common set of regions across the European Union (Haverkate and van Haselen, 1990; Rees, Stillwell and Convey 1992; Rees 1994a; van Imhoff et al 1994), (b) for a set of subnational areas within Great Britain (OPCS 1991; Siu, Fowkes, Nash, May and Rees 1994), (c) for a set of regional health areas within the UK (Williams, 1993 and Williams and Rees 1994) and (d) for a set of sub-local authority areas within a metropolitan region (West Yorkshire) (Rees 1994b).

The themes running through these applications are the drive to improve the benchmark database, the drive to think harder about the development of assumptions, the need to connect the migration component to labour market and housing variables and the drive to add further population and housing classifications to the basic demographic outputs.

2. PROJECTION AIMS

In any scientific project it is essential to define clearly at the start the aims. There are four combinations of purpose, I think, that motivate population projections:

purposes	pure	applied
general	1	2
specific	3	4

By **general** purpose is meant that the aim is to produce an agreed set of population figures for the future that can be used as the basis of national or local planning. National demographic agencies are normally charged with this task and produce tables of projected populations for the national population and for subnational areas (e.g. OPCS 1993; OPCS 1991). General purpose projections require some measure of consensus, and in the production of subnational projections there is often a process of consultation between producers and users about the assumptions fed into the projection. So, in the case of the English subnational projections migration assumptions developed by the Department of the Environment are circulated to local authorities and comments requested. However, a very strong case must be made to change these as any alteration will have a knock-on effect in other areas because the subnational migration model involves a multiregional component. The outputs of general purpose projections will be used by a variety of users in government, in business and in universities. These would fall in category 2 in the matrix above. An example of category 1 would be a set of general purpose, variant projections carried out for all subnational units by a non-governmental body.

By **specific** purpose is meant that the aim is to produce a projection for a particular group in the population or to assess the impact of a particular trend. Most activity in specific purpose projections takes place outside of the national demographic offices by local agencies or by academics. For example, Rees, Stillwell and Convey (1992) carry four alternative projections for the NUTS 1 regions of the European Union from January 1990, in order to assess what possible impact different migration scenarios might have on the future distribution and structure of regional populations. This is an example of category 3 above.

By **pure** purpose is meant that the projections are merely meant to inform the general pool of knowledge and debate about future population trends, whereas by **applied** purpose is meant that there is a specific customer for the projections who has a particular goal in mind.

So the projections carried out by Williams (1993) and Williams and Rees (1994) were pure projections designed to assess the likely impact on British regional populations of the HIV/AIDS epidemic. The principal focus of interest was in exploring the impact of different assumptions about the transmission dynamics between persons, groups and regions of HIV infection against a set of constant assumptions about the development of the demographic inputs.

By way of contrast, the projections carried out for the City of Swansea by GMAP Ltd and the School of Geography of the University of Leeds (Rees 1994) had a specific, applied purpose. The City Council was in negotiation with the Parliamentary Boundary Commission for Wales over the boundaries of local district wards (the areas used for the election of councillors under the British plurality or first-past-the-post electoral system) and the number of councillors to be elected from them. Specifically, the Council wanted advice on the likely future trends in the number of electors in each ward. All nationals aged 18 and over are eligible to vote and required to register as electors. To the Council was delivered a system for projecting ward populations, the assumptions for which could be designed and input by council officers in consultation with council elected members. This is an example of a subnational projection in class 4 of the matrix above.

At the start of any subnational projection task, it is essential to clarify and agree the aims. The designers and users must agree what is to be delivered, to whom and over what time scale. The larger the body of users and the tighter the timescale, the simpler must be the design adopted. More complex representations of population systems are better designed for a small number of users and sufficient time for their construction must be allowed. For example, the European Commission-EUROSTAT project carried out in 1993 on "Regional population and labour force scenarios for the EEA" carried out by the Netherlands Economic Institute (NEI) and collaborative institutes, there was a clear tension between the desire to adopt best practice and finest scale detail in the regional projections and the need to deliver scenarios and projections to a tight timetable.

3. DESIGN OF THE SYSTEM OF INTEREST

A subnational projection is the result of a bringing together of a set of interdependent components: the definitions of system variables and states of those variables, the design of a model that specifies how the system variables evolve over time, and the assumptions about the exogenous inputs to the model adopted. The first of these components is discussed in this section.

3.1 Entities

The phenomena of interest are subnational populations. The first design decision is whether to represent these populations as individuals or as groups such as households, which often act as a unit in consumption decisions and in migration. But individuals leave and enter households and create and dissolve them, so that it is difficult to keep track in official subnational statistics of households over time. For example, when a household is observed to increase by a person in size over a time, this may be due to a new birth, a new in-migrant or a balance involving deaths and out-migration as well. Without very good surveys of household transition dynamics (as available to Hooimeijer and Heida 1994), use of the household as the projection entity is very difficult, though cross-sectional analysis using a time series of household survey or census data is both feasible and well developed. So the entity of interest in projection is the individual and the links to households are made at each time cross-section.

3.2 Age groups and time intervals

Projection models involve the simultaneous definition of age groups and time intervals. It is essential that the temporal spans used in these two demographic axes are the same and that the temptation of mixing a longer age interval with a shorter time interval (due to deficiencies in the age classification of demographic data) is avoided as it will lead to logical inconsistencies and hence errors in the projection. Survival rates over a single year of time for five year age groups lead to the survival of persons in their starting age group beyond five years.

The choices boils down to two: (1) one year age and time intervals or (2) five age and time intervals.

The second choice has the advantage that only one fifth of the variables associated with the first choice are needed and is a popular one for pure research where the goal of the projection may be a methodological exploration or a long term projection (e.g. the 17 nation subnational projections reported in Rogers and Willekens, 1986).

However, in applied projections the demand is for projections that are responsive to yearly trends in inputs, that supply projected populations for each year and that provide single year of age detail. It is not that the users of single year of age projections intend to use every single age group figure (though they do make much more interesting pyramids - see Figure 3). Rather users wish to be able to create their own age group outputs that are tailored to the planning task in hand: ages 16-17 for studying the demand for post-compulsory schooling in the UK, ages 18-23 for studying the University student population, single years of age between 60 and 70 to study the effect of different pensionable age proposals, young persons between 18 and 24 for transport concessionary fare studies and so on. This desire for flexibility in outputs is taken up later in section 7 when outputs are discussed.

The consequence of adopting single ages is the *small number problem*, in which model variables cannot be reliably estimated using observed data for a particular subnational area and component. Action to overcome this problem must be taken either in the design of the model or in the routines used to estimate model variables (themes taken up later).

3.3 Age-time plan of observation

It is appropriate in virtually all projection models that the period-cohort age-time plan be used as the organising principle in model design.

3.4 The last age

With increasing longevity in European Union populations it is essential that the last age adopted be very old. Over half of men will be surviving to age 80 and more than fifty percent of women will be surviving beyond 85 within the time horizon of short or medium term projections, if they do not do so already. The last age interval must be at least 90+ and preferably 95+.

