Dynamics of spatial redistribution of population in Australia

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Abstract We consider some general properties of the process of migration of population and the estimates of the characteristic time scales of migration change in Australia. A simple stationary transition-probability model, based on the migration flows from 1991 ABS census between 43 statistical divisions (SD) of the east-coast states (Qld, NSW, ACT, Vic and SA), is used. It is shown that the characteristic time of "approach" of the population distribution to the equilibrium pattern (which would result if there are no further changes in the probabilities of migration) is 15-40 years for intra-state migration and around 100 years for the inter-state migration. The projections show that the currently fastest growing SDs on the east-coast (most of them are in Queensland) are likely to continue to be the leaders in growth, and some of them (such as Brisbane, Moreton, Wide Bay-Burnett, Far North (Qld) and Richmond-Tweed from NSW) can substantially increase their share in the total population of the east-coastal part of Australia.

Introduction

The spatial pattern of population distribution in an area or country is arguably one of the key determinants of social and human-environment interactions (Dovers *et al.*,1992, Hamilton and Cocks, 1996). Along with other parameters of the human population, such as the total size, age-structure, life style and affluence, it is important for addressing current and future demographic, socio-economic and environmental problems.

The processes which determine the population redistribution often demonstrate a high degree of complexity and variability (Rowland, 1979, Flood *et al*, 1991). They act in both directions, with the pattern of settlement affecting migration flows and vice versa. To build a comprehensive theory of migration which would include all important interactions and feedback mechanisms is not feasible until these relationships are better understood. In the meantime the most productive approach is to consider the migration processes from the ranges of different theoretical perspectives (Bell, 1992).

Multiregional population models and projections which are currently used to analyze the dynamics of spatial population redistribution are based on different sets of assumptions as to what effects are to be actually modelled and what could be considered as "external" trends. The main components of a regional demographic balance are natural growth, inter-regional and overseas in- and out-migration. While the trends of birth and mortality rates are usually assumed (with some ground) as having smooth and unidirectional characters of change, the problems with inter-regional mobility are related to the fairly complicated problem of understanding the changes in people's migration preferences under evolving economic, social and environmental conditions. These interactions can substantially affect migration flows, which could result in future distributions being very different from the projected ones, especially as we move further away from the calibration period. Yet projections present a valuable instrument even for studies addressing a long-term (50 and more years) view (Young, 1997). The reason is that in most cases one can expect that the consequences of the processes with very short time scales of change (for example, short cycles of economic growth and downturn, involving short variations in migrational behavior) will be determined not by these processes per se, but rather by somewhat averaged (and therefore less volatile) trends which can be captured if the calibration period is sufficiently long. The analysis of the long-term projections can also substantially enhance our understanding of current demographic processes (Rogers, 1984).

In order to clarify the causes of the high level of variance in migration flows, a relatively new generation of dynamic spatial population models was developed (Griffith and MacKinnon, 1981; Weidlich and Haag, 1988; Roy, 1991; Roy and Flood, 1992). In these models the effective migration rates are decomposed into relative "utility" values at the origins and destinations, and some normalizing parameters representing the level of interaction between them and the total mobility of population. After the parameters in these models are found one can try to interpret the observed pattern of the regional "utilities" as a weighted combination of some plausible explanatory variables (for example local natural or cultural amenities, level of unemployment, size of the population, income, etc.). The possibility to split a system (i.e. separately consider its constituent parts or drivers) is advantageous because it gives some indication of how to calculate the changes in migration rates in response to the changes in the pattern of population distribution. These models still need the inclusion of additional external information about the dynamics of the some explanatory variables, and in this sense are not closed.

