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MODELLING REGIONAL POPULATION GROWTH IN CHINA

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This paper develops a forward demographic rates-based multiregional population model on the basis of a set of multiregional population accounts. Forward emigration rates and immigration flows are adopted to describe the external migrations. The model is used to make consistent multiregional population projections of China at a provincial level. The model is calibrated using the 1982 census data and 1987 one percent population survey data. Other data sources have also been used to estimate and prepare necessary input data for the multiregional population model.

Three sets of multiregional population projections of China at provincial level are made for the period 1987-2087. It is found that the national population trend is a combination of various regional population trends. Some regions, such as Zhejiang, will reach their population peak as early as the beginning of the next century while other regions, such as Xinjiang, will face continuous population growth in the first half of the next century.

KEY WORDS: Multiregional modelling; Forward demographic rates; Population accounts; Population projection; Population model: China

INTRODUCTION

This study attempts to construct a multiregional population projection of China at a provincial level. This may reveal the future multiregional population dynamics of the country and the results may be useful for socio-economic planning (Song *et al.,* 1981; Hobcraft, 1989). A precise and straightforward multiregional population projection model based on forward demographic rates will be developed. The model will be calibrated using the 1982 census data and 1987 one-percent population sampling data (DPS, 1988a;b). It is probably the first attempt to develop a consistent multiregional (provincial level) population model of China and as a result the findings can only be regarded as preliminary. An earlier research constructed an urban-rural population model for a projection of urban-rural populations of China (Shen and Spence, 1994).

The forward demographic rates-based approach to multiregional population modelling needs some introductory discussion. It is true that significant progress has already been made in spatial population analysis. Multiregional population models were developed to line the population at the beginning and end of a period by a growth matrix consisting of transition probabilities (Rogers, 1966; 1973; 1975). A major problem here is how to calculate these transition probabilities or growth matrix more precisely. A major innovation was the introduction of multiregional population accounts (Rees and Wilson, 1977). Given successful
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estimation of the elements in the multiregional population accounts, transition probabilities can be straightforwardly calculated for population projections. It is noted that migration and mortality rates are not represented independently (they are combined into transition probabilities) in such population models. Thus it is only possible to use constant migration and mortality rates for population projections. An iterative population model was developed by Rees and Wilson (1977) using occurrence-exposure demographic rates. These rates can be correctly and precisely defined and can also be used to estimate multiregional population accounts. A transition probabilities matrix can be derived by matrix inversion from occurrence-exposure demographic rates (Rees, 1989; Rogers and Willekens, 1986; Willekens and Drewe, 1984). This matrix inversion procedure, however, may need to be repeated for each projection period if changing demographic rates are to be used for population projections.

A forward demographic rates-based approach has been developed more recently (Shen, 1994a). Forward demographic rates are similar to transition probabilities but mortality and migration rates are defined independently. This is achieved by dividing population into two categories - migrating population and non-migrating population. A set of extended multiregional population accounts is also used. Forward mortality or fertility rates (they may be termed probabilities) can be defined for the migrating population and the non-migrating population respectively and they can be linked together. Forward migration rates can also be defined. Transition probabilities are calculated by dividing transitions by the starting population in population accounts. It is difficult to define mortality probability independently in the context of transition probabilities as it is related to migration probability.

It has been demonstrated that forward demographic rates have unique relations with occurrence-exposure rates (Shen, 1994a). Different population projection models can be developed on the basis of occurrence-exposure rates and forward rates respectively and both .n-e correct if corresponding demographic rates are used. However, the forward demographic rates-based model does have the advantage that population projections can be simply carried out while an iterative procedure is needed for the occurrence-exposure rates-based population model. This paper will develop a more precise version of the forward demographic rates-based model by defining the relations between the one-period and half-period demographic rates more realistically. These relations are essential to link the one-period and half-period demographic rates defined for migrating and non-migrating populations respectively. External migration will also be included in the current version of the model in line with recent trends in multiregional population modelling (Rees, 1989; 1991; Rogers, 1989; Willekens and Drewe, 1984).

A FORWARD DEMOGRAPHIC RATES-BASED MULTIREGIONAL POPULATION MODEL

Definitions of Forward Demographic Rates

The spatial population system of interest here is an open system consisting of N regions, and is inter-related with the rest of the world via external migration. The rest of the world is not considered in the earlier version of the model while other definitions are similar (Shen, 1994a). For simplicity, the rest of the world is called region R and region $N+1$ alternatively. The same age and time intervals are assumed. All derivations are same for male and female populations except that fertility rates are defined for the female population only. So gender label g is omitted in most cases, but will be added back in the multiregional projection model.

Table 1 presents an example of population accounts of period-cohort a for two regions I and j (a=0,2, …..,A; $k = I, j)$ and the rest of the world (region R). The population accounts for he rest of the world is not and does not need to be complete. Only those population items of the rest of the world that are related with population system concerned are included. Period-cohort zero refers to the infants-cohort and A the last period cohort. The birth account in Table 2 shows the births produced by the female population of period-cohort a in each region. Similar population accounts

TABLE 1

Population account for period-cohort a

Starting Date	Ending state in period t to t+1					Total
	Survival in region			Death in region		
	i	j	R	i	j	
Region i	P_a^{eisi}	P_a^{eisj}	P_a^{eisR}	P_{ai}^{eidi} P_{aj}^{eidi} P_{aR}^{eidi}	P_{aj}^{eidj} P_{aj}^{eidj}	P_a^{i*}
Region j	P_a^{ejsi}	P_a^{ejsj}	P_a^{ejsR}	P_{ai}^{ejdi}	P_{aj}^{ejdj} P_{ai}^{ejdj} P_{aR}^{ejdj}	P_a^{j*}
Region R	P_a^{eRsi}	P_a^{eRsj}	✸	P_{ai}^{eRdi}	P_{aj}^{eRdj}	
Total	P_a^{*i}	P_a^{*j}	✸	P_a^{*dj}	P_a^{*dj}	P_a^{**}

TABLE 2

Birth account

Starting Date	Ending state in period t to t+1		Total
	Birth in region		
	i	j	
Region i	P_{ai}^{eibi} P_{aj}^{eibi} P_{aR}^{eibi}	P_{aj}^{eibj}	P_a^{ib*}
Region j	P_{ai}^{ejbi}	P_{aj}^{ejbj} P_{ai}^{ejbj} P_{aR}^{ejdj}	P_a^{jb*}
Region R	P_{ai}^{eRbi}	P_{aj}^{eRbj}	✸
Total	P_a^{*bi}	P_a^{*bj}	P_a^{*b*}

for a general case of an open system consisting of N regions can be obtained. Here, an extended multiregional population accounts is adopted. Population is divided into two categories: non-migrating population and migrating population. Migrating population may die in its origin and destination regions. Non-migrating population may die in one region only. The migrating population who died in the origin is termed potential migrating population. These potential migrants fail to realize migration because of death during the accounting period. The concept of potential migrating population is essential for the definition of forward demographic rates. (Shen, 1994a)

The variables are defined as follows :

P_a^{k*} is the starting population of region k in period t to $t+1$ in period-cohort a, k = 1,2,…,N. Period-cohort a refers to the same population group in the period t to t+1 that belongs to age-group a in time t.

P_a^{*k} is the ending population of region k in period t to t+1 in period-cohort a, k = 1,2,…,N.

P_a^{*dk} is the population in period-cohort a who died in period t to t+2 in region k, k =1,2,…,N.

P_a^{eksl} is the population of period-cohort a who exist in region k at time t and survive in region l in period t to t+1, k, l = 1,2,…,N.

P_a^{eksR} is the population of period-cohort a in region k at time t who emigrated to the rest of the world in period t to t+1, k = 1,2,. note that this term includes those emigrants who died in the rest of the world after emigration.

P_a^{eRsk} is the population of period-cohort a immigrated from the rest of the world who survive in region k in period t to t+1, k = 1,2,.

P_{ak}^{ekdk} is the population of period-cohort a who died in region k in period t to t+1 corresponding to non-migrating population in region k, k = 1,2,.

P_{al}^{ekdk} is the population of period-cohort a who died in region k in period t to t+1 corresponding to non-migrating population in region k to region l, k, l = 1,2,…,N; $k \neq l$. Here subscript ' indicates the destination region of potential migrants did not die in the origin region before migration.

P_{aR}^{ekdk} is the population of period-cohort a who died in region k in period t to t+1 corresponding to emigrating population from region k to the rest of the world, k = 1,2,…,N.

P_{al}^{ekdl} is the population of period-cohort a who died in region l in period t to t+1 corresponding to migrating population from region k to region l, k, l = 1,2,…,N; $k \neq l$.

P_{ak}^{eRdk} is the population of period-cohort a who died in region k in period t to t+1 corresponding to immigrating population from the rest of the world to region k, k = 1,2,…,N.

P_{ak}^{ekbk} is the births in region k in period t to t+1 produced by non-migrating population of period-cohort a in region k, k = 1,2,…,N.

P_{al}^{ekbk} is the births in region k in period t to t+1 produced by migrating population of period-cohort a from region k to region l, k, l = 1,2,…,N; $k \neq l$.

P_{aR}^{ekbk} is the births in region k in period t to t+1 produced by emigrating population of period-cohort a from region k to the rest of the world, k = 1,2,…,N.

P_{al}^{ekbl} is the births in region l in period t to t+1 produced by migrating population of period-cohort a from region k to region l, k, l = 1,2,…,N; $k \neq l$.

P_{ak}^{eRbk} is the births in region l in period t to t + 1 produced by immigrating population of period-cohort a from the rest of the world to region k, k = 1,2,…,N.

P_a^{kb*} is the number of births in period t to t + 1 produced in N regions by population of period-cohort a who are in region k at time t, k = 1,2,…,N.

P_a^{*bk} is the number of births in period t to t + 1 produced in region k by population of period-cohort a in all regions, k = 1,2,…,N.

Here the death components P_a^{ekdk} and the birth components P_a^{ekbk} have been further divided into two items corresponding to one non-migrating population (P_{ak}^{ekdk} or P_{ak}^{ekbk}) and N

migrating populations as well as one emigrating population ($\sum_{l=1; l \neq k}^{N+1} P_{al}^{ekdk}$ or $\sum_{l=1; l \neq k}^{N+1} P_{al}^{ekbk}$).

Population accounts equations can be obtained from the population accounts. The row sum equation of period-cohort a is as follows :

$$P_a^{k*} = \sum_{l=1}^{N+1} P_a^{eksl} + \sum_{l=1}^{N+1} P_{al}^{ekdk} + \sum_{l=1;l\neq k}^{N} P_{al}^{ekdl}, \qquad k = 1,2,\ldots,N. \tag{1}$$

Note that the emigrating population who die in the rest of the world have been counted in the emigrating population, P_a^{eksR} .

The column sum equations of period-cohort a are as follows:

$$P_a^{*k} = \sum_{l=1}^{N+1} P_a^{elsk}, \qquad k = 1,2,\ldots,N, \tag{2}$$

$$P_a^{*dk} = \sum_{l=1}^{N+1} P_{al}^{ekdk} + \sum_{l=1;l\neq k}^{N+1} P_{ak}^{eldk}, \qquad k = 1,2,\ldots,N, \tag{3}$$

There are similar accounting equations for births.