3.5 Sub-national units: scale and universe

There are two issues to be faced when defining the population of subnational units: their scale and their universe. The scale is usually a compromise between aims and availability. For example, in their projection model of UK subnational populations experiencing an HIV epidemic, Williams and Rees (1994) had to work with Regional Health Authority areas in the UK, because these were the smallest subnational units (across the country) for which HIV and AIDS statistics were published by the Public Health Laboratory Service and Communicable Disease (Scotland) Unit. The universe of units to adopt should cover the whole of the national territory, though it is not necessary to do this at the same scale. So, in a project carried out for West Yorkshire local authorities (Rees 1994), the unit used within each district is the electoral ward (chosen because of data availability), while the system is completed with a set of external zones consisting of the other 4 districts of the former metropolitan county plus the Rest of the UK. Decisions about what interaction occurs between the wards of interest and the Rest of the UK zone will be of particular significance in determining the outcome of the projection, given the large population for this residual region.

3.6 Hierarchical systems or bottom up/top down

If you carry out a subnational projection that covers all units in the national territory, then a simple summation of the subnational populations yields a national projection. It has been argued that this is a more valid projection that a single national projection because more homogeneous population groups (age-sex groups in subnational units) are used. The sum of subnational projected populations is usually slightly higher than the projected national population because the faster growing subnational populations gain in weight over the course of the projection.

The counter-argument is that the projection model variables are less reliably estimated at subnational level, particularly if single years of age are adopted. It makes sense in that situation to adjust subnational populations so that they agree with an independently derived national projection after both have been carried out.

This issue has surfaced in the sets of projections carried out for European Union regional population at NUTS 2 level by the Netherlands Economic Institute (Haverkate and van Haselen, 1990) and at NUTS 1 level by Rees, Stillwell and Convey 1992. Both models produced member state and regional projections, and in the former case the regional projections were constrained to the national projections. This is also the case in a current set of NEI projections for the CEC and

EUROSTAT in which the national constraints are the EUROSTAT member state projections.

However, this adjustment leads to a logical inconsistency between the inputs to the regional projections and the regional outputs. Take, for example, the fertility sub-models in such projections. Region-specific fertility rate trajectories are input and used together with the projected female population to compute the new births in the regions. Then, these new births, which have been survived and migrated appropriately to the end of the projection interval are adjusted up or down to agree with the national sums of regional projected populations. If these new adjusted regional populations are used to recompute the *output* fertility rates, then these will disagree with the *input* rates. Similar arguments apply to the other components. There may be iterative procedures that can be applied that will recompute the regional component rates so that they agree with the national component flows, but they need invention. We are in a situation of imperfect aggregation (Rogers 1976): perfect agreement can only be achieved by adjusting the input scenarios at one scale to agree with those at another.

3.7 Adding characteristics to the population

There is an increasing demand from users of population projections for the disaggregation of the population into additional dimensions. Users wish to know how the population forms into households and whether it is economically active or not. There are methods with a long pedigree for applying marital status probabilities, headship rates or activity rates to the projected population by age and sex to yield the numbers of households or numbers in and out of the labour force (van der Laan 1994) but they assume that suitable scenarios of headship and activity rates can be developed in the absence of supply-side information on the state of the housing and labour markets. A series of research projects in the Netherlands have integrated demographic projections into a housing market framework in an innovative way (Hooimeijer and Heida 1994), which has not been attempted in other European countries.

Another example of the need to combine demographic and other social classifications is in work to forecast the HIV/AIDS epidemic. Williams (1993) needed to add to the basic demographic categories of age, gender and region the behavioural categories of sexual orientation (homosexual, heterosexual) and injecting drug use. Note that these were not separate populations in the model but were allowed to interact through sexual partnerships.

3.8 Further disaggregation: the example of ethnicity

There is also a demand for projections of the populations of different ethnic groups in the large cities or urbanised regions of Europe where these groups are concentrated. However, this is a task in which a number of difficulties have to be overcome. These difficulties will be peculiar to the national context concerned. Here they are illustrated from a project to supply the districts of West Yorkshire with a small area population projection system (Rees 1994c).

The structure of the projection model is set out in Figure 1. Because of lack of ethnically classified data and constraints of computer memory, only two components were fully disaggregated by ethnic group: population and fertility, though, in addition, the *destination attractiveness* factors for wards which drive part of the intra-district migration model were calibrated separately for each ethnic group. These factors help distribute out-migrants from wards to other wards via a production-constrained spatial interaction model.

Figure 1. The structure of the West Yorkshire Population Modelling and Information System projection model for ethnic group populations

```
                      Ethnic group population estimates
                                    1991
------> Iterate to  ---              |
|       new interval    \            |
|                        \           V
|  ---> Iterate to -----> Start of interval
|  |    new ethnic           populations
|  |    group            for ethnic group e
|  |                                 |
|  |    Benchmark                    |                     Scenarios
|  |    estimates                    |
|  |                                 V
|  |    General  --------->  Mortality &  <--------- Mortality
|  |    mortality            Non-survival              scenario
|  |    rates                      |                   for year
|  |                                 |
|  |                                 V
|  |   General   --------> Emigration <---------- Emigration
|  |   emigration                  |                 scenario
|  |   rates                       |                 for year
|  |                                 V
|  |   General   -------> Immigration <--------- Immigration
|  |   immigration                 |                 scenario
|  |   rates                       |                 for year
|  |   with 1991 update            |
|  |                                 V
|  |   General        ---> Inter-district <------ Inter-district
|  |   inter-district         migration            migration
|  |   migration                   |               scenario
|  |   rates                       |
|  |                                 V
|  |   General  ---------> Intra-district <----- Ethnic
|  |   intra-district         migration          destination
|  |   migration                   |             factors
|  |   rates & ethnic              |
|  |   destination                 |
|  |   factors             End of interval
|  |                          populations
|  |                                 |
|  |                                 V
|  |   Ethnic ----------> Fertility rates <----- Ethnic
|  |   fertility                   |             fertility
|  |   estimates                   |             scenario
|  |   1981 & 1991                 V
|  |                        End of interval
|  |<-------------------    populations
|
|                              Constrain to
|                              general projected
|<----------------------        populations
```

An ethnic question has been asked only in the latest British Census of Population in 1991. Rees, Phillips and Medway (1994) provide a full discussion on the issues of defining and measuring race and ethnicity in a British context. People were asked to identify themselves as one of nine pre-specified groups, two of which requested further information and which lead to the identification of 34 groups in all. The Census Offices employ a ten group classification in ward tables but this was collapsed to six groups in the projection model to avoid very small numbers. These groups were: White, Black, Indian, Pakistani, Bangladeshi and Other, which had very different spatial distributions and demographic characteristics.

In order to compute the trends in ethnic group fertility rates and destination factors, it was necessary to make estimates of the ethnic distribution at the previous census in 1981. The ward populations were classified by country of birth of individual and for four broad groups only by country of birth of head of household. These statistics tended to misclassify two groups: the children born in the UK of parents who had been born abroad could not be distinguished; there were also older inhabitants who had been born abroad during the Imperial era, when their parents served as colonial administrators. A method had been developed by Haskey (1991) to estimate the 1981 Census population by ethnic group using a matrix of probabilities of ethnic group membership given country of birth derived from the Labour Force Surveys for 1979-81-83. However, these probabilities were available only for metropolitan counties, region remainders and other regions, a scale which leads to over-smoothing of small area ethnic populations. In the West Yorkshire estimations, probabilities of ethnic group given birthplace derived from the ward statistics of the 1991 Census were applied. These were spatially much more appropriate though temporally displaced by ten years. Figure 2 shows an example of the results of this estimation work for the Indian group in Bradford and Leeds. Here we see an ethnic group dispersing outwards in preferred directions into middle class suburbs, reflecting their upward social mobility and propensity to form new households.