In this paper we consider a rather specific aspect of the problem, namely the properties of migration matrices and the characteristic time scales of a migration processes in Australia. The primary motivation is to relate the current dynamics of the inter-regional population movement in Australia to a broader context of asymptotic properties of the population distribution. We use a simple stationary transition-probability model (Rogers, 1975), applied to the migration flows between 43 statistical divisions (SD) of the east-coast states of Australia (Qld, NSW, ACT, Vic and SA). The standard assumptions of this approach are that out-migration flows from the regions are proportional to their populations, and the probabilities of the inter-regional migration are constant over time. A similar model is used in the Victorian population projection framework for states and territories of Australia (Davenport and O'Leary, 1992). As was already mentioned, this set of assumptions is only one (although logically attractive) of many possibilities. For example, ABS (1994) in its population projections for Australian states, uses the assumption that the migration flows are constant over the next 50 years (with some minor adjustments for the nearest 4-5 years). From our point of view at the SD level of disaggregation the assumption of constant flows, given the decreasing populaticns in some SDs, could become infeasible in the future (*eg* result in total depopulation of some regions), and secondly, projections based on the assumption that out-migration flows from the regions are proportional to their populations appear to be a better candidate for being qualified as a "minimum assumption projections". We calculate the time intervals characterising the redistribution processes on different spatial scales and analyse some implications for the future spatial population distribution.

Basic equations

Let us consider the dynamics of migration redistribution in a system of n regions. The assumptions are: the only attributes of the regions are their populations $p_i(t)$ and their specific rates of the natural growth, the system and the population don't have a memory, population is homogeneous, and the migration flows from any region i to all other regions $j \neq i$ and to "overseas" is proportional to the population in region i. In this case the state of our system is fully determined by the n-dimensional column vector $P=(p_i,...p_n)^T$, where superscript ^{T} means the transposition, and the dynamics of P is described by the following system of n ordinary differential equations

$$P_t = (M + B - D - O)P + I, \qquad (1)$$

Here B and D are the diagonal matrices describing birth and mortality rates respectively, I (vector) and O (diagonal matrix) correspond to in- (from "overseas") and out (to "overseas")-migration fluxes, M is the migration matrix and P_t denotes the derivative of P over time. The matrix operator M represents the square matrix n by n with elements M_{ij}, where M_{ij} $(i,j=1,...n;$ $i \neq j)$ is the probability for a person residing in region j to move to i, and

$$M_{ii}(i=1,\ldots n) = -\sum_{j\neq i} M_{ji}$$

The only special features of M are that it is a real, nonsymmetric matrix with non-negative elements outside the main diagonal and non-positive diagonal elements. The simplest case, where the coefficients of migration, birth, death and out-migration are constant over time (so-called the Markov or stationary transition-probability model), allows analytical consideration.

The usual starting point is the analysis of a homogeneous system. In our case the homogeneous system results when we exclude for a while in-migration from "overseas", $I=0$, so that the system becomes

$$P_t = (M + B - D - O)P, \qquad (2)$$

It is convenient to further simplify (2) by defining new variable vector S

$$S = P\exp[-(b-d)t], \qquad (3)$$

where b and d are the averaged (over the all SDs) coefficients of birth rate and mortality. As is clear from the definition, vector S corresponds to the "artificial" population distribution which changes only due to migration and local variations δ_i in the natural growth. After substituting (3) to (2), we obtain

$$S_t = (M - O + \delta)S, \qquad (4)$$

The general solution of this linear system of ordinary differential equations with constant coefficients (in demographic context it was considered by Rogers (1966, 1975)) is determined by the eigenvalues $-\lambda_i$ of the matrix $(M\text{-}O+\delta)$ (all of them are negative, and therefore λ_i are positive):

$$S = c_0 W_0 \exp(-\lambda_0 t) + \sum_{i=1}^{n-1} c_i W_i \exp(-\lambda_i t) \qquad (5)$$

where c_i are coefficients and W_i are the corresponding eigenvectors. Note that transformation (3) corresponds to the shift of all the eigenvalues of the matrix $(M+B\text{-}D\text{-}O)$ by the number $-(b\text{-}d)$ and does not change the eigenvectors. According to the theorem of Perron-Frobenius the system (4) has a unique dominant (i.e.

maximum) eigenvalue $(-\lambda_0)$ with corresponding non-negative eigenvector W_o. It is this dominant eigenvalue which determines the latent dynamics of population redistribution between regions and therefore the first term in (5) gives the asymptotic solution of (4). Qualitatively it means that in the evolution of our system there is some initial period of "relaxation" when migration processes establish a stable inter-regional population structure (W_o), which subsequently evolves according to the first term in (5). Note that the solution depends on both in- and -out migration regional rates which cannot be aggregated into net migration flows.