As mentioned before, forward demographic rates need to be defined for migrating population and non-migrating population respectively so that forward mortality, fertility and migration rates can be defined independently. Generally, a forward demographic rate is defined as the amount of population change divided by the population at the beginning of a period. On average, a non-migrating population spends a whole accounting period in one region while a migrating population spends half of the accounting period in the origin and destination regions. Thus forward demographic rates can be defined in terms of the time unit of a whole period or a half period. One-period and half-period forward mortality rates can be defined for the non-migrating population and migrating population respectively as follows:

$$u_a^k = P_{ak}^{ekdk} / (P_a^{eksk} + P_{ak}^{ekdk}), \tag{4}$$

$$u_{0.5a}^k = P_{al}^{ekdk} / (P_a^{eksl} + P_{al}^{ekdl} + P_{al}^{ekdk}), \tag{5}$$

$$u_{0.5a}^l = P_{al}^{ekdl} / (P_a^{eksl} + P_{al}^{ekdl}). \tag{6}$$

Half-period forward mortality rates can be defined for emigrating and immigrating population respectively as follows :

$$u_{0.5a}^k = P_{aR}^{ekdk} / (P_a^{eksR} + P_{aR}^{ekdk}), \tag{7}$$

$$u_{0.5a}^k = P_{ak}^{eRdk} / (P_a^{eRsk} + P_{ak}^{eRdk}). \tag{8}$$

It is assumed that the half-period forward mortality rates $u_{0.5a}^k$ of region k defined in (5)-(8) are equal. It is useful to derive the relation between the one-period and the half-period forward mortality rates.

Assuming equal mortality rates in region k an region l, a one-period forward mortality rate can be defined:

$$u_{0.5a}^k = (P_{al}^{ekdk} + P_{al}^{ekdl}) / (P_a^{eksl} + P_{al}^{ekdl} + P_{al}^{ekdk}). \tag{9}$$

It can be derived by using (5) and (6) that

$$u_{0.5a}^k = 1 - (1 - u_a^k)^{1/2} = u_a^k / (1 + (1 - u_a^k)^{1/2}). \tag{10}$$

Note that an approximate expression of (10) has been used in the development of an earlier version of the model. (Shen, 1994a):

$$u_{0.5a}^{k}=0.5u_{a}^{k}/(1-0.25u_{a}^{k})=u_{a}^{k}/(1+(1-u_{a}^{k}+0.25(u_{a}^{k})^{2})^{1/2}). \quad (11)$$

There is an extra small item $0.25(u_a^k)^2$ in (11). This means that the model developed in this paper using (10) is more precise, at least theoretically, than the earlier one.

Similarly, one-period and half-period forward fertility rates can be defined for the non-migrating population and migrating population. For example,

$$f_{a}^{k}=P_{ak}^{ekbk}/(P_{a}^{eksk}+P_{ak}^{ekdk}), \quad (12)$$

$$f_{0.5a}^{k}=P_{al}^{ekbk}/(P_{a}^{eksl}+P_{al}^{ekdl}+P_{al}^{ekdk}). \quad (13)$$

The following relation between the one-period and the half-period forward fertility rates can be derived:

$$f_{0.5a}^{k}=f_{a}^{k}/(1+(1-u_{a}^{k})^{1/2})=f_{a}^{k}(1-(1-u_{a}^{k})^{1/2})/u_{a}^{k}. \quad (14)$$

Three forward internal migration rates $m_{1a}^{kl}, m_{2a}^{kl}, m_{3a}^{kl}$ can be defined as follows:

$$m_{1a}^{kl}=(P_{a}^{eksl}+P_{al}^{ekdl}+P_{al}^{ekdk})/P_{a}^{k*}, \quad (15)$$

$$m_{2a}^{kl}=(P_{a}^{eksl}+P_{al}^{ekdl})/P_{a}^{k*}=m_{1a}^{kl}(1-u_{0.5a}^{k})=m_{1a}^{kl}(1-u_{a}^{k})^{1/2}, \quad (16)$$

$$m_{3a}^{kl}=P_{a}^{eksl}/P_{a}^{k*}=m_{2a}^{kl}(1-u_{0.5a}^{l})=m_{2a}^{kl}(1-u_{a}^{l})^{1/2}=m_{1a}^{kl}(1-u_{a}^{k})^{1/2}(1-u_{a}^{l})^{1/2}. \quad (17)$$

Here three forward destination-specific migration rates are defined. All migrants, including potential migrants, are accounted in migration rate m_{1a}^{kl} .Only migrants that actually make migrations are accounted in migration rate m_{2a}^{kl}. Only survival migrants are accounted in migration rate m_{3a}^{kl}.

Two forward emigration rates m_{1a}^{kR}, m_{2a}^{kR} can be defined as follows:

$$m_{1a}^{kR}=(P_{a}^{eksR}+P_{aR}^{ekdk})/P_{a}^{k*}, \quad (18)$$

$$m_{2a}^{kl}=P_{a}^{eksR}/P_{a}^{k*}=m_{1a}^{kR}(1-u_{0.5a}^{k})=m_{1a}^{kR}(1-u_{a}^{k})^{1/2}. \quad (19)$$

All emigrants, including potential emigrants, are accounted in emigration rate m_{1a}^{kR} .Only emigrants that actually make emigrations are accounted in emigration rate m_{2a}^{kR}.

Estimation of Population Accounts and Forward Demographic Rates

Methods are required to estimate the forward demographic rates on the basis of the multiregional population accounts. It is assumed that the following population data are available: the ending population of period-cohort *a* P_a^{*k}; the emigration population P_a^{eksR}; the survival immigration population P_a^{eRsk}; the death population D_a^k who died at age *a* in region *k* in period *t* to *t* + 1; the birth population B_a^k produced by the female population at age *a* in region *k* in period *t* to *t* + 1; the total births in region *k*, i.e., the starting population of the infants-cohort (period-cohort zero) P_0^{k*}. Alternative equations to define the forward mortality and fertility rates will be discussed first.

It can be demonstrated that:

$$P_a^{*dk} = (P_a^{eksk} + 0.5\sum_{l=1;l\neq k}^{N+1}(P_a^{eksl} + P_a^{elsk}) + P_{ak}^{ekdk}$$
$$+ 0.5\sum_{l=1;l\neq k}^{N+1}(1+1/(1+(1-u_a^k)^{1/2}))(P_{al}^{ekdk} + P_{ak}^{eldk}) + 0.5\sum_{l=1:l\neq k}^{N} P_{al}^{ekdl})u_a^k. \quad (20)$$

Therefore, an alternative equation to define the forward mortality rate is as follows:

$$u_a^k = P_a^{*dk} / PST_a^{*dk}. \quad (21)$$

Here PST_a^{*dk} is the starting population corresponding to the death population P_a^{*dk} :

$$PST_a^{*dk} = P_a^{eksk} + 0.5\sum_{l=1;l\neq k}^{N+1}(P_a^{eksl} + P_a^{elsk}) + P_{ak}^{ekdk}$$
$$+ 0.5\sum_{l=1;l\neq k}^{N+1}(1+1/(1+(1-u_a^k)^{1/2}))(P_{al}^{ekdk} + P_{ak}^{eldk}) + 0.5\sum_{l=1:l\neq k}^{N} P_{al}^{ekdl}. \quad (22)$$

Similarly, an alternative equation to define the forward fertility rate is as follows:

$$f_a^k = P_a^{*bk} / PST_a^{*bk}. \quad (23)$$

Here PST_a^{*bk} is the starting population corresponding to the birth population P_a^{*bk} which has the same value as PST_a^{*dk}.

The estimation of the mortality rate of the infants-cohort will be discussed first. The following can be obtained from (5), (6) and (10)

$$P_{0l}^{ekdl} = P_0^{eksl}u_{0.5,0}^l / (1-u_{0.5,0}^l) = P_0^{eksl}(1-(1-u_0^l)^{1/2}) / (1-u_0^l)^{1/2}$$
$$= P_0^{eksl}u_0^l / (1-u_0^l + (1-u_0^i)^{1/2}), \qquad k,l = 1,2,\ldots,N; k \neq l, \quad (24)$$

$$P_{0l}^{ekdk} = (P_0^{eksl} + P_{0l}^{ekdl})u_{0.5,0}^k / (1-u_{0.5,0}^k)$$
$$= P_0^{eksl}u_0^k / ((1-u_0^l)^{1/2}) / (1-u_0^k + (1-u_0^k)^{1/2})), \qquad k,l = 1,2,\ldots,N; k \neq l. \quad (25)$$

Similarly, the following can be obtained from (7), (8) and (10) for external migrations:

$$P_{0k}^{eRdk} = P_0^{eRsk}u_0^k / (1-u_0^k + (1-u_0^k)^{1/2}), \qquad k = 1,2,\ldots,N, \quad (26)$$

$$P_{0R}^{ekdk} = P_0^{eksR}u_0^k / (1-u_0^k + (1-u_0^k)^{1/2}), \qquad k = 1,2,\ldots,N, \quad (27)$$

The following can be obtained from (1)-(3) as both the starting and ending populations for the infants-cohort are known:

$$P_{0k}^{ekdk} = P_0^{k*} - P_0^{*k} + \sum_{l=1;l\neq k}^{N+1}(P_0^{elsk} - P_0^{eksl} - P_{0l}^{ekdk}) - \sum_{l=1;l\neq k}^{N} P_{0l}^{ekdl}, \qquad k = 1,2,\ldots,N, \quad (28)$$

$$P_0^{eksk} = P_0^{*k} - \sum_{l=1;l\neq k}^{N+1} P_0^{elsk}, \qquad k = 1,2,\ldots,N, \quad (29)$$

$$P_0^{*dk} = P_0^{k*} - \sum_{l=1}^{N+1} P_0^{eksl} - \sum_{l=1;l\neq k}^{N} P_{0l}^{ekdl} + \sum_{l=1;l\neq k}^{N+1} P_{ok}^{eldk} = P_0^{k*} - P_0^{*k}$$
$$+ \sum_{l=1;l\neq k}^{N+1}(P_0^{elsk} - P_0^{eksl} + P_{0k}^{eldk}) - \sum_{l=1;l\neq k}^{N} P_{0l}^{ekdl}, \qquad k = 1,2,\ldots,N. \quad (30)$$

The forward mortality rate of the infants-cohort (*a*=0) can be calculated using Eq.(21).

