MULTIREGIONAL DEMOGRAPHY: FOUR ESSAYS

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PREFACE

One of the important research activities carried out at IIASA during the past several years has been the further development of multiregional mathematical demography – the study of spatial human population dynamics. This analysis has been used not only for the investigation of migrations between regions (multiregional) but also for the analysis of transitions between states of existence (multistate).

The Annual Meeting of the Population Association of America, held in San Diego, California, on 29 April to 1 May 1982, included in its agenda the first ever session on multiregional demography. The session contained four papers dealing with applications of the multiregional model. Three of these papers and the discussant's remarks are included in this collection. I am grateful to Alan Wilson, the editor of *Environment and Planning A*, for once again agreeing to publish a set of IIASA papers in his journal.

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Migration and settlement: a multiregional comparative study

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Abstract. In 1976, the International Institute for Applied Systems Analysis initiated a study of migration and population distribution patterns in its seventeen member nations. In each country, the analysis was carried out by national scholars using techniques of multiregional demography. In this paper the authors describe the organization of the study, discuss the data bases used, evaluate the main results obtained, and review some of the methodological research that has been generated by the study. Among the author's conclusions are recommendations for researchers wishing to carry out a multiregional demographic analysis.

1 Introduction

The 'population problem' in most parts of the world has two distinct dimensions: growth (positive or negative) and spatial distribution. Concern about population growth has focused attention on fertility patterns and has fostered family-planning and family-allowance programs in scores of countries. But, the issue of population distribution has only recently received serious analytical attention, as programs to encourage the development of economically declining regions, to stem the growth of large urban centers in the less-developed countries, and to revitalize the central cores of metropolitan areas have become parts of national agendas all over the globe.

The unanticipated postwar baby-boom had a salutary influence on demographic research. Extrapolations of past trends appropriately adjusted for expected changes in the age, sex, and marital composition of the population were very much wide of the mark. So long as trends were stable, demographic projections prospered; but when a 'turning point' occurred the projections floundered. The net result was increased pressure to consider the complex interrelationships between fertility behavior and socioeconomic development.

But, the poor predictive performance also had another important effect—it stimulated research in improved methods for *measuring* fertility and for understanding the *dynamics* by which it, together with mortality, determines the age composition of a population. Inasmuch as attention was principally directed at national population growth, measurement of internal migration and the *spatial* dynamics through which it affects a national settlement pattern were neglected. This neglect led Kirk (1960) to conclude, in his 1960 presidential address to the Population Association of America, that the study of migration was the stepchild of demography. Sixteen years later, Goldstein (1976, pages 19-21) echoed the same theme in *his* presidential address to the same body:

> "... the improvement in the quantity and quality of our information on population movement has not kept pace with the increasing significance of movement itself as a component of demographic change .... Redistribution has suffered far too long

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> from neglect within the profession .... It behooves us to rectify this situation in this last quarter of the twentieth century, when redistribution in all its facets will undoubtedly constitute a major and increasingly important component of demographic change ....."

Despite a general recognition that migration processes and settlement patterns are intimately related and merit serious study, one nevertheless finds that the dynamics of their interrelationships are not at all well understood. An important reason for this lack of understanding is that demographers have in the past neglected the spatial dimension of population growth. Thus, whereas problems of fertility and mortality long ago stimulated a rich and scholarly literature, studies of migration have only recently begun to flourish.

The pressing need for developing improved methods for measuring migration and understanding its important role in human spatial population dynamics led the International Institute for Applied Systems Analysis (IIASA) in 1976 to organize a multinational study of internal migration and population distribution patterns in its member countries. Recently developed techniques of multiregional demographic analysis (Rogers, 1975) provided the unifying methodological framework for this study, in which scholars from the seventeen member nations participated(1).

Multiregional demography deals with the evolution of spatially interdependent regional populations. It focuses on their sizes, age compositions, and geographical distributions, as well as on the changes of these characteristics over time. Such a perspective allows researchers to examine the demographic interactions between the urban and rural agglomerations that shape national human settlement patterns. The ability of such a method to identify the demographic impacts of interregional migration flows and of regionally differentiated regimes of mortality and fertility make it an especially useful tool for projecting subnational and multiregional populations. The Comparative Migration and Settlement (CMS) Study at IIASA was organized primarily to disseminate this tool to scholars and professionals dealing with population problems in the IIASA countries.

In this paper the authors focus on some of the results of the CMS study. The paper begins with a short review of the organization and design of the study, which had as a major objective the promotion of collaboration between scientists in member countries of IIASA. The next section describes the data base used for the study and in particular the severe data problems that resulted from the limited comparability and availability of regional statistics on mortality, fertility, and migration. Section 4 describes national and subnational patterns of mortality, fertility, and migration in the member countries. Section 5 considers the age compositions and regional distributions of the populations.

The delineation of appropriate regions for comparative analysis and the use of harmonized migration-statistics were not available options for this study. Consequently, the results reported in this paper should be interpreted with great care and some skepticism. The IIASA study is the first study of its kind, and a great deal has been learned about population redistribution patterns and about analytical-conceptual problems in comparative migration analysis. A rich agenda for future research is an important outcome of the CMS study. Thus, in the last section of the paper, an example is given of some of the research questions that have been generated by the study. The section considers problems of migration measurement (movement-versus-transition perspectives) and reports on experiments conducted to evaluate the reliability of the simple Markovian model, which underlies the multiregional analysis, and the accuracy of the procedures that were used to fit that model to the available data.

(1) A list of the scholars and their national reports appears in the appendix.

2 Design and organization of the CMS study

The design and organization of the CMS study were affected by the environment in which it was carried out(2). IIASA is an international nongovernmental organization, with scientific institutions in over two-dozen countries participating in its work. The most important of these are the National Member Organizations (NMOs), which are the representative bodies of the scientific communities in the seventeen member nations. The NMO countries differ (table 1) in size, level of development, and economic system as well as in the demographic characteristics of their populations. Large variations are also to be found in the characteristics and quality of available demographic data.

By engaging in research that is both interdisciplinary and international, IIASA tries to contribute to a better understanding, and ultimately to a resolution, of the problems that are of significance to its member countries. The CMS study was initiated in this context, having as its aim a quantitative assessment of patterns of migration and population redistribution in the NMO countries to be carried out by national scholars who would use the same methodology. A network of collaborating scholars was established, and multiregional demography was adopted as the common methodology, which, it was felt, would enhance the comparability of the results.

The CMS study involved a number of steps.

Data collection. The national collaborator assembled the population, birth, death, and migration data for the set of regions to be studied, using official published or unpublished sources. Regions were defined by the national scholars so as to make the results as useful to their country as possible.

Table 1. Basic demographic and economic indicators for IIASA member nations for 1978 [source: World Bank (1980) as presented in table 1 of Rees and Willekens (1981, page 4)].

Country	Area (1000 km^2)	Population ($\times 10^6$)	Population growth[a] (per 1000)	Crude birth rate (per 1000)	Crude death rate (per 1000)	Life expectancy at birth (years)	Total fertility rate (per woman)	GNP[b] per capita ($)
Austria	84	7.5	2	11	12	72	1.7	7030
Bulgaria	111	8.8	5	16	11	72	2.3	3230
Canada	9976	23.5	12	16	8	74	1.9	9180
Czechoslovakia	128	15.1	7	18	11	70	2.4	4720
FRG	249	61.3	1	9	12	72	1.4	9580
Finland	337	4.8	4	14	9	72	1.7	6820
France	547	53.3	6	14	10	73	1.9	8260
GDR	108	16.7	−2	13	13	72	1.8	5710
Hungary	93	10.7	4	16	12	70	2.2	3450
Italy	301	56.7	7	13	9	73	1.9	3850
Japan	372	114.9	12	15	6	76	1.8	7280
Netherlands	41	13.9	8	13	8	74	1.6	8410
Poland	313	35.0	9	19	9	71	2.3	3670
Soviet Union	22402	261.0	9	18	10	70	2.4	3700
Sweden	450	8.3	4	12	11	75	1.7	10210
United Kingdom	244	55.8	1	12	12	73	1.7	5030
USA	9363	221.9	8	15	9	73	1.8	9590

[a] The figures represent the average annual growth of population in 1970-1978 per 1000.

[b] GNP is the gross national product.

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(2) For an early description of the purpose and design of the study, see Rogers (1976a; 1976b).

Data processing. Data processing was generally done at IIASA. A package of standard computer-programs was developed for this purpose (Willekens and Rogers, 1978). In many cases, data processing also included data adjustment and the estimation of missing data. The standard output of the data processing consisted of single-region and multiregional life tables, measures of fertility and mobility, multiregional population projections, and statistics of the associated stable multiregional populations.

Analysis and preparation of report. The analysis of the computer output was done by the national scholars in close cooperation with IIASA. The analysis was complemented by a more traditional and descriptive exposition of recent migration patterns and spatial population structures, and each study included an overview of current migration and population distribution policies. The contributing scholars prepared a report on the basis of this research, following a common outline. The reports were published by IIASA, in the order listed in the appendix.

Four major outputs have resulted from the CMS study. The first is a collection of seventeen reports, each presenting a national demographic analysis as well as appendixes containing the observed data used for the particular country, age-specific rates, selected life-table results, and population projections. The second is the establishment of an active network of collaborating scholars in many countries, which is now linked by the newsletter POPNET. The third result that the study has generated is an IIASA data bank containing information on regional population structures and on the components of regional demographic change. Although this data bank has a number of weaknesses, it nevertheless is a unique resource for comparative regional demographic analysis; the results reported in this paper are based on this information. Last, the CMS study has generated a rich agenda for further research. For example, during the course of the study many of the currently available techniques for migration analysis and for subnational population projection were challenged. As a result, researchers in several IIASA countries are now working on specific topics of the continuing research agenda. A few of their findings will be mentioned in this paper.

3 Data base for the CMS study

The purpose of this section is to describe briefly the data base used in the CMS study and to list some of the problems encountered in preparing a complete data set for multiregional analysis.

Multiregional demographic techniques require more data than conventional methods. The necessary data consist of population, births, deaths, and migrants by age and region (and, if possible, by sex), and the migration data should be disaggregated by area of origin and area of destination.

Data on external migration are not necessary if the multiregional system may be assumed to be relatively unaffected by emigration and immigration, which was the assumption adopted by the CMS study.

For a number of reasons, the available published data were never complete or in the right form for use by the CMS study. In some instances, the data need was satisfied by special tabulations carried out by national statistical offices, but in most cases we had to rely on techniques of indirect estimation. The data base for the CMS study is discussed in some detail by Rees and Willekens (1981). In that paper, the authors present the time-and-space frameworks for which the data were collected and review the estimation techniques that were used to generate missing data, which generally were those referring to migration. Details on mortality data may be found in Termote (1982), on fertility data in Kim (1983), and on migration data in Rogers and Castro (1983). An overview of the data base is given below.

3.1 *Base period*

The first step in the initiation of the CMS study was the selection of a base period for which to obtain data. To reduce the amount of data processing involved, a decision was made to limit the base period to a single year whenever possible, the period selected being mainly determined by data availability. And whenever possible, the year selected was the most recent one for which a relatively complete set of necessary data was available. For countries with a registration system, that is, most European countries, a year in the mid-1970s was used, whereas for countries in which population censuses are the main source of migration data, the year of the last census was selected.

3.2 *Disaggregation by sex and age*

For the CMS study the population generally was not disaggregated by sex. Data availability was only a minor consideration in this decision. Although several countries did not have all of the requisite data disaggregated by sex, such data could have been estimated. A major consideration was methodological convenience, inasmuch as two-sex models are not yet fully developed in multiregional demography(3).

The age classification of the population in all but two instances was in terms of five-year age groups, with 85 being the highest open-ended age group in fifteen of the seventeen countries (the two exceptions were Finland and the German Democratic Republic). In some cases, this required an interpolation, extrapolation, or respecification of the age grouping.

3.3 *The multiregional system*

The selection of an appropriate set of regions was one of the most difficult tasks in the CMS study. Theoretical, methodological, and data considerations, as well as the interests of potential users, were all taken into account, and the outcome had to be a compromise. The concept of a region has always been much debated in social sciences, particularly in geography, where two conflicting views are often presented. The first sees countries as being divided up into functional regions, that is, areas centered on nodes around which human activities take place. The second views regions as homogeneous units of the nation; in this view spatial units are classified on the basis of their characteristics and not on the basis of their pattern of interaction with other units.

The identification either of functional or of homogeneous regions is generally made difficult, if not impossible, by data limitations. Furthermore, in most countries these regions have only a limited relevance for planning, because traditional administrative regions constitute regional planning units. Consequently, the main criterion for the selection of a multiregional system in the CMS study was neither nodality nor homogeneity but the relevance of the system for existing planning activities. The final selection of the set of regions was left to the national scholars participating in the project, because they were more informed about which multiregional systems were most relevant for their countries.

Table 2 lists the multiregional systems used in the CMS study. The regions are illustrated in figures 1 and 2.

Each regional system used in the CMS study has the advantage of being planning oriented, and therefore the problems of data availability are minimized. There are, however, important disadvantages, because the regions are not necessarily homogeneous with respect to their demographic characteristics, and they differ greatly in size. Both features complicate the comparative assessments of the analytic results of the study.

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(3) One of the more recent results of demographic research carried out at IIASA is an improved specification of a two-sex marriage model (Sanderson, 1981).

Table 2. The regions used in the Comparative Migration and Settlement Study [source: Rees and Willekens (1981, pages 44–45), with corrections by authors].

Country	Scale of regions		
	coarse	medium	fine
Austria	4 *Länder* aggregations [a]	9 *Länder* [bd] (states)	95 *Gemeinden*
Bulgaria		7 regions [bd]	28 districts
Canada		10 provinces [bd]	
Czechoslovakia	2 republics	10 regions [bd]	12 administrative regional units
FRG		10 *Länder* [bd] and West Berlin	58 functional urban regions
Finland		12 *lääni* [bd] (provinces)	16 economic regions
France	8 ZEATs [bd] (planning zones)	22 regions [c]	95 departments
GDR	5 regions [bd]	15 regions [cd] (districts)	219 *Kreise* (counties)
Hungary		6 economic planning regions [bd]	25 counties and county towns [c]
Italy	5 regions [bd]		20 administrative units [acd]
Japan		8 regions [bd]	47 prefectures
Netherlands	5 geographic regions [bd]	12 provinces [cd]	40 COROP regions [e] 129 economic geographic areas
Poland		13 regions [bd]	22 *voivodships* (until 1975) 49 *voivodships* (since 1975) [c]
Soviet Union	urban and rural areas [ad]	8 units: 7 urban regions and 1 rural remainder [bd]	15 republics
Sweden		8 regions [bd]	24 counties [c] 70 A-regions [f]
United Kingdom	2 standard regions and remainder of country [a]	10 standard regions [bd]	18 conurbations and region remainder 61 counties and regions
USA	4 regions [bd]	9 census divisions [a]	50 states

[a] Secondary multiregional analysis was carried out at this scale.

[b] Principal multiregional analysis was carried out at this scale.

[c] Additional single-region analysis was carried out at this scale.

[d] Data were provided in Research Report at this scale for multiregional analysis.

[e] COROP regions are officially defined labor-market areas that are used for reporting demographic and economic data.

[f] A-regions were defined for purposes of labor and service administration planning (as 'commuting regions').

Table 2 (continued)

Notes

Austria: The four regions are groupings of the nine Austrian *Länder*.

Bulgaria: The seven Bulgarian regions are groupings of twenty-eight administrative districts.

Canada: The Canadian study omits the Yukon and Northwest Territories from the multiregional analysis. The provinces are administrative units.

Czechoslovakia: Seven of the regional units fall in the Czech Republic and three in the Slovak Republic.

FRG: The *Länder* are administrative regions.

Finland: The provinces are administrative units.

France: The ZEATs are the *zones d'étude et d'aménagement du territoire*, originally defined for the regionalization of the Sixth National Plan. They are groupings of the twenty-two programming regions.

GDR: The multiregional analysis of the German Democratic Republic was carried out principally using five macroregions, though some analysis was done with fifteen regions, which were the fifteen administrative districts of the German Democratic Republic (*Bezirke*). The macroregions were aggregations of the administrative districts.

Hungary: The six regions are groupings of the twenty-five administrative districts.

Italy: The five regions are amalgamations of the twenty administrative units.

Japan: The eight regions are aggregations of the forty-seven administrative prefectures.

Netherlands: The five regions are groups of the eleven administrative provinces and the Ijsselmeerpolders.

Poland: The thirteen Polish regions are groupings of the forty-nine (post-1975) administrative *voivodships*. Before 1975 there were twenty-two *voivodships*.

Soviet Union: The urban regions are not contiguous.

Sweden: The regional units are amalgamations of counties (administrative units).

United Kingdom: The United Kingdom regional analysis covers eleven regions: the eight standard regions of England, plus Wales, Scotland, and Northern Ireland. In the multiregional analysis Northern Ireland was omitted. The three regions (coarse regionalization) are used in the United Kingdom chapter analysis and the Ledent and Rees (1980) study. The standard regions are aggregations for statistical purposes of the administrative counties.

USA: The four regions are aggregations of the nine census divisions, which are amalgamations of the fifty administrative states.

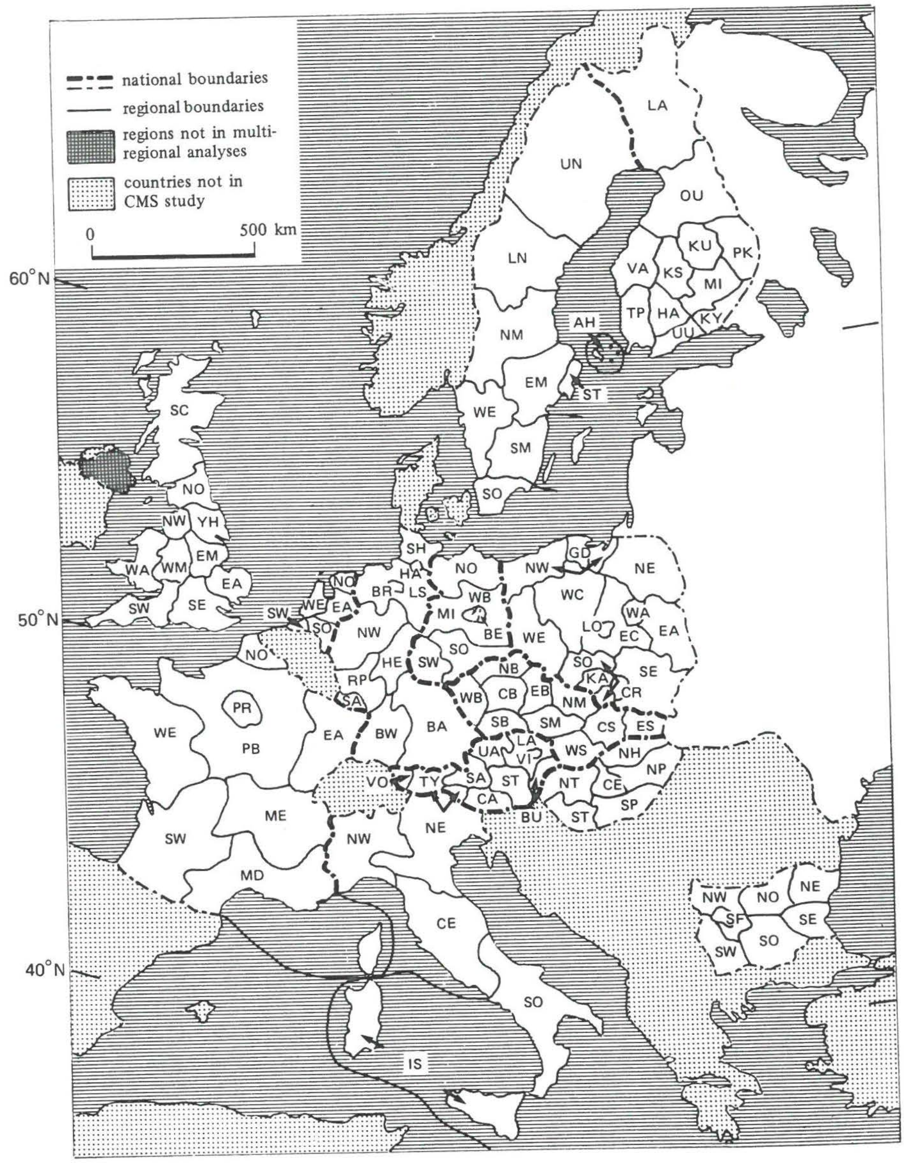


Figure 1. The regions in Europe used in the Comparative Migration and Settlement (CMS) Study [source: Rees and Willekens (1981, pages 46-49)].

Austria (1971)

BU	Burgenland
CA	Carinthia
LA	Lower Austria
UA	Upper Austria
SA	Salzburg
ST	Styria
TY	Tyrol
VO	Vorarlberg
VI	Vienna

Bulgaria (1975)

NW	Northwest
NO	North
NE	Northeast
SW	Southwest
SO	South
SE	Southeast
SF	Sofia

Czechoslovakia (1975)

CB	Central Bohemia
SB	Southern Bohemia
WB	Western Bohemia
NB	Northern Bohemia
EB	Eastern Bohemia
SM	Southern Moravia
NM	Northern Moravia
WS	Western Slovakia
CS	Central Slovakia
ES	Eastern Slovakia

FRG (1974)

SH	Schleswig-Holstein
HA	Hamburg
LS	Lower Saxony
BR	Bremen
NW	North Rhine-Westphalia
HE	Hesse
RP	Rheinland-Palatinate
BW	Baden-Württemberg
BA	Bavaria
SA	Saarland
WB	West Berlin

Finland (1974)

UU	Uusimaa
TP	Turku and Pori
AH	Ahvenanmaa
HA	Häme
KY	Kymi
MI	Mikkeli
PK	Pohjois-Karjala
KU	Kuopio
KS	Keski-Suomi
VA	Vaasa
OU	Oulu
LA	Lappi

France (1975)

PR	Paris Region
PB	Paris Basin
NO	North
EA	East
WE	West
SW	Southwest
ME	Middle East
MD	Mediterranean

GDR (1975)

NO	North
BE	Berlin
SW	Southwest
SO	South
MI	Middle

Hungary (1974)

CE	Central
NH	North Hungary
NP	North Plain
SP	South Plain
NT	North Trans-Danubia
ST	South Trans-Danubia

Italy (1978)

NW	Northwest
NE	Northeast
CE	Center
SO	South
IS	Islands

Netherlands (1974)

NO	North
EA	East
WE	West
SW	Southwest
SO	South

Poland (1977)

WA	Warsaw
LO	Łódź
GD	Gdańsk
KA	Katowice
CR	Kraców
EC	East-Central
NE	Northeast
NW	Northwest
SO	South
SE	Southeast
EA	East
WC	West-Central
WE	West

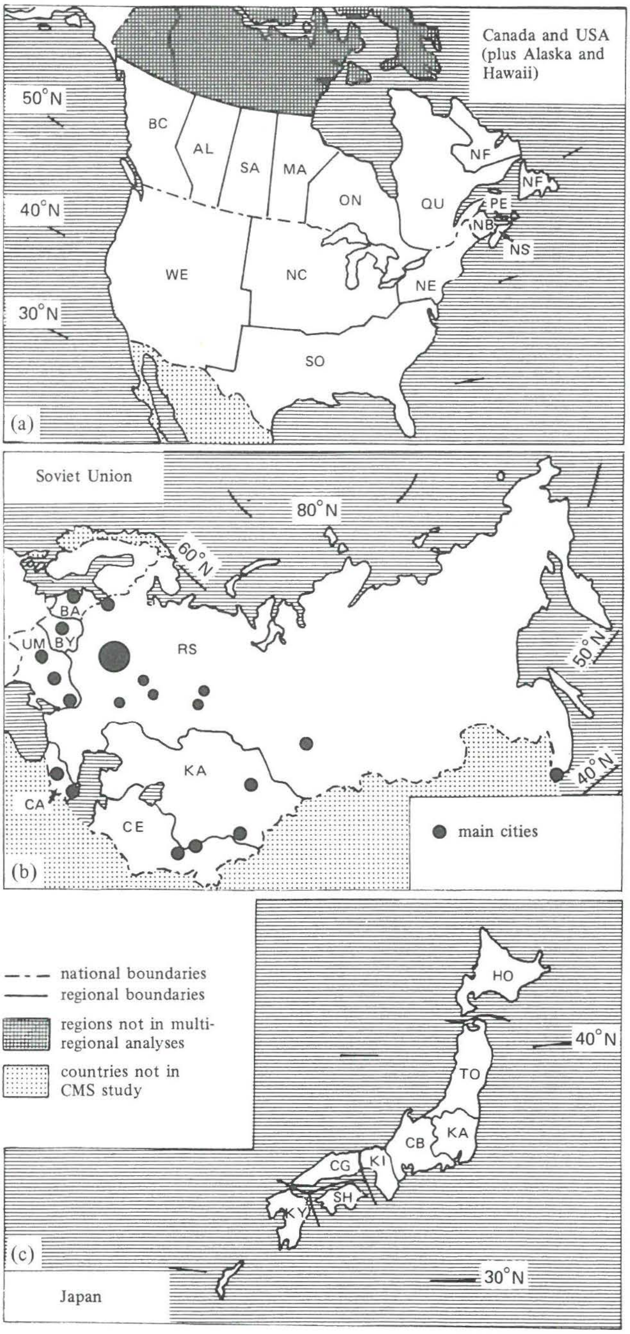
Sweden (1974)

ST	Stockholm
EM	East Middle
SM	South Middle
SO	South
WE	West
NM	North Middle
LN	Lower North
UN	Upper North

United Kingdom (1970)

NO	North
YH	Yorkshire and Humberside
NW	Northwest
EM	East Midlands
WM	West Midlands
EA	East Anglia
SE	Southeast
SW	Southwest
WA	Wales
SC	Scotland

Figure 1 (continued)



Canada (1971)

NF	Newfoundland
PE	Prince Edward Island
NS	Nova Scotia
NB	New Brunswick
QU	Quebec
ON	Ontario
MA	Manitoba
SA	Saskatchewan
AL	Alberta
BC	British Columbia

USA (1970)

NE	Northeast
NC	North Central
SO	South
WE	West

Soviet Union (1974)
Urban areas of:

RS	RSFSR
UM	Ukrainian and Moldavian SSRs
BY	Byelorussian SSR
CE	Central Asian Republics (Uzbeck, Kirgiz, Tadzhik, Turkmen SSRs)
KA	Kazakh SSR
CA	Caucasian Republics (Georgian, Azerbaijan, Armenian SSRs)
BA	Baltic Republics (Estonian, Latvian, Lithuanian SSRs)
RU	Rural areas of USSR

Japan (1970)

HO	Hokkaido
TO	Tohoku
KA	Kanto
CB	Chubu
KI	Chin-Chi
CG	Chugoku
SH	Shikoku
KY	Kyushu

Figure 2. The regions used in the Comparative Migration and Settlement (CMS) Study: (a) North America, (b) Soviet Union (RSFSR is the Russian Soviet Federal Socialist Republic; SSR is Soviet Socialist Republic), and (c) Japan [source: Rees and Willekens (1981, pages 46-49)].