Study area and migration data

Our model is based on the equations (1) and includes 43 regions - SDs of the east coast states of Australia: Queensland (11 SDs), NSW (12), ACT (2), Victoria (11) and South Australia (7). "Overseas" includes all the other regions in Australia (migration exchange with them is weaker) and the outside world. The list of SDs is given in the first column of the Table 1, the second column gives their populations in 1991.

The regional migration statistics are taken from the Integrated Regional Data Base, Version 2 (ABS, 1994). The SD level (in accordance with the Australian Standard Geographical Classification Version 2.1) is the smallest spatial scale which contains origin-destination specified migration data for the period 1986-1991. To find the elements of the migration matrix (the probabilities) we normalized the 5 year out-migration flows from the SDs by the sum of populations in these SDs in 1986-1990.

Dynamics of relaxation processes

An important problem to be addressed is the dynamics of the relaxation processes, which lead to the stable inter-regional structure of the population distribution. Particularly interesting is estimation of how long could this relaxation period last, and to compare the length of the transitional period with the characteristic times of socio-economic and ecological processes which can possibly change the migration coefficients.

The procedure of solving the eigensystems is very unstable, and even simple low-dimensional cases may need double-precision algorithms. Yet some useful qualitative information on the behavior of the solution can be obtained straightforwardly. The regional populations approach the stable distribution with different time scales, there being some "quick" and some "slow" regions dependent on the rate at which the population of the region achieves the balance of in- and out-migration (note that "quick" does not mean fast growing). The corresponding characteristic time can be estimated (at least by order of magnitude) as $\tau_i \sim |M_{ii}-O_i+\delta_i|^{-1}$, where O_i is the probability to migrate from i to overseas. The regions with small τ_i tend to quickly achieve dynamic balance with the rest of the system, and their further evolution follows the dynamics of the "slow" regions. Numerical estimates show that SDs with the biggest populations (the capital cities and the rest of biggest SDs) are always "slow" (τ_i ~40-100 years), while the small SDs (numbers 5, 7, 11, 25, 39, 42) are "quick" (15-25 years). This means that the out-migration plays relatively more important role for the small SDs. It appears that processes of redistribution also have a spatial hierarchical arrangement: the small SDs quickly establish a dynamic balance with the closest capital city and remain in balance all the time, while there is a much slower (with characteristic time of about one hundred years) underlying process redistributing the population towards Queensland SDs and establishing the stable distribution. The dominant $(-\lambda_0)$ gives the time scale 350 years, which corresponds to the time scale of a decrease of the total population given the present level of out-migration and no migration from the overseas.

Table 1 presents the characteristic times τ_i and the inverse eigenvalues $|\lambda_j|^{-1}$ of the system (4) (note that although any eigenvalue characterizes the system as a whole and cannot be attributed to a particular SD, the smaller τ_i give very good estimates for some eigenvalues $|\lambda_j| \sim \tau_i^{-1}$. It is also worth mentioning that the regional variations in natural growth do not have a substantial effect on the eigenvalues).