An iterative procedure is necessary to estimate the mortality rate of the infants-cohort as unknown mortality rates appear in the right-hand side of Eqs.(24)-(28) and (30). An initial forward mortality rate can be estimated using the following, which is derived by assuming same mortality rate in all regions, and using Eqs. (1) and (2):

$$
\begin{aligned}
u_0^k &= (P_{0k}^{ekdk} + \sum_{l=1;l\neq k}^{N+1}(P_{0l}^{ekdk} + P_{0l}^{ekdl})) / P_0^{k*} \\
&= (P_0^{k*} - P_0^{eksk} - \sum_{l=1;l\neq k}^{N+1} P_0^{eksl} + P_0^{eksR} u_{0.5,0}^k) / P_0^{k*} \\
&= (P_0^{k*} - P_0^{*k} + \sum_{l=1;l\neq k}^{N+1}(P_0^{elsk} - P_0^{eksl}) + 0.5 P_0^{eksR} u_0^k) / P_0^{k*}, \qquad k = 1,2,\ldots,N.
\end{aligned}
\tag{31}
$$

Note that P_{0R}^{ekdR} is generally not defined. But it is assumed here that:

$$P_{0R}^{ekdR} = P_0^{eksR} u_{0.5,0}^k = 0.5 P_0^{eksR} u_0^k. \tag{32}$$

Therefore, an initial forward mortality rate of the infants-cohort can be estimated using the following equation:

$$u_0^k = (P_0^{k*} - P_0^{*k} + \sum_{l=1;l\neq k}^{N+1}(P_0^{elsk} - P_0^{eksl})) / (P_0^{k*} - 0.5 P_0^{eksR}), \qquad k = 1,2,\ldots,N. \tag{33}$$

Now, the estimation procedure can be carried out by repeating calculations using (24)-(28), (30) and (21). Eqs. (29) and (33) will be used in the first step. Then new estimation of the mortality rate of the infants-cohort in (21) can be used in the next iteration. Unknown items in the population account of the infants-cohort are estimated by (24)-(29).

The death population P_0^{*dk} of the infants-cohort in region k was estimated by (30). The death population P_a^{*dk} of the remaining period-cohorts in the region k can be estimated using the following equations:

$$P_1^{*dk} = D_0^k - P_0^{*dk} + 0.5 D_1^k, \qquad k = 1,2,\ldots,N. \tag{34}$$

$$P_a^{*dk} = 0.5(D_{a-1}^k + D_a^k), \qquad a = 2,3,\ldots,A-1; k = 1,2,\ldots,N, \tag{35}$$

$$P_A^{*dk} = 0.5 D_{A-1}^k, \qquad k = 1,2,\ldots,N. \tag{36}$$

The estimation of the forward mortality rate of period-cohort a (a=1,2,…,A) will be discussed next. The ending population P_a^{*k} and death population P_a^{*dk} are known.

Similar to the infants-cohort, the following can be obtained from (5)=(8),(10) and (1)-(3) for period-cohort a:

$$
\begin{aligned}
P_{al}^{ekdl} &= P_a^{eksl} u_{0.5a}^l / (1 - u_{0.5a}^l) = P_a^{eksl}(1 - (1 - u_a^l)^{1/2}) / (1 - u_a^l)^{1/2} \\
&= P_a^{eksl} u_a^l / (1 - u_a^l + (1 - u_a^l)^{1/2}), \qquad k,l = 1,2,\ldots,N; k \neq l.
\end{aligned}
\tag{37}
$$

$$
\begin{aligned}
P_{al}^{ekdk} &= (P_a^{eksl} + P_{al}^{ekdl}) u_{0.5a}^k / (1 - u_{0.5a}^k) = P_a^{eksl} u_a^k / ((1 - u_a^l)^{1/2}(1 - u_a^k + (1 - u_a^k)^{1/2})), \\
&\qquad k,l = 1,2,\ldots,N; k \neq l.
\end{aligned}
\tag{38}
$$

$$P_{ak}^{eRdk} = P_a^{eRsk} u_a^k / (1 - u_a^k + (1 - u_a^k)^{1/2}), \qquad k = 1,2,\ldots,N. \tag{39}$$

$$P_{aR}^{ekdk} = P_a^{eksR} u_a^k / (1 - u_a^k + (1 - u_a^k)^{1/2}), \qquad k = 1,2,\ldots,N. \tag{40}$$

$$P_{ak}^{ekdk} = P_a^{*dk} - \sum_{l=1;l\neq k}^{N+1}(P_{al}^{ekdk} + P_{ak}^{eldk}), \qquad k = 1,2,\ldots,N. \tag{41}$$

$$P_a^{eksk} = P_a^{*k} - \sum_{l=1;l\neq k}^{N+1} P_a^{elsk}, \qquad k = 1,2,\ldots,N. \tag{42}$$

$$P_a^{k*} = \sum_{l=1}^{N+1} P_a^{eksl} + \sum_{l=1}^{N+1} P_{al}^{ekdk} + \sum_{l=1;l\neq k}^{N+1} P_{al}^{ekdl} = P_a^{*k} + \sum_{l=1;l\neq k}^{N+1} (P_a^{eksl} - P_a^{elsk}) + P_a^{*dk}$$
$$+ \sum_{l=1;l\neq k}^{N} P_{al}^{ekdl} - \sum_{l=1;l\neq k}^{N+1} P_{ak}^{eldk}, \qquad k = 1,2,\ldots,N. \tag{43}$$

The forward mortality rate of the period-cohort *a* can be calculated using Eq.(21).

An iterative procedure is again necessary to estimate the mortality rate of period-cohort *a* as unknown mortality rates appear in the right-hand side of (37)-(41) and (21). To estimate an initial forward mortality rate of period-cohort *a*, the following can be obtained from (1)-(3) by assuming the same mortality rate in all regions:

$$u_a^k = P_a^{*dk} / (P_a^{*k} + P_a^{*dk} + 0.5 \sum_{l=1;l\neq k}^{N+1} (P_a^{eksl} - P_a^{elsk}), \qquad k = 1,2,\ldots,N. \tag{44}$$

Here, as was the case with (30) for the infants-cohort, it is assumed that:

$$P_{aR}^{eksR} = P_a^{eksR} u_{0.5a}^k = 0.5 P_a^{eksR} u_a^k. \tag{45}$$

Now, the estimation procedure can be carried out by repeating calculations using (37)-(41), (43) and (21). Eqs.(42) and (44) will be used in the first step. Then a new estimation of the mortality rate of the period-cohort *a* in (21) can be used in the next iteration. Unknown items in the population account of the period-cohort *a* are estimated by (37)-(42).

It is straightforward to estimate the forward fertility rates and migration rates as the multiregional population accounts have been estimated above.

The birth population P_a^{*bk} can be estimated in the similar way as the death population P_a^{*dk}:

$$P_a^{*bk} = 0.5(B_{a-1}^k + B_a^k), \qquad a = a_1, a_1+1, \ldots, a_2 : k = 1,2,\ldots,N. \tag{46}$$

Here a_1 and a_2 are the first and last period-cohorts of the fertile female population. The forward fertility rate f_a^k can be estimated using (23). Three forward internal migration rates can be estimated using (15)-(17). Two forward emigration rates can be estimated using (18) and (19).

Multiregional Population Projection Model

Given the starting population, and forward mortality rates, fertility rates, internal migration rates, emigration rates, and immigration flows, multiregional population projections can be undertaken using a multiregional population projection model. The gender label *g* (*m* for male and *f* for female) will be added back in this section.

It can demonstrated that the total fertility rate $TFR^k(t+1)$ based on occurrence-exposure fertility rates can be calculated from forward fertility rates as follows:

$$TFR^k(t+1) = \sum_{a=a1}^{a2} (f_a^k(t+1) / (1 - 0.5u_{af}^k(t+1))), \qquad k = 1,2,\ldots,N. \tag{47}$$

The normal forward fertility rate is defined thus:

$$f_a^{nk}(t+1) = f_a^k(t+1) / TFR^k(t+1), \qquad k = 1,2,\ldots,N. \tag{48}$$

It can be demonstrated that various population items can be expressed in terms of forward demographic rates and the starting population:

$$P_{agk}^{ekdk} = (1 - \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl}) P_{ag}^{k*} u_{ag}^k, \tag{49}$$

$$P_{ag}^{eksk} = (1 - \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl}) P_{ag}^{k*}(1 - u_{ag}^{k}), \tag{50}$$

$$P_{agl}^{ekdk} = P_{ag}^{k*} m_{1ag}^{kl} / (1 - (1 - u_{ag}^{k})^{1/2}), \tag{51}$$

$$P_{agl}^{ekdl} = P_{ag}^{k*} m_{1ag}^{kl} / (1 - u_{ag}^{k})^{1/2} (1 - (1 - u_{ag}^{l})^{1/2}), \tag{52}$$

$$P_{ag}^{eksl} = P_{ag}^{k*} m_{1ag}^{kl} (1 - u_{ag}^{k})^{1/2} (1 - u_{ag}^{l})^{1/2}, \tag{53}$$

$$P_{agR}^{ekdk} = P_{ag}^{k*} m_{1ag}^{kR} u_{0.5ag}^{k} = P_{ag}^{k*} m_{1ag}^{kR} (1 - (1 - u_{ag}^{k})^{1/2}), \tag{54}$$

$$P_{ag}^{eksR} = P_{ag}^{k*} m_{1ag}^{kR} (1 - u_{ag}^{k})^{1/2}, \tag{55}$$

Substitute (49)-(55) and (39) into (22), and rearrange:

$$\begin{aligned} PST_{ag}^{*bk} = PST_{ag}^{*dk} &= P_{ag}^{k*}(1 - \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl}) + P_{ag}^{k*} \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl} / (1 + (1 - u_{ag}^{k})^{1/2}) \\ &+ \sum_{l=1;l\neq k}^{N} P_{ag}^{l*} m_{1ag}^{lk} (1 - u_{ag}^{l})^{1/2} / (1 + (1 - u_{ag}^{k})^{1/2} \\ &+ P_{ag}^{eksR} / (1 - u_{ag}^{k} + (1 - u_{ag}^{k})^{1/2}). \end{aligned} \tag{56}$$

Now, define the survival rate $s_{ag}^{kl}(t+1)$ and special rate $v_{ag}^{k}(t+1)$ as follows:

$$s_{ag}^{kk}(t+1) = (1 - \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl}(t+1))(1 - u_{ag}^{k}(t+1)), \qquad k = 1,2,\ldots,N, \tag{57}$$

$$\begin{aligned} s_{ag}^{kl}(t+1) &= m_{1ag}^{kl}(t+1)(1 - u_{ag}^{k}(t+1))^{1/2}(1 - u_{ag}^{l}(t+1))^{1/2}, \\ &k = 1,2,\ldots,N, k \neq l, \end{aligned} \tag{58}$$

$$s_{ag}^{kR}(t+1) = m_{1ag}^{kR}(t+1)(1 - u_{ag}^{k}(t+1))^{1/2} \qquad , k = 01,2,\ldots,N, \tag{59}$$

$$\begin{aligned} v_{ag}^{k}(t+1) &= 1 - \sum_{l=1;l\neq k}^{N+1} m_{1ag}^{kl}(t+1)(1 - 1/(1 + (1 - u_{ag}^{k}(t+1))^{1/2})), \\ &k = 1,2,\ldots,N, k \neq l, \end{aligned} \tag{60}$$

Finally, the following population projection model can be obtained. Births of gender g in region k can be projected using the following equation. Here S_{g}^{exk} is the ration of gender g in total births in region k:

$$\begin{aligned} P_{0g}^{k*}(t) = P_{g}^{*bk}(t+1) &= S_{g}^{exk} TFR^{k}(t+1) \sum_{a=a1}^{a2} f_{a}^{nk}(t+1)(P_{af}^{k*}(t) v_{af}^{k}(t+1) \\ &+ (\sum_{l=1;l\neq k}^{N} P_{af}^{l*}(t) s_{af}^{lk}(t+1) + P_{af}^{eRsk}(t+1)) / (1 - u_{af}^{k}(t+1) \\ &+ (1 - u_{af}^{k}(t+1))^{1/2})), \qquad k = 1,2,\ldots,N. \end{aligned} \tag{61}$$

The ending population in period t to t+1 can be projected using the following:

$$\begin{aligned} P_{ag}^{*k}(t+1) &= \sum_{l=1}^{N} P_{ag}^{l*}(t) s_{ag}^{lk}(t+1) + P_{ag}^{eRsk}(t+1), \\ &a = 0,1,\ldots,A; g = m,f; k = 1,2,\ldots,N. \end{aligned} \tag{62}$$

The starting population for the next projection period as follows:

$$P_{ag}^{k*}(t+1) = P_{a-1g}^{*k}(t+1), \qquad a = 1,\ldots,A-1; g = m,f; k = 1,2,\ldots,N, \tag{63}$$

$$P_{Ag}^{k*}(t+1) = P_{A-1g}^{*k}(t+1) + P_{Ag}^{*k}(t+1), \qquad g = m,f; k = 1,2,\ldots,N, \tag{64}$$

Eqs. (57-(64) constitute a multiregional population projection model of the open population system based on the forward demographic rates.

