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A Demographic Study of Hokkaido and the Rest of Japan

—The Application of the Multiregional Demographic Model—

Lai Yin Shem and Etsuo Yamamura

Department of Regional Planning, Division of Environmental Planning, Graduate School of Environmental Science, Hokkaido University, Sapporo, 060, Japan

Abstract

In order to study the demographic behaviour of Hokkaido in relation to the national context, a multiregional demographic model, developed by Andrei Rogers in 1978, was adopted. Conven tional demographic models deal with single-region populations which are assumed to be closed to migration. However, internal migration has been recognized as a dominant phenomena in inter-regional disparities. Thus, the multiregional demographic model was examined. The life table and projection matrix, like in the single-region model forms the methodological core of the multiregional model with its three sets of components-stocks, events and flows. This model was applied to a two-region study of Hokkaido and Rest of Japan using 1980 data. The multiregional life table, which describes the mortality and mobility history of a cohort, was computed. From this life table, a projection growth matrix with age-specific birth rates of parents, and survivorship rates was computed and a 40-year projection was derived. The multiple reiteration of this projection will ultimately converge in the stable population. Results of the computations show a striking high rate of out-migration of young people in the 15-19 years age-group from Hokkaido. The rapid change in age structure over the 40-year projection period for both regions is another striking observation.

Key Words: Multiregional demographic model, Population growth, Life table, Stable population, Hokkaido, Rest of Japan, Projection of population.

1. Introduction

Classical mathematical demographers have traditionally dealt with single-region populations which are assumed to be closed to migration. However, the major issues on population growth and development in both developed and developing economics can trace their origins to the differential impacts of human migration between rural-urban communities, city-suburban divisions and depressed-expanding subregions within national boundaries. Accordingly, a multiregional mathematical analysis was developed in the 1970's by Andrei Rogers and his colleagues and the methodology was perfected at the International Institute for Applied Systems Analysis (IIASA) in Austria.

Multiregional demography is the systematic study of human population trends and phenomena over time and space. Specifically, these trends are determined by the structual components, as age and sex; the vital components, as birth and death; and the spatial components, as in- and out-migration between regions- or, in other words, the population stocks, events and flows.

This paper presents a study on this multiregional population model and its application to a 2-region case of Hokkaido and the Rest of Japan. The results of the computations are presented and analyzed.

2. The single-region model

The single-region demographic model is first introduced as it forms the base of the multiregional model.

The life table and the population growth process forms the methodological core of the conventional single-region mathematical demography. The life table is a life history of a hypothetical group, or cohort, of people (in this case 100,000) as it is diminished gradually by deaths. The record begins at the birth of each member and continues until all have died. The computation of the single-region life table is summarized in the following Figure 1,

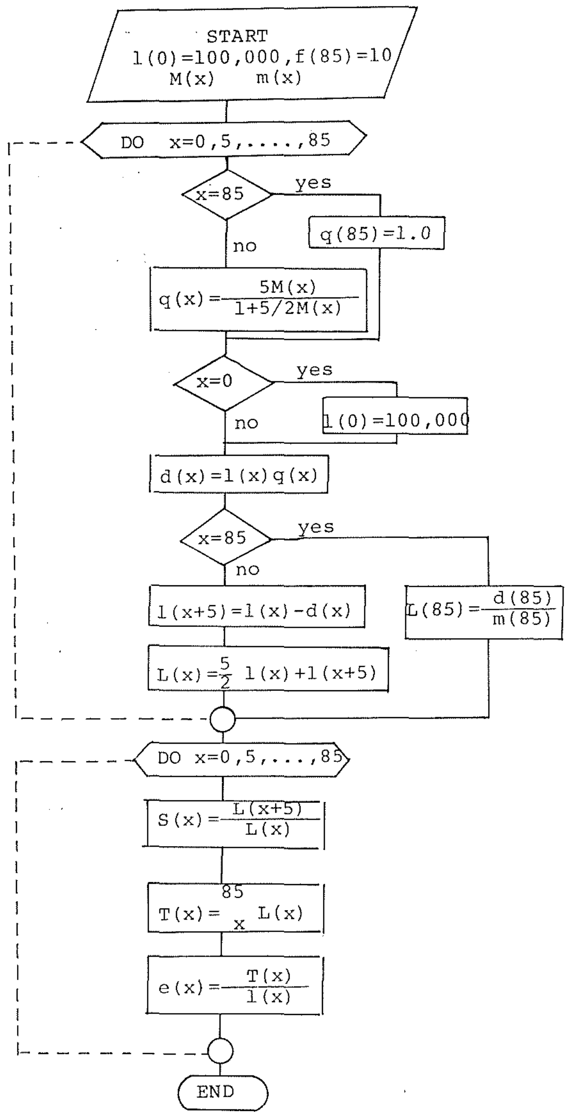

Figure 1. Flow for computation of life table.

where the age-specific variables are:

$q(x)$ = probability of dying.
$p(x)$ = probability of surviving.
$m(x)$ = annual death rate.
$d(x)$ = number of death rate.
$l(x)$ = number of survivors.
$L(x)$ = number of years lived.
$T(x)$ = expected total number of person years.
$e(x)$ = average expectation of life.
$s(x)$ = ratio surviving in age-group.

The population growth process is composed of the discrete formulation of Lotka's model which expresses the growth process of population by means of a matrix operation in which a population age distribution, set out as a vector, is multiplied by a projection matrix that survives that population forward toward time. Taking $K^{(t)}(x)$ as the number of people between ages x and $x+5$ (in a 5-year age group analysis) at time t, the projection process can be expressed compactly in matrix form. By grouping all the $K^{(t)}(x)$, for $x=0, 5, 10, \cdots z$ into the vector $\{\boldsymbol{K}^{(t)}\}$:

$$\{\boldsymbol{K}^{(t)}\} = \begin{Bmatrix} K^{(t)} & (0) \\ K^{(t)} & (5) \\ K^{(t)} & (10) \\ \vdots & \\ K^{(t)} & (z) \end{Bmatrix} \text{ where } K^{(t+1)}(x+5) = K^{(t)}$$

we have,

$$\{\boldsymbol{K}^{(t+1)}\} = \boldsymbol{S}\{\boldsymbol{K}^{(t)}\} \tag{1}$$

where,

$$\underset{\text{(survival vector)}}{\boldsymbol{S}=} \begin{bmatrix} 0 & 0 & 0 & \cdots\cdots\cdots & 0 \\ \frac{L(10)}{L(5)} & 0 & 0 & \cdots\cdots\cdots & 0 \\ 0 & \frac{L(10)}{L(5)} & 0 & \cdots\cdots\cdots & 0 \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ 0 & 0 & \cdots\cdots & \frac{L(z)}{L(z-5)} & 0 \end{bmatrix} \tag{2}$$

To obtain a complete projection, one must make an allowance for the expected number of babies born during those 5 years that survive to the end of the 5 year interval. This other positive element B may be expressed in the equation :

$$K^{(t+1)}(0) = \sum_{x=\alpha-5}^{\beta-5} \left\{ \frac{L(0)}{2} \left[F(x) + s(x)\, F(x+5) \right] \right\} K^{(t)}(\mathrm{x}) \tag{3}$$

where $F(x) = \dfrac{B(x)}{K(x)}$ or the annual age-specific birth rate.