An equivalent set of estimations were needed in order to establish a times series of fertility rates applicable to each ethnic group. Nationally, births are recorded by place of birth of mother and tables are published for districts with non-negligible non-White populations. Births by mother's country of birth were converted by multiplication by the probabilities of ethnic group given country of birth for each West Yorkshire district. This procedure tends to average out the fertility rates across the groups (see Table 1) because the lower fertility rates of the native born are combined with the higher fertility rates of the foreign born. The rapid fall in Indian sub-continent fertility rates over the 1981-91 decade is compatible with this assumed replacement in the fertile ages of a higher fertility immigrant generation by a lower fertility native generation.

However, work with ethnic group projections has not progressed as far as recognising the creation of new mixed groups during the course of the projection, except in the limited area of birthplace classification. A number of US studies have employed the categories foreign born, native born of foreign born parents and native born of native parents in national projections and state or region of birth in subnational projections.

Figure 2. The changing distribution of Indians in Bradford and Leeds: 1981-91

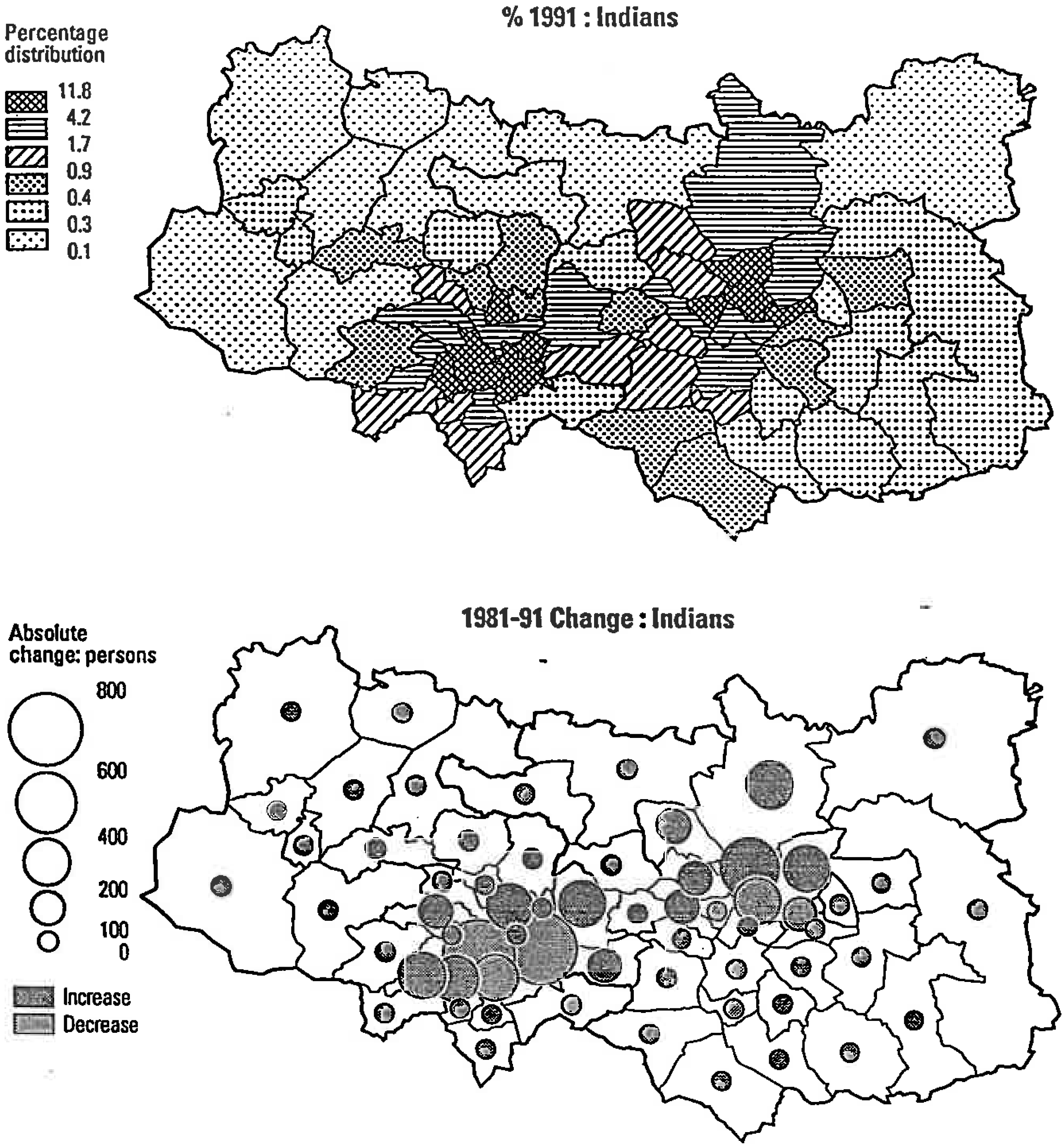


Table 1. Trends in total period fertility rates by country of birth of mother,England and Wales and by ethnic group of mother, Leeds

COB	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
UK	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8
India	3.1	3.0	2.8	2.8	2.9	2.9	2.7	2.8	2.4	2.2	2.1
Pak.& Bang.	6.5	6.3	6.1	5.7	5.6	5.6	5.2	4.9	4.7	4.7	4.6
E. Africa	2.1	2.1	2.0	2.1	2.1	2.0	2.0	2.0	1.9	1.8	1.8
R. Africa	3.4	3.3	3.1	2.9	3.0	2.8	3.2	3.6	4.2	4.1	4.2
Caribbean	2.0	2.0	1.8	1.8	1.8	1.8	1.9	1.8	1.6	1.6	1.5
Far East	1.7	1.9	2.1	2.2	2.0	1.9	1.8	1.9	1.7	1.7	1.7
Medit.	2.1	2.2	1.9	2.0	2.2	2.1	2.0	2.0	1.9	1.7	1.3
Remainder	2.3	2.3	2.4	2.3	2.3	2.3	2.5	2.7	2.4	2.2	2.4
Rest World	2.0	1.9	1.9	2.0	2.0	1.9	1.9	2.0	1.9	2.0	2.2

Ethnic Group	Mid-year to mid-year interval				
	1981-82	1982-83	1983-84	1984-85	1985-86
White	1.74	1.74	1.74	1.74	1.74
Black	1.81	1.72	1.63	1.63	1.63
Indian	2.87	2.73	2.63	2.68	2.73
Pakistani	5.48	5.32	5.07	4.85	4.81
Bangladeshi	8.19	7.96	7.57	7.24	7.19
Other	1.65	1.54	1.65	1.75	1.65
	1986-87	1987-88	1988-89	1989-90	1990-91
White	1.80	1.85	1.85	1.85	1.85
Black	1.68	1.68	1.54	1.41	1.37
Indian	2.64	2.59	2.44	2.15	2.02
Pakistani	4.64	4.34	4.12	3.98	3.95
Bangladeshi	6.93	6.48	6.16	5.77	5.71
Other	1.54	1.65	1.65	1.65	1.77

Source: OPCS (1993), Table 9.5, p.49 and author's estimates.
The raw data upon which the estimates are based are Crown Copyright.