DATA REQUIREMENTS OF THE MULTIREGIONAL PROJECTION MODEL

The above is a region- age- and gender-specific population model. It requires the base-year population as well as mortality, fertility and migration rates as input data. The spatial population system consists of some 29 provincial regions of mainland China (Fig.1). Hainan is included in Guangdong province. The age and time intervals used are five years. There are 21 period-cohorts in total. The period 1982-1987 is used to estimate most input data using the 1982 census data and the 1987 one percent population sampling data. The base year for population projection is 1987. The projection period runs from 1987 to 2087. Although a formal procedure to estimate forward demographic rates has been developed this is only used for estimation of mortality and migration rates. The one per thousand fertility sampling survey data in 1982 was used to estimate normal fertility rates.

Age-Specific Population in 1982 and 1987

Population data for both dates are available in form of five-year age groups (0-4, 5-9, etc.) However, the age-specific population data do not cover all populations in the 1982 census. First, there are age-unknown populations n most provinces. These age-unknown populations are allocated to age-groups in proportion to age-known populations in each province. Second, some 28,601 persons in Tibet were indirectly counted and their ages are also unknown. These people are allocated to age-groups again according to the age-known population in Tibet. Third, there are some 4,238,210 persons in the armed forces whose age distributions were not released. Some 100,000 of them are female. These age-unknown populations are allocated to age-groups from age 16 to age 22 assuming the same gender ratios in these age-groups. The gender rations (males per 100 females) in these age-groups are significantly low in the census data. A gender ration of 107.37 at age 23 is regarded as normal. It is also assumed that females and males in the armed forces have the same age distribution. The adjustment is carried out for China as a whole at first. Then the estimated age-known populations in the armed forces are allocated to provincial populations in proportion to their population in age-groups 4 and 5 (ages 15-24). As a result, it is found that over two-thirds of the persons in the armed forces were aged 18-20. Coale (1984) used a slightly different procedure to account for the armed forces in his estimation of the age-specific populations for the whole of China.

The available population data for 1987 are the 1% sampling population. These data need to be adjusted by the appropriate sampling ratios and to account for armed forces. It seems that these differ between regions. Regional sampling ratios are calculated and are used to adjust the sampling populations. These data are then adjusted again according to the sampling rations of male and female populations. The total male and female populations in 1987 can be calculated form SSB (1991). Male and female sampling ratios can be calculated from the sampling populations and the total populations excluding the armed forces.

According to SSB (1987) and DPS (1986b), it can be inferred that there were 3.14 million males and 0.10 million females in the armed forces in 1987. The adjustment procedure to account for these armed forces has been discussed elsewhere (Shen and Spence, 1994).

Total Birth in the Period 1982-1987

The population in the period-cohort zero in the beginning of the period is the total number of births in the period 1982-1987. Regional birth rates are applied to regional populations in each year of 1982-1985 to obtain the regional numbers of births in these years. These numbers of regional births are then adjusted to match the total births of China calculated in the same way as the regional numbers (DPS, 1988b; SSB, 1991). As the calibrating period runs from mud-1982 to mid-1987, only about half of the births in 1982 need to be included by applying a ratio of 55.19% which is the actual ration of births in the second half year in 1986 (DPS, 1988a). The numbers of regional births in the period from January 1986 to mid-1987 are available from the one-percent population sampling data and are adjusted by the regional sampling ratios as well (DPS,1988a). The population of period-cohort zero in 1982 is obtained by adding together these two parts of births in 1982-1985 and 1986-1987.

Origin- and Destination-Specific Migrations and Migration Rates

The origin- and destination-specific inter-provincial migration data are available from the 1987 one-percent population sampling data (DPS, 1988a). However, these migration data only record the last place of residence of a migrant in the period 1982-1987 which was different from that in 1987. Therefore, the last place of residence may not be the place of residence in 1982 as a migrant may make more than one migration in five-year period. The average five-year inter-provincial migration rate is known to be 0.59%. No in-migration to Tibet was recorded in 1% sampling data in 1987 as only its county population was covered. This may slightly underestimate the national average migration rate and underproject the future population in Tibet. It can be roughly estimated that the average one-year inter-provincial migration rate was only 0.118%. Assuming one migration in one-year, simple calculation shows that over 99.5% migrants will make only one migration in a five-year period. The proportion of multiple migrations is then less that 0.5%. Thus the last place of residence migration data can be used as the transitional migration data between 1982 and 1987 without large error.

A detailed analysis of internal migration in China has been undertaken using this set of migration data (Shen, 1994b). A new pattern of migration has emerged in the 1980s. The traditional migration direction was from the eastern developed regions to the north-western less developed regions in the pre-reform period before the late 1970s. However, all the coastal provinces except for Zhenjiang, Fujian and Guangxi have net in-migrations over the period 1982-1987. In particular, Shanghai, Beijing, Tianjin and Hebei had net in-migration rates over 0.3%. All other non-coastal provinces except for Hubei and Ningxia had net out-migrations over the same period. Qinghai, Heilongjiang, Gansu and Jilin particularly had high net out-migration rates. These regions received many migrants in the pre-reform period and now are losing population through migration. This is a result of socio-economic changes in China since the late 1970s. More flexible migration policies have been adopted and the emphasis for regional development has shifted to coastal areas in the eastern part of the country. Both of these have stimulated migrations from the north-western areas to the eastern coastal areas. This migration pattern will have important effects on the population dynamics in various regions. According to the population projections presented in the next section, Beijing and Shanghai will have smaller decreases in population than Zhenjiang in the next century due to in-migrations though they will have the lowest fertility rates.

The age distribution is not available for inter-provincial migrations. What is available is the age distribution of migrations of the national population. It is found that migrants were concentrated in age-groups 20-29. For simplicity, the age-specific inter-provincial migrations are estimated in such a way that normal age-specific migration rates were same in all regions.

These normal migration rates are also used to estimate the age-specific emigrations to the rest of the world. The emigration data are not available from the 1987 one-percent population sampling data. According to official sources (People's Daily, 1990), there were 94 thousand Chinese, excluding those for public affairs, going abroad in 1986 and 1987. It is noted that most of these international migrations were for study, work or joining family. Going abroad for non-public purpose was a new phenomenon in China in 1980s and a number of these Chinese may return home in two to four years especially those going abroad for language studies. For simplicity, the total number of emigrants in 1986 and 1987 is used as total emigrants in the five-year period 1982-1987. These total emigrations of China are allocated to provincial regions according to the distribution of those Chinese living abroad with non-residence registration status in the 1990 census (SSB, 1990). These amount to some 238 thousand, much less than 355 thousand of those going abroad in the period 1986-1989. This difference may be due to the fact that some people did not cancel their residence registration status when going abroad.

The age distribution of total immigrations from abroad is available from 1987 one-percent population sampling data (DPS, 1988a). According to the population model, survival immigration flows will be directly used for population projections There is no need to define any immigration rate. The total regional immigration flows are allocated to their period-cohorts using the national age distribution of total immigrations.

Age-Specific Mortality Rates

The estimation procedure for the infants-cohort mortality rates developed previously can be used for all period-cohorts. However, only the mortality rates of the period-cohorts with large number of deaths and high mortality rates can be reasonably estimated as they are less sensitive to the disturbance of various errors in the data available. Table 3 presents the regional mortality rates estimated for the period-cohorts 15-17 of the female population.

TABLE 3

Regional mortality rates (female, period-cohorts 15-17) and the ratio of regional to national mortality rates in China

Region	Mortality rate of period-cohort (per thousand)			Regional to National	
	15 (70-74)*	16(75-79)	17(80-84)	Female	Male
Beijing	211	320	494	0.86	0.74
Tianjin	200	328	537	0.87	0.76
Hebei	285	435	605	1.13	1.16
Shanxi	354	527	636	1.36	1.18
Inner Mongolia	345	432	655	1.25	1.38
Liaoning	294	397	543	1.08	0.94
Jilin	290	436	581	1.13	1.16
Heilongjiang	368	451	609	1.29	1.23
Shanghai	236	355	538	0.95	0.90
Jiangsu	162	286	492	0.76	0.82
Zhenjiang	139	305	512	0.76	0.81
Anhui	285	411	606	1.11	1.11
Fujian	199	305	464	0.81	1.09
Jiangxi	277	433	623	1.13	1.23
Shangdong	219	378	555	0.96	0.97
Henan	269	412	588	1.08	1.07
Hubei	289	462	621	1.17	1.20
Hunan	253	411	576	1.05	0.98
Guangdong	185	281	438	0.76	0.84
Guangxi	164	253	385	0.67	0.67
Sichuan	252	394	542	1.01	0.93
Guizhou	285	461	495	1.12	0.92
Yunnan	314	439	624	1.20	0.93
Tibet	370	752	591	1.56	1.41
Shaanxi	352	467	572	1.28	1.23
Gansu	359	475	644	1.33	1.10
Qinghai	151	352	498	0.78	0.97
Ningxia	272	322	455	0.95	0.83
Xinjiang	385	303	650	1.20	0.87

Note: *age group at the beginning of a five-year period.

The age-specific mortality rates for China as a whole can also be estimated by using the starting and ending populations in the calibration period 1982-1987 while disregarding the international migrations. Table 4 presents these results as estimation one. Note that only the mortality rates of period-cohorts 13-20 can be reliably estimated.

The national and regional mortality rates of the period-cohorts I S (70-74) through 17 (80-84) of the female population and those of the period-cohorts 14 (65-69) through 16 (75-79) of the male population are used to calculate ratios of regional to national mortality rates for the female and male populations respectively. The starting populations in the three period-cohorts involved are used as weights to balance the total number of regional deaths in these period-cohorts. These ratios are also presented in Table 3.

The regional to national ratios for females and males are generally consistent in the sense that most regions which have a female ratio over one will also have a male ratio over one. However, the relative female mortality rates in Liaoning, Hunan, Sichuan, Guizhou, Yunnan and Xinjiang are greater than the national average while their relative male mortality rates are generally lower. The situation is reversed in Fujian. The regional to national mortality ratio is well over 1.20 in Shaanxi, Inner Mongolia, Heilongjiang, Yunnan, Tibet and Shaanxi for the female population and in Inner Mongolia, Heilongjiang, Jiangxi, Hubei, Tibet and Shaanxi for the male population. The ratio is well below 0.80 in Jiangsu, Zhejiang, Guangdong, Guangxi and Qinghai for the female population and in Beijing, Tianjin and Guangxi for the male population. These ratios represent the differential mortality rates in various regions which have important effects on regional population dynamics.