The combined application of the two survival and birth equations (1) and (3) in matrix form may be expressed by the matrix multiplication $\boldsymbol{G}\{\boldsymbol{K}^{(t)}\}$, where $\boldsymbol{G}=\boldsymbol{S}+\boldsymbol{B}$. Thus, the population matrix takes the following form :

$$\{\boldsymbol{K}^{(t+1)}\} = \boldsymbol{G}\{\boldsymbol{K}^{(t)}\} \tag{4}$$

where, if $\alpha=10$, for example, then,

$$G=\begin{pmatrix} 0 & \frac{L(0)}{2(0)}\left[\frac{L(10)}{L(5)}F(10)\right] & \frac{L(0)}{2(0)}\left[F(10)+\frac{L(15)}{L(10)}F(15)\right] & \cdots 0 \\ \frac{L(5)}{L(0)} & 0 & 0 & \cdots 0 \\ 0 & \frac{L(10)}{L(5)} & 0 & \cdots 0 \\ \cdot & 0 & \cdot & \cdot \quad \cdot \\ \cdot & \cdot & \cdot & \cdot \quad \cdot \\ \cdot & \cdot & \cdot & \cdot\cdot \\ 0 & 0 & 0 & \cdots 0 \end{pmatrix} \quad (5)$$

This single-region matrix model may be applied to either sex. An appropriate life table can be computed for each sex and the age-specific rates of motherhood and fatherhood can be respectively introduced to obtain a separate projection for males.

The long-run implications of maintaining current age-specific birth and death rates through repeated multiplications of the matrix, $\{K^{(t+n)}\}=G^n\cdot\{K^{(t)}\}$ will ultimately converge into the stable population, where a stable age composition characterized by unchanging proportional relationship between the elements of its age distribution is achieved.

3. The multiregional model

The introduction of the migration factor between regions in a population system reduces the applicability and practicality of the single-region model in the computation of projections and distribution of multi-regional population systems. Therefore, the spatial component of population movements as summarised in the Lexis diagram below has been supplemented to the central concept of the life-table, growth process and stable population.

In this diagram, an individual's alternative movements between 2 regions are illustrated. Five classes of life lines are represented by A, B, C, D and E. Life line A represents a survivior in region 1 who does not migrate. B and E belong to those in region 1 who die during the unit age interval. C refers to individuals who outmigrates from region 1 to region 2 and returns before the end of the age interval. And D represents an individual in region 1 who outmigrates, survives the unit age interval, and does not return before the end of the interval.

The computation of a multiregional life table begins with the estimation of the age-specific outmigration and death probabilities:

${}^hp_{ij}(x)$=probability that an individual in region i at age x will survive and be in region j at age $x+h$.

${}^hq_i(x)$=probability that an individual in region i at age x will die before reaching age $x+h$.

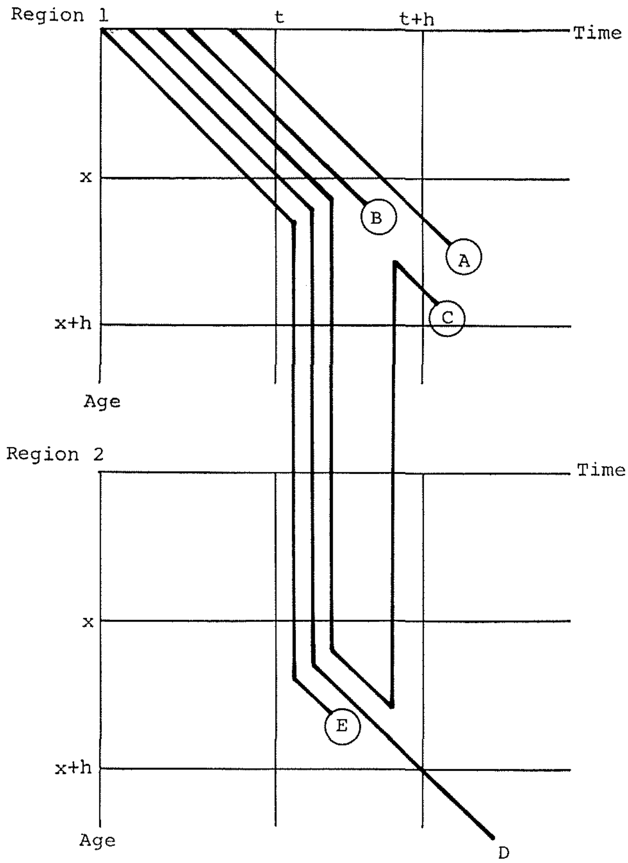

Figure 2. Two-region Lexis diagram (Source: Rogers, 1975).

${}_{ix}l_j(y)$ = expected number of survivors alive in region j at age y among the $l_i(x)$ individuals now alive in region i at age x.

${}_{ix}^{h}l_{jk}(y)$ = expected number of survivors alive in region k at age $y+h$, among the ${}_{ix}l_j(y)$ individuals now alive in region j at age y and previously living in region i at age x.

${}_{ix}^{h}d_j(y)$ = expected number of deaths between ages y and $y+h$ among the ${}_{ix}l_j(y)$ individuals now alive in region i at age x.

The computations of the multi-regional life table start with $l_i(x)$ and find ${}_{ix}^{h}l_{ij}(x)$ for all i, $j=1, 2, \cdots, m$, and then, by using ${}_{ix}^{h}l_{ij}(x)$, or the equivalent ${}_{ix}l_j(x+h)$, we calculate ${}_{ix}^{h}l_{jk}(x+h)$ and ${}_{ix}^{h}d_j(x+h)$ for each $i, j, k=1, 2, \cdots, m$, and we will obtain the corresponding ${}_{ix}^{h}L_{jk}(x+h)$, where,

${}_{ix}^{h}L_{jk}(y)$ = total person-years lived in region K, between ages y and $y+h$, by individuals who were alive in region j at age y and previously were living in region i at age x.

$$= \int_0^h {}_{ix}l_{jk}(y)\ dt.$$

The figure below graphically shows how Rogers traces the survivorship and migration history of the life table population in region i at age x.