3.4 *The measurement of migration*

A major problem in comparative migration analysis arises as a consequence of differences among countries in the procedures that are used to measure migration: a change of community of residence. There are, nevertheless, two principal types of data-collection procedures—registration systems and censuses—both of which are implemented in many countries. The registration system, generally used in Europe, requires each change of address to be registered with the local authorities. Thus every move (a passage from one place of residence to another) is counted and the aggregate statistical data that describe the number of moves are said to be *movement data*. Other countries, such as France, the United Kingdom, and the United States of America, derive migration statistics from a retrospective question in the national census. In such censuses, migration is measured by comparing places of residence at two consecutive points in time, the second of which is the time of enumeration. For most IIASA countries the first date is five years prior to the census; however, in France, the interval is seven years and in Japan it is only one year. In this form of migration measurement, individual moves are not recorded; what are recorded are transitions made between the start and the end of a given time interval. These data on migration are therefore referred to as *transition data*. Return migration and other multiple moves during the interval are not represented in transition data.

In the CMS study registration-based movement data and census-based transition data were both employed; movement data were used in eleven out of seventeen country studies and transition data were used in the remaining six studies (table 3).

Table 3. The Comparative Migration and Settlement Studies classified by type of migration data.

Movement data (registration)	Transition data [a] (census)
Bulgaria	Austria (5)
Czechoslovakia	Canada (5)
FRG	France [b] (7)
Finland	Japan (1)
GDR	United Kingdom (1 and 5) [c]
Hungary	USA (1)
Italy	
Netherlands	
Poland	
Soviet Union	
Sweden	

[a] The length of the reference period, in years, is given in parentheses.

[b] For the analysis, the seven-year transition rates were factored down to five-year rates (Ledent with Courgeau, 1982).

[c] The UK 1970 census contained questions on the place of residence one and five years ago. A comparison of the results obtained for the two intervals was made by Ledent and Rees (1980).

3.5 *Assessment*

It is clear from the above discussion that a comparative analysis of regional patterns of mortality, fertility, and migration in the NMO countries of IIASA is troublesome if not impossible. Because of the problems of comparability, we will place the major emphasis of our analysis on interregional differences within a country, paying only limited attention to differentials between countries.

The regions used in the CMS study are not uniformly defined and show considerable variation in size and degree of homogeneity. This complicates comparative analysis because the regional disaggregation scheme affects regional differentials in the components of demographic change. For a few countries (Austria, the German

Democratic Republic, Italy, the Netherlands, the Soviet Union, and the United Kingdom) the multiregional analysis was carried out at more than one level of disaggregation. The experiments illustrate the impact of regional disaggregation schemes on the results, some of which will be touched on in this paper.

Another major problem encountered in the CMS study is associated with national differences in migration measurement. The results of the demographic analysis are sensitive not only to the data-collection procedure adopted (registration versus census), but also to the length of the reference period employed for the measurement of migration in the census. In section 6 of this paper, a few implications of such differences are discussed.

4 Comparative analysis of mortality, fertility, and migration patterns

A comparative analysis requires answers to at least two questions: *what* is being compared, and *how* is the comparison carried out. The answer to the first question generally involves the selection of summary measures of mortality, fertility, and migration. The growth regimes are defined by sets of curves of age-specific rates (or probabilities). Levels are relatively easy to summarize, and the demographic literature contains several indicators of levels of mortality (for example, life expectancy or gross death rate), fertility (for example, gross reproduction rate), and migration (for example, gross migraproduction rate, the migration analog of the gross reproduction rate)(4). Age profiles may be summarized and parametrized by fitting mathematical functions to the age-specific schedules of rates.

The answer to the question of how comparisons are carried out involves the selection of measures of disparity. These measures describe the distributions of indicators around a central value (a mean or median). An example of a simple measure is the difference in absolute (or in relative) terms between the maximum and the minimum values of an indicator, for example, the expectation of life at birth. More complex measures may call for global indices of regional differentials, such as used by Termote (1982), for example.

4.1 *Mortality*

Termote (1982) examines regional mortality disparities in the IIASA member countries, using the data base assembled by the CMS study. This section of the paper draws on his analysis and on the several indices of regional mortality differentials set out in table 4. The table presents regional data for the expectation of life at birth, the first set of which is derived from conventional (single-region) life tables, the second from a multiregional life table. Several conclusions may be drawn from these data.

(a) On the whole, regional disparities in life expectancies at birth seem relatively small. In the single-region analysis the deviations between the highest and lowest values are largest in the Soviet Union (5.3 years), followed by France (4.5), and the United Kingdom (3.2). The smallest discrepancies are observed in Japan (1.3 years), Hungary (1.4), and the German Democratic Republic (1.5).

(b) The regional disaggregation influences the regional mortality disparities. The difference in the Soviet Union may in part be related to the peculiar regional disaggregation adopted. Seven of the eight regions are urbanized areas; region 8 is a combination of all the rural areas in the country and has the lowest life expectancy (68.2 years).

For a few countries, the analysis was carried out at more than one level of disaggregation (see Termote, 1982, page 24). A general conclusion of these experiments is that the greater the level of geographical detail, the larger the mortality difference. This conclusion indicates a lack of homogeneity among the larger regions.

(4) All are measures of the area under the curve defined by the schedule of age-specific rates.

(c) The single-region life-expectancy measures indicate larger regional mortality disparities than the multiregional measures: the range of the former is larger than the range of the latter. Rees (1979a), who first observed the relationship between the single-region and multiregional life-expectancy measures in the United Kingdom, suggested that the multiregional measures represent a regression of the single-region values to the mean. This phenomenon can be attributed to a combination of two factors: the interchange of people between regions through migration and the assumption that migrants do not carry their demographic history with them but adopt the demographic regime of growth of their new region of residence (the Markovian assumption).

The regression to the mean differs considerably between the seventeen countries (Rees and Willekens, 1981, page 87) and is highest in Japan and the Netherlands. An increase of 1 year in the single-region life-expectancy in these two countries leads, on the average, to an increase in the multiregional life-expectancy of 0.29 and 0.30 years, respectively. The lowest regression to the mean is exhibited by the data for Czechoslovakia and the Soviet Union.

The regional disparities exhibited in table 4 are for the total population. A disaggregation by sex suggests that regional disparities tend to be slightly higher for males than for females. In the Federal Republic of Germany, for instance, the female life-expectancies lie between 73.4 and 75.7 years; those for males vary between 66.5 and 69.4.

As we have seen, a comparative analysis of life expectancies indicates a relatively low level of regional disparity in most of the seventeen IIASA countries. But what about the age structure of mortality? For the comparative study of these age patterns, we considered the age-specific rates directly rather than parametrize the mortality schedules, because the data were available only for five-year age groups. Our results show large disparities in infant mortality (here defined as the mortality rate of the 0-4 age group) and in the mortality rates of young adults (those 15-29 years). In seven out of the seventeen IIASA countries, the highest regional infant-mortality rate is more than 50% above the lowest regional rate, and in all of the seventeen countries

Table 4. Regional differentials in the expectation of life at birth (both sexes combined).

Country	Reference year	Number of regions	Single-region measure			Multiregional measure	
			national	lowest	highest	lowest	highest
Austria	1971	9	70.5	69.6	71.7	69.9	71.6
Bulgaria	1975	7	70.9	69.9	71.8	70.5	71.4
Canada	1971	10	72.5	71.5	73.8	71.9	73.2
Czechoslovakia	1975	10	70.3	68.7	71.5	69.3	71.2
FRG	1974	11	71.9	70.4	72.8	71.4	72.3
Finland	1974	12	71.7	69.9	72.8	71.2	72.7
France	1975	8	73.5	70.2	74.7	73.3	74.2
GDR	1975	5	71.7	70.8	72.2	71.1	72.0
Hungary	1974	6	69.0	68.4	69.8	68.4	69.7
Italy	1978	5	74.1	73.5	75.3	73.8	75.0
Japan	1970	8	72.1	71.2	72.5	72.0	72.5
Netherlands	1974	5	74.7	74.0	75.7	74.3	74.8
Poland	1977	13	70.6	69.4	71.8	70.1	71.5
Soviet Union	1974	8	69.3	68.2	73.5	67.8	71.4
Sweden	1974	8	75.2	74.4	75.9	74.8	75.6
United Kingdom	1970	10	71.9	70.3	73.5	71.1	72.6
USA	1970	4	70.8	69.9	71.8	70.5	71.1

considered, this percentage is above 20% (Termote, 1982, page 27). The disparities are even greater when young adult mortality is considered: in seven countries the highest mortality rate for young adults is more than 50% above the lowest rate, and in all but one (United Kingdom), this percentage exceeds 30% (Termote, 1982, page 31). Infant and young adult mortality, therefore, account for most of the regional mortality disparities found in the seventeen countries.

4.2 *Fertility*

Considerable regional variations are also exhibited in the levels of fertility within IIASA countries. Table 5 gives, for each country, the national value and the lowest and highest regional gross reproduction rates (GRR). The largest regional disparities, measured as the difference between the highest and lowest GRR, are observed in the Soviet Union, Canada, and Poland. A woman in the urban areas of the Central Asian Republics of the Soviet Union (highest GRR) may expect to have more than twice the number of children, on the average, than a woman in the urban areas of the Baltic Republic (lowest GRR). In Newfoundland, Canada, the GRR is 73% higher than in Quebec. The United States of America and the German Democratic Republic exhibit the smallest differences in regional fertility levels, but it must be remembered that in the former case this is a consequence of the high level of regional aggregation.

Table 5. Regional differentials in gross reproduction rates (both sexes combined).

Country	Reference year	Number of regions	National	Lowest	Highest
Austria	1971	9	1.09	0.82	1.31
Bulgaria	1975	7	1.10	0.96	1.22
Canada	1971	10	1.23	1.10	1.90
Czechoslovakia	1975	10	1.21	1.13	1.39
FRG	1974	11	0.73	0.58	0.81
Finland	1974	12	0.79	0.73	0.96
France	1975	8	0.94	0.83	1.12
GDR	1975	5	0.76	0.74	0.80
Hungary	1974	6	1.14	0.99	1.36
Italy	1978	5	0.91	0.76	1.17
Japan	1970	8	1.05	1.01	1.15
Netherlands	1974	5	0.87	0.91	0.98
Poland	1977	13	1.10	0.81	1.41
Soviet Union	1974	8	1.33	0.97	1.92
Sweden	1974	8	0.92	0.86	0.97
United Kingdom	1970	10	1.18	1.11	1.26
USA	1970	4	1.26	1.22	1.30

4.3 *Migration*

The comparative analysis of migration is complicated by differences in reference periods and in sizes of regions. Although regional disparities in mobility levels, to a large extent, reflect such differences, migration-age profiles are not as sensitive to these time and space dimensions. This section, therefore, mainly considers the age structure of migration. The discussion of mobility levels is meant to be illustrative only and indicates the difficulties that complicate comparative migration analysis if appropriate data are not available.

A simple indicator of mobility (immobility) is the retention level, the proportion of a lifetime that a person may expect to spend in the region of birth. Table 6 shows that the largest regional disparities in retention levels are observed in the Federal Republic of Germany (0.423), Canada (0.417), and Japan (0.382).

The impact of regional disaggregation on the retention level is illustrated by the FRG study. In this country the lowest retention level is for the city region of Bremen, which with a population of 724000 in 1974 is the smallest region. The high level of out-migration is probably a result of the suburbanization process, which overlaps regional boundaries. The highest retention level is exhibited by the largest region, North Rhine-Westphalia, with a population of 17.2 million. Differences in retention levels therefore reflect not only mobility differentials but also size differences in the regions between which migration takes place.

The problems associated with comparisons of mobility levels are eased if we look at the age patterns of migration. Rogers and Castro (1981) in a study of over five hundred migration schedules of IIASA countries found remarkably persistent regularities. To carry out a comparative analysis, they parametrized the curves of age-specific migration rates using a model migration schedule that combined additively four simple curves: a negative exponential curve, two double exponential curves, and a constant curve. The full model schedule had eleven parameters of which seven determined the profile of the migration schedule, with the remaining four determining its level. Figure 3 shows such a model migration schedule. The four components, and their associated parameters, are:

(1) a single negative exponential curve of the pre-labor-force ages, with its parameter of descent α_1 and level coefficient a_1;

(2) a skewed unimodal curve of the labor-force ages, positioned at μ_2 on the age axis and exhibiting parameters of ascent λ_2 and descent α_2, with a level coefficient a_2;

(3) an almost bell-shaped curve of the post-labor-force ages, positioned at μ_3 on the age axis and exhibiting parameters of ascent λ_3 and descent α_3, with a level coefficient a_3;

(4) a constant curve, c.

Table 7 presents, by way of illustration, regional differentials of the parameters for males in the United Kingdom. The statistics are based on the fifty-nine schedules without a retirement peak and show large regional disparities. The mean age of the migration schedule ranges from 25 years to 36 years. The age at which the curve

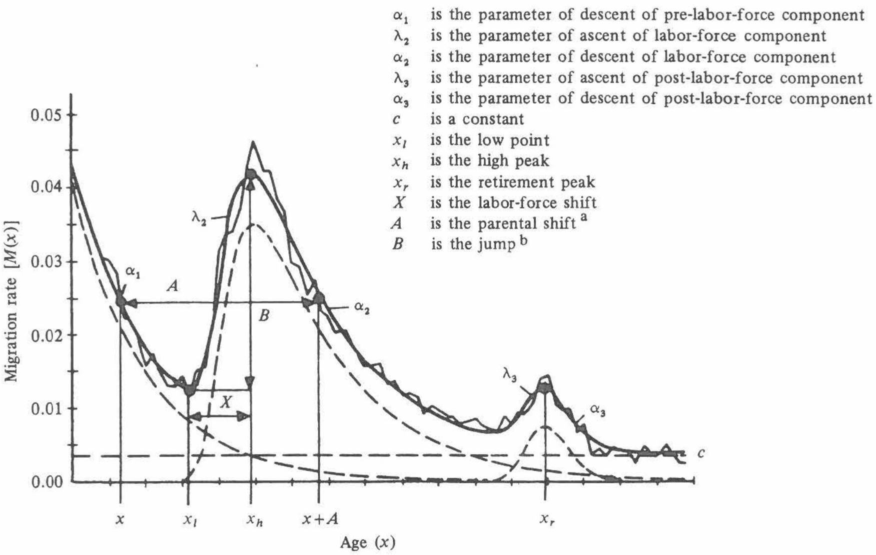
Table 6. Regional differentials in retention levels (both sexes combined).

Country	Number of regions	Retention levels		
		median	lowest	highest
Austria	9	0.819	0.732	0.882
Bulgaria	7	0.823	0.742	0.867
Canada	10	0.574	0.373	0.790
Czechoslovakia	10	0.777	0.640	0.848
FRG	11	0.475	0.271	0.694
Finland	12	0.439	0.310	0.592
France	8	0.682	0.572	0.705
GDR	5	0.745	0.725	0.800
Hungary	6	0.471	0.372	0.506
Italy	5	0.783	0.752	0.874
Japan	8	0.431	0.352	0.734
Netherlands	5	0.600	0.461	0.689
Poland	13	0.711	0.584	0.839
Soviet Union	8	0.472	0.330	0.666
Sweden	8	0.499	0.464	0.641
United Kingdom	10	0.539	0.411	0.653
USA	4	0.560	0.530	0.586

peaks (its high point x_h) ranges from 17 years (the flow from East Anglia to Southeast) to 28 years (the flow from Scotland to Northwest). The disparity between the position parameters of the labor-force component (μ_2) follows the same pattern. In fact, the parameters of the model schedule are not independent. Rogers and Castro (1981, page 21) conclude that a large fraction in the variation shown by the more than five hundred schedules they studied arises from changes in the values of four parameters and derived variables:

μ_2	the position parameter of the labor-force component,
δ_{12}	the index of child dependency, the ratio of a_1 (level of pre-labor-force component) to a_2 (level of labor-force component),
σ_2	the index of labor asymmetry, the ratio of λ_2 (parameter of ascent of labor-force component) to α_2 (parameter of descent of labor-force component),
β_{12}	the index of parental shift, the ratio of α_1 (parameter of descent of pre-labor-force component) to α_2 (parameter of descent of labor-force component).

Regional disparities in migration-age patterns may be studied by considering each of the parameters or combinations of them. The model schedules also may be classified into families on the basis of the values of these parameters. Rogers and Castro set out several families of migration schedules using the four measures listed above. Each measure defines two families, depending on whether its value is above or below the 'average'. (The average values are: $\mu_2 = 20$, $\delta_{12} = \frac{1}{3}$, $\sigma_2 = 4$, and $\beta_{12} = 1$.) Approximately 30% of the schedules for males in the United Kingdom are early peaking ($\mu_2 < 19$ years); about 50% of the schedules are 'normal' (that is, near the average profile). If we examine the index of child dependency, then 27% of the



α_1	is the parameter of descent of pre-labor-force component
λ_2	is the parameter of ascent of labor-force component
α_2	is the parameter of descent of labor-force component
λ_3	is the parameter of ascent of post-labor-force component
α_3	is the parameter of descent of post-labor-force component
c	is a constant
x_l	is the low point
x_h	is the high peak
x_r	is the retirement peak
X	is the labor-force shift
A	is the parental shift [a]
B	is the jump [b]

[a] The close correspondence between the migration rates of children and those of their parents suggests an important shift in observed migration schedules. If, for each point x on the post-high-peak part of the migration curve, we obtain by interpolation the age (where it exists), $x - A_x$ say, with the identical rate of migration on the pre-low-point part of the migration curve, then the average of the values of A_x, calculated incrementally for the number of years between zero and the low point x_l, will be defined as the observed parental shift A.

[b] B is the perpendicular distance between the peak and the base of a bell-shaped curve.

Figure 3. The model migration schedule; the four curves are described in the text [source: Rogers and Castro (1981, page 6)].

schedules are child dependent ($\delta_{12} > 0.4$) and 10% are labor dependent ($\delta_{12} < 0.2$). Close to 7% of the schedules are labor asymmetric ($\sigma_2 > 5$) and 73% are irregular ($\beta_{12} < 0.8$, or $\beta_{12} > 1.2$).

Table 7. Regional differentials of the model parameters for males in the United Kingdom; the statistics are based on the fifty-nine migration schedules without a retirement peak [source: Rogers and Castro (1981, page 58)].

Parameters and variables[a]	Summary statistics						
	lowest value	highest value	mean value	median	mode	SD[b]	SD/M[c]
GMR	0.03	1.06	0.16	0.10	0.08	0.18	1.17
a_1	0.009	0.042	0.021	0.020	0.017	0.007	0.321
α_1	0.022	0.266	0.100	0.099	0.107	0.048	0.484
a_2	0.016	0.112	0.059	0.061	0.069	0.017	0.282
μ_2	14.69	43.97	22.00	20.12	19.08	5.36	0.24
α_2	0.064	0.274	0.127	0.116	0.096	0.048	0.376
λ_2	0.061	0.907	0.259	0.240	0.272	0.151	0.580
c	0.000	0.006	0.003	0.003	0.002	0.002	0.542
$\bar{n}$	25.15	36.37	30.66	30.46	30.20	2.60	0.08
0-14 (%)	15.20	29.69	20.89	20.47	18.82	3.46	0.17
15-64 (%)	60.27	78.68	69.71	69.30	66.72	3.86	0.06
65+ (%)	1.36	16.64	9.40	9.56	6.71	3.74	0.40
δ_{1c}	0.00	108.15	10.10	6.40	5.41	16.03	1.59
δ_{12}	0.133	1.537	0.391	0.346	0.203	0.221	0.565
β_{12}	0.08	2.63	0.90	0.70	0.47	0.57	0.63
σ_2	0.30	11.99	2.50	2.07	0.89	2.02	0.81
x_l	6.91	17.19	12.70	12.61	12.56	1.82	0.14
x_h	17.11	28.14	23.17	22.82	22.07	1.82	0.08
X	4.50	16.93	10.47	10.35	10.09	2.21	0.21
A	22.34	34.75	30.56	30.77	31.65	2.65	0.09
B	0.011	0.044	0.023	0.023	0.023	0.006	0.253

[a] The definitions for the parameters and variables are: GMR is the observed gross migraproduction rate; a_1 is the level of pre-labor-force component; α_1 is the parameter of descent of pre-labor-force component; a_2 is the level of labor-force component; μ_2 is the position parameter of labor-force component; α_2 is the parameter of descent of labor-force component; λ_2 is the parameter of ascent of labor-force component; c is a constant component; $\bar{n}$ is the mean age of migration schedule; 0-14 (%) is the percentage of GMR in 0-14 age interval; 15-64(%) is the percentage of GMR in 15-64 age interval; 65+ (%) is the percentage of GMR in 65 and over age interval; $\delta_{1c} = a_1/c$; $\delta_{12} = a_1/a_2$; $\beta_{12} = \alpha_1/\alpha_2$; $\sigma_2 = \lambda_2/\alpha_2$; x_l is the low point; x_h is the high point; X is the labor-force shift; A is the parental shift; B is the jump.

[b] SD is the standard deviation.

[c] SD/M is the standard deviation divided by the mean.

5 Comparative analysis of population structure

Although the IIASA countries show considerable variation in national rates of fertility, they nevertheless are all tending toward levels of reproduction that are below replacement. By the end of the 1970s, not enough children were being born to replace their parents in thirteen of the seventeen countries; in the remaining four countries (Bulgaria, Czechoslovakia, Poland, and the Soviet Union) the number of children born was only slightly above replacement level. Consequently, in most IIASA national populations the elderly (that is, those above 65 years of age) increased their share of the total during that decade. Population aging and spatial redistribution are two principal dimensions illuminated by the CMS study.

5.1 *Population aging*

Table 8 describes the age compositions of the IIASA countries during years in the 1970s. The 'oldest' populations were France, Sweden, and the German-speaking countries of Europe (Austria, the Federal Republic of Germany, and the German Democratic Republic). They showed the highest fractions of population above 65 years of age and the oldest mean ages. Close behind these five countries were Italy and the United Kingdom. The 'youngest' countries on these indices were Canada and Japan; however, by 1980, sharp declines in fertility produced a substantial 'graying' of these populations as well.

Table 9 indicates some of the regional differences in age compositions within IIASA countries. Shown there are the lowest and highest percentages of populations aged under 15 and over 64. The region with the highest proportion of the aged (that is, of those 65 and over) was Vienna, Austria, with one out of every five residents being in that age group. Two regions exhibited the lowest proportion in Japan: the Hokkaido and the Kanto regions, each with approximately only 5.8% of their populations being aged 65 and over. A comparison of tables 8 and 9 indicates that differences in age compositions *within* countries are in many instances greater than those *between* countries.

Although the process of aging is becoming an important issue in all of the IIASA member countries, it will affect some countries more than others. Under current regimes of fertility and mortality, the proportion of the aged will decline, for example, in Austria (from 14.2% of the national population in 1971 to 12.1% by the year 2000), but it will increase rapidly in Japan (from 7.1% in 1970 to 12.5% by 2000) and the Federal Republic of Germany (from 14.3% in 1974 to 15.6% in 2000).

Given current migration patterns, some regions will experience a considerable aging of their populations, which will require adaptation on the part of the local economies, particularly the service sectors. In the Kanto region of Japan, for example, the number of aged persons will increase by 280% between 1970 and 2000. Because of the high

Table 8. Population structure in IIASA countries in the reference year.