TABLE 4

Age-specific mortality rates for China (per thousand)

Period-cohort	Estimation one		Estimation two	
	Female	Male	Female	Male
0 (infants)	91.29	77.04	29.50	28.98
1 (0-4)	0	0	7.70	7.78
2 (5-9)	0	0	2.61	3.40
3 (10-14)	15.43	11.91	3.40	3.70
4 (15-19)	12.33	29.28	5.58	6.26
5 (20-24)	3.39	2.41	6.23	6.95
6 (25-29)	18.56	19.65	6.22	7.59
7 (30-34)	5.19	14.10	7.45	9.03
8 (35-39)	5.47	27.09	9.48	12.51
9 (40-44)	2.23	33.12	14.38	19.24
10 (45-49)	2.30	26.76	21.85	31.10
11 (50-54)	11.04	28.13	36.65	49.13
12 (55-59)	37.97	53.42	56.85	83.79
13 (60-64)	83.86	123.38	87.14	137.71
14 (65-69)	157.61	205.93	144.07	209.54
15 (70-74)	250.12	327.76	224.79	306.76
16 (75-79)	380.70	464.28	342.58	435.08
17 (80-84)	543.46	629.55	489.73	579.5
18 (85-89)	704.30	750.30	662.98	735.12
19 (90-94)	742.97	739.36	844.34	878.08
20 (95+)	768.77	682.08	958.37	966.32

Notes: (1) Estimation one using starting and ending population in the period 1982-1987; (2) Estimation two using the one-year age-specific mortality rates in 1987; (3) Period-cohort zero refers to infants-cohort produced in a five-year period and period-cohort one refers to population aged 0-4 at the beginning of a five-year period, and so on.

National five-year age-specific mortality rates can also be estimated from the one-year age-specific mortality rates of urban and rural populations (Shen, 1994b; Shen and Spence, 1994). In that case, national one-year age-specific mortality rates were calculated first as weighted averages of urban and rural mortality rates. The following procedures are used to calculate the national five-year age-specific mortality rates.

First, the stable population by one-year period-cohort can be calculated using the national age-specific mortality rates for each gender. A stable population is a hypothetical population which has been subjected to constant mortality and fertility rates for a long time and has a constant age composition. Here, the stable population is used to account for the age composition by one-year age interval within each period-cohort of five-year age interval. Thus the stable population is used to calculate the starting population of five-year period-cohorts and the ending population by ageing on using the one-year age-specific mortality rates for a period of five years. Here, it is assumed that the number of births in period-cohort zero of the stable population P^1_{ag} is one.

The populations in the remaining one-year period-cohorts can be calculated using the following equation:

$$P_{ag}^{1} = P_{a-1g}^{1}(1-u_{a-1g}^{1}), \qquad a = 1,2,\ldots,100, \tag{65}$$

$$P_{101g}^{1} = P_{100g}^{1`}(1-u_{100g}^{1}) / u_{101g}^{1}. \tag{66}$$

Here P_{ag}^{1} is the stable population of period-cohort a of gender g by one-year age intervals denoted by superscript one and u_{ag}^{1} is the forward mortality rate of period-cohort a of gender g by one-year age intervals also denoted by superscript 1.

Second, the starting populations of five-year period-cohorts in a five-year period can be calculated as follows:

$$PST_{0g}^{5} = 5P_{0g}^{1} = 5, \tag{67}$$

$$PST_{ag}^{5} = \sum_{i=5a-1}^{5a} P_{ig}^{1}, \qquad a = 1,2,\ldots,19, \tag{68}$$

$$PST_{20g}^{5} = \sum_{i=96}^{101} P_{ig}^{1}. \tag{69}$$

Here PST_{ag}^{5} is the starting population of period-cohort a of gender g by five-year age intervals denoted by superscript 5.

Third, the ending populations of five-year period-cohorts in a five-year period can be calculated by aging on the stable populations of one-year age intervals for five years and adding up for the period-cohorts of five-year age intervals as follows:

$$PED_{0g}^{5} = \sum_{i=1}^{5} P_{0g}^{1} \prod_{k=0}^{i-1} (1-u_{kg}^{1}), \tag{70}$$

$$PED_{0g}^{5} = \sum_{i=5a-4}^{5} P_{ig}^{1} \prod_{k=0}^{4} (1-u_{i+kg}^{1}), \qquad a = 1,2,\ldots,19, \tag{71}$$

$$PED_{20g}^{5} = \sum_{i=96}^{101} P_{ig}^{1} (1-u_{101g}^{1})^{i-96} \prod_{k=0}^{100-i} (1-u_{i+kg}^{1}). \tag{72}$$

Here PED_{ag}^{5} is the ending population of period-cohort a of gender g by five-year age intervals denoted by superscript 5.

Fourth, the forward mortality rate u_{ag}^{5} for period-cohort a of gender g of five-year age intervals can be calculated from the starting and ending populations of this period-cohort in a five-year period as follows:

$$u_{ag}^{5} = 1 - PED_{ag}^{5} / PST_{ag}^{5}, \qquad a = 0,1,\ldots,20. \tag{73}$$

The national mortality rates of China calculated in this way are also presented in Table 4 as estimation two. It seems that the mortality rates of period-cohorts 13 (60 64) through 20 (95+) in estimation one and two are comparable. However, the mortality rates of period-cohorts 0 (0-4) through 12 (50-59) in estimation one are subject to statistical errors in the age-specific starting and ending populations in the period 1982-1987. These errors may be insignificant for age-specific populations. However, they may be significant for age-specific death populations which are much smaller. Therefore, the national mortality rates in estimation two will be used for population projections. These national mortality rates are used to calculate regional mortality rates using the ratios of regional to national mortality rates presented in Table 3. To keep consistency, the national mortality rates of period-cohorts 15 (70-74) through 17 (80-84) for the females and period-cohorts 14 (65-69) through 16 (75-79) for males in estimation one have been used in calculating these ratios of regional to national mortality rates.

Age-Specific Fertility Rates

National age-specific fertility rates for five-year age and time intervals can also be estimated from the age-specific fertility rates for one-year age and time intervals based on 1987 one-percent population sampling data. These again can be calculated as weighted averages of the urban and rural fertility rates estimated in the cited previous research. The following equations can be used to calculate the five-year age specific fertility rates from the one-year age-specific fertility rates of China. The procedures are similar to those used in the calculation of national five-year age specific mortality rates in estimation two above.

The number of births B5 produced by period-cohort a of five-year age and time intervals can be calculated as follows:

$$B_a^5 = \sum_{i=5a-4}^{5a} \sum_{k=0}^{4} P_{i+kf}^1 f_{i+k}^1, \qquad a = 3,4,\ldots,10. \tag{74}$$

Here P_{af}^1 *and* f_a^1 are the female stable population of period-cohort a calculated in the previous section and its fertility rate for one-year age and time intervals.

The forward fertility rate f_a^5 of period-cohort a of five-year age and time intervals can be calculated as follows:

$$f_a^5 = B_a^5 / PST_{af}^5, \qquad a = 3,4,\ldots,10. \tag{75}$$

It is not possible to derive region-specific fertility rates from the 1987 one-percent population sampling data available. The one per thousand fertility sampling survey conducted in 1982 by the State Family Planning Commission of China does however provide a detailed record of fertility in China and her provincial regions since the 1940s (Coale and Chen, 1987). The fertility rates for the 28 provincial regions of mainland China except Tibet in 1982 will be used to construct region-specific normal fertility rates for period-cohorts of five-year age and time intervals. The available data on fertility rates in 1982 are for period-cohorts of five-year age and one-year time intervals. Fig. 2 shows the meaning of the period-cohort fertility rate of five-year age and one-year time intervals f_a^{51} (area ADEH) and the period-cohort fertility rate of five-year age and time intervals f_a^5 (area AGEJ). Here the period fertility rate f_a^{P51} of five-year age and one-year time intervals (area ABEF) relates to births produced by the population reaching ages between a' -1 and a' + 4 in period t' to t' + 1. Similarly, the period fertility rate f_a^{P5} of five-year age and time intervals (area ACEG) relates to births produced by the population reaching ages between a' - 1 and a' + 4 (or between a - 1 and a in terms of five-year age interval) in period t' to t' + 5 (or in period to t+ 1 in terms of five-year time interval). For simplicity, period fertility rate f_a^{P51} (area ABEF) is estimated as the period-cohort fertility rate f_a^{51} (area ADEH). The period fertility *rate* f_a^{P5} *(area* ACEG) is estimated as five times the period fertility rate f_a^{P51} (area ABEF). The period fertility rate f_{a+1}^{P5} (area EGIJ) can be similarly estimated. It seems clear that the period-cohort fertility rate f_a^5 (area AGEJ) involves two component rates, f_a^{P5} and f_{a+1}^{P5} (areas ACEG and EGIJ respectively), and can be estimated as their average. Thus the following estimation equation is obtained:

$$f_a^5 = (0.5)(5)(f_a^{51} + f_{a+1}^{51})(1 - 0.5u_a^5), \qquad a = 3,4,\ldots,10. \tag{77}$$

Here a factor of $(1 - 0.5u_a^5)$ is also used to estimate the forward fertility rate of period-cohort af_a^5 from the original occurrence-exposure fertility rate f_a^{51}.

The normal fertility rate of period-cohort *a* can be calculated again using Eq. (76). The estimation procedure is applied to China as a whole and her 28 provincial regions. Table 5 presents the normal fertility rates of China estimated by the two procedures discussed above based on the one-percent population sampling data in 1987 and one per thousand fertility sampling data in 1982 respectively.

The normal fertility rates of period-cohorts 4 (15-19) through 7 (30-34) of China estimated using 1982 data are close to those estimated using 1987 data, though the fertility rates of period-cohorts 4 (15-19) and 5 (20-24) more or less increased and those of the remaining period-cohorts decreased during the period. The normal fertility rate had a peak of 0.37669 in period-cohort 5 (20-24) in 1982, increasing to 0.44239 in 1987. This change reflects a trend of further concentration of childbearing (at ages of 20-30) along with the decline of fertility in China over the period 19821987. A ratio of the normal fertility rate of China estimated by the 1987 data to that estimated by the 1982 data is calculated for each period-cohort and is applied to the regional normal fertility rates estimated by the 1982 data to update them. These adjusted fertility rates are re-normalized using Eq. (76) to obtain normal fertility rates for each of the provincial regions. Table 6 presents the adjusted normal fertility rates for the 28 regions.

TABLE 5

Normal fertility rates of China using 1982 and 1987 data

Period-cohort	Normal fertility rate using data in	
	1982	1987
3 (10-14 --15-19)*	0.01715	0.00803
4 (15-19 -- 20-24)	0.19792	0.21773
5 (20-24 -- 25-29)	0.37669	0.44239
6 (25-29 -- 30-34)	0.25874	0.22201
7 (30-34 -- 35-39)	0.09031	0.07586
8 (35-39 -- 40-44)	0.03894	0.02329
9 (40-44 -- 45-49)	0.01421	0.00667
10 (45-49 -- 50-54)	0.00283	0.00088

Note: * age-groups at the beginning and end of a five-year period respectively.