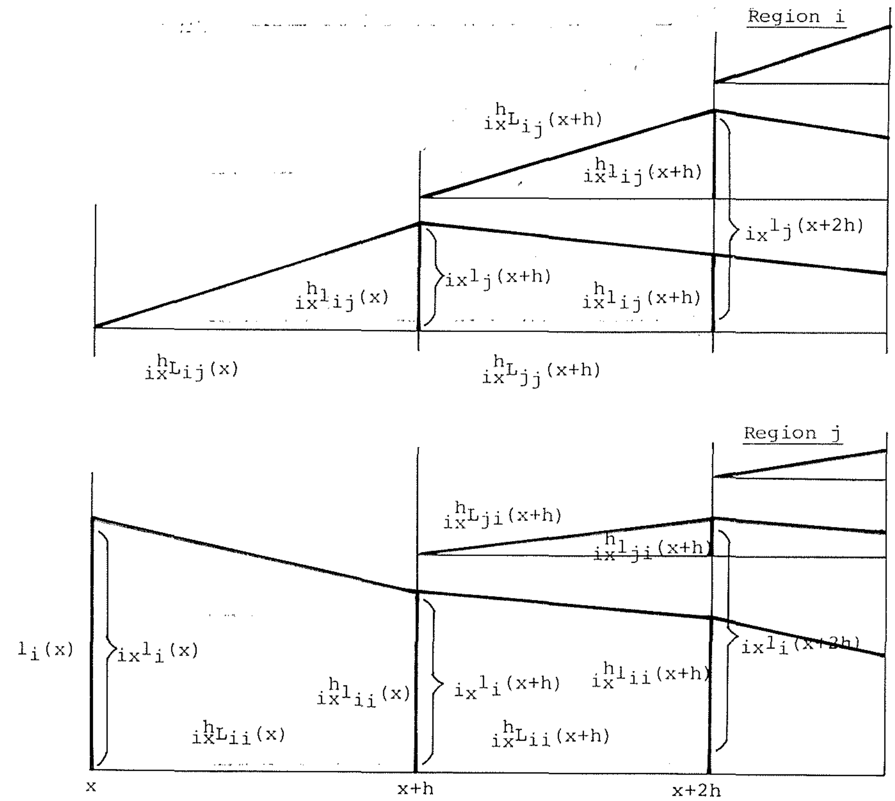

Figure 3. Survivorship and migration history of the cohort $l_i(x)$.

Of all the people in the initial cohort $l_i(x)$, ${}^h_{ix}l_{ij}(x)$ moved to region j during the following unit interval, living ${}^h_{ix}L_{ij}(x)$ person-years in that region by the end of the interval. The remaining people who survived in region i, that is, ${}^h_{ix}l_{ii}(x)$, lived a total of ${}^h a_{ii}(x){}^h_{ix}l_{ii}(x)$ person-years (a being the average number of years lived) in that region during the same interval. By adding the following three groups:

${}^h a_{ii}(x){}^h_{ix}l_{ii}(x)$ = person-years lived in region i

${}^h a_{ij}(x){}^h_{ix}l_{ij}(x)$ = person-years lived in region i by those in region i at age x who are in region j at age $x+h$

${}^h a_{i\delta}(x){}^h_{ix}d_i(x)$ = person-years lived in region i by those in region i at age x who die in the unit interval,

we obtain ${}^h_{ix}L_{ii}(x)$. Return migration from ${}^h_{ix}l_{ij}(x)$ to region i in the following unit interval will live a total ${}^h_{ix}L_{ji}(x+h)$ person-years there, and they join the surviving ${}^h_{ix}l_{ii}(x)$ nonmigrants in region i to form ${}_{ix}l_i(x+2h)$, that is the survivors of the original population in region i at age x now in region i at age $x+2h$.

After completing the survivorship and migration history of this group, we may compute the expectation of life beyond age x for the cohort $l_i(x)$ by:

$$ {}_{ix}e_j(x) = \frac{{}_{ix}T_j(x)}{l_i(x)} \tag{6} $$

where

$$ {}_{ix}T_j(x) = \sum_{y=x}^{z} \sum_{k=t}^{m} {}_{ix}^{h}L_{kj}(y) = \sum_{y=x}^{z} {}_{ix}^{h}L_{ij}(y) \tag{7} $$

z denoting the starting age of the interval. Age-specific out-migration and death rates are defined as :

$$ {}^{h}m_{ij}(x) = \frac{{}_{ix}^{h}l_{ij}(x)}{L(x)} = \frac{{}_{ix}^{h}l_{ij}(x)}{L(x)} \tag{8} $$

$$ {}^{h}m_{i\delta}(x) = \frac{{}_{ix}^{h}d_i(x)}{L(x)} = \frac{{}_{ix}^{h}d_i(x)}{L(x)} \tag{9} $$

Furthermore,

$$ q_i(x) = \frac{M_{ij}(x)}{\dfrac{1}{a_{ii}(x)} + \left[1 - \dfrac{a_{ij}(x)}{a_{ii}(x)}\right] M(x) + \left[1 - \dfrac{a_{i\delta}(x)}{a_{ii}(x)}\right] M_{i\delta}(x)} \tag{10} $$

$$ p_{ij}(x) = \frac{M_{ij}(x)}{\dfrac{1}{a_{ii}(x)} + \left[1 - \dfrac{a_{ij}(x)}{a_{ii}(x)}\right] M(x) + \left[1 - \dfrac{a_{i\delta}(x)}{a_{ii}(x)}\right] M_{i\delta}(x)} \tag{11} $$

where

$$ M_{ij}(x) = \frac{K_{ij}(x)}{P_i(x)} $$

In addition,

$$ {}_{ix}^{h}L_{ji}(y) = \sum_{k=1}^{m} {}^{h}a_{jk}(y)\, {}_{ix}^{h}l_{jk}(y) + {}^{h}a_{j\delta}(y)\, {}_{ix}^{h}d_j(y) \tag{12} $$

$$ {}_{ix}^{h}L_{jk}(y) = \left[h - {}^{h}a_j K(y)\right] {}_{ix}^{h}l_{jk}(y) \tag{13} $$

and for ages above 85 years,

$$ {}_{i80}^{\infty}L\cdot_i(85) = \frac{{}_{i80}l\cdot_i(85)}{\infty M_{i\delta}(85)} \tag{14} $$

$$ {}_{j80}^{\infty}L\cdot_i(85) = \frac{{}_{j80}l\cdot_i(85)}{\infty M_{i\delta}(85)} \tag{15} $$