Notes:
COB = Country of birth
Pak. = Pakistani
Bang. = Bangladeshi

4. DESIGN OF THE PROJECTION MODEL

Having specified the system of interest, the constructor of population projections then begins the task of model design. This design is always carried out in the light of the kind of data available, though this should never be accepted as too tight a constraint.

4.1 Macro or micro-representation

The first decision is whether to model groups of people or individuals. In modelling groups of people a deterministic approach results: a population stock is multiplied by a transition probability or to a population stock is applied an occurrence-exposure rate. The result is a population flow which enters the accounting equation for the new, end-of-period population. In modelling individuals a sampling approach is taken in which chance is allowed to select a outcome from a probability distribution across all possible outcomes.

Monte Carlo simulation has been applied successfully to the reconstruction of cross-sectional populations, though there is less need for such reconstructions since the advent of larger microdata samples from censuses and with expansion in the size of national household surveys. For example, in the UK we now have available two samples of anonymised records (SARs) from the 1991 Census: a 2% individual SAR which provides samples for 278 areas in Great Britain of 120,000 people or more (circa 1.1 million individuals) and a 1% household SAR (circa 0.5 million persons) which provides samples for 12 regions (Dale and Marsh 1993, Chapter 11). In addition, the Labour Force Survey has been increased in size to 150,000 sampled households per year (about 360,000 individuals). All of these datasets are now available to researchers through fast tabulation packages on a national datasets service at the University of Manchester accessed through a nationwide academic network (JANET).

Less success has been achieved in representing population dynamics in microsimulation models. There are probably two reasons for this. The first is that the sheer number of computations involved means that the number of individuals being simulated has to remain small so that a country-wide, multiregional system cannot be adopted. The second is that there is a lack of data on the socioeconomic transitions (between occupations, income states for example) for which the technique could be very suited.

The macro representation of individuals in projection models is therefore still the most common.

4.2 Net migration, migration pool or multiregional models?

In their survey of current practice across European Economic Area countries, van Imhoff, van Wissen and Spiess (1994) distinguish between these three types of method of incorporating migration into official subnational projection models. The reader is referred to their excellent survey and commentary on current practice. In net migration models, a vector of net migration rates by age and gender is applied to each region's population or a vector of net migration is added to the population. In migration pool models, out-migration intensities (occurrence-exposure rates or transition probabilities) are applied to appropriate populations at risk and the pool of out-migration is distributed to destinations using appropriate distribution factors which may vary by age and sex. In multiregional models a full set of age-sex specific and destination-specific migration intensities is applied to the appropriate origin populations, yielding migration flows between origins and destinations which automatically contribute to destination end-of-interval populations. Each of these models has its supporters and its critics.

The *net migration model* has been criticised as an inadequate representation of the population flows occurring in a system of regions and the interaction between them.

The *migration pool model* has been criticised for a logical inconsistency: that out-migrants from a region can end up being in- migrants in the same period.

The *multiregional model* has been criticised on two grounds. The first is that it is very difficult to estimate the origin- destination intensities for systems with very large numbers of regions. The second is that the long run application of constant matrices of origin-destination intensities can lead to unrealistic regional population redistribution (Werschler and Nault 1993).

All three models have been criticised for their "pure demography", failing to connect migration with their determinants (origin and destination attributes and the impedance on movement between them).

In practice, as van Imhoff et al (1994) demonstrate, most subnational projection models involve considerable adaptation of the simple form of the models.

The objection to migration pool models can be met by including the within region migration intensity in the model so that the pool contains all migrants generated in the country. Sometimes this will mean that only census migration data can be used because registers may fail to record intra-region migration. This is the case with the administrative register (the National Health Service Central Register of patient re-registrations between Family Health Service Authorities) used to record migration in the UK by quarter (Duke-Williams and Rees 1993).

The objection to the data requirements of multiregional models can be reduced by adopting model parameters for the age schedules of migration intensities (Rogers and Castro 1981). Use can be made of a small set of 7 or 11 or 13 parameters rather than 91 intensities for each region. Several authors have suggested that an alternative to multiplying origin populations by rates or probabilities of inter-regional transition is to set the interregional migration flow matrix exogeneously (for Canadian inter-provincial migration - Werschler and Nault, 1993) or through a species of spatial interaction model (for two sets of UK cities - Rees 1994b, 1994d; for Dutch municipalities - Hooimeijer et al 1994). When this is done the long run properties of the multiregional model are lost, but most projections are used in the short and medium term. The advantage of the approach is that policy relevant variables can be introduced.

4.3 A framework for comparing models

In practice, subnational models are a good deal more complex than these simple types, either because of a need to overcome the small number problem or because of a desire to introduce further features into migration process. Table 2 attempts to provide a common framework for comparing different models. Each model is described as an equation for generating the most detailed migration flow (origin by destination by age) in the system, even if the model never explicitly produces variables at such a detailed level.

Table 2. Alternative models of an interregional migration flow

Model	Equation
Pure multi-regional	$M^{ija} = p^{ia}\, m^{ija}$
Migration Pool	$M^{ija} = p^{ia}\, o^{ia}\, d^{ja}$
Combined model OPCS/DOE	$M^{ija} = p^{ia}\, o^{ia}\, p(j\|i,A)$
NEI model	$M^{ija} = p^{ia}\, m^{ij}\, m^{a}$
WYPMISmodel	
	$M^{ija}(1) = A^{i}(1)\, P^{i}\, o^{i}\, W^{j}\, f_1(c^{ij}) \text{ x } \{p^{ia}\, m^{Ia}(a) / \Sigma_a\, p^{ia}\, m^{Ia}(a)\}$
	$M^{ija}(2) = A^{i}(2)\, V^{i}\, h^{i}\, W^{j}\, f_1(c^{ij}) \text{ x } \{p^{ia}\, m^{Ia}(a) / \Sigma_a\, p^{ia}\, m^{Ia}(a)\}$
	$M^{ija}(3) = B^{j}\, P^{i}\, o^{i}\, N^{j}\, h^{j}\, f_2(c^{ij}) \text{ x } \{p^{ja}\, m^{Ja}(a) / \Sigma_a\, p^{ja}\, m^{Ja}(a)\}$
	$M^{kja}(4) = P^{k}\, m^{kJ}\, p(j\|J) \text{ x } \{p^{ka}\, m^{Ja}(b) / \Sigma_a\, p^{ka}\, m^{Ja}(b)\}$
	$M^{ika}(5) = P^{I}\, m^{Ik}\, p(i\|I) \text{ x } \{p^{ia}\, m^{Ia}(c) / \Sigma_a\, p^{ia}\, m^{Ia}(c)\}$
Improved WYPMIS model	
	$M^{ija}(1)$: substitute m^{ia} for $m^{Ia}(a)$
	$M^{ija}(2)$: substitute m^{ia} for $m^{Ia}(a)$
	$M^{ija}(3)$: substitute m^{ja} for $m^{Ja}(a)$
	$M^{kja}(4)$: substitute m^{ja} for $m^{Ja}(b)$
	$M^{ika}(5)$: substitute m^{ia} for $m^{Ia}(c)$