The normal fertility rates of all regions had a peak in period-cohort 5 (20-24). However, some regions had a higher peak of normal fertility rate than other regions. Beijing, Tianjin, Liaoning, Jilin, Jiangsu, Zhejiang, Shandong, Sichuan and Shaanxi had a peak of normal fertility rates over 0.47 in period-cohort 5 (20-24). Other regions had a more smooth fertility schedule. The peaks of normal fertility rates were below 0.40 in Guangxi, Guizhou, Yunnan, Qinghai and Xinjiang.

TABLE 6

Regional normal fertility rates of China for a five-year period based on one-year fertility data in 1982

Period-cohort	3 (10-14)**	4 (15-19)	5 (20-24)	6 (25-29)	7 (30-34)	8 (35-39)	9 (40-44)	10 (45-49)	TFR*
Beijing	0.00000	0.14807	0.50206	0.29959	0.04718	0.00000	0.00000	0.00000	1.33
Tianjin	0.00000	0.10431	0.48019	0.33170	0.06085	0.01110	0.00868	0.00000	1.66
Hebei	0.00402	0.16771	0.42061	0.26644	0.10475	0.02616	0.00712	0.00000	2.33
Shanxi	0.01060	0.23914	0.44304	0.22301	0.07224	0.00727	0.00162	0.00000	2.46
Inner Mongolia	0.00803	0.18766	0.42980	0.26325	0.09413	0.01255	0.00146	0.00000	1.97
Liaoning	0.00382	0.22929	0.50990	0.21773	0.02443	0.00904	0.00272	0.00000	1.51
Jilin	0.00458	0.26064	0.49895	0.19275	0.02972	0.00802	0.00228	0.00000	1.81
Heilongjiang	0.01105	0.26334	0.46945	0.19833	0.04337	0.00758	0.00381	0.00000	1.71
Shanghai	0.00434	0.15481	0.46304	0.28749	0.07614	0.01105	0.00000	0.00000	1.34
Jiangsu	0.00602	0.23716	0.48812	0.21684	0.03985	0.00536	0.00240	0.00118	1.94
Zhejiang	0.00853	0.27911	0.47633	0.17447	0.04133	0.01150	0.00400	0.00164	1.4
Anhui	0.01546	0.19663	0.43092	0.25096	0.07410	0.01969	0.00845	0.00065	2.51
Fujian	0.01004	0.26630	0.45361	0.17729	0.05626	0.02556	0.00783	0.00000	2.36
Jiangxi	0.01887	0.26474	0.41712	0.17790	0.08078	0.03134	0.00531	0.00081	2.46
Shandong	0.00219	0.19670	0.47747	0.24861	0.05983	0.01046	0.00164	0.00000	2.12
Henan	0.00340	0.18687	0.44627	0.25054	0.08518	0.02040	0.00387	0.00032	2.9
Hubei	0.00880	0.25995	0.45761	0.19227	0.05560	0.01648	0.00619	0.00000	2.5
Hunan	0.00676	0.23134	0.46615	0.21164	0.05415	0.01903	0.00709	0.00070	2.4
Guangdong	0.00974	0.18192	0.41170	0.24520	0.10600	0.03373	0.00699	0.00153	2.55
Guangxi	0.00390	0.17140	0.37885	0.24651	0.14354	0.04340	0.00809	0.00106	2.73
Sichuan	0.00538	0.25648	0.47675	0.19097	0.04571	0.01597	0.00536	0.00029	1.76
Guizhou	0.00778	0.16288	0.35807	0.23418	0.15109	0.06363	0.01632	0.00273	2.96
Yunnan	0.00843	0.19941	0.38257	0.21246	0.12599	0.05121	0.01390	0.00276	2.59
Tibet	n.a.								4.22
Shaanxi	0.00711	0.26397	0.47099	0.18792	0.05094	0.01245	0.00266	0.00087	2.71
Gansu	0.02264	0.24375	0.43244	0.20305	0.05006	0.02826	0.01548	0.00116	2.34
Qinghai	0.01371	0.13707	0.28360	0.24756	0.20112	0.08917	0.02435	0.00000	2.47
Ningxia	0.00503	0.21520	0.41056	0.21837	0.09445	0.02879	0.01940	0.00493	2.61
Xinjiang	0.01530	0.18018	0.37077	0.24739	0.13033	0.03973	0.01067	0.00240	3.16
China	0.01715	0.19792	0.37669	0.25874	0.09031	0.03894	0.01421	0.00283	2.25

Notes:* 1990 census data (SSB, 1991): **age-group at the beginning of a five-year period

Total Fertility Rates

Normal fertility rates have been estimated for 28 provincial regions of China and are assumed constant in multiregional population projections. Total fertility rates for the twenty five-year projection periods also need to be assumed for population projections. Three sets of urban-rural total fertility rates have been assumed for urban-rural population projections of China in previous research (Shen and Spence, 1994). In set (A), it is assumed that the total fertility rates of the urban and rural populations will remain unchanged from the base year 1987. In set (B), it is assumed that the total fertility rate of the urban population will gradually decline to 1.5 in 2000, remain unchanged until 2010, gradually increase to 2.2 in 2030, then remain unchanged until 2087. The total fertility rate of the rural population is assumed to decline gradually to 2.2 in 2020 and then remain unchanged until 2087. In set (C), it is assumed that the total fertility rate of the urban population will decline to 1.5 in 2000 and then remain unchanged until 2087. The total fertility rate trend of the rural population is assumed to be the same as in set (B). To make consistent population projections of China, three sets of national total fertility rates are calculated from these urban and rural total fertility rates and the projected proportions of urban and rural populations. It is noted that the national total fertility rate in set (A) shows a declining trend because of the increasing proportion of the urban population though constant total fertility rates are assumed for urban and rural populations respectively. These national total fertility rates refer to periods of one-year only. An average national total fertility rate for each five-year projection period can be calculated for each of the three sets of fertility assumptions (A), (B) and (C).

The total fertility rates for the 29 provincial regions of China in 1990 are available from the 1990 census (SSB, 1991). The regional to national ratio of total fertility rates in 1990 can be calculated. This ratio was well below 0.8 in Beijing, Tianjin, Liaoning, Heilongjiang? Shanghai, Zhejiang and Sichuan, and over 1.20 in Henan, Guangxi, Guizhou, Tibet and Xinjiang. It is difficult to project the regional differentials of total fertility rates for the projection periods. For simplicity, these ratios are applied to three sets of national total fertility rates assumed above to calculate regional total fertility rates for the twenty five-year projection periods (1987-2087). However, the actual national total fertility rates in the projection periods derived from these regional total fertility rates will be different from those assumed originally due to the changing shares of regional populations with different total fertility rates. The following adjustment ratio is calculated and used to re-adjust regional total fertility rates (TFR) to ensure the national total fertility rates actually used in population projections are equal to those assumed:

$$\text{Adjustment ration} = \frac{\text{National TFR assumed}}{\text{National TFR derived from regional TFRs'}} \tag{78}$$

Here, the national fertility rates derived from the regional total fertility rates can be calculated using the following equation:

National TFR derived from regional TFRs

$$= \sum_{a=3}^{10} \left(\sum_{k=1}^{N} TFR^k f_a^{nk} PST_{af}^k \Big/ \sum_{k=1}^{N} PST_{af}^k \right) \Big/ (1 - 0.5u_{af}^5). \tag{79}$$

Here, TFR^k *and* f_a^{nk} are the regional total fertility rate and normal fertility rate of period-cohort *a* of the female population in region *k*, respectively, and PST_{af}^k is the starting female population for the calculation of the number of births in region k. Three procedures have been combined in (79). First, the number of births produced by the female population of period-cohort *a* in region *k* is calculated by multiplying the regional total fertility rate, the normal fertility rate and the starting population of period-cohort *a*. Second, the total number of births of the country as a whole produced by the female population of period-cohort *a* is calculated by the summation of regional births. Then, a national forward fertility rate of period-cohort *a* is obtained by dividing the total number of births by the total number of the starting population of the country in period-cohort *a*. Third, a national total fertility rate can be calculated using (47) and (48).

Summary of Input Data and Assumptions for Multiregional Population Projections

The projection period runs from 1987 to 2087. The time and age intervals are five years in the population projection model. The spatial population system consists of 29 mainland provincial regions of China and is connected with the rest of the world via international migration. The base year is 1987. Age-specific regional populations have been prepared previously.

Constant regional mortality and normal fertility rates prepared previously are used in the population projections. Note that the normal fertility rates for Tibet are not available. According to the 1990 census (SSB, 1991), Tibet had the highest total fertility rate (4.22) among 30 provincial regions (including the new province of Hainan) in 1990 in China and Xinjiang had the second highest (3.16). It is likely that the fertility schedule of a population is associated with the size of its total fertility rate. For simplicity, the normal fertility rates of Xinjiang are assumed for Tibet.

Constant migration rates prepared previously will also be assumed for population projections with one exception. It is recognized that the number of Chinese going abroad has been increasing in recent years. According to official sources (People's Daily, 1990), the number was 40 thousand in 1986 and 133 thousand in 1989 excluding those going abroad for public affairs. In the estimation of emigration rates, a total number of emigrants of 94 thousand was assumed for China for the period 1982-1987. At the moment, it is difficult to project the number of emigrants in future as this depends on the situation in China as well as the restrictions of the destination countries. For simplicity, a total number of 665 thousand is assumed for a five-year period based on a simple grossing up of the figure in 1989. Comparing this number of emigrants with the 94 thousand assumed for the period 1982-1987, means that the emigration rates should be increased by a factor of about 7.07. This inflation figure is assumed for population projections.

Three sets of national total fertility rates have been assumed on the basis of three sets of urban and rural fertility rates assumptions in previous research to make consistent population projections. Table 7 presents the three sets of the national fertility rates assumed for the multiregional population projections of China. All these rates are based on occurrence-exposure fertility rates and are the averages for each five-year period. In projection (A), it is assumed that the national total fertility rate of China will decline from 2.356 in the first five-year period 1987-1992 to 1.850 in the last five-year period 1982-1987. Projection (B) assumes lower national total fertility rates for the period 1987-2027 and higher for the period 2027-2087 than projection (A). Projection (C) assumes lower total fertility rates than projections (A) and (B). Regional total fertility rates are calculated from national total fertility rates using constant regional to national ratios of total fertility rates prepared previously, and adjustment ratios in (78).

TABLE 7

Assumptions of national total fertility rates (A, B and C) for China

Period	A	B	C
1987-1992	2.356	2.310	2.310
1992-1997	2.317	2.195	2.195
1997-2002	2.283	2.090	2.090
2002-2007	2.245	2.003	2.003
2007-2012	2.204	1.949	1.928
2012-2017	2.166	1.956	1.860
2017-2022	2.132	2.012	1.808
2022-2027	2.101	2.100	1.776
2027-2932	2.073	2.180	1.753
2032-2037	2.045	2.206	1.731
2037-2042	2.017	2.205	1.709
2042-2047	1.990	2.205	1.688
2047-2052	1.996	2.204	1.670
2052-2057	1.945	2.204	1.654
2057-2062	1.926	2.204	1.639
2062-2067	1.908	2.204	1.625
2067-2072	1.891	2.203	1.621
2072-2077	1.876	2.203	1.600
2077-2082	1.863	2.203	1.589
2082-2087	1.850	2.203	1.580

Notes: These national total fertility rates assumptions are based on the urban and rural fertility rates assumptions. The total fertility rate of set (B) is not exactly constant after 2032 due to the rounding errors.