The composition of survivorship and outmigration proportion is done through the following equations :

$$ S_{ii}(x) = \left[\frac{{}_{i0}L_i(x+5)}{{}_{i0}L_j(x)} - \frac{{}_{j0}L_j(x+5)}{{}_{j0}L_j(x)}\right] \Big/ \left[\frac{{}_{i0}L_i(x)}{{}_{i0}L_j(x)} - \frac{{}_{j0}L_i(x)}{{}_{j0}L_j(x)}\right] \tag{16} $$

$$ S_{ij}(x) = \left[\frac{{}_{i0}L_j(x+5)}{{}_{i0}L_j(x)} - \frac{{}_{j0}L_j(x+5)}{{}_{j0}L_j(x)}\right] \Big/ \left[\frac{{}_{i0}L_j(x)}{{}_{i0}L_j(x)} - \frac{{}_{i0}L_i(x)}{{}_{j0}L_j(x)}\right] \tag{17} $$

3.1. The multiregional projection matrix

The matrix expression of the multiregional growth process using the multiregional matrix growth operator is

$$K^{(t+1)} = G\{K^{(t)}\} \tag{18}$$

where

$$\{K^{(t)}\} = \begin{Bmatrix} K_1^{(t)} \\ K_2^{(t)} \\ \cdot \\ \cdot \\ \cdot \\ K_m^{(t)} \end{Bmatrix} \text{ and } \{K_i^{(t)}\} = \begin{Bmatrix} K_i^{(t)}(0) \\ K_i^{(t)}(5) \\ \cdot \\ \cdot \\ \cdot \\ K_i^{(t)}(2) \end{Bmatrix}, \quad i = 1, 2, \cdots m,$$

and the multiregional matrix growth operator G is defined as :

$$G = \begin{bmatrix} G_{11} & G_{21} & \cdots & G_{m1} \\ G_{12} & G_{22} & \cdots & G_{m2} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ G_{1m} & G_{2m} & \cdots & G_{mm} \end{bmatrix} \tag{19}$$

where

$$G_{ij} = \begin{bmatrix} 0 & 0 & b_{ij}(\alpha-5) & \cdots & b_{ij}(\beta-5) & 0 & \cdots & 0 \\ s_{ij}(0) & & & & & & & \cdot \\ & s_{ij}(5) & & \cdot & & & & \cdot \\ & & & & \cdot & & & \cdot \\ & & & & & \cdot & & \cdot \\ & & & & & s_{ij}(z-5) & & 0 \end{bmatrix}$$

(α and β are delimiters of the childbearing ages).

3. 2. Multiregional stable growth

As mentioned before, a single-region population subjected to an unchanging regime of birth and death rates will ultimately achieve a stable age composition that increase at a constant intrinsic rate of growth. In the multiregional case of subregions, this argument can be extended in a similar manner to incorporate an unchanging multiregional schedule of fertility, mortality and internal migration.

In the consideration of only females up to the highest age of reproduction (β), the growth matrix can be partitioned into :

$$G = \begin{bmatrix} W_{ij} & 0 \\ L|_{ij} & Z_{ij} \end{bmatrix}$$

where

$$W_{ij}=\begin{bmatrix} 0 & 0 & b_{ij}(\alpha-5) & \cdot\cdot\cdot\cdot & b_{ij}(\beta-5) \\ s_{ij}(0) & & & & \cdot \\ & s_{ij}(5) & & & \cdot \\ & & \ddots & & \cdot \\ & & & s_{ij}(\beta-10) & 0 \end{bmatrix}$$

4. Application of the model

A collection of computer programs for the model has been prepared by Rogers, *et al.* (2). The authors of this paper first attempted to introduce a set of data inputs on a two-region demographic analysis of the rural and urban population characteristics of Hokkaido in Japan. Urban Hokkaido consisted of an integration of all counties classified under'shi'or city and rural Hokkaido included all'cho'and' son', or towns and villages. Data was obtained from the 1980 National Census, and the Hokkaido Sanitary Annual Reports.

However, when the program was run through with the data input, computations were interrupted at the points where invert matrices were administered. As short-distance rural-urban migration is naturally high in such an island population as Hokkaido, it is possible that the high ratio of migrants to total population may have negated the effectiveness of the invert matrix computations.

We therefore proceeded to examine the demographic behaviour of Hokkaido in the national context. Maintaining a 2-region analysis of Hokkaido-Rest of Japan, we applied another set of data inputs obtained from the 1980 National Census, the Hokkaido Sanitary Statistical Annual Reports and the 1980 Vital Statistics of Japan.

All computations were executed at the Hokkaido University Computer Center with Hitachi computers. The following is a break-up of data inputs.

All statistics below were obtained in 5-year age intervals for only women in Hokkaido and Rest of Japan.

4.1. Data inputs

① total population (a)
② number of births by women of childbearing age (b) (c)
③ deaths (b) (c)
④ in-and out-migration (a)

(a) National Census, 1980
(b) Hokkaido Sanitary Statistical Annual Reports, 1980
(c) Vital Statistics in Japan, 1980

5. Results and analysis

Table 1 shows the observed population characteristics that were fed into the program.

Mean ages were defined in the following way :

Table 1. Observed Population Characteristics

Region Hokkaido

Age	Population	Births	Deaths	Migration from Hokkaido to Hokkaido	Migration from Hokkaido to R. Japan
0	199061.	0.	395.	0.	2324.
5	226566.	0.	62.	0.	2311.
10	208182.	0.	34.	0.	1703.
15	200572.	424.	68.	0.	3878.
20	191405.	7195.	75.	0.	3442.
25	236955.	18799.	127.	0.	4436.
30	267680.	8733.	169.	0.	3534.
35	220272.	1234.	217.	0.	2221.
40	205548.	155.	273.	0.	1338.
45	196417.	3.	437.	0.	790.
50	173230.	0.	592.	0.	682.
55	146934.	0.	722.	0.	579.
60	116332.	0.	979.	0.	433.
65	94160.	0.	1338.	0.	410.
70	69525.	0.	1876.	0.	299.
75	46893.	0.	2253.	0.	195.
80	25470.	0.	2289.	0.	100.
85	12976.	0.	2292.	0.	39.
Total	2838178.	36543.	14198.	0.	28714.