Country	Reference year	Population ($\times 10^6$)	Mean age	% in age range				Elderly dependency ratio [a]
				0-14	15-64	65+	75+	
Austria	1971	7.5	36.1	24.4	61.3	14.2	4.7	0.23
Bulgaria	1975	8.7	35.2	22.2	66.8	10.9	3.3	0.16
Canada	1971	20.7	30.3	31.2	60.9	7.9	3.0	0.13
Czechoslovakia	1975	14.8	34.6	23.4	64.5	12.1	3.7	0.19
FRG	1974	62.0	36.8	21.7	64.0	14.3	4.7	0.22
Finland	1974	4.7	34.0	22.4	67.3	10.3	3.1	0.15
France	1975	52.4	35.9	22.7	63.1	14.2	5.6	0.23
GDR	1975	16.8	37.0	21.3	62.4	16.3	5.7	0.26
Hungary	1974	10.4	36.1	19.9	67.8	12.3	3.9	0.18
Italy	1978	56.6	35.6	23.3	63.9	12.8	4.5	0.20
Japan	1970	104.7	31.5	24.0	68.9	7.1	2.1	0.10
Netherlands	1974	13.5	33.1	26.1	63.3	10.6	3.9	0.17
Poland	1977	34.7	32.8	23.9	66.2	9.9	3.1	0.15
Soviet Union	1974	250.9	32.9	27.0	63.0	10.0	3.0	0.16
Sweden	1974	8.2	37.6	20.7	64.4	14.8	5.5	0.23
United Kingdom	1970	54.2	36.0	23.9	63.2	12.9	4.6	0.20
USA	1970	203.2	32.4	28.5	61.6	9.9	3.8	0.16

[a] Elderly dependency ratio $= \dfrac{\%(65+)}{\%(15\text{-}64)}$.

overall growth rate of the region, however, the share of the elderly will continue to be lower in Kanto than in the rest of Japan. Other regions experiencing a high increase in the number of aged persons by the year 2000 are British Columbia (220%) in Canada, the Caucasian Republics (210%) in the Soviet Union, and Sofia (200%) in Bulgaria. A few regions, mainly those centered on large cities, may expect a substantial decline in the number of their aged. In West Berlin, for example, the population in this age group will decrease by 55% and in Vienna by 35%. In 1971, one out of every five persons in Vienna was older than 65; by the year 2000, it will be one out of every seven (under the 1971 regimes of fertility, mortality, and migration).

Extrapolation of current trends identifies important differences in the graying of IIASA national populations; it also reveals important regional differences within countries. In a number of countries, one can already identify spatial concentrations of the aged: British Columbia in Canada, the Mediterranean Region in France, and the Shikoku Region in Japan. The analysis also shows that some regions with relatively old populations today are likely to exhibit younger age structures in the future, for example, Paris, Vienna, and West Berlin.

Table 9. Regional differentials in age composition in the reference year.

Country	Reference year	Number of regions	% population aged 0-14 [a]				% population aged 65+ [a]			
			N	L	H	$\frac{H-L}{N}$	N	L	H	$\frac{H-L}{N}$
Austria	1971	9	24.4	16.3	29.8	0.55	14.2	9.5	20.0	0.74
Bulgaria	1975	7	22.2	19.2	24.4	0.23	10.9	7.7	16.0	0.76
Canada	1971	10	31.2	29.9	38.8	0.31	7.9	6.0	10.9	0.62
Czechoslovakia	1975	10	23.4	18.9	28.6	0.41	12.1	9.1	15.7	0.55
FRG	1974	11	21.7	15.9	23.1	0.33	14.3	12.9	22.2	0.65
Finland	1974	12	22.4	21.2	26.7	0.25	10.3	7.3	13.4	0.59
France	1975	8	22.7	20.1	25.7	0.25	14.2	12.1	17.7	0.39
GDR	1975	5	21.3	20.0	24.0	0.19	16.3	13.5	17.9	0.27
Hungary	1974	6	19.9	16.1	23.9	0.39	12.3	11.2	13.7	0.21
Italy	1978	5	23.3	21.1	27.5	0.27	12.8	10.8	14.0	0.25
Japan	1970	8	24.0	22.9	26.0	0.13	7.1	5.8	9.9	0.58
Netherlands	1974	5	26.1	24.4	27.9	0.13	10.6	8.2	13.7	0.52
Poland	1977	13	23.9	17.4	26.8	0.39	9.9	6.3	11.5	0.53
Soviet Union	1974	8	27.0	21.3	34.7	0.50	10.0	6.3	12.0	0.57
Sweden	1974	8	20.7	19.6	21.9	0.11	14.8	12.8	16.8	0.28
United Kingdom	1970	10	23.9	22.5	26.2	0.15	12.9	11.0	14.9	0.30
USA	1970	4	28.5	27.2	29.2	0.07	9.9	8.9	10.6	0.17

[a] N means national; L means lowest; and H means highest.

5.2 *Population redistribution*

A number of IIASA member countries and regions within such countries may expect substantial changes in the age structures of their populations. Another demographic process that in some countries takes on an important dimension is the territorial redistribution of the national population. One of the most significant redistributions will probably occur in Japan. Whereas in 1970 the population of the largest region (Kanto) was 7.6 times the population of the smallest one (Shikoku); the ratio is expected to be 17.5 by the year 2000, and a further projection to stability shows it growing to 32.4. Table 10 sets out the long-run implications of current regimes of fertility, mortality, and migration for selected regions in IIASA countries.

Regions with declining population shares are, for example, Quebec, Vienna, the Northern Region in France, and the Kyushu Region in Japan. Areas with large gains in their shares of the total population are, for example, British Columbia, Berlin (German Democratic Republic), the Kanto Region of Japan, and the Central Asian Republics of the Soviet Union. It is a striking observation that, were the current regimes of the components of demographic growth to continue, almost half of the Japanese population eventually would live in the Kanto Region. The substantial changes expected in the population structure in Japan, both in age composition and in regional distribution, have led the government of Japan to initiate a study on population aging and on regional differences in aging populations. The analytical tools of multiregional demography, developed at IIASA were used in this analysis (Kawashima et al, 1981).

Table 10. Changes in shares of total population for selected regions in the IIASA member countries.

Country	Region	Regional share of national total (%)		
		reference year	year 2000	at stability
Austria	Vienna	21.7	17.9	7.4
Canada	Quebec	28.5	25.4	12.1
	British Columbia	9.8	12.9	21.1
France	Mediterranean	10.4	11.0	11.3
	North	7.5	7.2	6.7
GDR	Berlin	6.5	8.5	18.2
Italy	South	23.8	25.4	36.4
Japan	Kanto	28.9	38.9	46.6
	Kyushu	12.4	6.4	3.9
Soviet Union	Rural areas	40.4	24.8	20.2
	Central Asia	3.5	5.2	7.2
USA	West	17.1	20.7	23.0

6 Methodological research stimulated by the CMS study

The methodological work of the CMS study did not stop with the formalization of the analytical framework for spatial analysis adopted in the beginning of the study (Rogers, 1976a; 1976b). As that framework was applied to the various IIASA member countries, additional theoretical and empirical research was carried out to assess the validity and comparability of the various national results. Much of this research naturally was limited to the common element of each case study: the multiregional life table. Investigations were conducted to evaluate

(a) the *accuracy* of the procedure used to implement the simple Markov chain model, which underlies the multiregional life table,

(b) the *reliability* of this model.

6.1 *Estimation of survival probabilities in the CMS study*

The key element in the construction of a multiregional life table is the estimation of the age-specific probability matrices $\mathbf{p}_x$ from which all multiregional life-table functions originate. As noted in section 3.4, migration data may be collected by counting either movements (migrations) or transitions (migrants). Population registers record all changes of address and therefore represent the number of migrations observed during a given period, between each origin and destination. But, population censuses count the number of migrants who resided in a given region at an earlier fixed date and in another region at the time of the census. Since data on different geographical mobility flows are collected in these two ways, it is reasonable to expect that two distinct approaches to survival probability estimation would arise (Ledent, 1980). However, the earliest estimation methods (Rogers, 1973; 1975) developed approximate estimators that were consistent with both the movement and the transition perspectives by adopting the simplifying assumption that no multiple movements could take place within a unit age/time interval. These approximate estimators were called 'option 1' estimators (Rogers, 1975).

From an applied viewpoint, the problem was seen as one of appropriately measuring observed mobility rates. First, in the case of mobility data coming from a population register (movement perspective), each age-specific mobility rate M_x^{ij} could be readily estimated as the ratio of the observed number of movements (migrations) D_x^{ij} made from region i to region j over a given period $(t, t+T)$ by persons aged x to $x+n$ (at the time of the movement) to the number of person-years $\hat{K}_x^i$ lived in region i during that period by people aged x to $x+n$. Hence, taking the latter number as T times the arithmetic average of the beginning- and end-of-period populations aged x to $x+n$, M_x^{ij} could be derived from

$$\bar{M}_x^{ij} = \frac{2}{T}\,\frac{D_x^{ij}}{K_x^i(t)+K_x^i(t+T)}\,, \qquad j \neq i\,. \tag{1}$$

Alternatively, in the case of mobility data coming from a population census (transition perspective), Rogers (1975, pages 87–88) suggested that the number of transitions (migrants) O_x^{ij} from region i to region j observed over the period $(t, t+T)$ be simply substituted from the corresponding number of movements D_x^{ij}, which led to the following observed rate

$$M_x^{ij} = \frac{2}{T}\,\frac{O_x^{ij}}{K_x^i(t)+K_x^i(t+T)}\,, \qquad j \neq i\,. \tag{2}$$

Because of the assumption that only a single movement could occur per unit age/time interval, the application of 'option 1' estimators to mobility data for either movement or transition counts was perceived to be inadequate.

Fortunately, in the case of the movement perspective, this restrictive assumption could be relaxed (Schoen, 1975), and improved estimators, called 'option 3' estimators (Willekens and Rogers, 1978), could be obtained. The survival probability p_x^{ij} becomes the (j, i)th element of the matrix $\mathbf{p}_x$ (Rogers and Ledent, 1976):

$$\mathbf{p}_x = \left(\mathbf{I}+\frac{n}{2}\bar{\mathbf{M}}_x\right)^{-1}\left(\mathbf{I}-\frac{n}{2}\bar{\mathbf{M}}_x\right), \tag{3}$$

where $\mathbf{I}$ is an identity matrix, and $\bar{\mathbf{M}}_x$ is an age-specific matrix of annual mortality and mobility rates.

By contrast, in the case of the transition perspective, no useful alternative to the 'option 1' estimators was available. An attempt made by Rogers (1975, pages 85–88) led to estimators, known as 'option 2' estimators, which generally produced unstable results. Thus Willekens and Rogers (1978) suggested the substitution of 'option 3' for the 'option 1' estimators. The former seemed to yield more acceptable death probabilities than the latter, while producing very similar migration probabilities (Ledent and Rees, 1980, pages 53–57).

In other words, our initial investigations led us to conclude that, regardless of whether the mobility information available was in the count of movements or of transitions, the calculation of a multiregional life table could be performed by application of equation (3). It would be necessary, however, to measure the mobility rates appropriately, either by using equation (1), in the case of data counting movements, or by using equation (2), in the case of data counting transitions.

As shown in table 3, registration-based movement data for the CMS study were available in eleven out of the seventeen countries (that is, all of the European member nations of IIASA except Austria, France, and the United Kingdom) and census-based transition data were obtained in the other six (that is, the three countries just cited plus Canada, the United States of America, and Japan). The 'option 3' estimators were applied to all national case studies, except France. The French case study (Ledent with Courgeau, 1982) and additional analyses of the UK case study by Ledent and Rees (1980) incorporated some of the developments reported in this section.

We now shift the focus of our discussion to the transition perspective, for which only approximate estimators, 'option 1' and 'option 3', were found to be applicable. Fitting the latter estimators to the six IIASA countries with census-based mobility data revealed a certain ambiguity in the measurement of the observed mobility rates to be incorporated in equation (3). The definition of such rates in equation (2) does not indicate whether the age subscript attached to the numerator refers to the beginning of the period, the end of the period, or even the mid-period. Consequently, the observed rates were not measured uniformly; thus the numerator of equation (2) was measured with the age subscript referring to the end of the period in the Canadian case and to the beginning of the period in the US case.

Unfortunately, neither choice was correct because the transition perspective, unlike the movement perspective, does not allow an equivalence of the age/time space in which the data are gathered with that used in the model (Ledent and Rees, 1980, pages 45-47). Thus a possible procedure, used by Rees (1979a), is to estimate the number of migrants O_x^{ij} from data on adjacent groups, as follows

$$O_x^{ij} = \left(1 - \frac{T}{2n}\right) K_{x-n,\,\cdot}^{ij} + \frac{T}{2n} K_{x,\,\cdot}^{ij} \,, \qquad j \neq i \,, \tag{4}$$

where $K_{x,\,\cdot}^{ij}$ is the number of migrants from region i to region j relating to people aged x to $x+n$ at the beginning of the observation period(5).

Beyond the measurement of the mobility rates, a more important element of the transition perspective requiring improvement lay in the fundamental estimation equation which, as used in the CMS study, continued to be based on the assumption of no multiple movements. In attempting to relax this restrictive assumption, we explored two alternative approaches, hereafter denoted as approaches A and B.

First, we investigated whether the occurrence of multiple movements could be built into the 'option 1' framework (Ledent, 1982). The removal of the no-multiple-movement assumption allows deaths, occurring before age $x+n$ to the closed group of people present at age x in region i, to take place, not only in region i, but also in the other regions. New estimates, which did not differ significantly from those of the 'option 1' and 'option 3' methods, were then derived by disaggregating the total number of corresponding deaths according to the region of occurrence and introducing additional accounting equations. These equations reflect the hypothesis that when an individual moves into another region he or she becomes immediately subject to the risk of dying in that region.

The *first* approach (A) to relaxing Rogers's no-multiple-movement assumption was largely influenced by the classical estimation of survival probabilities in an ordinary life table; that is, it was based on the assumption of equal life-table and observed mobility *rates*. By contrast, the *second* approach (B) that was investigated drew on a

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(5) This revision of the measurement of the mobility rates was actually implemented in the UK case study (Rees, 1979a; 1979b).

technique sometimes used by demographers to calculate an ordinary life table, from census information, for countries in which the appropriate mortality data are lacking. This approach makes use of the concept of *survivorship proportions* and estimates the transition probability matrices $\mathbf{p}_x$ on the assumption of equal life-table and observed survivorship proportion matrices.

The initial development of this second approach was due to Rogers who devised the 'option 2' method, which was applicable to transition data over a fixed period of time. Specifically, this method derived the transition probability matrices $\mathbf{p}_x$ from the known values of the survivorship proportions $\mathbf{S}_x$ on the basis of an equation that follows from a linear estimation of the various numbers of person-years lived in the stationary population (Rogers, 1975, page 85).

'Option 2', however, led to unsatisfactory results in that the transition probability estimates that were obtained did not always lie between 0 and 1. The problem was traced to the inappropriateness of the underlying Markov chain model, whose impacts were amplified by the adoption of the linear integration hypothesis (Ledent and Rees, 1980, page 106).

The logic behind the 'option 2' method, however, is sound and it appears that more reasonable results may be obtained by the substitution of a somewhat different equation to link transition probabilities with survivorship proportions. For example, Rees and Wilson (1977) proposed the derivation of $\mathbf{p}_x$ by interpolating linearly between the survivorship proportions associated with the two age groups located immediately before and after age x. Recently, various extensions of this method, based on a cubic spline interpolation rather than a linear interpolation, were suggested by Ledent (1980, 1982) and Ledent and Rees (1980).

6.2 *Heterogeneity and the Markov chain model*

The above discussion has been devoted to an essentially empirical issue: the development of adequate methods for implementing the mathematical model underlying the multiregional life-table concept. Taking this model as given, we have attempted to devise appropriate probability estimation methods. Now we turn to an examination of the mathematical model itself.

The simple Markov chain model on which the multiregional life table is based relies on two stringent assumptions: the population-homogeneity assumption and the Markovian assumption. Evidence scattered throughout the literature, however, suggests that these two assumptions are far from being realistic. This casts doubts on the reliability of the statistics provided by a multiregional life table, even the most appropriately estimated one.

According to the assumption of population homogeneity, all individuals constituting the radix, or initial cohort, of a multiregional life table have identical demographic characteristics so that the same patterns of mortality and mobility apply to all. In the real world, however, mortality and especially mobility patterns generally vary from one homogeneous subgroup to another. Under these conditions it may be advisable to construct separate multiregional life tables for the mutually exclusive subgroups.

Ledent (1981), for example, showed that the calculation of multiregional life tables based on interregional mobility data cross-classified by place of birth produces significantly different results than those obtained without such a cross-classification. He calculated four multiregional life tables for data on the four US census regions observed during the period 1965-1970, one for each regional share of the initial cohort. Since the available mobility data were in the form of counts of migrants, he used the transition-based approach B.

The numerical results obtained by Ledent confirmed the general observation that the probability of moving from region *i* to region *j* is smaller for those born in region *i* and much higher for those born in region *j* than for those born neither in region *i* nor in region *j*.

Total years of expected life—disaggregated into periods specific to the regions in which they are to be spent—were found to be substantially different from the corresponding figures obtained in simple multiregional life-table calculations using the same data but aggregated over all regions of birth. According to Ledent's calculations using data for the United States of America, switching from place-of-birth-independent to place-of-birth-dependent mobility data cuts the proportion of lifetime to be spent outside the region of birth by about half, except in the case of Western-born women for whom the cut amounts to slightly more than 70%.

The second important assumption implicit in a Markov chain model is the so-called Markovian property, which holds that the probability of an individual changing states is independent of his or her past mobility history. Obviously this assumption does not adequately reflect reality, especially in the case of geographical mobility. Individuals who have just moved are prone to move again, either to a third region or back to their region of origin. They tend, in consequence, to constitute a pool of 'chronic' movers (Morrison, 1971).

The Markovian assumption has important consequences for the statistics of a multiregional life table, consequences that are likely to occur between, as well as within, the various age intervals considered. Regarding the impacts *between* the age intervals, we note that the Markovian assumption is used to proceed from one age interval to the next. Therefore, everything else being equal, the degree of error increases with the number of age intervals. To put it in approximate but more revealing terms, the model based on single-year groups (generally eighty-five such age groups plus one open-ended group for age 85 and over) uses the Markov assumption eighty-six times, whereas the model based on five-year age groups (generally seventeen such age groups plus one open-ended group of age 85 and over) uses it only eighteen times. Thus, the wider the age interval, the smaller the number of intervals and the smaller the impact of the Markovian assumption.

This conclusion, however, is valid only to the extent that everything else is indeed equal—that is, the age-specific transition probabilities in the models both with one-year and with five-year age groups are known exactly. Since this is not the case, we are brought naturally to the second impact of the Markovian assumption, the one *within* age groups.

In this case, we must distinguish between the movement and transition perspectives, which appear to be affected differently. In the movement perspective the estimation equations reflect a mobility process that is close to being Markovian, throughout each age interval, thus giving rise to little return or chain migration. We believe that the estimators of the movement perspective, therefore, fail to account adequately for return migration. In other words, the Markovian assumption tends to inflate migration probabilities and to deflate retention probabilities, a phenomenon that actually is well substantiated in the literature on social mobility (for example, see Singer and Spilerman, 1978). Moreover, since the importance of return migration and the bias introduced therefrom tend to increase with the length of the observation period, the smaller the age interval, the more accurate the transition probability estimates.

In contrast to the movement perspective, the transition perspective (if correctly implemented) adequately accounts for return and chain migration; this is especially the case in approach B. Moreover, such a statement applies regardless of the choice of the age interval width, *n*, provided that it is equal to the length of the observation period, *T*.

The consequences of violating the equality between length of age interval and observation period have been well illustrated by Rees, who analyzes a three-region system of the United Kingdom and a population disaggregated into five-year and one-year age groups. The migration (retention) probabilities obtained using one-year mobility data (Rees, 1979a) are substantially higher than those obtained using five-year mobility data (Rees, 1979b). In other words, taking $n > T$ rather than $n = T$ leads to transition probabilities that suffer from the same defect as those derived in the movement perspective; they fail to account accurately for multiple movements.

Summarizing, we note that the Markovian assumption affects the movement perspective both within and between age groups, that is, it tends to exaggerate at any single age the probability of transferring to another region. As a result

(a) the smaller the age interval width, the more reliable the transition probability estimates, *but*

(b) the age interval width has no impact on the reliability of the multiregional statistics relating to an extended period of time (possibly a lifetime).

The transition perspective is affected by the Markovian assumption only at the passage from one age group to the next so that, compared with the movement perspective, it attenuates the stringent consequences of this assumption. Therefore,

(a) the width of each age interval n has no bearing on the reliability of the transition probability estimators so long as $n = T$;

(b) the larger the T (regardless of n), the better the estimates of the multiregional statistics relating to an extended period of time because of the less-frequent use of the Markovian assumption when advancing through the age groups.

Finally, going one step further, we argue that the availability of mobility data in the count of transitions over a longer period (for example, $T = 5$) necessarily leads to substantially better statistics than the availability of similar data over a shorter period and hence of data in the count of movements (regardless of the length of the observation period). Consequently, it is impossible to carry out a direct comparison of the results obtained in the various national case studies of the CMS project, in which these alternative types of data were used.

7 Concluding remarks

A comparative analysis of patterns of migration and population distribution requires comparable data bases and the application of uniform analytical techniques to derive demographic measures that are truly comparable. The CMS study satisfied the second requirement by consistently applying the methods of multiregional demography, which provides the analytical framework needed to integrate migration flows with regional fertility and mortality patterns. This is necessary because population redistribution is not only a consequence of migration; regional differences in fertility and mortality regimes also determine spatial population change. The application of this framework in each of the seventeen studies was made possible by the availability of a standard package of computer programs.

The major obstacle in the CMS study was the inadequacy of the data bases. Data, particularly those describing migration, were incomplete in several countries and were never directly comparable. The problem of incomplete data was resolved by the application of estimation techniques developed for this purpose (Willekens et al, 1981), but the limitations in comparability could not be dealt with satisfactorily. Methodological research, which was lacking at the time, has only recently been initiated. As a consequence, cross-national comparisons of the results of the CMS study have been de-emphasized in this paper. Interregional comparisons are drawn instead.

The comparative research revealed the following:

Mortality. Although regional disparities in aggregate levels of mortality, expressed as life expectancies, are small, there are considerable differences in mortality regimes. Large disparities in infant mortality and young adult mortality are evident.

Fertility. Fertility disparities are significant, both in terms of level and of age structure. Countries with large regional variations in the levels of fertility also tend to have large regional variations in the age pattern of fertility.

Migration. The comparison of migration levels is impossible unless measures can be developed that remove the effects of variations in reference periods and in sizes of regions. Regional disparities in retention levels confound the effects of regional size and mobility level. The age profile of migration is less affected by differences in spatial and temporal dimensions. Parametrization of migration schedules indicates large regional variations—variations that are not random but that exhibit systematic patterns, which allows the development of synthetic *model* schedules. Families of migration schedules may be distinguished on the basis of the values exhibited by the parameters of such model migration schedules.

A comparative analysis like the CMS study can give the impression (at least to the researchers involved) that it creates more problems than it solves. The application of the improved methodology of multiregional analysis to the conventional data bases that are currently available poses many problems. Because of the methods considered, weaknesses in the data were revealed that otherwise might have remained hidden, thus generating new empirical and methodological research efforts.

A few illustrations of the research generated by the CMS study were presented in the latter half of this paper. Such research has produced several interesting conclusions, which help us to judge the validity and comparability of the various national results and to advise researchers on the appropriate design of future studies of this sort.

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APPENDIX

Table A1. Comparative migration and settlement study research reports.

Title	Author/editor	Reference number
Theory and models		
Migration and Settlement: Selected Essays [reprinted from a special issue of *Environment and Planning A* 1978 **10**(5)]	A Rogers (Ed.)	RR-78-6
Migration and Settlement: Measurement and Analysis	A Rogers, F Willekens	RR-78-13
Spatial Population Analysis: Methods and Computer Programs	F Willekens, A Rogers	RR-78-18
Migration Patterns and Population Redistribution [reprinted from *Regional Science and Urban Economics* 1979 **9** 275–310]	A Rogers	RR-80-7
Essays in Multistate Demography [reprinted from a special issue of *Environment and Planning A* 1980 **12**(5)]	A Rogers (Ed.)	RR-80-10
Multidimensionality in Population Analysis [reprinted from *Sociological Methodology* Ed. K Schuessler, 1980 (Jossey-Bass, San Francisco, CA) pp 191–218]	N Keyfitz	RR-80-33
Advances in Multiregional Demography	A Rogers (Ed.)	RR-81-6
Model Migration Schedules	A Rogers, L Castro	RR-81-30
National case studies		
Migration and Settlement:		
1. United Kingdom	P Rees	RR-79-3
2. Finland	K Rikkinen	RR-79-9
3. Sweden	Å Andersson, I Holmberg	RR-80-5
4. GDR	G Mohs	RR-80-6
5. Netherlands	P Drewe	RR-80-13
6. Canada	M Termote	RR-80-29
7. Hungary	K Bies, K Tekse	RR-80-34
8. Soviet Union	S Soboleva	RR-80-36
9. FRG	R Koch, H-P Gatzweiler	RR-80-37
10. Austria	M Sauberer	RR-81-16
11. Poland	K Dziewoński, P Korcelli	RR-81-20
12. Bulgaria	D Philipov	RR-81-21
13. Japan	Z Nanjo, T Kawashima, T Kuroda	RR-82-5
14. USA	L Long, W Frey	RR-82-15
15. France	J Ledent with D Courgeau	RR-82-28
16. Czechoslovakia	K Kühnl	RR-82-32
17. Italy	D Campisi, A La Bella, G Rabino	RR-82-33

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Marriage, divorce, and remarriage from retrospective data: a multiregional approach

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Abstract. In this paper the author applies the framework of multiregional population analysis to marital status changes as revealed by longitudinal retrospective data on marital histories collected as part of the June 1975 Current Population Survey supplement. Four marital statuses are used: never married, presently married, divorced, and widowed. Marital status life tables are computed for three periods: 1960-1965, 1965-1970, and 1970-1975, and, for each period, differences between males and females and between whites and blacks are described. We examine the proportion of a life-table cohort ever marrying, the mean age at first marriage, the number of marriages per person marrying, the proportion of marriages ending in divorce, the average duration of a marriage (or a divorce, or a widowhood), and the like.