MULTIREGIONAL POPULATION PROJECTIONS FOR CHINA

This section will discuss the results of multiregional population projections using the population model developed in this paper. Three sets of projections (A), (B) and (C) were made using the three sets of national total fertility rate assumptions. Many results were generated with regard to the numbers of births, deaths, internal migrations, external migrations for the projection period 1987-2087. Here the emphasis will be placed only on population change in the 29 provincial regions of China in the period 1987-2087. Subsequent research will report on findings relating to the ageing of population and the changing labour force. A population index is defined as the total population of a region in year t divided by its total population in the base year 1987. Tables 8, 10 and 11 present three projections (A), (B) and (C) of regional population indexes respectively for the period 1987-2087.

According to projection (A) in Table 8, the total population of China will increase by about 50% in the period 1987-2042 and then decline slowly until 2087. By the year 2087, the total population will be about 30% more than that in 1987. For China as a whole, a growing stage and a stable or slowly declining stage can be identified with a division around 2040. However, this national trend is just a combination of various regional trends. Some regions will reach their population peaks much earlier. Zhejiang will reach its population peak as early as in the year 2002. Liaoning, Jilin, Heilongjiang and Shanghai in 2012. Henan, Guangxi, Guizhou, Tibet and Xinjiang will show continuous growth of population in the whole projection period. It seems that those regions which reach their population peaks earlier will have a lower rate of population growth in their growing period compared to other regions and have smaller population indexes in subsequent years. Figs. 3(a) and (b) present the regional population indexes of projection (A) in 2042 and 2087 respectively.

TABLE 8

Projections of regional population index for fertility rate assumption (A) in China

Region/Year	1987	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2087
Beijing	1	1.07	1.16	1.2	1.22	1.2	1.14	1.06	0.97	0.90	0.82	0.80
Tianjin	1	1.07	1.18	1.23	1.27	1.26	1.21	1.14	1.06	0.98	0.90	0.87
Hebei	1	1.08	1.23	1.34	1.44	1.50	1.50	1.49	1.45	1.40	1.34	1.32
Shanxi	1	1.08	1.23	1.33	1.42	1.47	1.48	1.46	1.43	1.38	1.32	1.30
Inner Mongolia	1	1.07	1.19	1.25	1.28	1.26	1.19	1.09	0.99	0.89	0.80	0.76
Liaoning	1	1.06	1.13	1.15	1.13	1.06	0.94	0.82	0.69	0.58	0.49	0.45
Jilin	1	1.07	1.16	1.20	1.2	1.15	1.05	0.93	0.82	0.71	0.61	0.57
Heilongjiang	1	1.05	1.13	1.14	1.12	1.05	0.93	0.81	0.69	0.58	0.49	0.46
Shanghai	1	1.05	1.08	1.09	1.07	1.01	0.92	0.83	0.75	0.67	0.61	0.58
Jiangsu	1	1.08	1.19	1.24	1.29	1.28	1.23	1.16	1.08	1.00	0.92	0.88
Zhejiang	1	1.04	1.09	1.08	1.05	0.97	0.85	0.72	0.60	0.49	0.40	0.37
Anhui	1	1.09	1.28	1.39	1.51	1.59	1.62	1.62	1.60	0.56	1.52	1.50
Fujian	1	1.09	1.26	1.39	1.51	1.58	1.61	1.60	1.55	0.49	1.42	1.40
Jiangxi	1	1.09	1.27	1.41	1.54	1.63	1.66	1.66	1.62	1.57	1.51	1.49
Shandong	1	1.08	1.22	1.30	1.38	1.40	1.37	1.32	1.25	1.17	1.08	1.05
Henan	1	1.11	1.33	1.49	1.69	1.86	1.98	2.09	2.17	2.23	2.28	2.31
Hubei	1	1.10	1.27	1.39	1.52	1.59	1.63	1.64	1.62	1.59	1.54	1.53
Hunan	1	1.09	1.25	1.35	1.45	1.50	1.51	1.49	1.44	1.38	1.32	1.29
Guangdong	1	1.10	1.29	1.46	1.62	1.75	1.84	1.90	1.93	1.93	1.92	1.92
Guangxi	1	1.09	1.29	1.46	1.62	1.77	1.87	1.93	1.97	1.97	1.97	1.98
Sichuan	1	1.06	1.17	1.20	1.21	1.18	1.09	0.99	0.87	0.76	0.67	0.63
Guizhou	1	1.10	1.34	1.55	1.74	1.93	2.07	2.18	2.26	2.32	2.36	2.39
Yunnan	1	1.09	1.27	1.42	1.55	1.65	1.70	1.70	1.68	1.64	1.60	1.58
Tibet	1	1.12	1.40	1.67	2.01	2.39	2.78	3.22	3.67	4.14	4.64	4.92
Shaanxi	1	1.10	1.27	1.39	1.53	1.60	1.66	1.69	1.69	1.68	1.65	1.65
Gansu	1	1.09	1.25	1.35	1.44	1.48	1.47	1.43	1.37	1.30	1.23	1.20
Qinghai	1	1.06	1.20	1.32	1.39	1.43	1.44	1.41	1.35	1.29	1.23	1.21
Ningxia	1	1.13	1.40	1.64	1.87	2.06	2.20	2.29	2.33	2.34	2.33	2.34
Xinjiang	1	1.12	1.37	1.59	1.81	2.02	2.17	2.31	2.41	2.49	2.55	2.59
China	1	1.08	1.23	1.33	1.42	1.47	1.48	1.46	1.41	1.37	1.32	1.30

Note: The population index is the population in year *t* divided by the population in 1987.

Fig. 4 presents the trends of regional population indexes for each region. According to Fig. 4, the ranks of regional population indexes change little during the projection period. By the year 2087, Zhejiang will have the smallest population index of 0.37 resulting from its low total fertility rate and high net out-migration in the early years of the projection period. Due to net in-migration, Beijing, Tianjin and Shanghai will have a greater population indexes of 0.8, 0.87 and 0.58 respectively in 2087 than Zhejiang though their total fertility rates are also low and population as a whole will decline. Here, the impact of migration on regional population growth is quite clear.

In summary, the following regions will have less population in 2087 than in 1987:

Beijing, Tianjin, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang and Sichuan. Among these regions, Beijing, Tianjin, Liaoning, Shanghai, Jiangsu, Zhejiang are in the more developed east economic zone of China. Sichuan is the most populous province in China. The remaining provincial regions will have more population in 2087 than in 1987. The second populous province - Shandong - will increase by some 8% over this period. Table 9 reports the projections of regional populations for fertility rate assumptions (A) for China.

TABLE 9

Projections of regional populations for fertility rate assumptions (A) for China (millions)

Region/Year	1987	2042	2087
Beijing	10.0	11.4	8.0
Tianjin	8.4	10.2	7.4
Hebei	57.8	86.9	76.2
Shanxi	27.3	40.3	35.5
Inner Mongolia	20.8	24.8	15.9
Liaoning	38.3	36.2	17.4
Jilin	23.8	24.9	13.6
Heilongjiang	34.2	31.9	15.6
Shanghai	12.7	11.6	7.4
Jiangsu	64.4	79.2	57.0
Zhejiang	41.8	35.7	15.5
Anhui	53.6	86.7	80.6
Fujian	28.3	45.6	39.7
Jiangxi	36.1	60.0	53.6
Shandong	80.0	109.9	83.9
Henan	80.4	158.8	185.3
Hubei	51.3	83.6	78.5
Hunan	58.6	88.5	75.8
Guangdong	65.3	120.5	125.3
Guangxi	40.7	76.0	80.6
Sichuan	106.1	116.0	67.0
Guizhou	30.9	64.1	74.0
Yunnan	35.6	60.4	56.3
Tibet	2.1	5.8	10.3
Shaanxi	31.3	51.9	51.5
Gansu	21.3	31.3	25.7
Qinghai	4.2	6.1	5.1
Ningxia	4.4	9.6	10.2
Xinjiang	14.2	31.0	36.9
China	1084.0	1599.1	1409.8

Note: The figures for 1987 are base year populations.

Using the fertility assumption (B), the trend of the national population is similar to that in projection (A). The total population of China will increase by 40% in the period 1987-2032 and then decline slowly. By the year 2087, the total population will be about 36% more than in 1987.

Projection (B) assumes a lower national total fertility rate than projection (A) in the period 1987-2027 but a higher national fertility rate at a replacement level than projection (A) in the period 2027-2087. Due to the effect of this assumption, some regions now reach their population peaks earlier in projection (B) than in projection (A). According to Table 10, Liaoning, Heilongjiang and Shanghai now reach their population peak by the year 2002 along with Zhejiang. More regions will show more continuous population growth, though slowly, until 2087 in addition to Henan, Guangxi, Guizhou, Tibet and Xinjiang in projection (A). These regions include Anhui, Hubei, Guangdong, Yunnan, Shaanxi and Ningxia. Figs. 3(c) and (d) present the regional population indexes of projection (B) in 2042 and 2087 respectively. In the year 2042, all regions will have less population in projection (B) than in projection (A). Generally, most regions will have more population by the year 2087 in projection (B) than in projection (A). However, Beijing, Liaoning, Heilongjiang, Shanghai and Zhejiang will have almost same population by the year 2087 in projection (B) as in projection (A).