Region R. Japan

Age	Population	Births	Deaths	Migration from R. Japan to Hokkaido	Migration from R. Japan to R. Japan
0	4149316.	0.	6551.	2832.	0.
5	4889547.	0.	963.	2518.	0.
10	4364815.	2.	563.	1370.	0.
15	4048560.	6737.	1008.	1348.	0.
20	3880910.	136964.	1355.	3275.	0.
25	4495887.	374712.	2051.	4671.	0.
30	5350186.	179619.	3057.	3653.	0.
35	4606865.	27510.	3943.	2078.	0.
40	4178510.	3265.	5339.	1015.	0.
45	4057241.	141.	8.088.	660.	0.
50	3653059.	0.	11240.	565.	0.
55	3102126.	0.	14298.	378.	0.
60	2519317.	0.	18694.	302.	0.
65	2221022.	0.	28415.	294.	0.
70	1705316.	0.	40294.	227.	0.
75	1187971.	0.	53898.	224.	0.
80	675928.	0.	56893.	92.	0.
85	357411.	0.	61257.	40.	0.
Total	59443856.	728950.	317907.	25542.	0.

Table 2. Multiregional (Two-Region) Life Table

Age	Q (X, 1)	P (X, 1, 1)	P (X, 2, 1)	L (X, 1, 1)	L (X, 2, 1)	LL (X, 1, 1)	LL (X, 2, 1)	M (X, 2, 1)	MD (X, 1)	S (X, 1, 1)	S (X, 2, 1)	E (X, 1, 1)	E (X, 2, 1)
0	0.009816	0.934052	0.056132	100000.	0.	4.83513	0.14033	0.011675	0.001984	0.941274	0.053095	51.64	27.31
5	0.001358	0.949030	0.049613	93405.	5613.	4.55159	0.39602	0.010200	0.000274	0.953952	0.044960	47.27	27.43
10	0.000812	0.959165	0.040022	88658.	10228.	4.34280	0.59953	0.008180	0.000163	0.933292	0.065468	42.73	27.07
15	0.001673	0.906316	0.092011	85054.	13754.	4.05403	0.88236	0.019335	0.000339	0.909236	0.088948	38.37	26.49
20	0.001948	0.912335	0.085717	77107.	21541.	3.68854	1.23917	0.017983	0.000392	0.910459	0.087242	34.32	25.63
25	0.002658	0.908359	0.088983	70434.	28026.	3.36381	1.55293	0.018721	0.000536	0.920166	0.076932	30.64	24.42
30	0.003142	0.933249	0.063609	64118.	34091.	3.10171	1.80128	0.013202	0.000631	0.939483	0.056503	27.30	22.91
35	0.004898	0.946203	0.048899	59950.	37960.	2.91896	1.96517	0.010083	0.000985	0.953668	0.040573	24.21	21.14
40	0.006614	0.961585	0.031801	56808.	40647.	2.78706	2.06982	0.006509	0.001328	0.965342	0.025841	21.33	19.22
45	0.011051	0.969254	0.019695	54674.	42146.	2.69252	2.12294	0.004022	0.002225	0.966618	0.019413	18.59	17.21
50	0.016926	0.963899	0.019175	53027.	42771.	2.60428	2.14686	0.003937	0.003417	0.960361	0.019077	15.98	15.17
55	0.024256	0.956693	0.019051	51145.	43103.	2.50249	2.15432	0.003941	0.004914	0.949071	0.018337	13.48	13.15
60	0.041168	0.941104	0.017728	48955.	43070.	2.37629	2.13535	0.003722	0.008416	0.926656	0.018786	11.08	11.12
65	0.068542	0.911303	0.020155	46096.	42344.	2.20325	2.07417	0.004354	0.014210	0.884426	0.019251	8.85	9.16
70	0.126241	0.854934	0.018825	42034.	40623.	1.94984	1.93703	0.004301	0.026983	0.815383	0.017262	6.80	7.29
75	0.214368	0.769120	0.016511	35960.	36858.	1.59112	1.66933	0.004158	0.048046	0.704334	0.014296	5.04	5.62
80	0.366762	0.620104	0.013134	27685.	29915.	1.12165	1.24446	0.003926	0.089870	0.852289	0.026383	3.61	4.20
85	1.000000	0.0	0.0	17181.	19864.	0.95716	1.17499	0.003006	0.176634	0.0	0.0	2.58	3.17

Age	Q (X, 2)	P (X, 2, 2)	P (X, 1, 2)	L (X, 2, 2)	L (X, 1, 2)	LL (X, 2, 2)	LL (X, 1, 2)	M (X, 1, 2)	MD (X, 2)	S (X, 2, 2)	S (X, 1, 2)	E (X, 2, 2)	E (X, 1, 2)
0	0.007865	0.988853	0.003282	100000.	0.	4.97213	0.00820	0.000683	0.001579	0.992655	0.002908	78.38	1.17
5	0.000984	0.996511	0.002505	98885.	328.	4.93605	0.02218	0.000515	0.000197	0.997159	0.002028	73.99	1.18
10	0.000644	0.997821	0.001536	98557.	559.	4.92302	0.03117	0.000314	0.000129	0.997517	0.001539	69.09	1.15
15	0.001243	0.997172	0.001585	98364.	688.	4.91284	0.03667	0.000333	0.000249	0.995703	0.002804	64.16	1.12
20	0.001743	0.994234	0.004022	98149.	779.	4.89499	0.04712	0.000844	0.000349	0.993514	0.004475	59.27	1.09
25	0.002279	0.992783	0.004938	97650.	1106.	4.86735	0.06480	0.001039	0.000456	0.993285	0.004149	54.42	1.04
30	0.002852	0.993858	0.003290	97044.	1486.	4.83965	0.07982	0.000683	0.000571	0.993687	0.002751	49.61	0.98
35	0.004271	0.993542	0.002188	96542.	1706.	4.81362	0.08831	0.000451	0.000856	0.992985	0.001697	44.82	0.90
40	0.006367	0.992446	0.001187	96002.	1826.	4.78343	0.09239	0.000243	0.001278	0.990868	0.000995	40.09	0.81
45	0.009918	0.989286	0.000797	95335.	1870.	4.74214	0.09394	0.000163	0.001993	0.986646	0.000774	35.43	0.72
50	0.015267	0.983979	0.000753	94351.	1888.	4.68064	0.09448	0.000155	0.003077	0.980334	0.000670	30.86	0.63
55	0.022782	0.976629	0.000589	92875.	1891.	4.59039	0.09387	0.000122	0.004609	0.969896	0.000578	26.40	0.54
60	0.036427	0.963002	0.000571	90741.	1864.	4.45393	0.09174	0.000120	0.007420	0.950442	0.000587	22.06	0.45
65	0.061987	0.937400	0.000613	87416.	1806.	4.23492	0.08763	0.000132	0.012794	0.913431	0.000589	17.90	0.37
70	0.111557	0.887861	0.000583	81981.	1699.	3.87000	0.07999	0.000133	0.023628	0.844427	0.000646	14.03	0.29
75	0.203744	0.795508	0.000749	72819.	1501.	3.26931	0.06773	0.000189	0.045370	0.731860	0.000584	10.59	0.22
80	0.347693	0.651851	0.000455	57953.	1209.	2.39364	0.04961	0.000136	0.084170	0.920392	0.000952	7.77	0.16
85	0.000000	0.0	0.0	37793.	776.	2.20440	0.04456	0.000112	0.171391	0.0	0.0	5.72	0.12