1 Introduction

Many phenomena in the social sciences have as their central feature the fact that individuals make transitions over their lifetimes from one discrete status to another. Geographic mobility is one such example. If we imagine the population of a country as comprising an interconnected system made up of separate states or regions, then commonly an individual will live in more than one state during his lifetime. Some individuals may never leave their state of birth, whereas others may return to it at a later age (DaVanzo, 1980). Other aspects of human behavior that are formally analogous to physical moves between physical regions include transitions from one marital status to another, entry into and exit from the labor force, social and occupational mobility, changes in the living arrangements of children, and the completion or resumption of education.

Until recently, methods did not exist to capture simultaneously the full range of individuals' lifetime experiences as related to the number of possible transitions actually experienced and the amount of time spent in each state. Such formal demographic models as developed by Coale (1972) and Keyfitz (1968) lacked a spatial dimension, and life-table processes, including multiple decrement life tables, failed to allow for reentry into previously occupied statuses. Even the use of proportional hazards models that permit the researcher to introduce covariates into the life-table analysis is limited to exits from a single state.

Work to remedy these deficiencies has been pioneered by Rogers, who first introduced the multiregional life table (Rogers, 1973a; 1973b) and later generalized the results in single-region demography to include many regions simultaneously (Rogers, 1975). Multiregional, or increment-decrement, life tables permit simultaneous entry into (increments) and exit from (decrements) the l_x column of multistate life tables. The distinctive feature of the increment-decrement approach is that age-specific gross flows into and out of categories are explicitly taken into account.

In the past several years, theoretical work on the construction of increment-decrement life tables has been advanced through further contributions by Rogers and his colleagues (see, for example, Rogers and Ledent, 1976; 1977; Willekens and Rogers, 1978; Keyfitz, 1979; Rees, 1980; Rogers, 1980; 1981; and Willekens et al, 1982) and by Schoen (1975; 1976; 1977; 1979) and Schoen and Land (1979).

There is now growing agreement on the proper way to calculate life-table transition probabilities, although the matrix formulation of the problem that Rogers recommends is simpler and permits greater flexibility in applications.

Techniques of multiregional population analysis were developed initially to model patterns of interregional migration within a country. As long as a closed population can be subdivided into regions and data are available to describe the gross (as opposed to net) flows of individuals from one region to another, multistate methods are appropriate. A major example of applied work using the multiregional framework can be found in the country reports of the Comparative Migration and Settlement (CMS) Study, carried out by the International Institute for Applied Systems Analysis (IIASA), in collaboration with scholars from each of the seventeen member countries of IIASA. The aim of this project is a quantitative assessment of migration and population distribution patterns in member nations when a common analytic strategy is applied(1).

However, from their early uses, multistate methods have been applied to such other areas as tables of working life showing movements into and out of the labor force (Hoem and Fong, 1976; Schoen and Woodrow, 1979; Smith, 1980; Willekens, 1980), marital status changes (Schoen and Nelson, 1974; Schoen and Urton, 1977; 1979; Krishnamoorthy, 1979; Koesoebjono, 1981; and Willekens et al, 1982), living arrangements of children (Hofferth, 1982), the educational system (Stone, 1971; 1975), social mobility (Illingworth, 1976), and fertility (Suchindran et al, 1977; Koo and Suchindran, 1978; Suchindran and Koo, 1980).

Each of these uses of multiregional methods possesses certain common features. They are applicable to situations in which the central interest is in describing the patterns of individuals' transitions between and among mutually exclusive, discrete statuses and to situations in which it is recognized that not all individuals will experience all possible transitions over their lifetimes. The methods themselves allow for reentry into previously occupied statuses, for the possibility that not all statuses will be experienced by all individuals, and for the fact that the order in which alternative states are experienced varies across individuals. The flexibility of these methods in characterizing the heterogeneity of individual experience over time and as individuals age makes them particularly well suited to a study of life-course transitions.

The purpose of this paper is to apply the methods of multiregional demographic analysis to data on the self-reported marital histories of adult men and women in the United States of America with the aim of clarifying the lifetime experiences of Americans with regard to marriage, marital disruption, and remarriage. As we have noted, the application of multistate methods to marital status changes is not new, nor even is their use with data from the United States of America. The contribution of this paper lies elsewhere. First, one of the advantages of the matrix-oriented formulas provided by Rogers (1975) and Willekens and Rogers (1978) is that population-based and status-based life-table measures may both be computed(2). These specific procedures have not been applied to US data. Second, the work by Schoen and Nelson (1974) and Krishnamoorthy (1979) uses census and vital statistics data. In my study I rely on self-reported event histories of the marital careers of men and women. These event histories present some special opportunities in the construction

(1) The techniques of multiregional demographic analysis that are used in these country reports and the associated computer programs are described in Willekens and Rogers (1978). The member nations are the Soviet Union, Canada, Czechoslovakia, France, German Democratic Republic, Japan, Federal Republic of Germany, Bulgaria, United States of America, Italy, Poland, United Kingdom, Austria, Hungary, Sweden, Finland, and The Netherlands.

(2) For the distinction between these two concepts, see Willekens et al (1982) and the discussion to follow.

of occurrence–exposure transition rates. Last, no multistate life-table analysis of US data has examined differentials between whites and blacks in the incidence of marriage, divorce, and remarriage.

2 The nature of marital status transitions

In the research discussed here, I have followed convention by distinguishing four marital status categories: never married, presently married, divorced, and widowed. Each marital status is viewed as a discrete 'state' that an individual may occupy, and the event, for example of becoming married for the first time may be thought of as a move or a transition from the never married state to the presently married state. The full range of marital status transitions that I entertain is shown in figure 1.

Transitions between the never married and presently married states are possible in one direction only. Persons who are presently married may become divorced, widowed, and remarriages by divorced and widowed persons are possible. Notice that no direct transitions between the widowed and divorced states are permitted. Death may occur at any age and in any marital status in which case individuals encounter a transition to the absorbing state 'dead'. Figure 1 is a moderately complex representation of the process by which the marital status composition of a population undergoes change. On a simpler level, we could distinguish between the never married and the ever married states. But, a more disaggregated configuration of marital patterns than that in figure 1 would recognize separated persons as belonging to a distinct marital status group. And it may even prove useful to distinguish between individuals married for the first time and those in a second or higher-order marriage.

One of the advantages of adopting a multiregional life-table approach to marital status changes is that it allows us to summarize in a compact way the marital careers of men and women over their lifetimes. With this lifetime perspective, we are able to answer a number of important questions.

(1) With respect to patterns of first marriage, what is the proportion of a cohort ever marrying? What is the mean age at marriage?

(2) With regard to the presently married state, what is the expected length of a marriage, and the number of marriages per person marrying?

(3) How frequent is remarriage among the divorced population, and how does it contrast with that among the widowed population? How do average ages at remarriage compare for divorced and widowed persons?

(4) What is the probability that a marriage will end in a divorce or a widowhood? What is the average age at widowhood? What is the average age at widowhood and at divorce?

(5) On the basis of current rates of mortality, marriage, divorce, remarriage, and the like, what fraction of one's life can an individual expect to spend single, married, widowed, and divorced? How do these proportions vary between whites and blacks and between males and females?

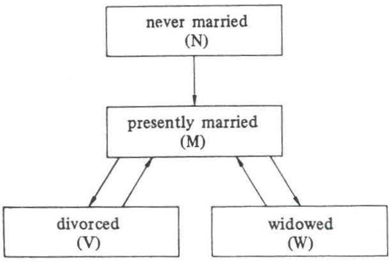

Figure 1. The nature of marital status transitions when four marital status categories are recognized.

3 Data and methods

3.1 *Data*

To implement the multiregional approach requires data on the transitions that individuals make over their lifetimes between and among alternative marital status categories. Such data have been collected periodically by the US Bureau of the Census as special supplements to the monthly Current Population Survey (CPS). In this paper I rely on information obtained from the marital and fertility history supplement to the June 1975 CPS.

The CPS deals mainly with labor-force data and is the source of the monthly unemployment rate estimates for the USA. Questions relating to labor-force participation are asked about each household member of fourteen years or older(3). In June 1975, supplemental questions relating to marital history were also asked of the same sample. In addition to their current marital status, persons were asked how many times they had been married, when they had married for the first time, whether that marriage had ended in widowhood or divorce, and when that marriage had ended (if it was no longer intact). And if they had remarried, individuals were asked when they had entered their latest marriage and when that marriage had ended (if it was no longer intact). All dates were recorded in terms of month and year, and this detail was used in deriving age at each event or the interval between events (US Bureau of the Census, 1976). In the case of nonresponses, values were allocated to persons by substituting a value that was reported by a previously processed person of similar characteristics.

For the purpose of this analysis, persons who reported their current marital status as "separated" were considered to be in the presently married category. In addition, persons who said they had been married three or more times were excluded, since it was preferable to work with continuous marital histories and since the June 1975 CPS asked only about an individual's first and most recent marriage. The sample is not much affected if it is restricted to persons married fewer than three times. The US Bureau of the Census reports that of all men born between 1900 and 1959, 26.1% were single in 1975, 62.5% were married once, 9.8% twice, and 1.5% three or more times. The age of the respondent naturally affects this distribution. Less than 1% of men born in 1945 or later were married three or more times, in comparison with 3.4% of men born between 1900 and 1909. The statistics for women are nearly equivalent. Of those born between 1900 and 1959, 20.6% were single in 1975, 67.0% were married once, 10.8% married twice, and 1.7% had married three or more times. The maximum percentage of any birth cohort marrying three or more times (3.7%) was for the cohort of women born between 1900 and 1904 (US Bureau of the Census, 1976). With this restriction, there are 98 806 cases left in the sample.

3.2 *Methods*

The multiregional life-table approach developed by Rogers relies on a Markov transition probability matrix to summarize the marital careers of cohorts of individuals. In a Markov process, one necessary assumption is that rates of dying and of moving from one state to another depend only on age and the state in which the person is currently living (Krishnamoorthy, 1979). The mathematics of Rogers's methodology as applied to marital status life tables have been fully described in a recent paper by Willekens et al (1982). To perform the computations reported here, I have relied on a modification of the computer program reproduced in Willekens and Rogers (1978).

(3) The CPS is limited to the civilian population of the USA, excluding the relatively small number of inmates of institutions.

The particular adaptation, termed LIFEINDEC, is designed to handle situations in which individuals are born in only one state and in which age intervals are of unequal width (Willekens, 1979).

As in the ordinary single-state, single-decrement life table, the transition probabilities in a multiregional life table determine all other life-table parameters. There are two approaches to computing these multistate transition probabilities, and which one is chosen usually depends upon the form of the available data. In the 'transition' approach, an interstate passage is viewed as a change in state between two points in time. The data are in the form of survivorship proportions and are derived from the number of transitions (or movers). A typical application is to interregional migration, where data are often based on answers to the census question, "Where did you live n years ago?" By contrast, in the 'movement approach' an interstate passage is an instantaneous event similar to a birth or a death, and the frequency of these events (moves) is measured by occurrence–exposure transition rates.

These data on the marital event histories of men and women lend themselves to either computational procedure. But, since the death data needed to accompany the information on marital status changes are in the form of death rates rather than survivorship proportions, I have adopted the 'movement' perspective for the marital status transition rates as well. To be precise, each age-specific marital status transition rate or occurrence–exposure rate is computed just like any other demographic rate, namely, as the number of occurrences of an event (E) during a specified period of time to the population 'at risk' of experiencing the event, divided by the number of person-years lived by the population 'at risk' during the same period of time.

We need to calculate age-specific transition rates for each of the five possible transitions in figure 1. These rates are then entered into the LIFEINDEC computer program. To give one example, assume the time period in question is 1970–1975 (specifically, 1 June 1970 to 31 May 1975) and that we are interested in the behavior of white females between exact age 20 and exact age 21. Then the age-specific transition rate of moving from the never married state (N) to the presently married state (M) is given by

$$\mathrm{N}^{\mathrm{M}}_{R_{20}} = \begin{array}{l}\text{the number of first marriages}\\ \text{during the period 1970–1975}\\ \text{to never married white females}\\ \text{between exact ages 20 and 21}\end{array} \Bigg/ \begin{array}{l}\text{the number of person-years lived}\\ \text{during the period 1970–1975}\\ \text{by never married white females}\\ \text{between exact ages 20 and 21}\end{array}$$

The remaining four transition rates are defined in a similar fashion. The rate from married to divorced, for instance, contains the number of divorces in the numerator and the number of person-years lived by married persons in the denominator.

To give the reader some sense of the age pattern of the underlying data, I have graphed in figure 2 the complete set of transition rates for each of the five possible transitions corresponding to white females in the period 1970–1975. Notice that, with the exception of the transition to widowhood, most of the activity is concentrated in the age range 15 to 44.

In addition to marital status transition rates, we need death rates by age and by marital status to compute the increment–decrement life-table transition probabilities. In this particular application, we require death rates by age, race, sex, and marital status since we want to examine differentials between males and females and between blacks and whites. Death rates in this degree of detail have been published for the USA only as recently as 1959–1961 (National Center for Health Statistics, 1970a, 1970b). To obtain death rates since 1959–1961, a process of indirect standardization was employed (Shryock and Siegel, 1980, pages 421–422), whereby death rates for 1959–1961 are applied to populations disaggregated by age, race, sex, and marital status to compute the expected number of deaths in a particular age-race-sex category on the assumption that 1959-1961 death rates still hold in the later period. Then, based on the proportionate differences between the expected number and the actual number of deaths, death rates in the same age-race-sex category in 1959-1961 are given an equal proportionate adjustment.

Age-specific transition rates and death rates are then used to produce the multiregional life-table transition probabilities using a procedure similar to that in the ordinary life-table case. The matrix formula (Willekens and Rogers, 1978) is

$$\mathbf{P}(x) = [\mathbf{I}+\tfrac{5}{2}\mathbf{M}(x)]^{-1}[\mathbf{I}-\tfrac{5}{2}\mathbf{M}(x)] ,$$

where $\mathbf{P}(x)$ is the matrix of transition probabilities, $\mathbf{M}(x)$ is the matrix of age-specific mortality and marital status transition rates, $\mathbf{I}$ is the identity matrix, and five-year ($n = 5$) age intervals are assumed. One matrix of survival probabilities is calculated for each exact age (0, 5, 10, ...). The elements $p_{ij}(x)$ of $\mathbf{P}(x)$ represent the probability that an individual in state i at exact age x will survive and be in state j at exact age $x+5$. Since the probability of surviving and of dying must sum to unity, the probability of dying between exact age x and $x+5$ can be found by subtraction. The complete set of transition probabilities for white US females for 1970-1975 is shown in appendix table A1. Notice that the probabilities for each age sum to one.

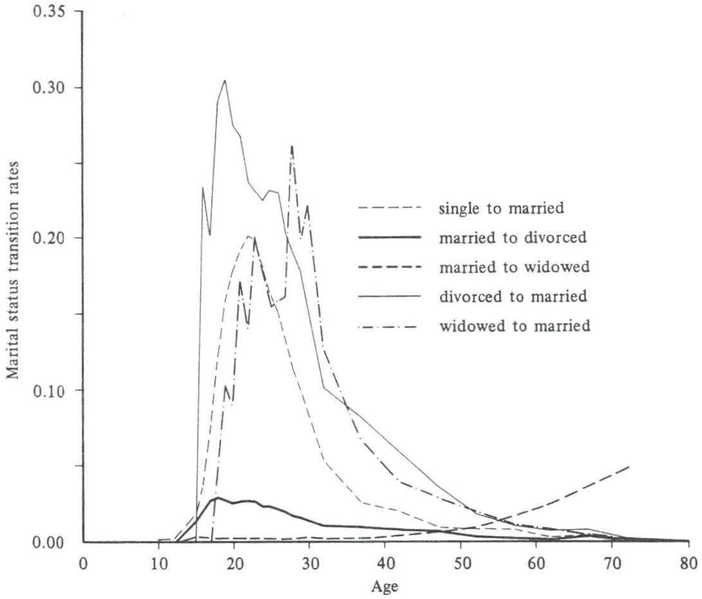

Figure 2. Marital status transition rates for white US females, 1970-1975.

4 Results

Marital status life tables reflect in a compact way the implications of a given set of death rates and marital status transition rates by tracing out the lifetime experiences of a hypothetical birth cohort of individuals, if these individuals are subject at each age to the risks of dying and of changing marital status that have been observed in an actual population. In this paper, I discuss the results of marital status life tables calculated for three time periods: 1960-1965, 1965-1970, and 1970-1975. In addition, for each time period, separate life tables have been estimated for white females, black females, all females, white males, black males, and all males. Tables 1, 2 and 3 are limited to white females in 1970–1975. They represent the types of life-table parameters one may obtain with a multiregional approach and illustrate the greater flexibility in handling the data when the computations are cast in matrix form. Tables 4 and 5 compare the lifetime experiences of several US subpopulations with regard to the more interesting issues in family demography.

Table 1 is analogous to the l_x column of an ordinary life table. It shows the expected number of survivors to any exact age x and how the survivors would be distributed by marital status, given the underlying mortality and marital status transition rates, if 100000 individuals began life together in the single (that is, never married) state. In the June 1975 CPS very few persons reported marriages occurring prior to age 15. Moreover, given the favorable mortality experience of white females in the 1970–1975 period, an estimated 90% of an initial cohort would survive to age fifty-five, when over 75% of the survivors would be married.

One interesting way to gauge the tempo of marital events in a life-table cohort is to note the age at which the expected number of persons in each marital status reaches a maximum. For the single population this age is age 0, because persons are removed from the single category by death and first marriage, and reentries to the single state are by assumption not possible. The greatest number of married persons

Table 1. Expected number of survivors at exact age x from a cohort who were single at age 0 in each status for white US females, 1970–1975.

Age (x)	Total	Single	Married	Divorced	Widowed
0	100000	100000	0	0	0
1	98592	98592	0	0	0
5	98349	98349	0	0	0
10	98203	98203	0	0	0
15	98076	97194	882	0	0
16	98030	95334	2665	25	6
17	97980	91545	6302	116	18
18	97927	94313	13213	363	39
19	97870	74023	22970	804	72
20	97810	62057	34267	1364	122
21	97749	50796	44778	2023	152
22	97687	40851	53854	2806	176
23	97625	32470	61278	3687	190
24	97561	25890	66963	4489	219
25	97495	21101	71070	5055	269
26	97427	17581	73995	5549	302
27	97357	14842	76293	5872	350
28	97285	12822	77905	6210	347
29	97210	11332	79175	6287	416
30	97133	10175	80071	6409	478
35	96652	7282	81031	7659	679
40	95930	6233	80036	8266	1395
45	94834	5454	77884	8728	2767
50	93155	5086	74025	9111	4933
55	90660	4725	69019	8933	7984
60	87076	4355	60991	8644	13086
65	81993	4058	50413	8009	19514
70	74728	3621	38555	7162	25389
75	64494	3142	24497	6149	30706

is at age 35, of divorced persons at age 50, and of widowed persons at ages 75 and over. In the early stages of its life cycle a cohort becomes increasingly married. For white females in 1970–1975, for example, approximately five out of every six survivors to age 35 or 40 is in the presently married category. As the cohort continues to age, higher male mortality pushes more women into the widowed group, so that by age 75 nearly half the survivors in table 1 are widowed.

Shown in table 2 are measures of life expectancy at exact age *x* for persons who were in the single state at exact age 0. These figures are what Willekens et al (1982) refer to as population-based measures, and they are computed as the total number of person-years remaining to be lived beyond age *x* in each marital status divided by the number of survivors to age *x*. Based on data for 1970–1975, the average cohort member at birth has a total life expectancy of 76.6 years, of which 24.3 years can be expected to be lived in the single state, 38.3 years in the married state, 4.8 years as divorced, and 9.2 years widowed. By the time the cohort reaches age 18, remaining life expectancy has been reduced to 60.2 years, but this reduction is due almost entirely to a corresponding reduction in time spent never married. At age 18, 11.6% of remaining cohort life expectancy will be lived in the single state in contrast to 31.8% at birth. But, even though the absolute number of years lived in the married state changes little between ages 0 and 18, as a percentage of the total across all

Table 2. Expectations of life (in years) by status for a cohort who were single at age 0 for white US females, 1970–1975.

Age (*x*)	Total	Single	Married	Divorced	Widowed
0	76.61667	24.33066	38.26437	4.82312	9.19855
1	76.70399	23.67107	38.81097	4.89202	9.32995
5	72.88829	19.72458	38.90669	4.90403	9.35296
10	67.99297	14.75027	38.96449	4.91137	9.36685
15	63.07306	9.78868	38.99265	4.91775	9.37902
16	62.10730	8.81126	38.99277	4.91992	9.38337
17	61.13841	7.86206	38.96669	4.92169	9.38799
18	60.17143	6.96844	38.88828	4.92192	9.39281
19	59.20619	6.16360	38.72607	4.91883	9.39772
20	58.24213	5.47174	38.45718	4.91076	9.40247
21	57.27843	4.89792	38.07704	4.89652	9.40698
22	56.31453	4.43194	37.59642	4.87492	9.41128
23	55.34995	4.05923	37.03061	4.84475	9.41538
24	54.38582	3.76279	36.39758	4.80602	9.41944
25	53.42213	3.52433	35.71423	4.76031	9.42329
26	52.45900	3.32827	34.99463	4.70921	9.42691
27	51.49640	3.16415	34.24799	4.65394	9.43035
28	50.53432	3.02432	33.48094	4.59530	9.43378
29	49.57285	2.90241	32.69878	4.53456	9.43712
30	48.61197	2.79402	31.90511	4.47282	9.44004
35	43.84138	2.35636	27.89677	4.13119	9.45708
40	39.15250	2.02188	23.90921	3.74723	9.47420
45	34.57625	1.73715	20.02255	3.34255	9.47401
50	30.15431	1.48558	16.30661	2.92405	9.43808
55	25.91531	1.25592	12.81085	2.50696	9.34161
60	21.87909	1.04693	9.60550	2.10552	9.12115
65	18.08046	0.85530	6.80425	1.72830	8.69261
70	14.59527	0.68153	4.48940	1.38880	8.03555
75	11.51455	0.52750	2.75766	1.09319	7.13620

marital statuses, the figure rises from 49.9% to 64.6%. Because most of the person-years that women live in the widowed state are experienced when they become older, the fraction of total remaining life expectancy women can look forward to as a widow rises with age. For white females at age 65, this is 48.1%, and it increases to 62.0% at age 75.

One of the advantages of using Rogers's matrix form of computation for marital status life tables is that it permits one to derive status-based measures of life expectancy. Even though the underlying transition probabilities remain unchanged, it is possible with the matrix approach to consider a cohort starting at any age and in any marital status. Some illustrations are given in table 3(4). For example, persons who are married at age 45 have on average 34.75 additional years remaining to be lived, of which 23.26 will be spent married, 1.40 divorced, and 10.09 widowed. Several points are noteworthy. First, marital status differentials in mortality are small enough, and there is sufficient interchange of individuals between marital statuses that, for most ages except the very oldest, total life expectancy at age x depends little on marital status at age x. At age 30, for instance, life expectancy varies from a low value of 48.0 years for single persons to a high value of 48.7 years for married individuals.

However, the *distribution* of remaining life expectancy across marital status categories depends very much on one's marital status at age x. Table 3 thus reflects in another way the fact that, with the exception of becoming widowed, much of the change in marital status that white females in the USA experienced in the period 1970–1975 was confined to ages under 45. Regardless of one's marital status at age 18, more person-years are likely to be lived in the married state than in any other state. In some sense, then, the married state acts like a magnet for young adults attracting people to it. Even those who have already rejected one marriage partner and who are divorced at age 18 have not rejected the institution of marriage, because over two-thirds of their remaining life expectancy of 60.1 years will be spent in the married state.

In contrast, by age 45 the picture is strikingly different. At that age, persons are likely to spend the largest share of their remaining years in the marital status they have attained by age 45. If individuals have never married by age 45, it is unlikely that they will ever do so. If they are married, only one-third of their remaining years will be spent not married, and most of those will be spent widowed. And if they are widowed or divorced at age 45, they can look forward to most of their remaining years in the same marital status.

In his important study of historical patterns of marriage, marital dissolution, and remarriage in the USA, Cherlin (1981) argues that an important task for the demographer is to shape the mass of statistical data on family life "into a coherent picture of the lifetime experiences of men and women" (page 7). In its analysis of the marital history data from the June 1975 CPS, the US Bureau of the Census (1976; 1977) focuses attention on selected episodes in the marital careers of men and women, but there seems to be no convenient way that the Bureau of the Census has found of synthesizing this rich variety of experience into summaries of lifetime patterns. In tables 4 and 5, I make a step in this direction by presenting comparative summary statistics on lifetime experiences of marriage, marital disruption, and remarriage.