Table 2. Continued: Definitions

Variables

M = migrants (transition definition)
P = population
m = migration probability
p = conditional probability
o = probability of migration from origin
d = probability of migration to destination
c = interaction cost/impedance (measured by distance)
f1, f2 = functions applied to c, usually negative exponential
A, B = balancing factors
W = attractiveness of destination factor
V = housing units removed (e.g. through demolition or conversion)
h = persons per household

Subscripts

a = age (fine)
A = age (broad)

i = origin zone
j = destination zone

I = all origin zones
J = all destination zones

k = external zone

(1) = turnover migration between internal zones
(2) = demolition migration between internal zones
(3) = new housing migration between internal zones
(4) = in-migration from external zones
(5) = out-migration to external zones

(a) = probability applies to within district migration
(b) = probability applies to into district migration
(c) = probability applies to out of district migration

Abbreviations

OPCS/DOE = Office of Population Censuses and Surveys/Department of the Environment
NEI = Netherlands Economic Institute
WYPMIS = West Yorkshire Population Modelling and Information System

The pure multiregional model is very simple: the origin population is multiplied by an origin to destination migration probability which is age specific. But the data requirements are very large: the number of regions squared times the number of age groups.

The migration pool reduces the number of variables required by treating origins and destinations independently, though unrealistically.

The third model shows a compromise between the first two where the out-migration from origins is treated in age detail but interregional probabilities used only for a few broad ages with similar behaviour. This is the approach in the England subnational model where just 4 broad ages are used.

The fourth model, the DEMETER 2015 model of NEI, is even simpler, using all age interregional migration probabilities and national probabilities by age.

The next example is from a recently completed system for local authorities in West Yorkshire (Rees 1994b). Migration internal to the UK is modelled in five separate streams: the first three are separate, housing related migration flows between wards involving the existing housing stock (1), demolished or converted housing (2) or new housing construction (3). The fourth flow is of migration from zones external to the district into wards and the fifth is the migration flow out of wards to external zones. The first three migration flows are modelled by three spatial interaction models as all age flows and disaggregated using probabilities by age for within district migration as a whole for which Census data were available. These probabilities are multiplied by the relevant ward population so that the age distribution of migrants reflects the ward's age structure as well as the shape of the migration schedule.

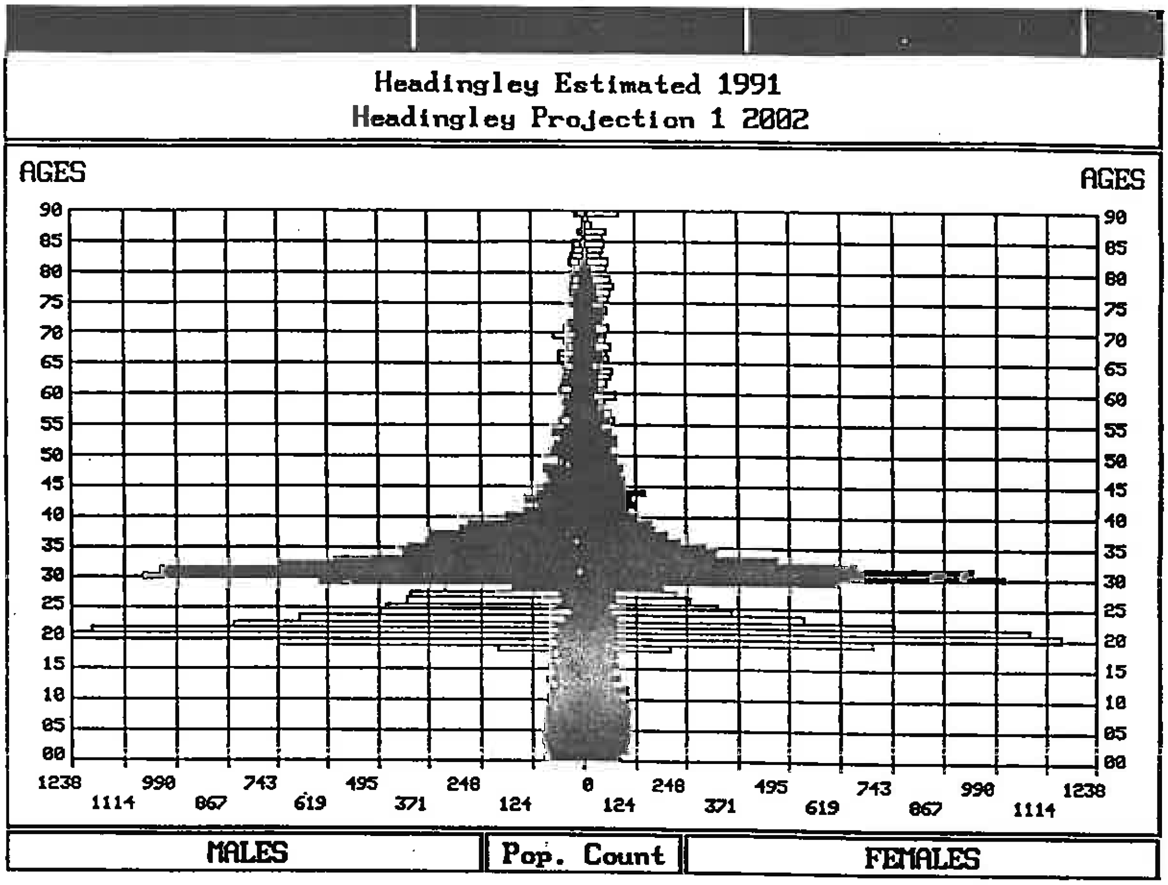
In a sensitivity analysis of the model applied to Leeds, Langston (1994) has shown that one ward in particular produced results that departed from expectations. The population pyramids for 1991 and 2002 for the Headingley ward in Leeds are shown in Figure 3. This ward is the area where students attending the University of Leeds and Leeds Metropolitan University reside. What the model is doing is allowing these students to age in place beyond the end of their course. What it should be doing is vigorously exporting them out of the city 3 to 4 years after importing them. It is hoped that the introduction of new information on both total migration and age specific migration from the 1991 Census which has only just become available will supply better information to a modified WYPMIS model.