$$\bar{m}_i = \sum_x \left(x + \frac{NY}{2}\right) \cdot c_i(x)/100$$

where

$c_i(x)$ = percentage distribution

NY = age interval

$\left(x + \frac{NY}{2}\right)$ = average of the interval

The mean age for Hokkaido was 34.26 years while that for Japan was 35.00 years.

The multiregional life table, which is a device for showing the mortality and mobility history of a cohort (100,000 population), is presented in Table 2 for Hokkaido and the Rest of Japan.

In Table 2:

$Q(x, i)$ = Probability that an individual at age x in region i will die before reaching age $x+5$.

$P(x, j, i)$ = probability that an individual at age x in region i will be in region j at age $x+5$, i. e. 5 years later.

$L(x, j, i)$ = number surviving at exact age x in region j, of 100,000 born in region i. This is also the probability that a baby born in region i, will survive and be in region j at exact age x, multiplied by 100,000.

$LL(x, j, i)$ = total years lived between ages x to $x+5$ in region j, per unit born in region i.

$M(x, j, i)$ = age-specific migration rate from region i to j.

$MD(x, i)$ = age-specific death rates in region i.

$S(x, j, i)$ = proportion of people in region i and aged x to $x+4$ that will survive to be in region j and aged $x+5$ to be $x+9$, five years later.

$E(x, j, i)$ = expectation of life of i-born people at age x, that will be lived in in region i, that is, the average number of years lived in region j by i-born people, subsequent to age x.

Initial computation of the multiregional life table begins with the estimation of age-specific death and outmigration probabilities which are derived from observed values or rates of mortality and migration. These probabilities for the female population of Hokkaido and Rest of Japan are represented by Q and P values.

Thus the probability that a 15-year old girl will die before she reaches 20 in Hokkaido is 0.001673.

By consecutively multiplying these probabilities of the birth cohort, we obtain the life history of the cohort. Thus, of the 100,000 babies born in Hokkaido, 982 (or 100,000×0,009816) will die before they reach 5, while 5613 (or 100,000×0.056132) will move to the Rest of Japan. This leaves 93405 or 93.4% in Hokkaido and will be there at exact age 5. This value is represented by $L(x, 1, 1)$.

At exact age 5, of the remaining 93405 who stayed in Hokkaido, the number of girls dying before reaching age 10 is 127 (93405×0.001358), while the number moving to Rest of Japan is 4634 (93405×0.049613) leaving 88644. But here, we must also consider return migration, i. e. of the 5613 who moved to Rest of Japan in the previous interval. In Rest of Japan, they die, moved back to Hokkaido or stay there. Assuming that mortality and migration behaviour depends on the region of residence at the beginning of the interval, then 6 (5613×0.000984) will die, and 14 (5613×0.002505) will move back to Hokkaido increasing the remaining population there to 88658 (88644+14). By following this procedure until the last age group, the life history of the entire cohort of Hokkaido can be derived.

The LL columns show the number of years individuals at age x may expect to live in that region in the next five years. $LL(x, j, i)$ denotes the average duration of residence in region j by an i-born person and this depends on 2 components-the probability of surviving to age x_i and average time spent in region j in a 5-year interval by a person of age x at the beginning of the interval.

The S columns show survivorship and outmigration proportions. The number 0.04496, for example, is the proportion of the girls residing in Hokkaido and 5 to 9 years old that will be alive and in the Rest of Japan 5 years from now.

The E columns represents expectations of life at age x by region of birth of the person. A girl born in Hokkaido may expect to live another 69.8 years when reaching 10 years of age. Of this, 42.73 years will be spent in Hokkaido and 27.07 years in Rest of Japan.

General observations of the table reveal higher death rates for Hokkaido though not remarkably so. In order to view the trends better, Figures 4 and 5 have been plotted. In Figure 4, both regions show dominantly high fertility at ages from 25–29, with Rest of Japan having a slightly higher rate of fertility. Mean ages for childbearing is 27.64 for Hokkaido and 27.79 for Rest of Japan.

It is interesting to note that in Fig. 4, the fertility rates are slightly higher. However, when we calculate the birth rates for the entire population, we obtain 12.9 births per thousand population for Hokkaido and 12.3 for Rest of Japan. This could show the relative youthfulness of Hokkaido's population, i. e., the concentration of population around the childbearing ages has ultimately reduced the fertility within these ages.

Let us take a look at migration rates in Figure 5. Although values of both regions were plotted on differing scales, the shape of the curves are similar.

Model migration schedules demonstrating the selectivity of migration with respect to age has also been studied in detail by Rogers (3). In general, it has been observed that the highest rates of migration are those of young adults in their early twenties, while the lowest rates are those in their teens. The migration rates of young children mirror those of their parents. A 'retirement peak' is also found especially directing towards regions with warmer climates and better social facilities.