Much recent attention has been focused on the propensity of young men and women in the USA to refrain from entering into marriage as early as their older siblings or parents have done. The percent of never married females aged 20–24 increased, for example, from 35.8% in 1970 to 50.2% in 1980, and for men the corresponding figures are 54.7% and 68.6% (US Bureau of the Census, 1981).

(4) Willekens et al (1982) point out that Schoen and Nelson (1974) and Krishnamoorthy (1979) have derived and discussed population-based measures of the duration of married life, but it is only in the context of a multiregional approach that status-based measures can be obtained.

Table 3. Expectations of life (in years) by status at age x for white US females, 1970-1975.

Age (x)	Total	Status			
		single	married	divorced	widowed
Single at age x					
18	60.15685	8.09369	37.97504	4.78209	9.30605
19	59.17574	8.14922	37.13496	4.66371	9.22787
20	58.18672	8.62425	35.96336	4.49587	9.10324
21	57.19014	9.42518	34.54390	4.28905	8.93202
22	56.18459	10.59796	32.84618	4.03911	8.70138
23	55.16811	12.20448	30.82603	3.74171	8.39591
24	54.14212	14.17940	28.53935	3.40691	8.01648
25	53.11285	16.28381	26.17517	3.06234	7.59155
26	52.08302	18.44431	23.78986	2.71735	7.13152
27	51.04994	20.75510	21.30896	2.36374	6.62215
28	50.02191	22.94580	18.93735	2.03151	6.10726
29	49.00267	24.89853	16.76244	1.73104	5.61068
30	47.99161	26.67133	14.73858	1.45484	5.12688
35	43.11218	31.27455	7.96022	0.60238	3.27507
40	38.48973	31.11758	4.84111	0.27294	2.25813
45	34.02878	30.20490	2.41843	0.08187	1.32361
50	29.75920	27.20744	1.56929	0.03782	0.94466
55	25.62823	24.09978	0.91055	0.01664	0.60127
60	21.62074	20.93190	0.39226	0.00528	0.29131
65	17.83083	17.28023	0.30936	0.00365	0.23759
70	14.26124	14.06321	0.10817	0.00111	0.08875
75	11.03969	10.82732	0.11573	0.00120	0.09544
Married at age x					
18	60.26611	0.0	44.64055	5.71095	9.91463
19	59.30690	0.0	43.78973	5.60676	9.91042
20	58.34593	0.0	42.93750	5.50060	9.90784
21	57.38319	0.0	42.07999	5.39356	9.90966
22	56.41933	0.0	41.23126	5.27321	9.91488
23	55.45445	0.0	40.38853	5.14443	9.92150
24	54.49059	0.0	39.55075	5.01088	9.92897
25	53.52704	0.0	38.70782	4.88302	9.93621
26	52.56485	0.0	37.87849	4.73870	9.94767
27	51.60385	0.0	37.05692	4.58662	9.96033
28	50.64366	0.0	36.23944	4.42869	9.97555
29	49.68350	0.0	35.40916	4.28894	9.98542
30	48.72479	0.0	34.59177	4.13734	9.99570
35	43.97090	0.0	30.63898	3.24860	10.08334
40	39.30357	0.0	26.85838	2.30655	10.13867
45	34.75293	0.0	23.26144	1.39745	10.09404
50	30.36157	0.0	19.79033	0.70580	9.86545
55	26.15976	0.0	16.34349	0.41064	9.40562
60	22.21524	0.0	13.36322	0.23700	8.61502
65	18.57779	0.0	10.78613	0.16422	7.62744
70	15.35919	0.0	8.53662	0.08063	6.74194
75	12.93958	0.0	7.06226	0.07312	5.80420

Table 3 (continued)

Age (x)	Total	Status			
		single	married	divorced	widowed
Divorced at age x					
18	60.12752	0.0	41.60663	8.68843	9.83248
19	59.15602	0.0	40.57874	8.76269	9.81462
20	58.17563	0.0	39.40399	8.98316	9.78849
21	57.19499	0.0	38.26595	9.17141	9.75766
22	56.20934	0.0	37.06918	9.42425	9.71592
23	55.22589	0.0	35.95235	9.60586	9.66771
24	54.23933	0.0	34.78259	9.85206	9.60469
25	53.25021	0.0	33.56239	10.16345	9.52438
26	52.25053	0.0	32.16519	10.67299	9.41237
27	51.24194	0.0	30.60326	11.37485	9.26385
28	50.23566	0.0	29.09265	12.04480	9.09823
29	49.22655	0.0	27.54993	12.77092	8.90572
30	48.21465	0.0	25.95749	13.57383	8.68334
35	43.23907	0.0	18.87241	17.07184	7.29483
40	38.38652	0.0	12.12320	20.85393	5.40939
45	33.75746	0.0	6.60635	23.72620	3.42491
50	29.40648	0.0	3.31488	24.09509	1.99651
55	25.33978	0.0	1.85268	22.23648	1.25063
60	21.52576	0.0	1.16251	19.51880	0.84445
65	17.93900	0.0	0.72807	16.64885	0.56207
70	14.65735	0.0	0.33348	14.05190	0.27197
75	11.84494	0.0	0.36917	11.17030	0.30547
Widowed at age x					
18	59.69963	0.0	38.80206	4.86726	16.03032
19	58.81424	0.0	38.28951	4.78980	15.73494
20	57.92845	0.0	37.89120	4.72708	15.31019
21	56.99542	0.0	37.02930	4.58942	15.37671
22	56.06841	0.0	36.34705	4.47630	15.24509
23	55.10735	0.0	35.29184	4.29954	15.51599
24	54.15163	0.0	34.34001	4.13762	15.67400
25	53.20226	0.0	33.52278	3.99589	15.68359
26	52.24792	0.0	32.68166	3.84851	15.71777
27	51.28847	0.0	31.81009	3.69673	15.78165
28	50.27621	0.0	30.13208	3.41194	16.73219
29	49.27779	0.0	28.76294	3.18103	17.33382
30	48.25073	0.0	27.03174	2.89149	18.32750
35	42.93808	0.0	16.25534	1.32089	25.39185
40	37.96024	0.0	9.71973	0.55472	27.68579
45	33.27979	0.0	5.88867	0.22559	27.16553
50	28.83182	0.0	3.22217	0.08279	25.52686
55	24.61725	0.0	1.57544	0.02960	23.01221
60	20.63333	0.0	0.73730	0.01102	19.88501
65	16.90311	0.0	0.36084	0.00369	16.53857
70	13.46533	0.0	0.14063	0.00146	13.32324
75	10.35660	0.0	0.07202	0.00064	10.28394

Table 4. Summary measures of lifetime experiences of marriage, marital dissolution, and remarriage, by race and sex for the United States of America, 1960-1975.

Population	(1) Prop. ever marrying	(2) Mean age at first marriage	(3) Average duration marriage (years)	(4) Marriages p. person marrying	(5) Prop. marriages ending in divorce	(6) Prop. marriages ending in w'hood	(7) Mean age at divorce	(8) Mean age at w'hood	(9) Average duration divorce (years)	(10) Average duration w'hood (years)	(11) Remarr. divorced persons p. divorce	(12) Remarr. widowed persons p. w'hood	(13) Mean age at remarr. from divorce	(14) Mean age at remarr. from w'hood
White females														
1970-1975	0.927	22.05	30.01	1.38	0.304	0.467	33.02	65.47	12.46	15.44	0.742	0.102	34.74	51.81
1965-1970	0.944	21.72	32.11	1.29	0.219	0.549	33.34	64.56	12.55	15.46	0.750	0.112	35.86	52.28
1960-1965	0.941	21.55	33.83	1.24	0.187	0.559	31.77	64.15	12.79	15.51	0.744	0.095	34.21	52.85
Black females														
1970-1975	0.846	25.07	24.58	1.29	0.283	0.491	34.51	60.07	17.13	18.67	0.667	0.079	40.62	45.15
1965-1970	0.879	23.10	25.29	1.30	0.252	0.530	34.61	58.78	15.12	17.44	0.679	0.111	38.78	47.92
1960-1965	0.894	22.64	29.29	1.25	0.197	0.487	32.51	59.42	14.10	17.02	0.760	0.100	39.88	42.33
All females														
1970-1975	0.917	22.37	29.39	1.37	0.301	0.470	33.16	64.85	12.96	15.72	0.735	0.102	35.35	51.20
1965-1970	0.936	21.88	31.35	1.29	0.222	0.546	33.49	63.97	12.86	15.61	0.741	0.113	36.20	51.80
1960-1965	0.934	21.67	33.32	1.24	0.188	0.551	31.83	63.68	12.98	15.56	0.746	0.095	34.95	51.75
White males														
1970-1975	0.917	24.13	32.70	1.34	0.250	0.180	35.09	68.66	5.76	7.03	0.833	0.251	36.63	59.74
1965-1970	0.926	23.95	34.13	1.28	0.201	0.200	33.64	68.03	6.47	7.35	0.835	0.266	36.18	60.65
1960-1965	0.914	23.89	36.43	1.22	0.167	0.179	34.74	68.18	7.68	7.35	0.784	0.264	36.96	60.89
Black males														
1970-1975	0.869	26.01	28.45	1.32	0.267	0.193	37.34	65.02	6.51	9.20	0.777	0.173	38.73	55.09
1965-1970	0.884	24.84	28.24	1.32	0.244	0.220	33.44	64.37	7.25	9.22	0.800	0.213	37.75	60.69
1960-1965	0.864	25.89	30.26	1.27	0.206	0.168	32.65	61.97	9.34	8.73	0.775	0.300	39.02	56.56
All males														
1970-1975	0.911	24.31	32.27	1.34	0.251	0.180	35.28	68.28	5.84	7.27	0.828	0.240	36.85	59.53
1965-1970	0.920	24.04	33.50	1.29	0.205	0.201	33.61	67.63	6.57	7.51	0.833	0.261	36.44	60.66
1960-1965	0.908	24.08	35.78	1.22	0.171	0.177	34.45	67.58	7.89	7.51	0.788	0.261	37.38	60.02

Note. The abbreviations used in the headings are prop., proportion; p., per; w'hood, widowhood; remarr., remarriage(s).

Data shown in columns 1 and 2 of table 4 confirm these trends. In the decade separating 1960–1965 and 1970–1975, females have exhibited an increasing tendency to postpone marriage and even to avoid it altogether. The statistics for black females are particularly noteworthy. For this group, the mean age at first marriage rose by almost 2.5 years to over 25 years, and the proportion of a life-table cohort ever marrying fell from nearly 90% to less than 85%. Data for males portray similar tendencies, but the effects are much less pronounced.

The average duration of a marriage (column 3) is computed by dividing the total number of person-years lived in the married state by the total number of marriages. Over the decade of observation, the average duration of a marriage decreased significantly in all race–sex groups. Based on individuals' self-reported behavior, the decline was greatest among black females (4.7 years) and least among black males (1.8 years). Black marriages tend to be of shorter duration than white marriages, partly because blacks marry later than whites and have shorter life expectancies. As we shall see, the smaller mean marital duration is also related to the increase in divorce. But column 4 indicates that divorce is not a terminal event, because well over one-quarter of all persons who marry later remarry. Remarriage is somewhat more common among whites than among blacks.

There is widespread agreement that marital disruption through divorce is becoming an increasingly common phenomenon in the USA, but there has not developed a consensus on the best way to measure its incidence. Preston (1975) estimated that 44% of marriages would end in divorce, based on disruption rates prevailing in 1973. When the analysis is recast in terms of marriage cohorts, Preston and McDonald (1979) estimate that the proportion of marriages ending in divorce rose from about 0.05 for marriages contracted after the Civil War to about 0.12 at the turn of the century to nearly 0.25 at the start of World War 2. These authors project that more than one-third of the marriages contracted in the first half of the 1960s will eventually be disrupted by divorce.

Both Schoen and Nelson (1974) and Krishnamoorthy (1979) have constructed marital status life tables for US females based on vital statistics and census data, and have estimated the probability that a marriage will end in divorce. Their estimates are 0.259 for 1960 (Schoen and Nelson, 1974) and 0.363 for 1970. Our estimates (column 5) also indicate that the incidence of divorce is increasing for all race–sex groups, but our measured levels are below those obtained from vital statistics data(5).

Glick and Norton, in their analysis of the June 1975 CPS marital history data (US Bureau of the Census, 1976), use a projection technique to estimate the proportion of first marriages of young adults that may end in divorce by the time these persons reach old age. [For a full statement of this projection method, see Glick and Norton (1973).] Their projections imply that about one-third of the married persons between 25 and 35 years old in 1975 may eventually end their first marriage in divorce, including those who have already done so. Moreover, they estimate that four-tenths of the persons in their late twenties and early thirties who had entered their second marriage (after their first marriage had ended in divorce) may expect to have their second marriage end in redivorce.

(5) There is evidence that divorce is underreported in the June 1975 CPS. We have compared the number of divorces registered by the US Vital Statistics System with the weighted number of divorces reported by men and women in the CPS data for each year between 1970 and 1974. For men, the self-reported number of divorces is approximately 55% as many as were recorded in vital statistics, and the corresponding figure for women is roughly 70%. There is evidently a greater reluctance to report divorces than marriages. Similar comparisons for the same period show that about 85–90% of marriages are reported for men and roughly 90–95% for women.

Marriages can terminate through divorce or with the death of either spouse. A comparison of the numbers in columns 5 and 6 shows that, for females, marriages are considerably more likely to end in widowhood than in divorce, whereas for men, at least for the most recent period, marriages have a higher risk of terminating in divorce than in the death of the spouse. This striking difference between men and women in the proportions of marriages ending in widowhood is largely due to higher male mortality.

Because becoming divorced is commonly the result of choices made voluntarily whereas becoming widowed is not, the average age at divorce is usually far lower than the average at widowhood. The data in columns 7 and 8 show that widowhood occurs roughly 30 to 35 years later than divorce. Black females are likely to experience divorce at a somewhat later mean age than white females, whereas for blacks generally, widowhood occurs at younger ages than it does for whites. In the latter instance, the phenomenon is largely attributable to higher mortality among blacks. Males endure shorter spells of divorce and widowhood than do females (columns 9 and 10). In addition, despite the fact that divorce occurs at an earlier age than widowhood, it tends not to last any longer. This finding is attributable to differentials between divorced and widowed persons in remarriage propensities.

The probabilities of remarriage following a divorce (column 11) suggest that current high rates of marital dissolution through divorce reflect a disenchantment with a particular marriage partner rather than a rejection of the institution of marriage itself. Black females have the lowest rates of remarriage after divorce, down to two-thirds in 1970–1975. By contrast five out of six divorced white males eventually remarry. Chances of remarrying after the death of a spouse are substantially smaller, especially for women for whom the probability is about 10% (column 12).

The mean age at remarriage after a divorce (column 13) is usually several years greater than the average age at divorce. But just the opposite is true in the case of widowhood. For females, especially, remarriage after widowhood occurs at comparatively young ages (column 14). In general, the mean age at remarriage after the death of a spouse is 10 or 15 years *less* than the mean age at widowhood. This paradox suggests that, even though the probability of remarriage is small for women, it is the youngest widows who are the most likely to remarry. This conclusion is confirmed by figure 2 which shows that transition rates from widowed to married are highest between ages 25 and 30. The likelihood of an older widow becoming remarried is greatly lowered by the fact that higher male mortality reduces the supply of potential husbands of comparable age.

One of the most telling ways of revealing a population's experience of marriage, marital disruption, and remarriage is to disaggregate life expectancy at birth into the proportions expected to be lived in each marital status category. These decompositions, which reflect average individual experience, are shown in table 5.

With the exception of black females, the average individual can at birth expect to spend the majority of his/her lifetime in the presently married state. For white males, this proportion reaches close to 60%. Nevertheless, the fraction of total lifetime spent married has been declining for all groups, and for black females in 1970–1975 it fell below the expected proportion spent never married.

Because individuals are born into the never married category, it is not surprising to find that time spent never married is second in importance to time spent married. White females exhibit the lowest proportions in the never married state (about 0.3) because they marry soonest, have the largest fractions ever marrying, and display the highest life expectancies at birth. Black males spend the largest share of any race-sex group never married, partly because of their later age at first marriage and partly because they have the shortest life expectancy at birth.

Marital disruption, including both divorce and widowhood, accounts for a much smaller share of total lifetime. For all females in 1970–1975, the combined proportion was 0.186, and for all males, 0.049. Because of the rise in the frequency of marital disruption from divorce, the proportions of total lifetime spent divorced have been growing both for men and for women, but especially for women. However, the most evident differences are observed in the amount of time spent widowed. Females spend more total years widowed than men do for two reasons; females live longer, and the proportion of total lifetime spent widowed is about five or six times greater than for males.

Table 5. A decomposition of life expectancy (in years) at birth by time spent in each marital status category, by race and sex for the United States of America, 1960–1975 (figures in parentheses refer to proportions of total life expectancy in each marital status category).

Population	Life expectancy at birth (years)	Marital status			
		never married	presently married	divorced	widowed
White females					
1970–1975	76.62	24.33 (0.318)	38.26 (0.499)	4.82 (0.063)	9.20 (0.120)
1965–1970	75.68	22.81 (0.301)	39.16 (0.517)	3.35 (0.044)	10.36 (0.137)
1960–1965	74.92	22.67 (0.303)	39.38 (0.526)	2.78 (0.037)	10.09 (0.135)
Black females					
1970–1975	71.42	29.16 (0.408)	26.92 (0.377)	5.30 (0.074)	10.04 (0.141)
1965–1970	69.07	25.27 (0.366)	28.88 (0.418)	4.36 (0.063)	10.56 (0.153)
1960–1965	68.73	23.72 (0.345)	32.67 (0.475)	3.10 (0.045)	9.24 (0.134)
All females					
1970–1975	75.90	24.90 (0.328)	36.85 (0.486)	4.89 (0.064)	9.26 (0.122)
1965–1970	74.82	23.08 (0.308)	37.95 (0.507)	3.46 (0.046)	10.33 (0.138)
1960–1965	74.07	22.80 (0.308)	38.53 (0.520)	2.81 (0.038)	9.92 (0.134)
White males					
1970–1975	68.67	25.21 (0.367)	40.15 (0.585)	1.77 (0.026)	1.55 (0.023)
1965–1970	68.22	24.38 (0.357)	40.55 (0.594)	1.54 (0.023)	1.75 (0.026)
1960–1965	68.08	24.65 (0.362)	40.54 (0.595)	1.43 (0.021)	1.47 (0.022)
Black males					
1970–1975	62.80	26.22 (0.417)	32.56 (0.518)	1.99 (0.032)	2.03 (0.032)
1965–1970	61.70	24.36 (0.395)	32.92 (0.533)	2.06 (0.033)	2.36 (0.038)
1960–1965	62.39	25.60 (0.410)	33.08 (0.530)	2.10 (0.034)	1.60 (0.026)
All males					
1970–1975	67.89	25.28 (0.372)	39.23 (0.578)	1.78 (0.026)	1.59 (0.023)
1965–1970	67.38	24.34 (0.361)	39.66 (0.589)	1.59 (0.024)	1.79 (0.027)
1960–1965	67.34	24.71 (0.367)	39.67 (0.589)	1.49 (0.022)	1.47 (0.022)

5 Discussion

In interpreting the results of this analysis, it is helpful to review the assumptions underlying the construction of a multiregional marital status life table. Because the computations are derived from a Markov transition probability matrix, it is necessary to assume that the transition probabilities depend only on age and current status and are independent of previous status or of time spent in the current status. Ledent (1981) has shown that this is not a tenable assumption in the instance of geographic migration. In the USA, at least, persons in region *i*, at age *x* have a higher probability of moving to region *j* if they were born in region *j* than if they were not. This type of population heterogeneity can violate the Markovian assumption.

Another type of heterogeneity can be embodied in nuptiality data. Plateris (1979) has investigated the dependence of divorce on marital duration and has found that US marriages are most likely to be disrupted by divorce within two to four years after marriage. Hannan has even suggested that, in US data, the duration effect swamps the age effect, so that for newly married persons both at age 20 and at age 40, the probability of a divorce within two years is about the same, but for persons aged 30, the probability of a divorce by age 35 is not the same for a person married one year and a person married five years(6). In addition, Sanderson has pointed out that a second type of heterogeneity can arise with regard to marriage order(7), and, as noted above, Glick and Norton have estimated that second marriages have a higher probability of ending in divorce than first marriages (US Bureau of the Census, 1976).

To some extent, problems of population heterogeneity can be addressed by stratifying the population into relatively homogeneous groups. Thus, in this example, separate marital status life tables were produced for race and sex. The dependence of divorce on marriage order can be handled by creating more marital status categories, and in work I am now beginning with the marital history data collected in the June 1980 CPS, I am dividing the married category into persons married for the first time and those married two or more times.

Duration dependence is potentially more difficult to incorporate into a multiregional marital status life table. Ledent (1980) has suggested that this problem can also be handled by increasing the state space. In this instance it might require dividing the presently married category into subcategories that depended on marital duration. Alternatively, continuous-time models of marital behavior have been developed that incorporate duration dependence (Hannan et al, 1977; Tuma et al, 1979). A challenge for researchers is to extend multistate demography to include this added feature.

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APPENDIX

Table A1. Age- and marital-status-specific transition probabilities for white US females, 1970–1975.

Age	Transition probability from presently single to					Transition probability from presently married to				
	death	single	married	divorced	widowed	death	single	married	divorced	widowed
0	0.014084	0.985916	0.0	0.0	0.0	0.0	0.0	1.000000	0.0	0.0
1	0.002460	0.997540	0.0	0.0	0.0	0.0	0.0	1.000000	0.0	0.0
5	0.001483	0.998517	0.0	0.0	0.0	0.0	0.0	1.000000	0.0	0.0
10	0.001298	0.989719	0.008984	0.0	0.0	0.0	0.0	1.000000	0.0	0.0
15	0.000465	0.980866	0.018509	0.000129	0.000031	0.000651	0.0	0.982239	0.013787	0.003324
16	0.000501	0.960258	0.038771	0.000419	0.000051	0.000631	0.0	0.975411	0.021347	0.002611
17	0.000538	0.920994	0.077310	0.001073	0.000085	0.000610	0.0	0.969894	0.027341	0.002156
18	0.000578	0.877963	0.119521	0.001814	0.000124	0.000590	0.0	0.967510	0.029858	0.002042
19	0.000616	0.838339	0.158647	0.002241	0.000157	0.000569	0.0	0.969656	0.027821	0.001954
20	0.000656	0.818549	0.178333	0.002347	0.000115	0.000550	0.0	0.972224	0.025956	0.001271
21	0.000698	0.804218	0.192395	0.002599	0.000089	0.000531	0.0	0.971917	0.026636	0.000916
22	0.000744	0.794835	0.201610	0.002723	0.000088	0.000513	0.0	0.971995	0.026634	0.000858
23	0.000801	0.797341	0.199168	0.002591	0.000099	0.000532	0.0	0.972819	0.025665	0.000984
24	0.000866	0.815035	0.181890	0.002097	0.000112	0.000550	0.0	0.975462	0.022772	0.001217
25	0.000936	0.833169	0.163900	0.001908	0.000087	0.000570	0.0	0.975394	0.022992	0.001043
26	0.001011	0.844235	0.152997	0.001656	0.000100	0.000591	0.0	0.976721	0.021401	0.001287
27	0.001094	0.863913	0.133569	0.001346	0.000078	0.000612	0.0	0.978299	0.019936	0.001153
28	0.001184	0.883744	0.114045	0.000925	0.000101	0.000634	0.0	0.981528	0.016078	0.001760
29	0.001282	0.897952	0.099874	0.000795	0.000097	0.000657	0.0	0.981650	0.015771	0.001922
30	0.007705	0.715667	0.267991	0.007767	0.000870	0.004287	0.0	0.933404	0.056036	0.006274
35	0.011752	0.855938	0.128464	0.003082	0.000764	0.006561	0.0	0.935484	0.046438	0.011517
40	0.016816	0.875025	0.104967	0.002074	0.001117	0.010217	0.0	0.931071	0.038158	0.020554
45	0.023404	0.932591	0.042642	0.000620	0.000742	0.016145	0.0	0.922429	0.027954	0.033472
50	0.031593	0.928859	0.038284	0.000267	0.000997	0.024741	0.0	0.912144	0.013339	0.049776
55	0.041910	0.921811	0.034523	0.000171	0.001585	0.036942	0.0	0.868044	0.009251	0.085762
60	0.059802	0.931835	0.007797	0.000023	0.000543	0.054428	0.0	0.813916	0.005386	0.126271
65	0.086511	0.892354	0.019270	0.000069	0.001796	0.082208	0.0	0.748541	0.006262	0.162988
70	0.131489	0.867632	0.000765	0.000001	0.000113	0.126685	0.0	0.629462	0.002495	0.241357
75	1.000000	0.0	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0

Table A1 continues over

Table A1 (continued)

Age	Transition probability from presently divorced to					Transition probability from presently widowed to				
	death	single	married	divorced	widowed	death	single	married	divorced	widowed
0	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0	0.0	1.000000
1	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0	0.0	1.000000
5	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0	0.0	1.000000
10	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0	0.0	1.000000
15	0.001284	0.0	0.0	0.998716	0.0	0.003704	0.0	0.0	0.0	0.996296
16	0.001216	0.0	0.234072	0.764402	0.000309	0.003420	0.0	0.0	0.0	0.996580
17	0.001234	0.0	0.202193	0.796352	0.000221	0.003158	0.0	0.0	0.0	0.996842
18	0.001210	0.0	0.290408	0.708080	0.000301	0.002794	0.0	0.102658	0.001558	0.892990
19	0.001213	0.0	0.303205	0.695282	0.000301	0.002597	0.0	0.089217	0.001260	0.906925
20	0.001231	0.0	0.274774	0.723817	0.000177	0.002320	0.0	0.170263	0.002241	0.825176
21	0.001241	0.0	0.266574	0.732061	0.000124	0.002171	0.0	0.141112	0.001906	0.854812
22	0.001262	0.0	0.235469	0.763167	0.000102	0.001958	0.0	0.200564	0.002709	0.794769
23	0.001307	0.0	0.230654	0.767924	0.000115	0.001918	0.0	0.178023	0.002316	0.817743
24	0.001353	0.0	0.224207	0.774302	0.000138	0.001878	0.0	0.154833	0.001735	0.841504
25	0.001395	0.0	0.232055	0.766427	0.000123	0.001820	0.0	0.158237	0.001842	0.838101
26	0.001441	0.0	0.230989	0.767420	0.000150	0.001764	0.0	0.161808	0.001752	0.834676
27	0.001502	0.0	0.203299	0.795080	0.000119	0.001652	0.0	0.261914	0.002639	0.733794
28	0.001559	0.0	0.189684	0.808589	0.000168	0.001642	0.0	0.198499	0.001611	0.798249
29	0.001617	0.0	0.178940	0.819269	0.000174	0.001584	0.0	0.220345	0.001754	0.776317
30	0.008658	0.0	0.508389	0.481304	0.001650	0.007873	0.0	0.643550	0.018652	0.329925
35	0.012605	0.0	0.400674	0.584336	0.002384	0.011840	0.0	0.336050	0.008063	0.644046
40	0.018140	0.0	0.294583	0.684142	0.003135	0.017071	0.0	0.197765	0.003908	0.781256
45	0.025833	0.0	0.177697	0.793375	0.003094	0.024627	0.0	0.144015	0.002094	0.829264
50	0.036357	0.0	0.089780	0.871526	0.002337	0.034747	0.0	0.093295	0.000686	0.866272
55	0.050670	0.0	0.051111	0.895872	0.002347	0.048055	0.0	0.057567	0.000285	0.894094
60	0.070402	0.0	0.038558	0.888355	0.002684	0.068342	0.0	0.030878	0.000092	0.900689
65	0.101629	0.0	0.039994	0.854649	0.003728	0.100240	0.0	0.021573	0.000077	0.878110
70	0.152563	0.0	0.002078	0.845051	0.000308	0.148909	0.0	0.008271	0.000013	0.842808
75	1.000000	0.0	0.0	0.0	0.0	1.000000	0.0	0.0	0.0	0.0

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A multiregional population-projection framework that incorporates both migration and residential mobility streams: application to metropolitan city-suburb redistribution

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Abstract. In this paper the author introduces a population-projection framework that incorporates interregional migration and intraregional residential mobility streams to project future population sizes both across and within regions in a manner that is consistent with existing migration theory. The author presents a general matrix model of the framework, shows how its parameters can be estimated from fixed-interval census migration data, and discusses how the framework can be employed to 'update' population projections when recent, more limited data sets become available. These features of the framework are demonstrated with intrametropolitan central-city-suburb projections for selected US Standard Metropolitan Statistical Areas over the period, 1970-2020.