Returning to the initial formulation with natural growth, from (3) we receive

$$P = S\exp[(b-d)t], \tag{6}$$

On the basis of (6) we can obtain the solution of the non-homogeneous system, which would include in-migration from "overseas". Let's introduce the determinant Δ which is composed of the transposed eigenvectors (including the exponential multipliers) $W_j^T exp[(-\lambda_j+(b-d))t] = (w_{j,1}, w_{j,2} \ldots w_{j,n}), j=0,\ldots n-1$

$$\Delta = \begin{vmatrix} w_{0,1} & w_{0,2} & \cdots & w_{0,n} \\ w_{1,1} & w_{1,2} & \cdots & w_{1,n} \\ \cdots & & & \cdots \\ w_{n-1,1} & w_{n-1,2} & \cdots & w_{n-1,n} \end{vmatrix}$$

and the determinants Δ_v, which is obtained from Δ after replacement of the vth row with a transposed vector of the regional "overseas" in-migration I^T. Then all the solutions of (1) can be presented in the following form

$$\psi_p = \sum_{v=0}^{n-1} w_{v,p}\left(\int \frac{\Delta_v}{\Delta}dt + c_v\right), \quad p = 1,\ldots n \tag{7}$$

In the case of the constant "overseas" in-migration this can be re-written as

$$\psi_p = \sum_{v=0}^{n-1} w_{v,p}\left(B_v \exp[\lambda_v t-(b-d)t]+c_v\right),\quad p=1,..n \qquad (8)$$

where B_v are some constants. The conclusion which follows from (8) and which is intuitively clear, is that if not too high, the constant in-migration from overseas into a naturally growing total population slightly changes the dynamics of the "relaxation" stage, but eventually becomes negligible simply because its relative intake compared with growing population becomes small. In the case of a declining population in-migration leads to the new steady regional distribution determined by the distribution of regional intakes.

Migration redistribution in Australia

In the following table we present some numerical results describing the dynamics of the population redistribution. Column 2 gives the populations of SDs in 1991, 3 and 4 - inverse moduli of the eigenvalues $|\lambda_j|^{-1}$ of the system (4) and the characteristic times τ_i (all in years), 5 and 6 - the populations of SDs in 1991 and 2050 expressed as a ratio to the total population of the east-coast states in 1991 and 2050 correspondingly, 7 - the shares of SDs populations in stable distribution (which would appear after 2100). The overseas migration is not included as its relative effects strongly depends on the dynamics of the future natural growth. Note only that initially it leads to the faster growth of the fastest-growing SDs, but does not have any substantial effects on the stable distribution.

Table 1

	Statistical Division	Pop. in 1991	$\lvert\lambda_i\rvert^{-1}$	τ_i	1991	2050	>2100
1	Brisbane (Qld)	1357986	46.39	46.38	0.0904	0.1177	0.1572
2	Moreton (Qld)	489622	33.52	32.31	0.0326	0.0583	0.0758
3	Wide Bay-Burnett (Qld)	195563	26.58	28.11	0.013	0.0193	0.0257
4	Darling Downs (Qld)	194136	27.3	29.45	0.0129	0.0163	0.022
5	South West (Qld)	29182	12.25	12.43	0.0019	0.0012	0.0016
6	Fitzroy (Qld)	168375	30.95	30.88	0.0112	0.0141	0.0194
7	Central West (Qld)	13326	13.9	13.92	0.0009	0.0007	0.0009
8	Mackay (Qld)	110301	29.11	29.71	0.0073	0.0091	0.0123
9	Northern (Qld)	182581	26.23	28.08	0.0122	0.0144	0.0185
10	Far North (Qld)	181399	38.01	36.55	0.0121	0.0162	0.0216
11	North West (Qld)	38221	15.74	15.86	0.0025	0.002	0.0026
12	Sydney (NSW)	3672855	96.61	54.85	0.2446	0.1801	0.1482
13	Hunter (NSW)	531965	48.73	47.93	0.0354	0.0391	0.0376
14	Illawarra (NSW)	349574	41.37	46.27	0.0233	0.0272	0.0252
15	Richmond-Tweed (NSW)	179525	36.78	33.32	0.012	0.0182	0.0208
16	Mid-North Coast (NSW)	240910	32.14	31.79	0.016	0.0216	0.0211
17	Northern (NSW)	185354	27.01	28.42	0.0123	0.0119	0.012
18	North Western (NSW)	115557	27.3	28.91	0.0077	0.0078	0.0073
19	Central West (NSW)	170123	29.74	30.54	0.0113	0.0107	0.0096
20	South Eastern (NSW)	168409	26.03	27.87	0.0112	0.0133	0.0128
21	Murrumbidgee (NSW)	147300	29.74	30.38	0.0098	0.0096	0.0091
22	Murray (NSW)	108882	25.69	26.94	0.0073	0.0076	0.0071
23	Far West (NSW)	28277	24.24	26.7	0.0019	0.0012	0.0011
24	Canberra (ACT)	288195	31.3	31.18	0.0192	0.0211	0.0214
25	ACT - Balance (ACT)	1125	11.48	11.49	0.0001	0.0001	0.0001
26	Melbourne (Vic)	3156706	349.6	69.07	0.2102	0.1834	0.1564
27	Barwon (Vic)	228474	71.77	49.56	0.0152	0.0175	0.0166
28	Western District (Vic)	102562	31.75	31.6	0.0068	0.0057	0.0049
29	Central Highlands (Vic)	139092	37.74	35.77	0.0093	0.0106	0.0095
30	Wimmera (Vic)	53275	27.96	29.29	0.0035	0.003	0.0025
31	Mallee (Vic)	82006	34.37	32.57	0.0055	0.0055	0.005
32	Loddon-Campaspe (Vic)	177134	34.59	32.96	0.0118	0.0141	0.0129
33	Goulburn (Vic)	153999	27.3	29.05	0.0103	0.0113	0.0105
34	Ovens-Murray (Vic)	91036	27.6	29.16	0.0061	0.0072	0.0069
35	East Gippsland (Vic)	66919	26.02	27.11	0.0045	0.0046	0.0042