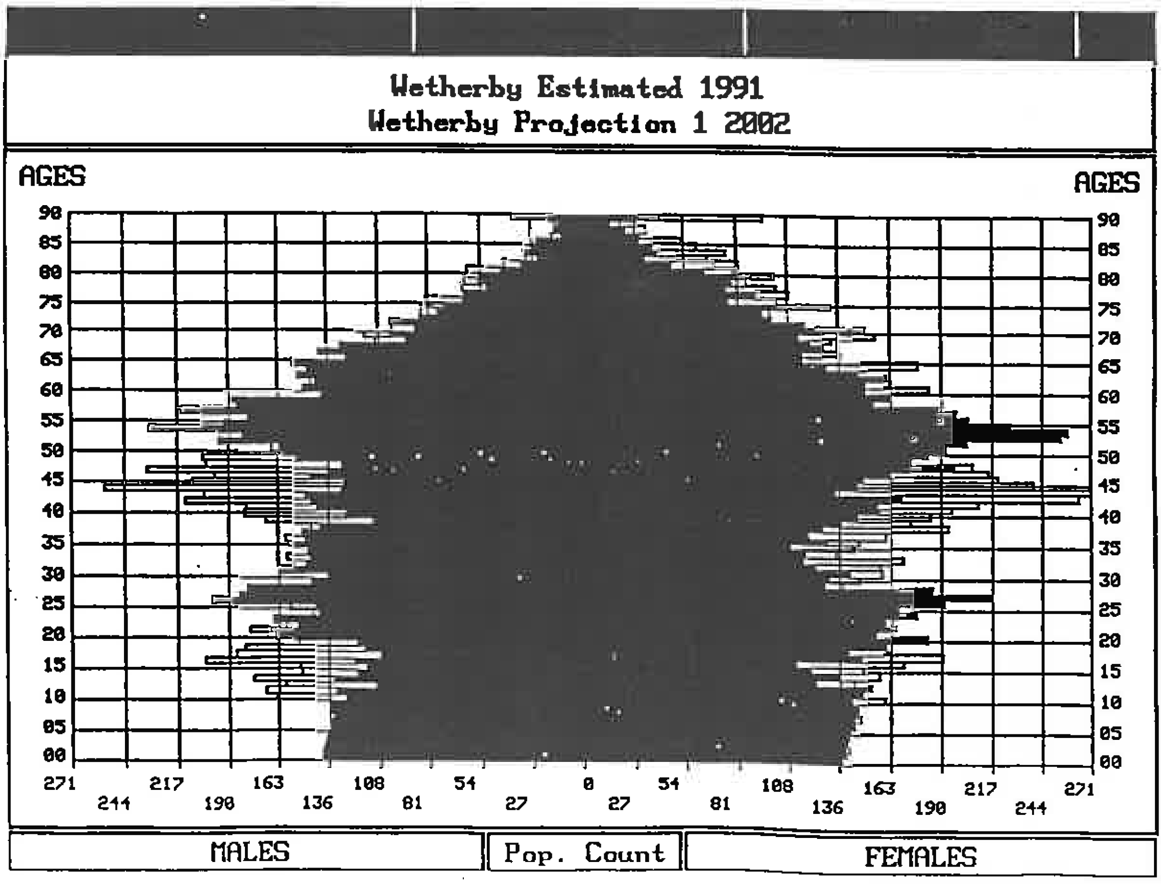
4.4 Movement or transition model?

Attention needs to be given to the distinction which has been stressed by Jacques Ledent and myself that any subnational projection model must take into account the way in which migration has been measured. Briefly, two methods are available for measuring migration which are compatible with regional population projections.

(1) A comparison is made of the regional locations of the population at two fixed points in time, *n* years apart. This is usually achieved through a retrospective question in a national census. The time interval should be either one or five years to be useful for demographic projections. This is the *transition* type of migration data.

Figure 3. Population pyramids for the 1991 and 2002 populations of Headingley and Wetherby wards in Leeds





(2) A count is made of the inter-regional moves that occur during a time interval through change of address registers. This is the *movement* type of migration measure.

The transition type of migration measure is criticised for omitting to measure all migrations in the interval: these are resolved into the one "net" move between start and end of the interval. The criticism levelled against the movement type is that no knowledge is gathered of the start of interval or end of interval location of the migrating individuals. However, neither of these two criticisms is vital as long as the correct intensity measures of migration are used and employed in the correct form of the projection model.

4.5 Simultaneous, sequential and iterative model

There are many styles for putting together the equations that constitute subnational projection models. Van Imhoff et al (1994) distinguish between simultaneous and sequential models. *Simultaneous* models involve gathering together all the relevant terms into matrices of start state by finish state or origin by destination and applying these matrices of transition probabilities or movement rates to vectors of subnational populations. In practice it is probably easier from a programming point of view and from the point of view of seeing clearly the outcome of decisions about particular components to arrange the computations as a *sequential* series of processes applied to the population, being careful to sequence the calculations in a logical order with the correct conditionalities. However, there may be some dependence between the ordering of component computations and results.

There is an additional class of solution methods which it is probably worth mentioning, although again these have not been adopted in any official projection. A third solution is to *iterate*. A movement type projection model can be represented as an iterative sequence:

(1) use the start population as the initial population at risk

(2) input occurrence-exposure rates of death, emigration and inter-regional migration

(3) compute an initial estimate of the flows concerned

(4) work out an estimate of the final population using these flows and immigration assumptions

(5) compare the final populations of successive iterations

(6) if they differ by more than half a person in any category, revise the population at risk estimate using the start populations and latest final population estimates and then return to step (3) and repeat the calculations.

The advantage of adopting an iterative approach as opposed to a simultaneous one is it provides a flexible projection tool in which the components can be treated separately (see Rees 1984 for an example).

4.6 Sensitivity testing

Projection model design should include the flexibility to carry out sensitivity tests. These are essential when complex models have been constructed to derive confidence in their outputs. The user needs to be convinced that change in an input variable will produce a logical response in terms of output. Sensitivity testing is not just variant projections writ large but should be a systematic attempt to compute the range of variation around the main forecasts that might occur through measurement or specification error.

An example is the programme of sensitivity testing carried out by Williams (1993) in her work on the simulation of the HIV/AIDS epidemic across UK regions. Table 3 shows the results of a set of sensitivity tests on the main epidemiologic parameters used in the combined demographic-epidemiologic model. Low and high scenario were devised for each parameter set, with values being adjusted to 50% and 150% of the baseline estimate respectively. The table reports the parameter values and one of the main outcomes, the cumulative number of HIV infections to the year 2000 in the UK.

Some of the results were unsurprising, others less so. The assumed size of the gay and drug using populations, a subject of much controversy, does not appear to affect forecasts much. Changes in the level of injecting and sexual activity do not produce great changes in numbers infected. What does affect outcomes profoundly are the infection probabilities on sexual and injecting contact: safe sex and sterile needles really matter. There should be no slackening in the educational and persuasive effort by health authorities, voluntary groups and the community to ensure infection probabilities are kept low. Not all changes are in obvious directions: spreading sexual activity between ages slows down the epidemic compared with concentrating it within age groups. There is relatively little variation across regions in these results, and alteration of interregional contact assumptions in the simulation model produced very little change in infection outcomes. This should not really be surprising since we know that there is relatively little difference in the forecasts of the UK population as a sum of its parts compared with as a single unit (the current regional distribution does not depart very much from its stable equivalent).

5. DEVELOPMENT OF THE BENCHMARK DATABASE

In this section, the concept of a benchmark database is developed, which has proved to be extremely useful in small area projections in the UK.

5.1 Definition

A benchmark database is a consistent time series of population stocks and demographic components from which initial inputs to a projection model can be drawn and from which trends can be inferred. EUROSTAT has adopted this approach in building up consistent time series in its published volumes and REGIO database for European Union regions. At the small area level in the UK this often means that a database must be developed from the last census, which contains the only comprehensive data on small area populations.