1 Introduction

In this paper I introduce a multiregional population-projection framework that extends the existing methodology in order to project *intra*regional redistribution across community populations that are subject to change due to interregional migration and intraregional residential mobility streams. I present a general matrix model of the framework, indicate how the rates and populations-at-risk of the framework can be computed from fixed-interval census or survey migration data, and show how the framework can be employed to 'update' population projections when recent, more limited data sets become available. The capabilities of the framework are then illustrated with application to a specific intraregional redistribution context—central-city-suburban redistribution within US metropolitan areas. Central-city-suburban projections to the year 2020 are produced for three selected standard metropolitan statistical areas (SMSAs) based on 1970 US Census migration data and 'updated' on the basis of subsequently available survey migration tabulations.

The framework presented here is predicated on the assumption that a multiregional projection methodology is of greatest value when the regions employed in the analysis reflect 'origins' and 'destinations' that are consistent with the movement process itself. For example, previous research has shown that internal migration is motivated largely by economic considerations so that individual migrants and their families tend to be responsive to 'pushes' and 'pulls' of entire labor-market areas (Lowry, 1966; Lansing and Mueller, 1967; Greenwood, 1975; 1981). For this reason, nationwide schemes of labor-market area regionalization such as the Metropolitan Economic Labor Areas in the United Kingdom, the Bureau of Economic Analysis Areas in the United States of America, and the sets of functional urban regions that have recently been defined for many European countries (Hall and Hay, 1980), constitute appropriate regional schemes for undertaking multiregional population-projections in these countries, using the methodology specified by Rogers (1975), Willekens and Rogers (1978), and others. The interregional *j*-to-*k* (1) migration streams in these analyses will be consistent with the structure of internal migration processes. They will also facilitate more theoretically

(1) This paper uses subscripts *j* and *k* instead of the *i* and *j*, respectively, used by Willekens and Rogers (1978) to indicate regions. This avoids confusion with mobility-incidence rate, *i*.

valid simulations and updates of the projections than would be possible if a more arbitrary regionalization scheme were employed.

The principle of defining regional schemes to be consistent with mobility processes underlies the projection framework presented here. This framework focuses both on *inter*regional and on *intra*regional projections—that are generated both by *migration* and by *residential mobility* streams. Although the scholarly literature on population movement shows migration and residential mobility to be distinct from each other in many respects—in individual motivation, frequency of occurrence, subgroup selectivity, etc (Morrison, 1972; Long, 1973; Speare et al, 1975; Goodman, 1978)—they are also distinct in terms of geographic scope. Unlike migration which, by virtue of its job-relatedness, tends to occur over long distances and between labor markets, the term 'residential mobility' is used to characterize mover adjustments to changing requirements for housing, neighborhood amenities, public services, and other attributes of local communities that lie within each labor-market area. This distinction is made in the framework which treats interregional (or inter-labor-market) movement as migration, and intraregional movement between communities within a single labor market as residential mobility. The latter communities are, therefore, subject to population change due both to interregional migration and to intraregional residential mobility streams(2).

This framework extends the multiregional methodology advanced by Rogers (1975) and Willekens and Rogers (1978) by producing population projections for communities within labor-market regions as well as across labor-market regions through the introduction of a second 'layer' of areas. Although it would be possible to generate community-population projections with the existing methodology by simply extending the first 'layer' of regions into more states, this practice would run counter to mobility literature which makes a clear distinction between migration components and residential mobility components of community-population change. The projection framework introduced here produces projections both across and within regions in a manner that is consistent with the underlying migration and residential mobility processes.

Four sections of this paper follow. In section 2, I provide a nontechnical overview of the migration and residential mobility processes that underlie the projection framework, using the example of city–suburb redistribution within a metropolitan area. In section 3, I present a detailed explanation of the projection methodology providing, first, equations that designate populations-at-risk and rates specific to the projection of intrametropolitan central-city–suburban redistribution. This is followed by a matrix-model specification for the general process of projecting populations within l subregions of n regions and a discussion of rate computation and 'updating' strategies. In section 4, the framework is applied to the projection of central-city–suburban population change for three US SMSAs based on rates calculated from 1970 US Census migration data as well as to an update of these projections based on more current estimates for some of the rates from survey data. A brief conclusion follows as section 5.

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(2) The operational distinction between migration and residential mobility is not always made on the basis of movement across or within labor-market areas. Government statistical agencies often make this distinction on the basis of administrative units. The US Census Bureau, for example, defines migration as movement across a county administrative unit, despite the fact that labor-market areas generally consist of groups of counties (US Bureau of the Census, 1970).

2 Intraregional redistribution: the case of the central city and suburbs(3) of a metropolitan area

The migration and residential mobility processes that are incorporated into the projection framework advanced below can be portrayed for the case of central-city–suburban redistribution in a single metropolitan area. With the assumption that the metropolitan area of interest constitutes a self-contained labor-market region within a nationwide system of labor-market regions, movement-induced population change for the entire metropolitan area results from the two interregional migration streams:

I out-migration from the metropolitan area to the rest of the country,
II in-migration to the metropolitan area from the rest of the country,

where stream I pertains to the sum of interregional migration streams that lead from the metropolitan area to other labor markets in the country, and stream II pertains to the sum of those streams which lead from other labor-market areas to the metropolitan area.

However, movement-induced population change for only the central city portion of the metropolitan area is the result of two *inter*regional migration-stream components:

IA out-migration from the central city of the metropolitan area to the rest of the country,
IIA in-migration to the central city of the metropolitan area from the rest of the country,

and two *intra*regional residential mobility streams:

III intrametropolitan residential mobility from the central city to the suburbs,
IV intrametropolitan residential mobility from the suburbs to the central city.

Comparable migration-stream components IB and IIB (defined by replacing the term 'suburbs' for 'central city' in the IA and IIA stream definitions) in addition to residential mobility streams III and IV are, likewise, responsible for population change in the suburban (residual, noncentral) portion of the metropolitan area.

The utility of distinguishing the migration stream from the residential-mobility-stream components of intrametropolitan population change is clearly demonstrated in table 1

Table 1. Contributions to central-city, suburb, and SMSA population change, 1965–1970 attributable to net migration and net intrametropolitan residential mobility for Detroit, Atlanta, and Houston SMSAs (source: 1970 US Census tabulations adjusted for 'residence five years ago not known').

Population size and components of change	Detroit			Atlanta			Houston		
	central city	suburbs	SMSA	central city	suburbs	SMSA	central city	suburbs	SMSA
1970 population (in thousands)	1511	2688	4199	497	893	1390	1231	753	1985
Components of 1965–1970 population change (as percent of 1970 population size)									
Net migration [a] and mobility	−12.6	3.5	−2.3	−8.9	14.3	6.0	−0.7	17.9	6.4
Net migration [a] to outside SMSA	−2.3	−2.3	−2.3	1.5	8.5	6.0	5.1	8.4	6.4
Net mobility within SMSA	−10.3	5.8		−10.4	5.8		−5.8	9.5	

[a] Migration pertains to internal migration only.

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(3) This discussion of the city–suburban redistribution process is consistent with the 'analytic framework' I have previously advanced to examine the determinants and migration-stream components of city–suburban redistribution within a single migration-interval (Frey, 1978b; 1979b). The projection methodology presented in section 3 represents an extension of this framework to a more general projection-model.

which contrasts the experiences of three US SMSAs—Detroit, Atlanta, and Houston—that differ significantly in the levels of metropolitan-wide net in-migration sustained over the 1965-1970 period. Here the 1965-1970 net movement figures for their central cities and suburbs are decomposed into net movement attributable to interregional migration streams and net movement attributable to intraregional residential mobility streams.

The comparison points up the significance of the migrant attractivity of the metropolitan area for redistribution across communities within the SMSA. Although all three SMSAs sustain city-to-suburb population redistribution due to net residential mobility streams alone, this redistribution is countered in Atlanta and Houston by net migration gains both in the central city and in the suburbs—associated with the strong metropolitan-wide migrant 'pull' in these SMSAs. These data support the contention that entire labor-market areas constitute appropriate 'origins' and 'destinations' for interregional migration streams, whereas smaller communities are more likely to serve these roles for local residential mobility streams.

It is useful to view the streams contributing to this redistribution process as occurring in a sequence of two analytically distinct stages. The first stage is named 'the interregional exchange' stage and refers to the exchange of interregional migration streams between each pair of labor-market areas in the nationwide system of regions. The second stage is named the 'intraregional allocation' stage and refers to the cross-community residential mobility streams of the residents of the region who were not attracted out of the region in the first stage, as well as the allocation of all in-migrants to the region (generated in the first stage) to common types of destinations within the region. From the perspective of a given metropolitan area, streams I (including IA and IB) and II as defined above, are the results of the interregional exchange stage of the process, whereas streams III and IV, IIA and IIB result from the intraregional allocation stage of the process.

The two-stage process suggests that the streams of interregional in-migrants to communities that are located within a region should be viewed as the result of both stages. In the case of in-migration in streams IIA and IIB to the central cities and suburbs of the metropolitan area, it follows that
IIA:

[in-migration to the metropolitan area from the rest of the country (stage 1)]
× [city-destination-propensity rate of metropolitan area in-migrants (stage 2)],

and IIB:

[in-migration to the metropolitan area from the rest of the country (stage 1)]
× [suburb-destination-propensity rate of metropolitan area in-migrants (stage 2)],

where the destination-propensity rate, in this context(4), indicates the proportion of the in-migrants to the metropolitan area that locates in a specific community (central city or suburb) destination. This designation of the two stages is consistent with the premise that the entire region (metropolitan area) represents an appropriate labor-market destination for interregional migrants, but that within-region communities represent appropriate *local* destinations for interregional migrants.

The destination-propensity rate can also be incorporated into the analysis of the residential mobility streams—although these streams are generated entirely within the second stage of the two stages outlined above. It is useful to view the stream

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(4) I have defined the destination-propensity rate (Frey, 1978b) as the proportion of migrants or movers of a specified origin that locate in a specified destination. It should be applied to an at-risk population of movers or migrants and should always indicate their location of destination (for example, the *k* destination-propensity rate of *j*-origin movers).

rate of residential movement from community a to community b as the product of: (1) a *mobility-incidence rate*—the proportion of at-risk residents of community a that moves anywhere within the region (including within community a); and (2) a *destination-propensity rate*—the proportion of movers originating in community a that locate in community b. This parametrization of the a-to-b stream rate is motivated by literature on residential mobility decisionmaking which suggests that 'resident's decision to move' and 'mover's destination choice' are subject to different individual and areal determinants (Rossi, 1955; Speare et al, 1975). Moreover, redistribution analyses which have incorporated the above parametrization (Frey, 1978a; 1978b; 1979a; 1983) indicate that the latter destination-propensity rates tend to vary more widely across areas, and vary differently across individual characteristics (for example, age) than do mobility-incidence rates. Incorporating distinct mover's destination-propensity rates into the second stage of the redistribution process permits local movers to be allocated to community destinations in the same manner that in-migrants to the region are allocated.

The redistribution process that affects the metropolitan area example can now be stated as follows: the interregional exchange directs migration streams from the central-city and suburb portions of the area to other regions at the same time that migrant streams, originating in these regions, descend upon the area. The intraregional allocation stage then produces 'pools' of local movers (as determined by the mobility-incidence rates of each community) and allocates these mover pools and metropolitan in-migrants to community (central city and suburb) destinations through appropriate destination-propensity rates.

3 The projection framework

3.1 *Equations for central-city–suburban projections*

The relationships that are composed of populations-at-risk and rates necessary to project future central-city and suburb sizes, based on the redistribution process discussed in the previous section, will be presented here. I shall, first of all, specify the equations which are used to project the population of an entire metropolitan area (region) j when that metropolitan area is a part of a nationwide systems of regions k, $k = 1, ..., n$. Given beginning-of-period (t) regional population sizes disaggregated by age categories: 0–4, 5–9, ..., 65–69, ⩾70, the following relationships compute the end-of-period ($t+1$) regional populations

$$K_j^{(t+1)}(x+5) = s(x)K_j^{(t)}(x) - s(x)K_j^{(t)}(x)\left[\sum_{\substack{k=1\\k\neq j}}^{n} m_{jk}(x)\right] + \sum_{\substack{j=1\\k\neq j}}^{n} s(x)K_k^{(t)}(x)\,m_{kj}(x)\,, \tag{1}$$

for end-of-period ages 5–9, 10–14, ..., ⩾75, and

$$K_j^{(t+1)}(0) = \sum_{x=10}^{45} \{2.5s(0)\,[f_j(x)K_j^{(t)}(x) + f_j(x+5)K_j^{(t+1)}(x+5)]\}\,, \tag{2}$$

for end-of-period ages 0–4; where

$K_k^{(t)}(x)$ is the total population of region k ($k = 1, ..., n$), aged x to $x+4$ at time t,

$m_{jk}(x)$ is the interregional migration rate—the proportion of residents of region j, aged x to $x+4$ at time t, and surviving to time $t+1$, that resides in region k at time $t+1$,

$s(x)$ is the survival rate—the proportion of the population aged x to $x+4$ at time t, that is alive at time $t+1$,

$s(0)$ is the survival rate of births—the proportion of persons born between time t and $t+1$ that survives to age 0–4 at time $t+1$,

$f_j(x)$ is the fertility rate—the average annual number of births to persons aged x to $x+4$ in region j.

Equation (1) indicates that the end-of-period populations for metropolitan area j for age categories equal to or greater than the period length (five years) are equivalent to the beginning-of-period populations reduced by the sum of all out-migration streams to other regions in the system and augmented by the sum of all in-migration streams from other regions in the system. All beginning-of-period migrant and nonmigrant populations have 'survived' to the end-of-period with age-specific survival rates which, for convenience of exposition, are assumed to be constant across regions for migrant categories. The end-of-period population of metropolitan area i, as specified in equation (2), is calculated from a knowledge of the populations of childbearing age at the beginning and at the end of the period; the age-specific fertility rates for metropolitan area j; and the survival rate of births.

The projection equations (1) and (2) are consistent with multiregional cohort component projection-systems advanced previously (Rogers, 1975; Rees and Wilson, 1977; Willekens and Rogers, 1978). Given initial population sizes for all regional populations by five-year age categories, and values for the rates $m_{jk}(x)$, $s(x)$, and $f_j(x)$, equations (1) and (2) can be used to project population sizes for metropolitan area j (or any other region k in the system) over as many periods as is desired.

The extension of this methodology to project intrametropolitan (intraregional) redistribution across the central-city and suburb subregions of a metropolitan area (region) j makes use of equations (3), (4), (5), and (6). Equations (3) and (4) are subregional analogs of equation (1) and compute end-of-period $(t+1)$ city and suburb population sizes for the age categories: 5–9, 10–14, ..., ⩾75 ⁽⁵⁾. Likewise, equations (5) and (6) are subregional analogs of equation (2) and compute end-of-period city and suburb population sizes for the 0–4 age category:

$$\begin{aligned}K_{j,\mathrm{c}}^{(t+1)}(x+5) = {} & s(x)K_{j,\mathrm{c}}^{(t)}(x) - s(x)K_{j,\mathrm{c}}^{(t)}(x)m_{j,\mathrm{co}}(x)\\ & - s(x)[K_{j,\mathrm{c}}^{(t)}(x) - K_{j,\mathrm{c}}^{(t)}(x)m_{j,\mathrm{co}}(x)]i_{j,\mathrm{c}}(x)p_{j,\mathrm{cs}}(x)\\ & + s(x)[K_{j,\mathrm{s}}^{(t)}(x) - K_{j,\mathrm{s}}^{(t)}(x)m_{j,\mathrm{so}}(x)]i_{j,\mathrm{s}}(x)p_{j,\mathrm{sc}}(x)\\ & + s(x)K_{j,\mathrm{o}}^{(t)}(x)p_{j,\mathrm{oc}}(x)\ ,\end{aligned} \tag{3}$$

$$\begin{aligned}K_{j,\mathrm{s}}^{(t+1)}(x+5) = {} & s(x)K_{j,\mathrm{s}}^{(t)}(x) - s(x)K_{j,\mathrm{s}}^{(t)}(x)m_{j,\mathrm{so}}(x)\\ & - s(x)[K_{j,\mathrm{s}}^{(t)}(x) - K_{j,\mathrm{s}}^{(t)}(x)m_{j,\mathrm{so}}(x)]i_{j,\mathrm{s}}(x)p_{j,\mathrm{sc}}(x)\\ & + s(x)[K_{j,\mathrm{c}}^{(t)}(x) - K_{j,\mathrm{c}}^{(t)}(x)m_{j,\mathrm{co}}(x)]i_{j,\mathrm{c}}(x)p_{j,\mathrm{cs}}(x)\\ & + s(x)K_{j,\mathrm{o}}^{(t)}(x)p_{j,\mathrm{os}}(x)\ ,\end{aligned} \tag{4}$$

$$K_{j,\mathrm{c}}^{(t+1)}(0) = \sum_{x=10}^{45}\{2.5s(0)[f_j(x)K_{j,\mathrm{c}}^{(t)}(x) + f_j(x+5)K_{j,\mathrm{c}}^{(t+1)}(x+5)]\}\ , \tag{5}$$

$$K_{j,\mathrm{s}}^{(t+1)}(0) = \sum_{x=10}^{45}\{2.5s(0)[f_j(x)K_{j,\mathrm{s}}^{(t)}(x) + f_j(x+5)K_{j,\mathrm{s}}^{(t+1)}(x+5)]\}\ , \tag{6}$$

where $s(x)$, $s(0)$, and $f_j(0)$ are defined as above and

$K_{j,\mathrm{c}}^{(t)}(x)$ is the city population within metropolitan area j, aged x to $x+4$ at time t,
$K_{j,\mathrm{s}}^{(t)}(x)$ is the suburb population within metropolitan area j, aged x to $x+4$ at time t,

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(5) These equations are similar to those employed in Frey's (1978b; 1979b) analytic framework to examine the components of central-city-suburban population redistribution in a single interval. In the earlier specification [see equations (7) and (8) in Frey (1978b) or equations (1) and (2) in Frey (1979b)], population totals were represented by the letter P rather than the present K, in-migrants to the metropolitan area were represented by the factor M_o rather than by the present $K_{j,\mathrm{o}}^{(t)}$ and there was not an explicit subscript-j-designation for the metropolitan area of an (x)-designation for each age class.

$m_{j,\mathrm{co}}(x)$	is the out-migration rate from the city—the proportion of city residents of metropolitan area j, aged x to $x+4$ at time t, and surviving to time $t+1$, that resides outside metropolitan area j at time $t+1$,
$m_{j,\mathrm{so}}(x)$	is the out-migration rate from the suburbs—the proportion of suburb residents of metropolitan area j, aged x to $x+4$ at time t, and surviving to time $t+1$, that resides outside metropolitan area j at time $t+1$,
$s(x)K^{(t)}_{j,\mathrm{o}}(x)$	is the number of surviving in-migrants to metropolitan area i—the sum of all residents outside metropolitan area j, aged x to $x+4$ at time t, that survives and resides in metropolitan area j at time $t+1$,
$i_{j,\mathrm{c}}(x)$	is the mobility-incidence rate for nonmigrating city-residents—the proportion of city residents of metropolitan area j, aged x to $x+4$ at time t, surviving to time $t+1$, and not migrating out of the metropolitan area, that resides in a different dwelling unit in metropolitan area j at time $t+1$,
$i_{j,\mathrm{s}}(x)$	is the mobility-incidence rate for nonmigrating suburb-residents—the proportion of suburb residents of metropolitan area j, aged x to $x+4$ at time t, surviving to time $t+1$, and not migrating out of the metropolitan area, that resides in a different dwelling unit in metropolitan area j, at time $t+1$,
$p_{j,\mathrm{cs}}(x)$	is the suburb-destination-propensity rate for city-origin movers—the proportion of city residents of metropolitan area j, aged x to $x+4$ at time t, surviving and residing in a different dwelling unit in metropolitan area j at time $t+1$, that resides in the suburbs at time $t+1$,
$p_{j,\mathrm{sc}}(x)$	is the city-destination-propensity rate for suburb-origin movers—the proportion of suburb residents of metropolitan area j, aged x to $x+4$ at time t, surviving and residing in a different dwelling unit in metropolitan area j at time $t+1$, that resides in the city at time $t+1$,
$p_{j,\mathrm{oc}}(x)$	is the city-destination-propensity rate for in-migrants to the metropolitan area—the proportion of in-migrants to the metropolitan area j, aged x to $x+4$ at time t, and surviving at time $t+1$, that resides in the city at time $t+1$,
$p_{j,\mathrm{os}}(x)$	is the suburb-destination-propensity rate for in-migrants to the metropolitan area—the proportion of in-migrants to the metropolitan area j, aged x to $x+4$ at time t, and surviving to time $t+1$, that resides in the suburbs at time $t+1$.

Equation (3) indicates that the end-of-period city population is equal to the beginning-of-period city population which has survived, reduced by the number of out-migrants and city-to-suburb residential movers, and augmented by the number of suburb-to-city residential movers and in-migrants to the SMSA. Similarly, equation (4) indicates that the end-of-period suburb population is equal to the beginning-of-period suburb population which has survived, after out-migrants and suburb-to-city movers are removed, and after city-to-suburb movers and SMSA in-migrants are added.

The populations-at-risk and rates can be looked upon in light of the two-stage redistribution process reviewed in the previous section. The 'interregional exchange' involves applying out-migration rates ($m_{j,\mathrm{co}}$ and $m_{j,\mathrm{so}}$) to the beginning-of-period city and suburb populations, respectively, to produce out-migration streams from the city and suburbs to other regions; in-migration from other regions is represented by the parameter $s(x)K^{(t)}_{j,\mathrm{o}}(x)$. In the second 'intraregional allocation' stage of the redistribution process, two pools of local residential movers are produced by applying rates of mobility incidence ($i_{j,\mathrm{c}}$ and $i_{j,\mathrm{s}}$) to those city and suburb residents that did not migrate out of the metropolitan area. These pools are designated as

$s(x)[K_{j,\mathrm{c}}^{(t)}(x) - K_{j,\mathrm{c}}^{(t)}(x)m_{j,\mathrm{co}}(x)]i_{j,\mathrm{c}}(x)$, and $s(x)[K_{j,\mathrm{s}}^{(t)}(x) - K_{j,\mathrm{s}}^{(t)}(x)m_{j,\mathrm{so}}(x)]i_{j,\mathrm{s}}(x)$, respectively. Appropriate destination-propensity rates $[p_{j,\mathrm{cs}}(x), p_{j,\mathrm{sc}}(x), p_{j,\mathrm{oc}}(x), p_{j,\mathrm{os}}(x)]$ are applied to each of these pools and to the surviving in-migrants to the SMSA, to allocate these movers and migrants to central-city and suburb destinations.