In Figure 5, we can observe these characteristics for Rest of Japan. The labour force peak occurs at 25–29 years of age with also a substantially high rate at 20–24 age interval. This is reflected again in the migration of young children of ages

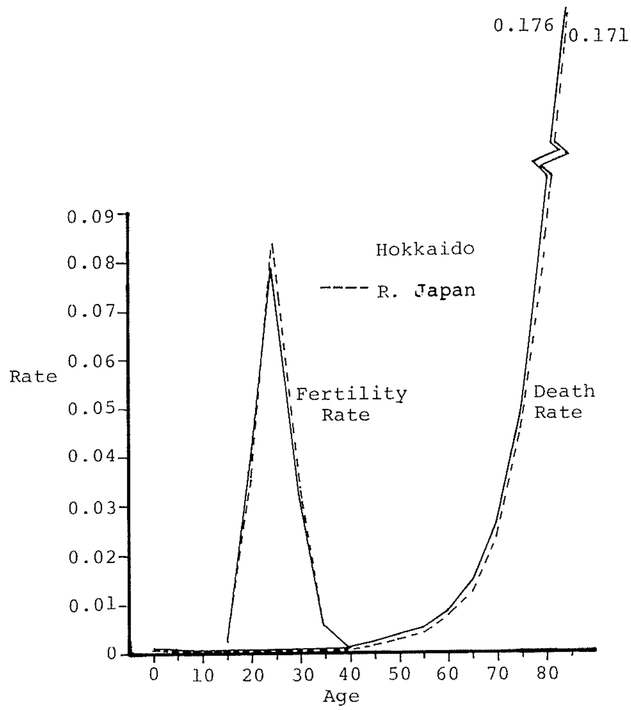

Figure 4. Fertility and death rates.

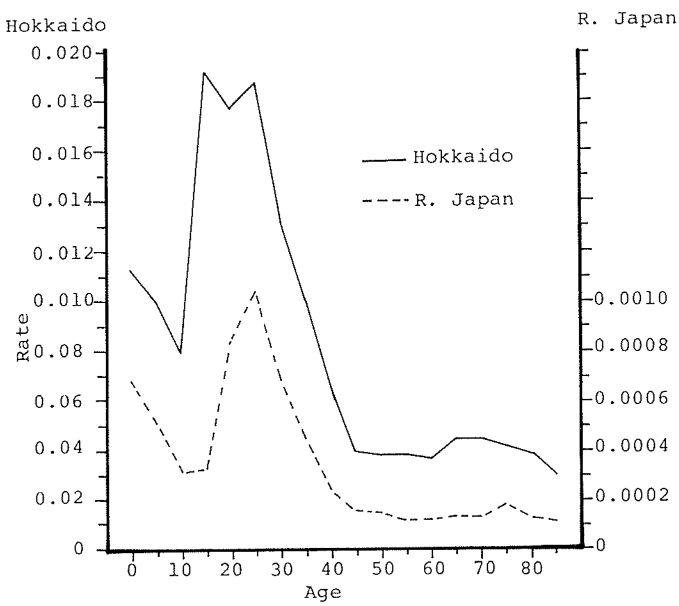

Figure 5. Migration rates.

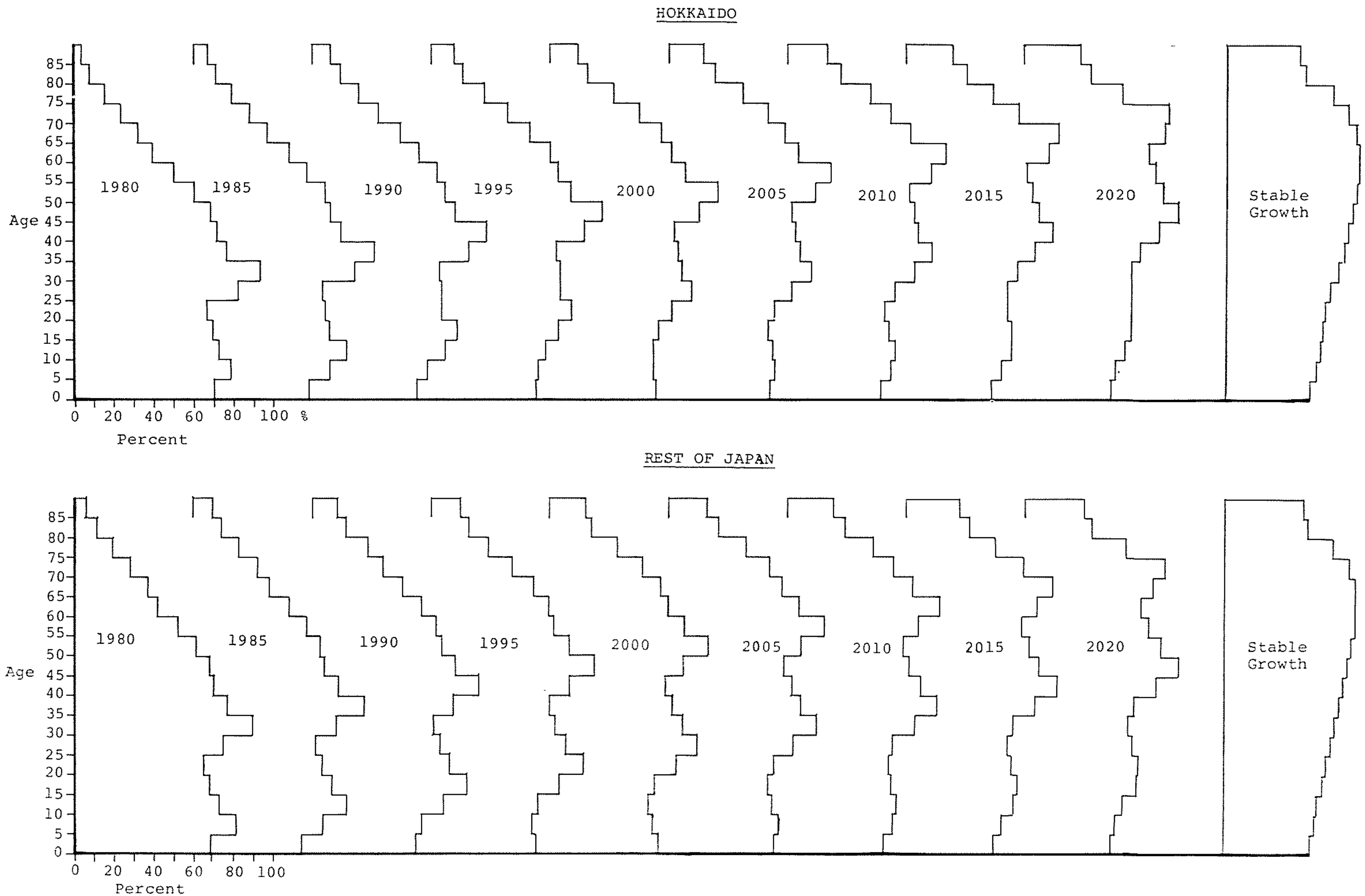

Figure 6. Population half-pyramid for females—Hokkaido and Rest of Japan.

0–9 years. After the labour force peak, rates rapidly descent and remain almost calm until a belated 'retirement' bump at the 75 years interval.