5.2 Steps to achieve consistency

To achieve consistency, several tasks must be undertaken.

Table 3. Results of sensitivity testing of an HIV/AIDS simulation model for UK regions

Sensitivity test	Parameter values Baseline	Low	High
Gay and drug population			
% of population homosexual	6	3	9
No.s injecting drugs (1000s)	145	72.5	217.5
Cumulative HIV+ to 2000	57,625	55,820	58,325
Degree of drug use			
Average no. of shared injections	42	21	63
Cumulative HIV+ to 2000	57,625	54,043	62,991
Relative levels of infectivity			
At HIV+:ARC:AIDS stages	1:1:3	1:1:1	2:1:6
Cumulative HIV+ to 2000	57,625	79,168	55,725
Infection probabilities			
Male to male	0.250	0.125	0.375
Male to female	0.200	0.100	0.300
Female to male	0.120	0.060	0.180
Vertical (mother to foetus)	0.200	0.100	0.030
Cumulative HIV+ to 2000	57,625	36,434	97,297
Sexual activity			
Annual partner change rates[1]	1.1-2.6	50%	150%
Cumulative HIV+ to 2000	57,625	55,820	58,325
Mixing of age groups			
Distribution of contacts[1]	Complex	Within age group only	Equal contacts all ages
Cumulative HIV+ to 2000	57,625	89,371	76,411
Mixing of behaviour groups			
Concentration within same group[1]	Complex	Low	High
Cumulative HIV+ to 2000	57,625	61,524	53,903

Source: Tables 6.24, 6.25 and 6.18 in Williams (1993).
Notes:
1. Full details in Williams (1993), Table 6.18.

(1) All stocks and components data must be estimated for a fixed *spatial framework*. Such is the electoral system in the UK that the most useful unit, the local government ward for which a great many statistics are published, is in continual change as an effort is made to maintain equality of influence across all voters. Ward reorganisations are frequent after UK censuses. Considerable effort must be expended in re-estimating the relevant statistics for new wards or in future proofing projection systems. The West Yorkshire Population Model and Information System (WYPMIS) has such a requirement: it has modules for updating all benchmark components year by year and routines for converting old ward outputs into new ward outputs using simple apportionment techniques.

(2) All stocks and components must be estimated for a fixed *temporal framework*. Data for some components come on a calendar year basis, whereas other data refer to mid-year to mid-year intervals. A decision needs to be taken on which is the more appropriate time frame and non-conforming datasets converted through interpolation and other techniques to the new time frame. In Table 1, for example, published national and local data for births come for calendar years (top panel of the table) but are needed in the projection for mid-year to mid-year intervals.

(3) It is also important to ensure the consistency of demographic stocks and components. This is a natural outcome of the process of building year by year accounts. However, in countries without reliable population registers, these year by year accounts and population estimates can cumulate errors. Checks and adjustments are possible every 5 or 10 years with the publication of the periodic census, unless there is systematic underenumeration in the census. This is what appears to have happened in the 1991 Census in the UK. Severe undercounts were detected at ages 1-44, particularly among men. This is thought to be related to avoidance an unpopular local tax, since repealed, called the Poll Tax. The Census Offices worked hard at producing revised and demographically more sound mid-year estimates for 1991 based on the 1991 Census but with allowances made for these undercounts.

(4) In the context of small area projections an additional step is necessary: the undercount estimated at the local government district scale must be distributed to the subdistrict areas. The technique used in the WYPMIS system was to use census information on the distribution of imputed households (households from whom no return was obtained but which the enumerator felt sure were actually living at a residence).

5.3 Filling the gaps in migration data

Particularly vital for good subnational projections is the development of good migration databases. In the UK considerable progress has been made in this respect recently both by the Census Offices and by researchers. OPCS publish each quarter records of the re-registrations of National Health Service patients across Family Health Service Authority boundaries. Work by Duke-Williams and Rees (1993) and Stillwell, Duke-Williams and Rees (1993) has consolidated the records from mid-1975 onwards into a consistent time series database. From mid-1983 onwards this database covers 125 areas in the country and holds the individual movement records. A computer system called TIMMIG has been designed to produce tables of migration information from this database on a flexible basis. Between 1975 and 1983, the information comes as origin-destination, origin-age and destination-age tables on a five year age group basis but from 1983 onwards any origin-destination-age table on a single year of age basis can be extracted. We are currently filling the final gaps in this system (for migration between Health

Board Areas in Scotland from 1983) and hope to make it available, subject to Census Office approval, for general use.

At a finer spatial in the UK, the researcher must rely on Census migration data. The Census Offices delivered (in May 1994) the Special Migration Statistics from the 1991 Census of Population. The version of the SMS purchased by the Economic and Social Research Council for use by the academic community consists of two machine readable datasets.

(1) SMS Set 1 holds 1 table of 10 counts of migrants by age and gender and 1 table of 2 counts for wholly moving households and the residents within them for all flows between the wards of England and Wales and the postal sectors of Scotland (10,933 units in all). This dataset occupies .95 of gigabyte in raw form but is to be compressed into a smaller file accessible via the QUANVERT database package for academic community use.

(2) SMS Set 2 holds 10 (England) or 11 (Wales and Scotland) tables of counts of migrants between the 459 districts of Great Britain. Table 3 of the SMS provides flows by five year age groups and sex (except for 0 year olds who are ignored and 15 and 16-19 year olds who are distinguished). This dataset occupies .4 of a gigabyte but will again be compressed to allow faster access to academic community researchers.

Any future subnational projection (official or unofficial) will use these datasets as their starting point because of the fine spatial detail provided, but will tap into the NHS Register based data to monitor trends at a larger spatial scale.

6. DEVELOPMENT OF SCENARIOS

In the past relatively little attention was paid to the development of specifically subnational scenarios for the component inputs to projection models. However, considerable attention has been devoted to this topic by EUROSTAT and the European Commission (DG XVI) in their Regional Demographic and Labour Force Scenarios project of 1993, which has been reviewed in Rees (1994a). Here we will look at just one aspect: the development of scenarios for interregional migration.

The problem in this area is that there are too many variables to think about in most models. It is therefore necessary to think seriously about the conversion of the migration variables into model schedules.

This has been accomplished very successfully for the age dimension with the widespread adoption of the model migration schedules of Rogers and Castro (1981), a series of multiexponential functions. The existence of this methodology means that the introduction of single year of age migration probabilities is feasible even if migration data classified to such detail are not available.

However, this only solves part of the problem. There is still the origin-destination matrix of migration flows and probabilities to develop scenarios for. The solution is, of course, to develop parsimonious models of these interactions, drawing on the wide body of experience in the modelling of migration and other interactions. Spatial interaction models attempt to reduce the forecasting problem by adopting a mostly fixed interaction matrix (costs/distances between origins and destinations) and concentrating attention on the projection of origin and destination terms only. The number of variables to be forecast is reduced from n^2 to 2n.