Relationships (3) and (4) indicate how the two-stage redistribution process affects central-city and suburb change within metropolitan area j. The 'interregional exchange' also involves linking migration streams into and out of metropolitan area j with other regions in the multiregional system. The linkage between equations (3) and (4) and the standard multiregional projection equation [(1) above] which incorporates interregional migration streams $m_{jk}(x)$, is made through equations (7) and (8):

$$s(x)K_{j,\mathrm{o}}^{(t)}(x) = \sum_{\substack{k=1\\k\neq j}}^{n} s(x)K_{k}^{(t)}m_{kj}(x)\ , \tag{7}$$

$$m_{j,\mathrm{co}}(x) = m_{j,\mathrm{so}}(x) = \sum_{\substack{k=1\\k\neq j}}^{n} m_{jk}(x)\ . \tag{8}$$

Equation (7) indicates that the term $s(x)K_{j,\mathrm{o}}^{(t)}(x)$ in equations (3) and (4) is equivalent to the final term in equation (1)—the sum of the survivors from in-migration streams from all other regions in the system. Equation (8) makes the assumption that age-specific metropolitan out-migration rates for city and suburb residents are both equivalent to metropolitan-wide out-migration rates. This assumption is consistent with the view that the metropolitan area rather than the city or suburb represents the appropriate 'origin' for interregional migration(6). The assumption made in relationship (8) also reduces the complexity of the data that are required to estimate the various in- and out-migration rates (to be discussed below).

Additional note should be taken of the conditionalities associated with intra-metropolitan residential mobility in equations (3) and (4). As specified, mobility-incidence rates, $i_{j,\mathrm{c}}$ and $i_{j,\mathrm{s}}$, are conditional on residents not migrating out of the metropolitan area during the period. Because only one movement transition can be recorded over the period, it is assumed that a residential move is not substitutable for a migratory move. Hence, an individual is only 'at-risk' of moving locally, if an interregional migration is not undertaken. This assumption also simplifies the data requirements for estimation, as will be discussed below.

The foregoing equations (1)–(8) constitute the methodology for projecting city-suburb redistribution within a single metropolitan area that is part of a nationwide system of regions. Given initial population sizes for the city and suburbs of the metropolitan area (in addition to those for other regions in the system) by five-year age categories, and given values for the rates $i_{j,\mathrm{c}}(x)$, $i_{j,\mathrm{s}}(x)$, $p_{j,\mathrm{cs}}(x)$, $p_{j,\mathrm{sc}}(x)$, $p_{j,\mathrm{oc}}(x)$, and $p_{j,\mathrm{os}}(x)$ [in addition to those for rates $m_{jk}(x)$, $s(x)$, and $s(0)$], these equations can be employed to project city and suburb population sizes for metropolitan area j over as many periods as desired. This specification follows from the two-stage redistribution process discussed in the previous section of the paper, and is consistent with the conventional interregional population-projection methodology [as designated in equations (1) and (2) only], if relationships (7) and (8) can be assumed.

(6) If this assumption is not made, then

$$\sum_{\substack{k=1\\k\neq j}}^{n} m_{jk}(x) = \frac{[K_{j,\mathrm{c}}^{(t)}(x)m_{j,\mathrm{co}} + K_{j,\mathrm{s}}^{(t)}(x)m_{j,\mathrm{so}}]}{[K_{j,\mathrm{c}}^{(t)}(x) + K_{j,\mathrm{s}}^{(t)}(x)]}\ ,$$

rather than the relationship in equation (8).

3.2 *General matrix model of the projection framework*

The above set of relationships can be specified in a matrix model of the projection framework that is general to l subregions within n regions. If one begins with

$$\bar{K}^{(t)}(x) = \begin{bmatrix} \bar{K}_1^{(t)}(x) \\ \bar{K}_2^{(t)}(x) \\ \vdots \\ \bar{K}_n^{(t)}(x) \end{bmatrix} \quad \text{and} \quad \bar{K}_j^{(t)}(x) = \begin{bmatrix} K_{j,1}^{(t)}(x) \\ K_{j,2}^{(t)}(x) \\ \vdots \\ K_{j,l}^{(t)}(x) \\ K_{j,\mathrm{o}}^{(t)}(x) \end{bmatrix} ,$$

where

$\bar{K}^{(t)}(x)$ is a column vector of population totals for n regions and their subregions, for ages x to $x+4$,

$\bar{K}_j^{(t)}(x)$ is a column vector of subregional populations of region j, for ages x to $x+4$, with elements $K_{j,a}^{(t)}(x)$ (where $a = 1, ..., l$) and $K_{j,\mathrm{o}}^{(t)}(x)$,

$K_{j,a}^{(t)}(x)$ is the population of region j, subregion a, aged x to $x+4$ at time t,

$K_{j,\mathrm{o}}^{(t)}(x)$ is the number of in-migrants to region j between time t and $t+1$, aged x to $x+4$ at time t (initially assigned a 0 value in the projection process);

then the equation projecting end-of-period populations from beginning-of-period populations in age classes 0–4, 5–9, ..., ⩾70 is

$$\bar{K}^{(t+1)}(x+5) = \{\mathbf{p}(x)\mathbf{i}(x) + [\mathbf{I} - \mathbf{i}(x)]\}\bar{\mathbf{m}}(x)s(x)\bar{K}^{(t)}(x) , \tag{9}$$

where

$s(x)$ is the survival rate expressed in scalar form,

$\bar{\mathbf{m}}(x)$ is an $(l+1)n \times (l+1)n$ matrix of interregional migration rates (in terms of rates m_{jk} as illustrated below),

$\mathbf{i}(x)$ is an $(l+1)n \times (l+1)n$ matrix of intraregional mobility-incidence rates [in terms of the rates $i_{j,a}(x)$ as illustrated below],

$\mathbf{p}(x)$ is an $(l+1)n \times (l+1)n$ matrix of destination-propensity rates for intraregional movers and interregional in-migrants [in terms of rates $p_{j,ab}(x)$ and rates $p_{j,\mathrm{o}b}(x)$ as illustrated below],

$\mathbf{I}$ is an $(l+1)n \times (l+1)n$ identity matrix.

When it is assumed that there are two regions ($n = 2$), each with two subregions ($l = 2$), the elements of $\bar{\mathbf{m}}(x)$, $\mathbf{i}(x)$, and $\mathbf{p}(x)$ can be specified as

$$\bar{\mathbf{m}}(x) = \left[\begin{array}{ccc|ccc} 1-\sum\limits_{k \neq 1} m_{1k}(x) & 0 & 0 & 0 & 0 & 0 \\ 0 & 1-\sum\limits_{k \neq 1} m_{1k}(x) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_{21}(x) & m_{21}(x) & 0 \\ \hline 0 & 0 & 0 & 1-\sum\limits_{k \neq 2} m_{2k}(x) & 0 & 0 \\ 0 & 0 & 0 & 0 & 1-\sum\limits_{k \neq 2} m_{2k}(x) & 0 \\ m_{12}(x) & m_{12}(x) & 0 & 0 & 0 & 0 \end{array}\right]$$

where

$m_{jk}(x)$ is the interregional migration rate—the proportion of residents in region j, aged x to $x+4$ at time t and surviving to time $t+1$, that resides in region k at time $t+1$;

$$\mathbf{i}(x) = \left[\begin{array}{ccc|ccc} i_{1,1}(x) & 0 & 0 & 0 & 0 & 0 \\ 0 & i_{1,2}(x) & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & i_{2,1}(x) & 0 & 0 \\ 0 & 0 & 0 & 0 & i_{2,2}(x) & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right] ,$$

where

$i_{j,a}(x)$ is the mobility-incidence rate for subregion a residents—the proportion of residents of region j and subregion a, aged x to $x+4$ at time t, surviving to time $t+1$, and not migrating out of the region, that resides in a different dwelling unit in region j at time $t+1$;

and

$$\mathbf{p}(x) = \left[\begin{array}{ccc|ccc} 1-p_{1,12}(x) & p_{1,21}(x) & p_{1,o1}(x) & 0 & 0 & 0 \\ p_{1,12}(x) & 1-p_{1,21}(x) & p_{1,o2}(x) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 1-p_{2,12}(x) & p_{2,21}(x) & p_{2,o1}(x) \\ 0 & 0 & 0 & p_{2,12}(x) & 1-p_{2,21}(x) & p_{2,o2}(x) \\ 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right] ,$$

where

$p_{j,ab}(x)$ is the destination-propensity rate for subregion-a-origin movers—the proportion of residents of region j and subregion a, aged x to $x+4$ at time t, surviving and residing in a different dwelling unit in region j at time $t+1$, that resides in subregion b at time $t+1$,

$p_{j,ob}(x)$ is the destination-propensity rate for in-migrants to region j—the proportion of in-migrants to region j, aged x to $x+4$ at time t and surviving to time $t+1$, that resides in subregion b at time $t+1$.

Equation (9) can now be viewed in terms of the two-stage redistribution process discussed earlier. The 'interregional exchange' stage of the process is represented by the factor, $\bar{\mathbf{m}}(x)s(x)$, which redistributes migrants from one region to another. The 'intraregional allocation' stage can be viewed as the sum of two factors: $[\mathbf{I}-\mathbf{i}(x)]$ which identifies subregional residents who do not undertake a residential move and who reside in the same dwelling unit at the end of the period; and $\mathbf{p}(x)\mathbf{i}(x)$ which both identifies residential movers among the subregional population and redistributes those movers, as well as redistributing regional in-migrants, to subregional destinations at the end of the period. This specification of the destination-propensity-rate matrix, $\mathbf{p}(x)$, treats the allocation to subregions of residential movers and regional in-migrants as like-processes and is consistent with the view that these mover and migrant groups are influenced by the same subareal attractions in their 'choice of destination' within the region.

The second of the two relationships which constitute the projection process projects end-of-period population totals for the 0–4 class:

$$\bar{K}^{(t+1)}(0) = \sum_{x=10}^{45} 2.5s(0)[\bar{\mathbf{F}}(x)\mathbf{K}^{(t)}(x)+\bar{\mathbf{F}}(x+5)\bar{\mathbf{K}}^{(t+1)}(x+5)] , \tag{10}$$

where

$s(0)$ is the survival rate of births expressed in scalar terms [as in equations (2), (5), and (6)],

$\bar{\mathbf{F}}(x)$ is an $(l+1)n \times (l+1)n$ matrix of fertility rates [specified below in terms of elements $f_j(x)$].

When it is assumed that the subregions of each region will exhibit the same fertility rates as the region, the $\bar{\mathbf{F}}(x)$ matrix for an illustrative two-region model is specified as follows:

$$\bar{\mathbf{F}}(x) = \left[\begin{array}{ccc:ccc} f_1(x) & 0 & 0 & 0 & 0 & 0 \\ 0 & f_1(x) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \hdashline 0 & 0 & 0 & f_2(x) & 0 & 0 \\ 0 & 0 & 0 & 0 & f_2(x) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right],$$

where

$f_j(x)$ is the fertility rate—the average annual number of births to persons aged x to $x+4$ in region j.

The reader should note that, although the framework outlined in relationships (9) and (10) can handle up to l subregions within each region, the number of subregions can vary across regions, and there need not be any subregions in one or more regions. In the first instance, only relevant subareas should be given initial year ($t = 1$) populations in submatrix $\bar{\mathbf{K}}_j^{(t)}(x)$ for the region, with all other $\bar{K}_{j,a}^{(t)}(x)$ elements given a value of 0. In the second instance, the initial year population of the total region should be inserted in the $K_{j,o}^{(t)}(x)$ element, with all other elements given a value of 0. For both instances, appropriate changes need to be made within the $\bar{\mathbf{m}}(x)$, $\mathbf{p}(x)$, and $\mathbf{i}(x)$ matrices. Taken together, relationships (9) and (10) constitute a more general model of the two-stage interregional and intraregional projection-process than was specified for the particular example of intrametropolitan city-suburban redistribution earlier in this section. Because the end-of-period matrix $\bar{\mathbf{K}}^{(t+1)}(x)$ for ages 5-9, 10-14, ..., represents the beginning-of-period matrix $\bar{\mathbf{K}}^{(t)}(x)$ for the subsequent projection-period, these relationships can produce projected population sizes for l subregions within n regions for any desired number of periods.

3.3 *Rate calculation and data considerations*

An important feature of the two-stage projection-process is its relatively parsimonious data requirements for estimation of mobility rates. If the conventional 'single-stage' multiregional methodology were adapted to accommodate projections of l subregions within n regions, the number of new 'regions' would simply be expanded to ln and it would be necessary to compile a nationwide origin-destination matrix of $ln \times ln$ movement flows to estimate the movement rates for the projection framework.

The two-stage model requires only a nationwide origin-destination matrix of $n \times n$ flows, and an $l \times l$ origin-destination matrix for each region (or for those regions where a subregion projection is desired). In a nation of five regions with two subregions each, the first methodology would require a 10 x 10 nationwide-flow matrix, and the second methodology would require a 5 x 5 nationwide matrix and a 2 x 2 matrix for each of the five subregions. The latter, more compact nationwide-flow matrix is advantageous for rate estimation, because it is likely to yield far fewer sparsely populated flows than would be the case with the full-scale nationwide subregion-to-subregion matrix.

The basic migration and mobility parameters that are required for matrix relationship (9) [or for equations (1), (3), (4), (7), and (8) in the specific city-suburb example] are: m_{jk} for origin region j and destination region k ($j, k = 1, 2, ..., n$); $i_{j,a}$, $p_{j,ab}$, and $p_{j,ob}$ for up to l subregions, a, b, within one or more of the n regions. With the assumption that the period t to $t+1$ is equal to the age-category interval (five years in this case), all of these rates can be estimated from the following fixed-interval migration tabulations that are available from a census:

tabulation A nationwide population aged $\geqslant 5$, *cross tabulated* by region of residence, region of residence five years ago, and five-year age groups;

tabulation B regional population (for each region of interest), aged $\geqslant 5$, *cross tabulated* by residence in same or different dwelling unit as five years ago, subregion of residence (within the region) five years ago, and five-year age categories⁽⁷⁾.

The rates are computed as follows:

$$m_{jk}(x) = \frac{\begin{array}{l}\text{region k residents, aged $x+5$ to $x+9$ at census,}\\ \text{who resided in region j, five years ago}\end{array}}{\begin{array}{l}\text{all national residents aged $x+5$ to $x+9$ at census,}\\ \text{who resided in region j, five years ago}\end{array}} ;$$

$$i_{j,a}(x) = \frac{\begin{array}{l}\text{all region j residents, aged $x+5$ to $x+9$ at census,}\\ \text{who lived in a different dwelling unit located in}\\ \text{subregion a of that region, five years ago}\end{array}}{\begin{array}{l}\text{all region j residents, aged $x+5$ to $x+9$ at census,}\\ \text{who resided in the same or different dwelling unit}\\ \text{in subregion a of that region, five years ago}\end{array}} ;$$

$$p_{j,ab}(x) = \frac{\begin{array}{l}\text{subregion b, region j residents, aged $x+5$ to $x+9$}\\ \text{at census, who lived in a different dwelling unit}\\ \text{located in subregion a of that region, five years ago}\end{array}}{\begin{array}{l}\text{all region j residents, aged $x+5$ to $x+9$ at census,}\\ \text{who lived in a different dwelling unit located}\\ \text{in subregion a of that region, five years ago}\end{array}} ;$$

$$p_{j,ob}(x) = \frac{\begin{array}{l}\text{subregion b, region j residents, aged $x+5$ to $x+9$}\\ \text{at census, who lived in a different dwelling unit}\\ \text{located outside the region j, five years ago}\end{array}}{\begin{array}{l}\text{all region j residents, aged $x+5$ to $x+9$ at census,}\\ \text{who lived in a different dwelling unit outside}\\ \text{region j, five years ago}\end{array}}$$

The survival and fertility parameters, $s(x)$ and $f_j(x)$, required for matrix relationships (9) and (10) [or equations (2), (5), and (6) in the specific city–suburb example] can be computed in a more straightforward fashion with available vital statistics data and census tabulations, using standard techniques (Shryock and Siegel, 1971; Rogers, 1975).

Notice that only the nationwide tabulation A is necessary to compute the $m_{jk}(x)$ interregional migration rates needed to construct matrix $\bar{\mathbf{m}}(x)$ in equation (9). Only region-specific tabulations B are necessary to compute the incidence rates $i_{j,a}(x)$ and and propensity rates $p_{j,ab}(x)$ and $p_{j,ob}(x)$ needed for matrices $\mathbf{i}(x)$ and $\mathbf{p}(x)$. It should now be clear why movement-rate estimation becomes simplified when it is assumed

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(7) Some data sources do not distinguish between same and different dwelling-unit residences for individuals that do not move across subregion boundaries. This precludes estimation of separate mobility-incidence rates and destination-propensity rates for residential movers in equation (9). An alternative specification for such data sources is offered in the appendix to the paper by Long and Frey (1982).

that (1) all subregional residents in a given region exhibit the same age-specific out-migration rates [as in equation (8) in section 3.1, or in $\overline{\mathbf{m}}(x)$ in section 3.2]; and (2) intraregional mobility-incidence rates are conditional on residents not migrating out of the region [as defined in equations (3) and (4) in section 3.1; and in matrix $\mathbf{i}(x)$ of section 3.2]. If assumption (1) were not made, then it would be necessary to tabulate a nationwide $ln \times n$ origin-destination migration matrix to compute all $m_{jk}(x)$. Likewise, if assumption (2) were not made, the same matrix—in addition to tabulation B—would be necessary to compute all $i_{j,b}(x)$.

An important feature of this projection framework is its capability to produce 'updated' projections when current, but limited, data become available. For example, assume that equations (9) and (10) were employed to produce intraregional and interregional projections on the basis of fixed-interval migration tabulations A and B that were available with the past census. Several years after the census is taken, a comprehensive survey of residents in one region j becomes available, which includes appropriate information to compile a *current* tabulation B. This allows the researcher to produce an 'updated' projection of subregions within region i based on the same interregional migration, fertility, and mortality parameters $[\overline{\mathbf{m}}(x), s(x), f_j(x)]$ as the last projections, but based on more current intraregional allocation parameters for region j $[i_{j,a}(x), p_{j,a}(x), p_{j,ob}(x)]$.

In this vein, it should be noted from the above that the destination-propensity rates, $p_{j,ab}(x)$ and $p_{j,ob}(x)$ needed for the $\mathbf{p}(x)$ matrix in equation (9) can be computed from a survey of the movers in a region. Thus, the availability of a current survey of movers provides the capability of updating past projections, if one is willing to assume that the previous $i_{j,a}(x)$ rates, in addition to the previous $m_{jk}(x)$, $s(x)$, and $f_j(x)$ rates, hold for the current update. Because age-specific incidence rates tend to vary less across time and space than destination-propensity rates and because the latter are directly linked to the intraregional mover and migrant allocation-process (Frey, 1978b; 1979b), an updating of intraregional projections on the basis of current destination-propensity rates constitutes an inexpensive means of compiling timely projections between censuses.

4 Application to three US metropolitan areas

4.1 *Baseline projections from 1970 census data*

The projection framework outlined in the previous section will be employed to project intrametropolitan central-city-suburban redistribution for three large SMSAs—Detroit, Atlanta, and Houston. The largest US SMSAs are generally recognized to be self-contained labor-market regions, and have been included as such both in the Bureau of Economic Analysis and in the State Economic area-regionalization schemes(8). The three SMSAs selected for this application display distinctly different core-periphery and metropolitan-wide population change patterns over the base period for the projection 1965-1970. Detroit represents a declining industrial metropolis that has sustained considerable city loss and core-periphery decentralization; Atlanta is a growing SMSA, although also undergoing a significant intrametropolitan city-suburb redistribution; Houston, growing faster than Atlanta or Detroit, registers moderate growth in its central city as a consequence of a much less pronounced decentralization process.

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(8) These constitute alternative regionalizations of the national territory wherein the regions approximate single labor-market areas. The 183 Bureau of Economic Analysis Areas, designated by the Bureau of Economic Analysis, approximate self-contained commuting regions based on the nodal functional concept [see discussion in Hall and Hay (1980, pages 3-14]. The 510 State Economic Areas designated by the US Bureau of the Census (1970) represent groups of counties that are homogeneous with respect to social and economic characteristics.

For simplicity of exposition, the interregional and intraregional projections to be undertaken for each SMSA will be based on a simple two-region system where one region consists of the SMSA of interest, and the other region consists of the 'rest of the USA'. The intraregional projection will then occur within the SMSA region—across the central-city and suburban 'subregions' of the SMSA. This simplified regional system therefore requires that a separate projection analysis be undertaken for each SMSA. (A more elaborate analysis would include all national labor-market areas—including the three SMSAs—in the regional scheme, and would require only one projection analysis.) The projection process is consistent with equations (1)-(8) which are tailored to the specific case of city-suburb redistribution where there are two regions ($n = 2$), such that $j = 1$ for the SMSA of interest and $j = 2$ for the rest of the country. Alternatively, the more general specifications in relationships (9) and (10) also apply where $n = 2$ and $l = 2$ in region 1, such that a and b can be designated as c or s (for central city or suburbs) in the SMSA of interest.

Appropriate fixed-interval migration data are available from special tabulations from the 1970 US census and from the US Bureau of the Census (1973). These data make it possible to derive tabulation A to compute the interregional exchange rates [$m_{12}(x)$ and $m_{21}(x)$]; and tabulation B to compute the intraregional allocation rates [$i_{j,\mathrm{c}}(x)$, $i_{j,\mathrm{s}}(x)$, $p_{j,\mathrm{cs}}(x)$, $p_{j,\mathrm{sc}}(x)$, $p_{j,\mathrm{oc}}(x)$, $p_{j,\mathrm{os}}(x)$]. The census tabulations were adjusted for a mover's unknown residence five years prior to the census by allocating 'unknowns' to locations appropriate to individuals with similar race, age, and socioeconomic characteristics. The tabulations were also adjusted for census underenumeration using measures developed by the US Bureau of the Census (1977b). The 1965-1970 migration and residential mobility parameters for the Detroit SMSA are shown in table 2. In these projections, nationwide age-specific survival rates [$s(x)$] and nationwide age-specific fertility rates [$f_j(x)$] are assumed to hold for all regions and periods.

Table 2. Migration and residential mobility parameters for Detroit SMSA, based on 1965-1970 period (source: 1970 US Census tabulations adjusted for 'residence five years ago not known' and census underenumeration). The symbolic parameters are explained in the text.

Age at start of period, x to $x+4$	SMSA out-migration rate	Surviving in-migrants to SMSA	Mobility-incidence rates of		Destination-propensity rates of			
			city residents	suburb residents	city-origin movers	suburb-origin movers	in-migrants to SMSA	
	$\sum_{k=1, k \neq j}^{n} m_{jk}(x)$	$\sum_{k=1, k \neq j}^{n} s(x)K_k^{(t)}m_{kj}(x)$	$i_{j,\mathrm{c}}(x)$	$i_{j,\mathrm{s}}(x)$	$p_{j,\mathrm{cs}}(x)$	$p_{j,\mathrm{sc}}(x)$	$p_{j,\mathrm{oc}}(x)$	$p_{j,\mathrm{os}}(x)$
0-4	0.1054	45988	0.5910	0.3755	0.3165	0.0796	0.3520	0.6480
5-9	0.0820	31505	0.4749	0.2712	0.2956	0.0775	0.3004	0.6996
10-14	0.1264	24915	0.4294	0.2504	0.2780	0.1044	0.3731	0.6269
15-19	0.2215	54233	0.6509	0.6018	0.2888	0.1353	0.4072	0.5928
20-24	0.1513	61445	0.7713	0.6774	0.3808	0.1062	0.3515	0.6485
25-29	0.1267	31351	0.6644	0.4736	0.3680	0.0899	0.3353	0.6647
30-34	0.0878	20542	0.5372	0.3494	0.3269	0.0804	0.3329	0.6671
35-39	0.0870	16431	0.4467	0.2430	0.3314	0.0939	0.2465	0.7535
40-44	0.0552	12179	0.3692	0.2097	0.3304	0.0913	0.2651	0.7349
45-49	0.0540	8487	0.3429	0.2078	0.3613	0.1195	0.3492	0.6508
50-54	0.0774	4924	0.3122	0.1959	0.3772	0.1336	0.3635	0.6365
55-59	0.0735	3902	0.3059	0.1876	0.3430	0.1105	0.3810	0.6140
60-64	0.0983	3253	0.2838	0.1896	0.4002	0.1363	0.4644	0.5356
65-69	0.0904	2728	0.2761	0.2043	0.3060	0.1325	0.3658	0.6342
⩾70	0.0874	6043	0.3084	0.2304	0.3683	0.2058	0.3867	0.6133

The former were compiled from work by the US Department of Health Education and Welfare (1975) and the latter were taken from work by the US Bureau of the Census (1977b).