36	Gippsland (Vic)	169170	38.5	37.28	0.0113	0.0117	0.0103
37	Adelaide (SA)	1057161	81.88	54.17	0.0704	0.064	0.0515
38	Outer Adelaide (SA)	93200	23.89	25.66	0.0062	0.0073	0.0061
39	Yorke and Lower North (SA)	43881	21.21	21.85	0.0029	0.0024	0.0019
40	Murray Lands (SA)	67443	27.2	28.48	0.0045	0.0041	0.0033
41	South East (SA)	62855	30.23	30.66	0.0042	0.0032	0.0025
42	Eyre (SA)	33165	22	22.75	0.0022	0.0013	0.001
43	Northern (SA)	88594	24.49	26.91	0.0059	0.0042	0.0032

As one can see the fastest growing SDs on the east-coast (most of them are in Queensland) are likely to continue to be the growth leaders. This situation could be changed if there is severe "depletion" in the population in SDs which serve as sources of in-coming migrants to the fast-growing SDs, but obviously this is not the case. Not many SDs are likely to substantially increase their share of the total population on the east coast, however we note amongst them Brisbane, Moreton, Wide Bay-Burnett, Far North (Qld) and Richmond-Tweed from NSW.

Note that the analysis of the equilibrium population distribution of the Australian states is given in Rowland (1979) and Bell (1992).

Conclusion

In this paper we used the standard stationary migration-probability model to estimate the stable spatial pattern of population distribution which would eventuate if the existing migrational rates will persist. We found that the dynamics of "relaxation" of the presently existing population distribution to the stable distribution has a spatial hierarchy of time scales. Usually, smaller SDs quickly (in 15-40 years) establish a dynamic equilibrium with the nearest capital city and remain in balance all the time while there is a much slower (with characteristic time of the order of one hundred years) underlying process redistributing the population towards Queensland SDs. The inter-regional migration is relatively more important for SDs with smaller populations. The existing distribution is fairly close to the stable one, but the existing deviations from the state of equilibrium appear to indicate that the time of change of the population' migrational preferences is less then 30-40 years. The fastest growing SDs on the east-coast (most of them are in Queensland) are likely to continue to be the leaders in growth, and some of them (such as Brisbane, Moreton, Wide Bay-Burnett, Far North (Qld) and Richmond-Tweed from NSW) can substantially increase their share in the total population of the east-coastal part of Australia.

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