How easy is it to forecast trends in origin and destination components in an interaction model? Analysis of an extensive time series for UK regions over the period 1975-89 (Stillwell, Rees and Boden 1992) suggests that this is a difficult task (Figure 4). Very different trends occur in the generation (origin) and attraction (destination) components of many regions, and there is a wide variety of experiences. The outcome of subnational projections based on a constant assumption of interregional migration probabilities would have produced very different pictures of the future populations of these regions based on 1975-76, 1981-81 or 1988-89 patterns. In the UK the official subnational projections have long been criticised for failing to take into account post-1981 shifts in migration patterns, sticking persistently to the patterns of 1980-81, the year prior to the 1981 Census which was one of depressed economic and migration activity, as 1990-91 will turn out to have been as well. At the very least subnational projections should be based on the experience of a run of years in which the ups and downs of economic cycles are smoothed out.

7. DESIGN OF OUTPUTS

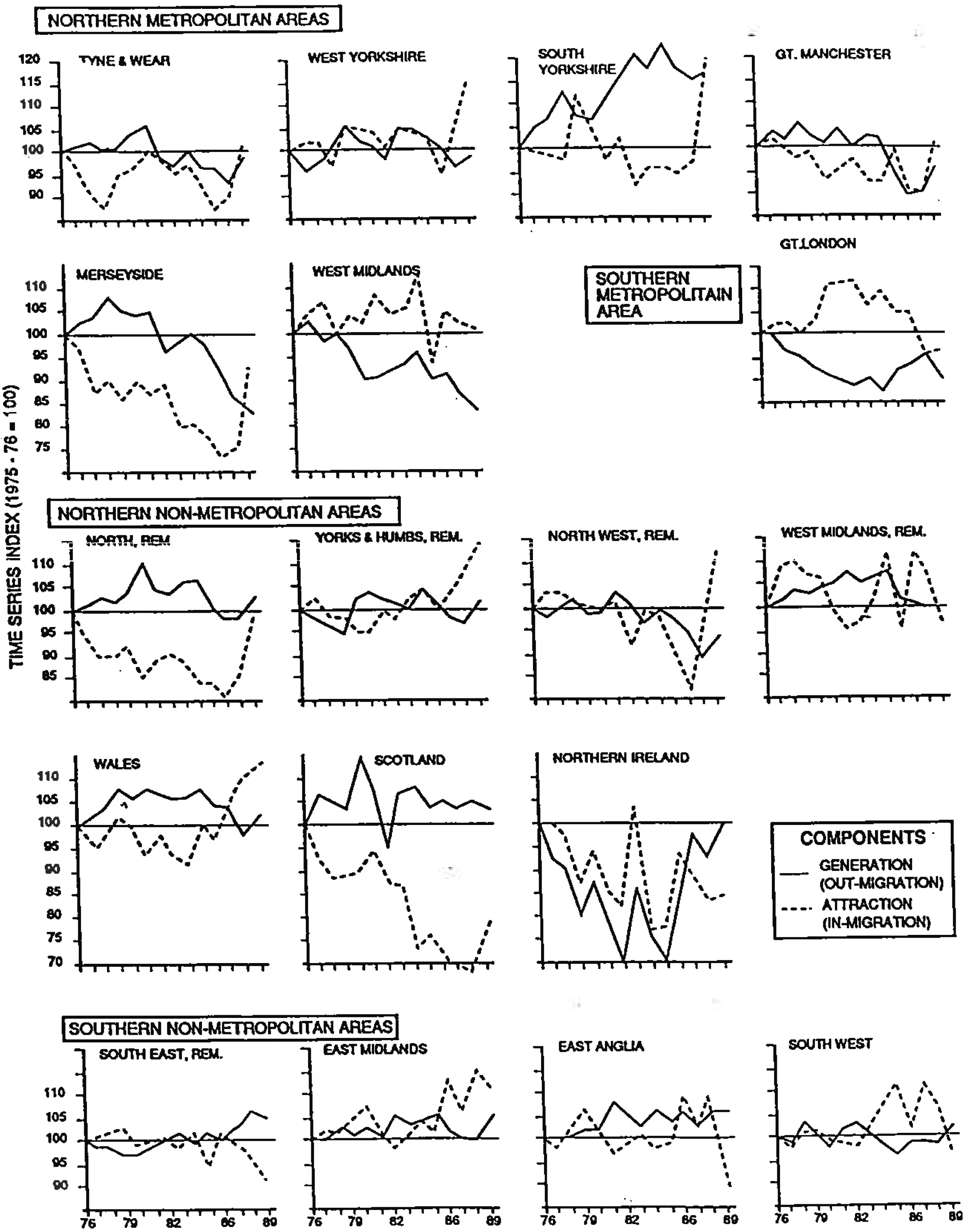
A final issue that deserves brief attention is that of design of outputs from a projection. Traditionally, these have been in the form of published tables, interpreted graphically and verbally in the accompanying reports. But the printed report can contain only a small fraction of the outputs from a set of subnational projections. The solution has been to provide additional tables on other media such a microfiche cards, microfilm, computer printouts, magnetic tapes or floppy discs. Such solutions assume a set of fixed table outputs.

However, what users are now demanding is a much more flexible set of outputs embedded in an intelligent information system. At its simplest such systems provide users with their own table making, graph making and map making facilities (e.g. the WYPMIS system). Users can compose their own age groupings in a flexible way. Such information systems, however, are built upon the creation of a set of fixed, but larger tables that do not always provide all the information about the projections that users require.

The next step is therefore to convert the aggregate population results of a projection into an database of counts of stocks or flows at the finest spatial and characteristic detail. From these building blocks the user should be able to construct a very wide variety of output tables (as in the 1975-83 part of the TIMMIG system referred to earlier). The ultimate step, however, would be to represent population sequences and connecting events as individual level databases capable of flexible aggregation in a huge number of ways (as in the 1983-93 part of the TIMMIG system).

Subnational population projections are carried out using a fixed set of subnational areas. Users might want projections for very different geographies. At the moment only very crude apportionment techniques can be used. Siu et al (1994), for example, struggled with the problem of converting the official subnational projections for Great Britain from 171 administrative areas into the 15 urban size and rural settlement type classification used in the National Travel Survey in a study of the potential impacts of demographic changes on travel demand. A matrix

Figure 4. The generation and attraction components of migration for metropolitan and non-metropolitan regions, 1975-89



assigning the populations of the 171 areas to the 15 categories is being developed using dated Census information and many approximations. There is also the added difficulty that the areal extent of the 15 settlement type categories will, of course, change. So the assumption of a fixed assignment between the administrative areas and the transport-relevant spatial areas will worsen over time. The provision of subnational projection models which meet this kind of need is a challenge for the future.

8. SUMMARY

This paper has presented the issues that must be addressed by researchers preparing new subnational population projections. There are no ideal solutions. Aspirations in terms of desired knowledge must be matched to available information, though not because reasonable estimates of the inputs to more sophisticated models can now be made from cruder data. Decide clearly about aims, entities, age-time plan, last age, scale of spatial unit, universe of units, national subnational interaction, nondemographic population characteristics, macro or micro representation, form of the migration sub-model, nature of the migration data is á vis the model, organisation of the model equations, a programme of sensitivity testing, consistency in benchmark data, scenario design methods and output flexibility and you should generate extremely valuable knowledge about the future states of subnational populations!

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