Table 3 displays total (age-aggregated) rates associated with 'the interregional exchange' and 'intraregional allocation' redistribution stages for each SMSA. These make it clear that, in the exchange with other regions, Detroit fares less well than either Atlanta or Houston—by suffering a net out-migration to the rest of the country. In the intraregional allocation stage, however, Detroit and Atlanta are most alike. Although mobility-incidence rates are fairly similar for all three SMSAs, it is clear that the Detroit and Atlanta destination-propensity rates will bring about a greater city-to-suburb allocation of movers and in-migrants within those SMSAs than will be the case in Houston.

The results of the projection process for each SMSA are shown in table 4(9). The projections for individual SMSA population sizes are consistent with the interregional-exchange-stage rates that generate the projections. The SMSA population of Detroit grew the least—34% over the fifty-year period; while Atlanta and Houston increased their 1970 populations by 109% and 115%, respectively.

With respect to intrametropolitan redistribution, the data in table 4 show the Detroit share of the SMSA population to decrease from 37% to 24% over the fifty-year period; and to sustain a projected absolute decline of 11% of its 1970 population. The Atlanta central-city share of the SMSA population undergoes a decrease of similar magnitude—36% to 25%, but manages to enjoy a projected population gain of 43% of its 1970 size. The projected city-suburban decentralization process is much less accentuated in the Houston SMSA. Here, the central city retains the majority share of the SMSA population throughout the projection interval—declining slightly from 62% to 52%. The projected population-gain of the city over the period is 79% of the 1970 population.

Table 3. Migration and residential mobility parameters for the total populations of Detroit, Houston, and Atlanta SMSAs, based on the 1965-1970 period (source: 1970 US Census tabulations adjusted for 'residence five years ago not known' and census underenumeration).

Parameter	Detroit	Atlanta	Houston
Interregional exchange stage			
SMSA out-migration rate	0.1055	0.1583	0.1334
Surviving in-migrants to SMSA			
in hundreds	3279	2769	3574
as a percentage of initial population	0.0823	0.2300	0.2105
Intraregional allocation stage			
Mobility incidence rate for city residents	0.4677	0.5305	0.4937
Mobility incidence rate for suburb residents	0.3229	0.4143	0.3625
Suburb-destination-propensity rate for city-origin movers	0.3312	0.3512	0.2310
City-destination-propensity rate for suburb-origin movers	0.1021	0.1311	0.2368
City-destination-propensity rate for SMSA in-migrants	0.3481	0.2756	0.6034
Suburb-destination-propensity rate for SMSA in-migrants	0.6519	0.7244	0.3966

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(9) The reader will notice that these projections differ from those presented for the Pittsburgh and Houston SMSAs in Long and Frey (1982, section 4.2). The latter are not strictly estimated with the closed-system interregional and intraregional methodology advanced here in that the in-migration component $[s(x)K_{j,\mathrm{o}}^{(t)}(x)]$ was generated by applying observed 'in-migration/beginning-of-period-resident' ratios to the age-disaggregated population of the SMSA at the beginning of each period. Hence, the resulting SMSA projections are not consistent with projections for a system of regions which lies outside the SMSA boundaries.

Table 5 provides insights into how the migration, residential mobility, and natural increase components of change contribute to the city-suburb redistribution process of each SMSA over the fifty-year projection-period. The data parallel those presented for the base period in table 1. Again, each SMSA undergoes a significant projected city-to-suburb redistribution as a result of the intrametropolitan residential mobility

Table 4. Projected population sizes and city and suburb shares of the population, for 1970-2020 for Detroit, Atlanta, and Houston SMSAs [source: projection equations (1)-(8) in text; with all input populations and rates from 1970 US Census tabulations adjusted for 'residence five years ago not known' and census underenumeration].

Population size and city and suburb shares	Year					
	1970	1980	1990	2000	2010	2020
Detroit SMSA						
Total size (in thousands)	4328	4570	4899	5171	5485	5798
Population share (%)						
city	36.6	30.3	27.0	25.3	24.6	24.3
suburb	63.4	69.7	73.0	74.7	75.4	75.7
Atlanta SMSA						
Total size (in thousands)	1437	1795	2148	2448	2737	2998
Population share (%)						
city	36.4	29.5	26.6	25.4	25.1	25.0
suburb	63.6	70.5	73.4	74.6	74.9	75.0
Houston SMSA						
Total size (in thousands)	2048	2566	3097	3551	3991	4396
Population share (%)						
city	62.3	57.1	54.2	52.8	52.3	51.9
suburb	37.7	42.9	45.8	47.2	47.7	48.1

Table 5. Contributions to projected central-city, suburb, and SMSA population change, for 1970-2020 attributable to natural increase, net migration, and net intrametropolitan residential mobility for Detroit, Atlanta, and Houston SMSAs [source: projection equations (1)-(8) in text; with all input populations and rates from US Census tabulations adjusted for 'residence five years ago not known' and census underenumeration].

Projected population size and projected components of change	Detroit			Atlanta			Houston		
	central city	suburbs	SMSA	central city	suburbs	SMSA	central city	suburbs	SMSA
Projected 2020 population size (in thousands)	1407	4390	5797	748	2250	2998	2280	2116	4396
Components of 1970-2020 population change[a] (as percent of 2020 population size)									
Natural increase	43.5	38.3	39.6	46.7	41.4	42.7	43.8	36.0	40.1
Net migration and mobility	−56.0	−0.9	−14.2	−16.6	18.0	9.4	0.2	27.4	13.4
Net migration to outside SMSA	4.2	−20.2	−14.2	10.7	8.9	9.4	25.2	0.5	13.4
Net mobility within SMSA	−60.2	19.3		−27.3	9.1		−25.0	26.9	

[a] The contribution to 1970-2020 population change attributable to each component (that is, natural increase, net migration, net mobility) is calculated by summing the contribution of that component to population change during each period, 1970-1975, ..., 2015-2020, over the ten five-year periods of the projection span. This sum of period contribution is then expressed as a percentage of the projected 2020 population size of the appropriate area (that is, central city, suburb, SMSA).

streams. However, this redistribution is 'cushioned' in Atlanta and Houston as a result of net in-migration to the SMSA as a whole—and to city and suburb subregions. The data show clearly that the prospects of long-term population gains for all subregions in a labor-market area are enhanced when the labor market, as a whole, sustains a constant net in-migration vis-à-vis other labor markets.

4.2 *'Updating' the projections with post-census survey data*

As indicated in section 3.3, the projection framework advanced here provides the capability for updating projections when recent, more limited mobility-tabulations become available for single regions in the regional system. Large-scale post-1970 surveys of movers in the Detroit, Atlanta, and Houston SMSAs provide the opportunity to perform updates to the 'baseline' 1970 census-based projections presented above. These updated projections will assume the same rates for interregional migration, mobility incidence, survival, and fertility as did the baseline projections. However their destination-propensity rates ($p_{j,\mathrm{cs}}$, $p_{j,\mathrm{sc}}$, $p_{j,\mathrm{oc}}$, and $p_{j,\mathrm{os}}$) will be calculated from the survey data collected in the late 1970s. The survey tabulations that are used to estimate the late 1970s destination-propensity rates are compiled from the metropolitan area-wide Annual Housing Surveys undertaken in the Atlanta, Houston, and Detroit SMSAs in 1975, 1976, and 1977, respectively [as discussed by US Bureau of the Census (1977a; 1978; 1980)]. Approximately 15000 households are interviewed in each SMSA survey, which ascertains the number and ages of household members, and if the household (head) has changed residence over the previous year, and the location of the previous residence, whether in city or suburb or outside the SMSA. The post-1970 destination-propensity rates used in updating the 1970 census-based projections for each SMSA were calculated from a tabulation of mover-household members(10).

Figure 1 provides some indication of how age-specific destination-propensity rates for the late 1970s, to be used in the updated projections, differ from those for the late 1960s. Because of the limited sample size of the Annual Housing Survey, it is necessary to collapse age categories into end-of-period values: 5-14, 15-24, 25-34, 35-44, 45-54, and ≥55. Late 1970s and late 1960s rates are both presented in this manner to facilitate comparisons. In general, there is a tendency toward increased city-to-suburb redistribution. All three SMSAs show lower city-destination-propensity rates both for suburban-origin movers and for metropolitan in-migrants in the late 1970s than in the late 1960s [figures 1(b) and 1(c)]. Further, Atlanta shows a significant increase in its suburb destination-propensity-rate for city-origin movers [figure 1(a)]. This tendency is not exhibited for either Detroit or Houston.

The updated intrametropolitan projections for the three SMSAs can be contrasted with the baseline projections in figure 2. Both sets of projections begin with 1970, and progress through ten five-year periods to the year 2020. They differ only in the destination-propensity rates that are assumed. Hence, these comparisons provide a means of evaluating the long-term redistribution implications of changes in intrametropolitan destination selections by movers and migrants in the late 1970s, when all other migration, mortality, and fertility assumptions are held constant.

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(10) For each metropolitan area, a tabulation was prepared for members of households whose head moved during the year preceding the survey. The tabulations cross-classified the city and suburb location at the date of the survey by city, suburb, or outside the SMSA locations of previous residence for household members in age classes 5-14, 15-24, 25-34, 35-44, 45-54, and ≥55 at the time of the survey. Hence, the destination-propensity rates compiled from these data are based on mobility observations over a one-year (not five-year) period and pertain to the end-of-period household population (not total population) in each SMSA. In generating the projections, destination-propensity rates for five-year age-class multiples (that is, 5-14) are applied to each five-year age group in the class (for example, 5-9 and 10-14).

It is clear from the plots that the more recently registered destination-propensity rates will provide a more significant city-to-suburb redistribution of population in all three SMSAs, than would have occurred on the basis of late 1960 rates. The updated projections show that the share of SMSA population living in the central city of Detroit will fall to 18%, as contrasted with the 24% share with the baseline projections. The newly projected central-city share for Atlanta for the year 2020 is only 12% as contrasted with the previously projected 25% share. The central city and suburbs of Houston will grow rapidly under each projection. However, the 'updated' projection no longer shows the central city to dominate the suburbs throughout the projection period. By the year 1990, the suburbs of Houston are now projected to overtake the central city.

Although the updated projections represent something of a compromise between older projections, wherein all rates were calculated from data for the same base-period, and the need to produce equally elaborate projections from the current year, they do constitute a means to assess the aggregate implications of intercensal movement-patterns until a more satisfactory data base becomes available with the

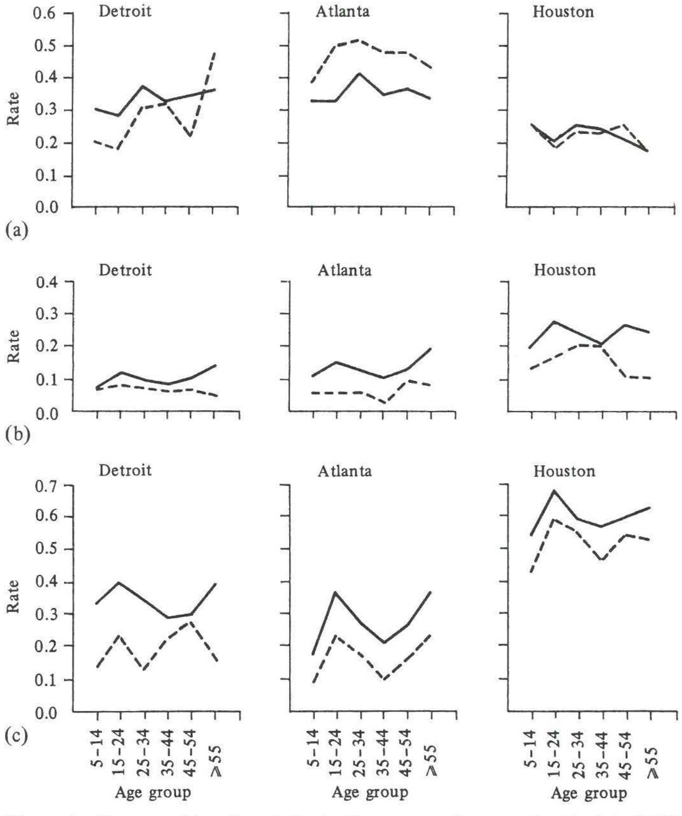

Figure 1. Mover and in-migrant destination-propensity rates for the late 1960s (solid lines) and late 1970s (dotted lines): (a) suburb destination-propensity rates for city-origin movers, (b) city-destination-propensity rates for suburb-origin movers, (c) city-destination-propensity rates for SMSA in-migrants. (Note: Rate is defined as the proportion of *a* residents of an area, aged x to $x+4$ at time t, who survive and live in another area or in a different dwelling unit in the same area at time $t+1$.)

next census. The 'updated' projections above, for example, serve to counter a popularly held view that a significant 'return to the city' had occurred in large metropolitan areas since the 1970 census was taken.

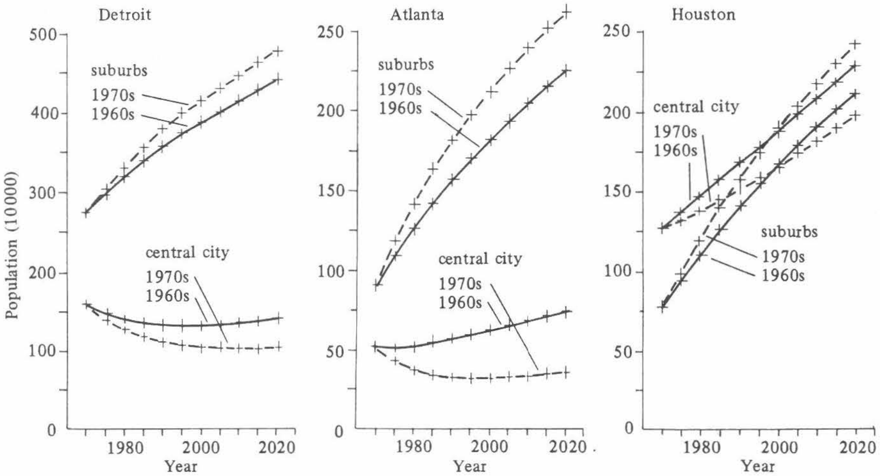

Figure 2. Alternative projections of city and suburb population sizes, for 1970-2020 based on assumptions of late 1960s and late 1970s destination-propensity rates for Detroit, Atlanta, and Houston SMSAs.

5 Conclusion

I have introduced in this paper a population-projection framework that incorporates both interregional migration and intraregional residential mobility streams to project future population sizes both across and within regions in a manner that is consistent with existing multiregional migration theory. I have also shown how the framework can be operationalized with fixed-interval migration data that are commonly available from censuses and surveys. A significant advantage of this framework over the existing multiregional projection methodology is its parsimonious data requirements when both interregional and intraregional projections are desired. It also permits the user to 'update' baseline projections when recent, more limited regional survey data become available. These features of the framework were demonstrated through projections of intrametropolitan central-city-suburban redistribution for three US SMSAs based on migration data from the 1970 US Census and metropolitan area-wide Annual Housing Surveys undertaken in each SMSA over the 1975-1977 period. Although this inter/intraregional projection-framework can be employed with any regionalization scheme the user desires, it is most consistent with underlying migration and residential mobility processes when the 'regions' correspond to self-contained labor-market areas such as Standard Metropolitan Statistical Areas or Bureau of Economic Analysis Areas in the United States of America, or Metropolitan Economic Labor Areas in the United Kingdom.

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Multiregional mathematical demography: themes and issues

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Abstract. People live in many regions and move between those regions over time. These facts have been incorporated into demographic analysis via the subfield of multiregional mathematical demography. In this paper the author reviews themes in that subfield over the past two decades and discusses current issues that have yet to be resolved.

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 characterised 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 issue 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.

(1) 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).

(2) 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.

(3) 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 system.

The analysis can begin at one of two points—with data on the transitions that people make (migrations between regions between fixed start and finish points) or with data on the movements that populations make (migrations between regions without reference to end time points). The data are assembled in accounts matrices that ensure consistency of different inputs and complete specification of all relevant transitions or movements. Notice that only methods for the building of 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 (linear, cubic, exponential, or interpolative-iterative) to represent 'life years lived' 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 migration data classified by place of birth.

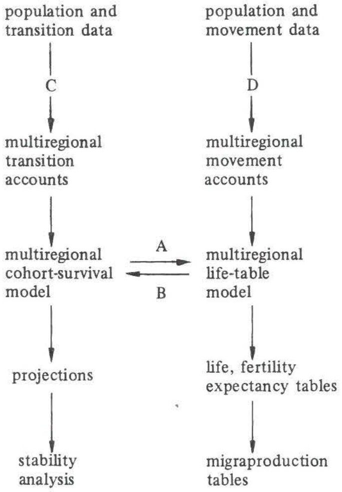


Figure 1. How the different approaches to multiregional mathematical demography have converged.

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 the International Institute for Applied Systems Analysis (Rogers et al, 1983). First, a series of seventeen 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]. Second, a series of papers are in preparation that compare results in the different countries (Liaw, 1981; Rees and Willekens, 1981; Rogers and Castro, 1981; Termote, 1981).

The case studies document, for a set of developed North American, European, and Asian nations, the way in which life expectancies vary across regions within countries, the way in which life expectancies by region of birth which incorporate 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. Last, the set of seventeen 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 (for example, see 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 (1983) 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 by applying entropy-maximising, information-theoretic, and contingency-table techniques (Willekens, 1977; Willekens et al, 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 was somewhat dependent on the availability of published migration data. Frey (1983) suggests that more interesting spatial shifts are going on within and between metropolitan areas in the United States of America, 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–nonmetropolitan population shifts currently in full spate in the United Kingdom. Problems in obtaining suitable data for these more spatially disaggregated systems are tackled by model redesign by Frey (1983), 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 et al, 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 et al (1978) on model migration schedules has been applied to local area migration profiles in the Martin et al 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 (OPCS) subnational projection model, the model is essentially the migration component of a multiregional cohort-survival model. The equation for forecasting migration is

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

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, and 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 twelve groups of in-migration profiles and twelve 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 et al (1978) model function in rearranged form (see Bates and Bracken, 1982). The term R^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. Last, 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 (1983) 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 instructive to construct a 'multiregional' cohort-survival model for Welsh-only speakers, bilingual Welsh and English speakers, and English-only speakers in Wales 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 fully understand 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 areas) measured directly, since these are the lifeblood of multiregional models. A number of researchers (Courgeau, 1973; 1980; Rees, 1977; Ledent, 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) recognises three types of direct migration-measure in chapter 2 of his book:

(1) migrations (moves, movement),
(2) migrants (movers, transitions),
(3) "les dernières migrations ou derniers migrants" (migrations or migrants classified by last place of residence).

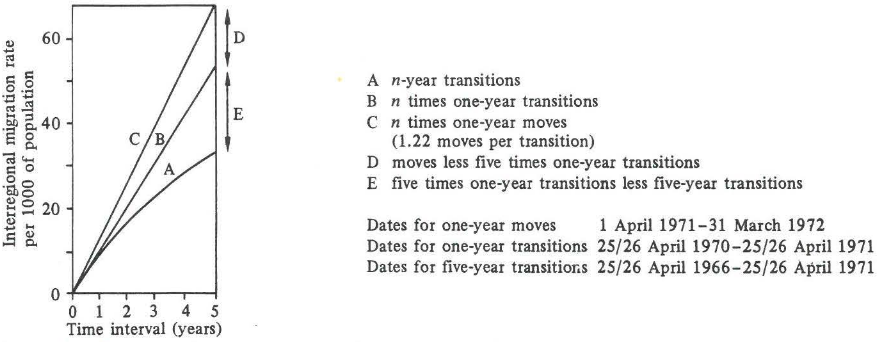
The first migration-measure counts all changes of region in a time interval, but without reference to initial state or final state in that period. The second migration-measure counts all changes between initial and final states in a time interval, without reference to intermediate migrations. The first 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 United Kingdom. There is a difference, D, between using one-year



A n-year transitions
B n times one-year transitions
C n times one-year moves (1.22 moves per transition)
D moves less five times one-year transitions
E five times one-year transitions less five-year transitions

Dates for one-year moves 1 April 1971–31 March 1972
Dates for one-year transitions 25/26 April 1970–25/26 April 1971
Dates for five-year transitions 25/26 April 1966–25/26 April 1971

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

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 interregional transition over a one-year period there were 1.22 interregional moves. The difference, E, is between five times the number of one-year transitions and one times the number of five-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 at the start over five years until aged 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

Table 1. Alternative estimates of transition probabilities [source: estimated from data in Kitsul and Philipov (1981, pages 2 and 24); all probabilities have been made conditional on survival].

General structure of the matrix

			To at age 20		
			1	2	3
From at age 15	East Anglia	1	p_{11}	p_{12}	p_{13}
	Southeast	2	p_{21}	p_{22}	p_{23}
	Rest of Britain	3	p_{31}	p_{32}	p_{33}

Alternative one-year data to derive the matrix

movement data[a]			transition data		
0.957	0.023	0.020	0.966	0.019	0.016
0.002	0.980	0.018	0.002	0.983	0.015
0.001	0.012	0.987	0.001	0.010	0.989

Alternative estimates for the five-year matrix

Matrix based on migration rates from five x one-year matrix:

movement data			transition data		
0.785	0.115	0.100	0.825	0.095	0.080
0.010	0.900	0.090	0.010	0.915	0.075
0.005	0.060	0.935	0.005	0.050	0.945

Matrix based on conventional equation[b]			Matrix based on fifth power of the one-year transition data matrix		
0.842	0.084	0.074	0.840	0.086	0.075
0.010	0.920	0.069	0.010	0.919	0.947
0.005	0.047	0.947	0.005	0.048	0.947

[a] Estimates based on ratios of moves to transitions derived from Ogilvy (1980).

[b] The conventional estimating equation can be found in equation (1) of Kitsul and Philipov (1981) or 'option 3' of Willekens and Rogers (1978).

and the second on transition data. The first two alternative estimates use these 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 to the fifth power, we would obtain probabilities of staying of 0.839, 0.918, and 0.945 for the three regions. Yet the transition probabilities based on observed five-year migrant tables are:

$$\begin{array}{ccc} 0.895 & 0.057 & 0.047 \\ 0.008 & 0.950 & 0.043 \\ 0.003 & 0.032 & 0.965\ . \end{array}$$

What lessons do we learn from these alternative estimates? First, if we use movement data we are liable to exaggerate the amount of interregional transfer occurring over five years. Second, 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. Third, 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-year 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.

(1) 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).

(2) 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. But, at the international level, return migration is likely to be very important. In the paper by 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 five-year out-migration rates from one-year rates at the regional scale. Another piece of evidence is for international migration to and from the United Kingdom. Table 2 shows a classification of immigration and emigration by citizenship and we see that a large proportion of the migrants were returnees.

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. But Long and Frey (1982) choose to use special tabulations of one-year migration rates from the Current Population Survey of the USA in preference to the readily available five-year migration rates. The UK Census Office dropped the 1971 practice of both a one-year 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 of one measure over another, given that both or all are available, will depend on the purpose of the analysis. 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 five-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. But, if one is interested in working out lifetime mobility rates (migra-production 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 USA computed by Long and Boertlein (1981) for inter-county migration together with the equivalent ratios for residential mobility in Great Britain.

Others have shown the considerable effect that controlling for much of the 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-year 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

Table 2. Immigration and emigration for the United Kingdom (UK) in 1980 from and to the rest of the world (RW) [source: International Passenger Survey statistics, OPCS (1981)].

Migration	Number of citizens (in thousands)			Return migrants (%)
	UK	non-UK	UK + non-UK	
From UK to RW	150	79	229	34
From RW to UK	67	107	174	79

enable me to recover from the Registrar General's deletion of the five-year question in the 1981 Census.

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

Denominator time interval (years)	US intercounty migration [a] numerator time interval (years)		GB residential mobility [b] numerator time interval (years)	
	1	5	1	5
1	1.0	3.16 (2.93)	1.0	2.96
5	0.32 (0.34)	1.0	0.34	1.0

[a] Data for US migration in 1970-1975 and 1975-1980 (in brackets) are from Long and Boertlein (1981).

[b] Data for mobility in Great Britain in 1966-1971 and 1970-1971 are taken from OPCS (1978).

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 hundred-region systems. Two problems occur. First, can the general computer programs for multiregional population analysis (Willekens and Rogers, 1978—SPA; Rees, 1983—ABM) handle the expanded arrays generated in these many-region systems? Second, do the arrays become too sparse (that is do they have too many zero entries or small number entries)?

The answer to the first question is as yet unknown, because the programs have not been used with very large systems, but current versions on the University of Leeds Amdahl VM470 computer comfortably cater for up to twenty 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 Greater London Council (GLC) model (Gilje and Campbell, 1973; Congdon et al, 1981) or in the DoE England and Wales model (Martin et al, 1981). Both decoupled models are rather specific to the systems being studied and the associated computer programs are nontransferable. 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 detail about age and sex 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, OPCS, 1981, page 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 twenty-region system consisting of the metropolitan counties and their equivalent, region remainders and nonmetropolitan 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 twenty areas is associated with a metropolitan-nonmetropolitan 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 1966-1971 interregional 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).

One 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 researcher do 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 United Kingdom 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-nonnative 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 nondemographic systems*

Most economic-demographic or general urban models have a fairly simple demographic structure that deals with migration to and from study zones or the study system in fairly 'bundled' terms rather than in a multiregional fashion. The demographic component is kept simple 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 interregional 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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