On the other hand, however, Hokkaido shows a very interesting curve. The curve starts with a noticeably high rate of migration of children. However, where teenagers from 15–19 years old in Rest of Japan show low points, this represents the highest peak for Hokkaido. A small valley occurs for the 20–24 interval and rises again from 25–29. Thereafter, it drops sharply until 45 years onwards. The retirement peak comes as expected at 65 years old.

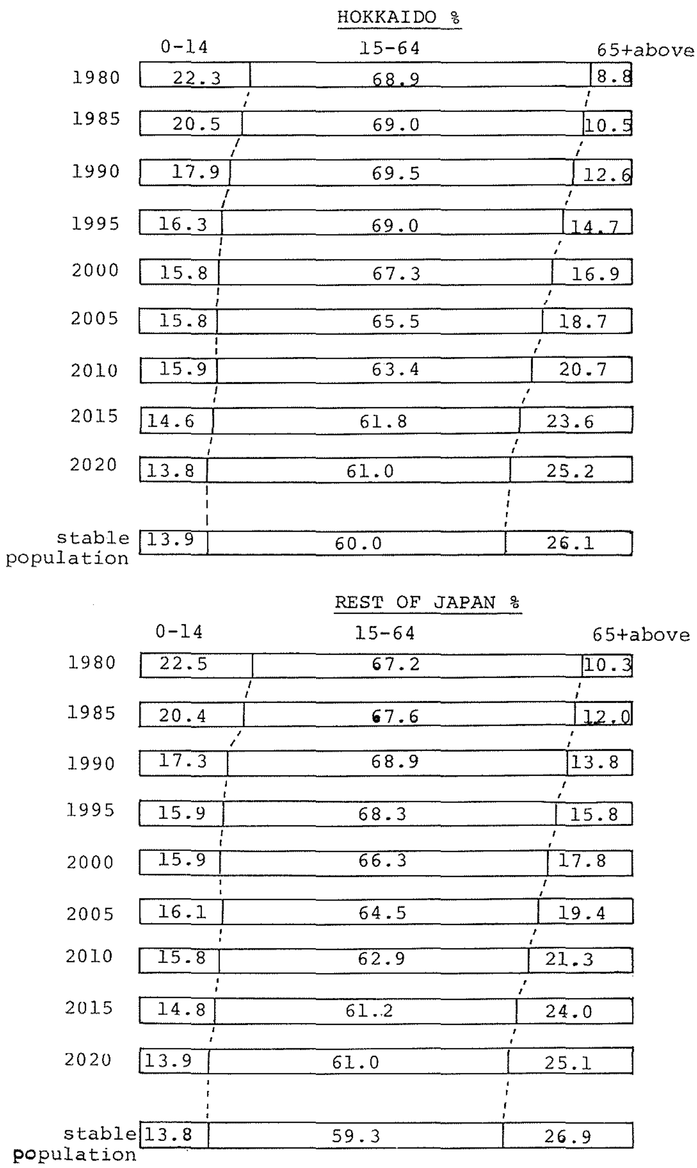

Figure 7. Change in demographic structure by age-group.

Population growth was discretely projected using a constant growth matrix, and for a long enough period of time, the ultimate (stable) growth ratio and stable distribution becomes independent of the current growth rate and population distribution (Rogers, 1978). Figures 6, 7 and 8 graphically show the results of the projection. In Figure 6, the change in age composition for Hokkaido and Rest of Japan in shown. General trends include the 'echoing' of the post-war baby boom (around 30-34 years) as successive generations are created although diminishing in size with each generation. Rapid aging of population is observed in both regions, as is also shown in Figure 7, while the young and labour population up to 64 years of age rapidly decrease. The aging seems to be setting in faster fowards the final scenario where stable growth is achieved. Rest of Japan will have a greater percentage than Hokkaido concentrated in the older age brackets.

In terms of total population, Hokkaido will reach its peak in the year 2000 and Rest of Japan in 2005 after which both descend as gradually as they ascended.

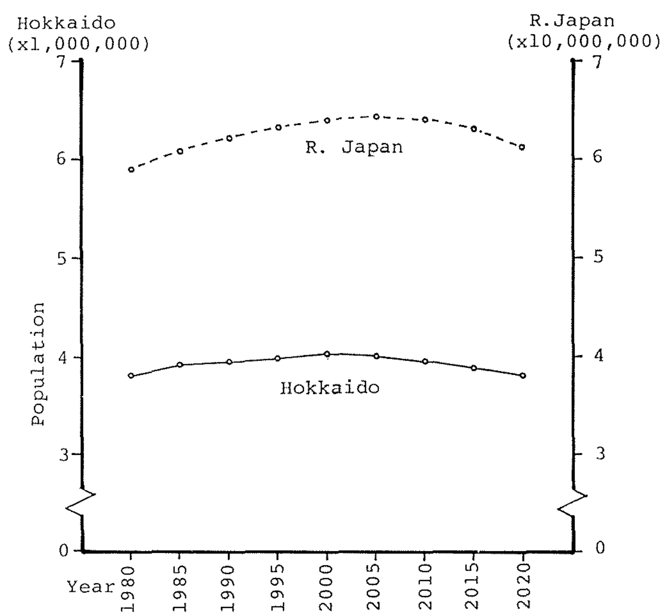

Figure 8. Projected population.

6. Conclusion and further research

The multiregional life table can be seen as a relatively useful tool when compared to the single region life table as the spatial dimension incorporated in the model allows the researcher to focus on population projections in specific regions while considering important migrational relations with adjacent regions. It is also interesting to note how structural changes of a cohort take place during population growth.

In the population projection from 1980 to 2020, results of the computations show a definite aging trend of female population in the years 2020, with an ultimate stable population described by an inverted pyramid. Hokkaido will reach its peak population with 3,007,857 females in the year 2000, while Rest of Japan will top at 64,391,120 females in 2005. Thereafter, the totals gradually fall. The reason why Hokkaido's population starts to fall faster than that of Rest of Japan may be due to the higher rate of out-migration of young population. This outmigration of education- and job-seeking population especially those in the 15–19 and 25–29 year age-groups is a case for concern.

Thus, further research is necessary on simulation studies especially concerning policy changes and implementations. Since birth and death rates are relatively unchangeable in the short run, migration rates can be influenced to certain extent. This migration variable can be interlinked with economic, physical and social variables. These two sets of variables are closely interrelated. By manipulating migration volumes it is possible to simulate hypothetical outcomes of population projections and their age distributions.

The strictly demographic character of the model, however, may impose limitations on the model. The interlinkages of the model with socio-economic policies are weak or non-existent.

In order to enhance its practicality, this model should be made more flexible and responsive to the general socio-economic system.

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