TABLE 10

Projections of regional population index for fertility rate assumption (B) in China

Region/Year	1987	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2087
Beijing	1	1.07	1.15	1.18	1.19	1.16	1.09	1.00	0.92	0.86	0.81	0.80
Tianjin	1	1.07	1.16	1.21	1.23	1.21	1.15	1.08	1.01	0.94	0.89	0.88
Hebei	1	1.08	1.21	1.30	1.38	1.42	1.42	1.41	1.39	1.37	1.36	1.37
Shanxi	1	1.08	1.21	1.28	1.36	1.39	1.39	1.38	1.37	1.35	1.34	1.36
Inner Mongolia	1	1.06	1.17	1.22	1.23	1.20	1.13	1.04	0.95	0.86	0.80	0.79
Liaoning	1	1.05	1.12	1.12	1.09	1.02	0.90	0.77	0.66	0.56	0.48	0.45
Jilin	1	1.06	1.15	1.17	1.16	1.10	1.00	0.88	0.77	0.68	0.60	0.58
Heilongjiang	1	1.05	1.11	1.11	1.08	1.00	0.89	0.76	0.65	0.56	0.48	0.46
Shanghai	1	1.04	1.07	1.07	1.04	0.97	0.88	0.79	0.71	0.64	0.59	0.58
Jiangsu	1	1.08	1.18	1.21	1.24	1.22	1.17	1.10	1.03	0.96	0.91	0.90
Zhejiang	1	1.04	1.08	1.06	1.02	0.94	0.82	0.69	0.57	0.47	0.39	0.37
Anhui	1	1.09	1.26	1.34	1.44	1.50	1.53	1.54	1.54	1.54	1.55	1.57
Fujian	1	1.09	1.24	1.35	1.44	1.50	1.52	1.51	1.49	1.46	1.44	1.45
Jiangxi	1	1.08	1.25	1.37	1.47	1.54	1.57	1.57	1.55	1.54	1.54	1.55
Shandong	1	1.08	1.20	1.27	1.32	1.33	1.30	1.25	1.19	1.13	1.09	1.08
Henan	1	1.11	1.31	1.44	1.60	1.75	1.86	1.99	2.10	2.21	2.35	2.44
Hubei	1	1.10	1.25	1.34	1.45	1.50	1.54	1.55	1.56	1.56	1.57	1.60
Hunan	1	1.09	1.23	1.30	1.38	1.42	1.43	1.41	1.38	1.36	1.34	1.34
Guangdong	1	1.10	1.27	1.41	1.55	1.66	1.75	1.81	1.85	1.90	1.95	2.00
Guangxi	1	1.09	1.27	1.41	1.55	1.68	1.77	1.84	1.90	1.95	2.02	2.07
Sichuan	1	1.06	1.16	1.17	1.17	1.13	1.04	0.94	0.83	0.73	0.66	0.64
Guizhou	1	1.09	1.31	1.49	1.65	1.82	1.96	2.07	2.19	2.30	2.44	2.54
Yunnan	1	1.08	1.25	1.37	1.48	1.56	1.61	1.62	1.62	1.62	1.63	1.66
Tibet	1	1.12	1.37	1.59	1.88	2.23	2.61	3.08	3.61	4.22	4.98	5.44
Shaanxi	1	1.10	1.25	1.34	1.45	1.51	1.56	1.59	1.62	1.66	1.69	1.74
Gansu	1	1.09	1.23	1.31	1.37	1.40	1.39	1.35	1.31	1.28	1.25	1.26
Qinghai	1	1.06	1.18	1.28	1.32	1.36	1.37	1.35	1.31	1.28	1.26	1.27
Ningxia	1	1.12	1.38	1.59	1.78	1.95	2.08	2.17	2.24	2.31	2.38	2.44
Xinjiang	1	1.11	1.35	1.53	1.71	1.90	2.05	2.20	2.34	2.48	2.65	2.77
China	1	1.08	1.22	1.29	1.36	1.40	1.40	1.38	1.36	1.34	1.34	1.36

Projection (C) assumes lower national total fertility rates than projections (A) and (B) in the period 1987-2087. According to Table 11, the total population of China will increase by 35% in the period 1987-2022, and then decline slowly until 2087. By the year 2087, the total population of China will be only 90% of that in 1987. Due to the assumption of lower total fertility rates, most regions will reach population peaks much earlier in projection (C) than in either of the other projections. All regions except Tibet will show a trend of population decline before 2087. For example, Liaoning, Heilongjiang, Shanghai and Zhejiang will reach their population peaks by the year 2002. Figs. 3(e) and (f) present the regional population indexes of projection (C) in 2042 and 2087 respectively. In the years 2042 and 2087, all regions will have less population in projection (C) than in projections (A) and (B). Liaoning, Jilin, Heilongjiang, Shanghai, Zhejiang and Sichuan will have less than 50% population in 2087 than in 1987. Another eleven regions including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Jiangsu, Fujian, Shandong, Hunan, Gansu and Qinghai will also have less population in 2087 than in 1987. However, only five regions including Henan, Guizhou, Tibet, Ningxia and Xinjiang will have 50% more population in 2087 than in 1987.

CONCLUSION

An attempt has been made here to make consistent multiregional population projections of China at a provincial level. A forward demographic rates-based multiregional population model is developed on the basis of a set of multiregional population accounts. In the model, forward emigration rates and immigration flows are adopted to describe the external migrations between the spatial population system concerned and the rest of the world. The model is calibrated using the 1982 census data and 1987 one-percent population survey data. Other data sources have also been used to estimate and prepare necessary input data for the multiregional population model.

Three sets of multiregional population projections of China at provincial level have been made. The national population trend is a combination of various regional population trends. Some regions, such as Zhejiang, will reach their population peak as early as the beginning of the next century while other regions, such as Xinjiang, will face continuous population growth before the 2050s.

According to projections (A), (B) and (C) using different fertility rate assumptions. many provincial regions of China will experience a decline of population in the future. It is of concern that there may be severe problems of labour shortage and population ageing in China as a whole and in particular regions in the future. This research methodology of course also permits calculations of the elderly and labour force fractions of the population over the projection period and under the variety of fertility assumptions. It is clear that the wide ranging regional variations in demographic trends projected by the model may have important implications for these and other aspects of the population distribution of the future China. Such findings and implications will be the focus of future research.

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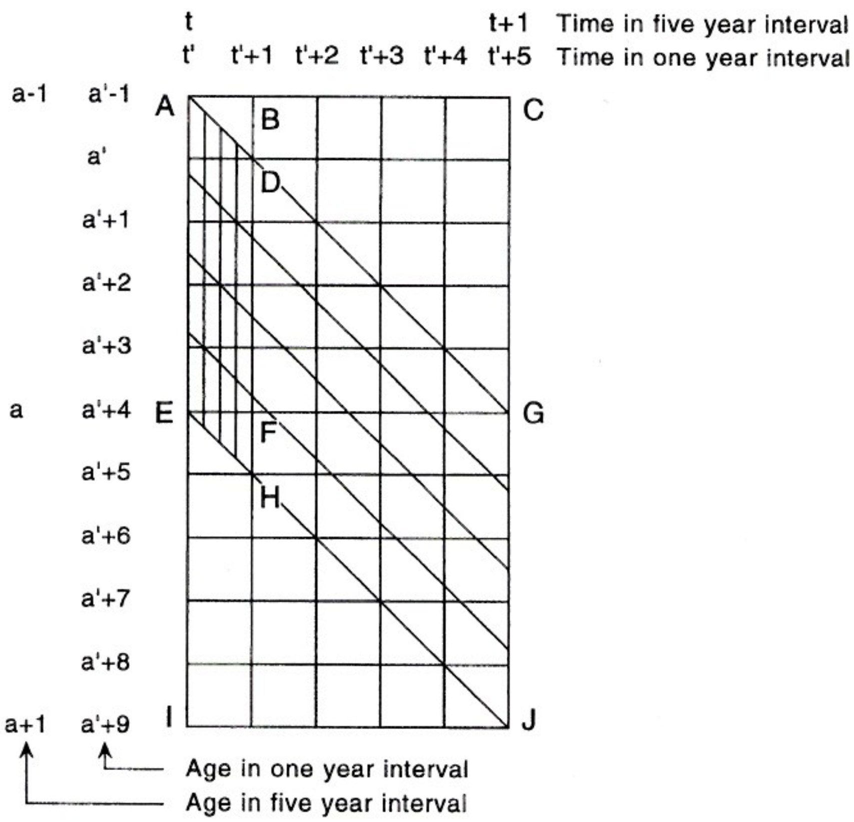
FIGURE 1. Provincial regions in China.



Area ADEH: period-cohort fertility rate of five year age and one year time intervals
Area AGEJ: period-cohort fertility rate of five year age and time intervals
Area ABEF: period fertility rate of five year age and one year time intervals
Area ACEG: period fertility rate of five year age and time intervals

FIGURE 2. Lexis diagram showing the meaning of various fertility rates.

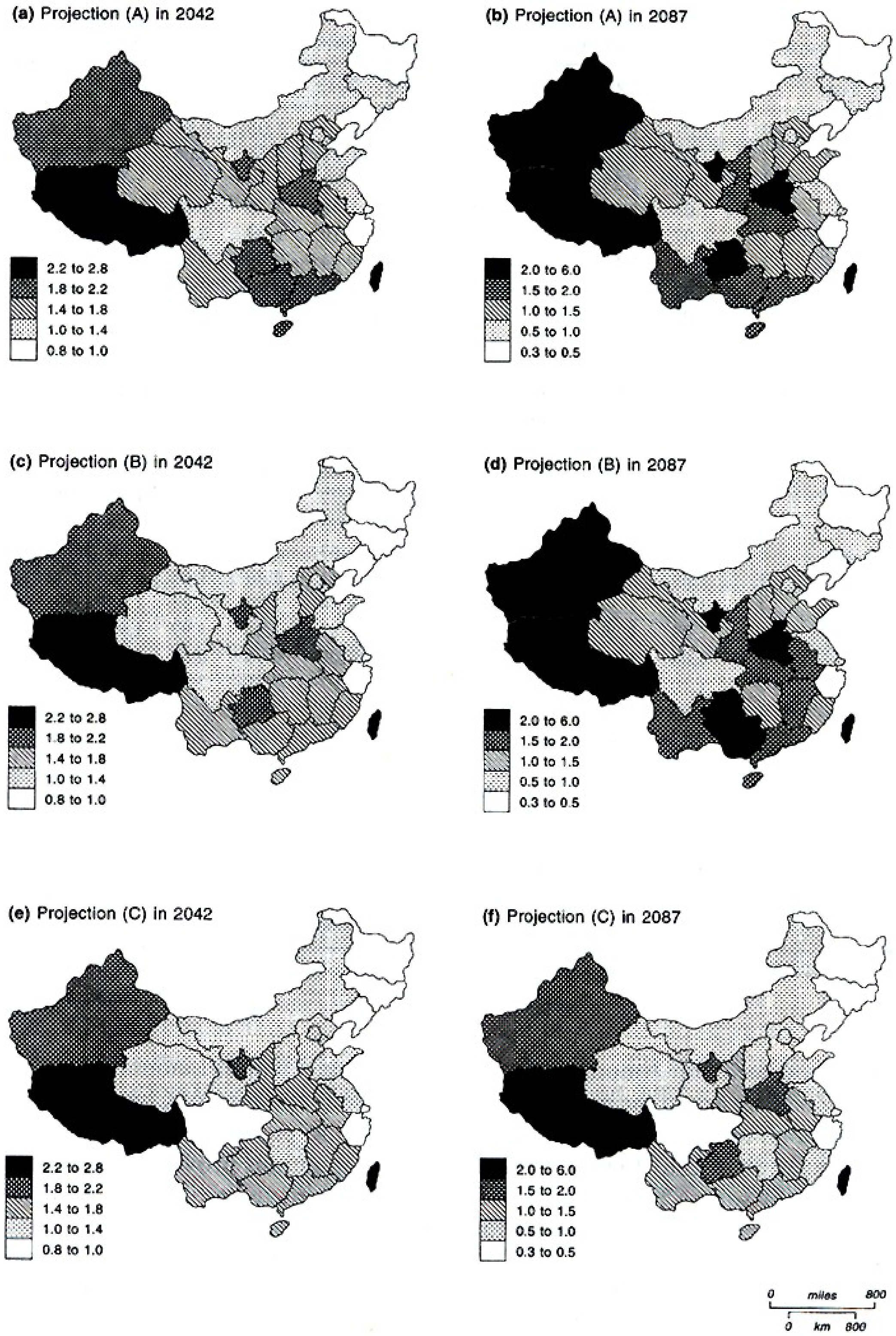


FIGURE 3. Projections of regional population index for fertility assumptions A, B and C in China.

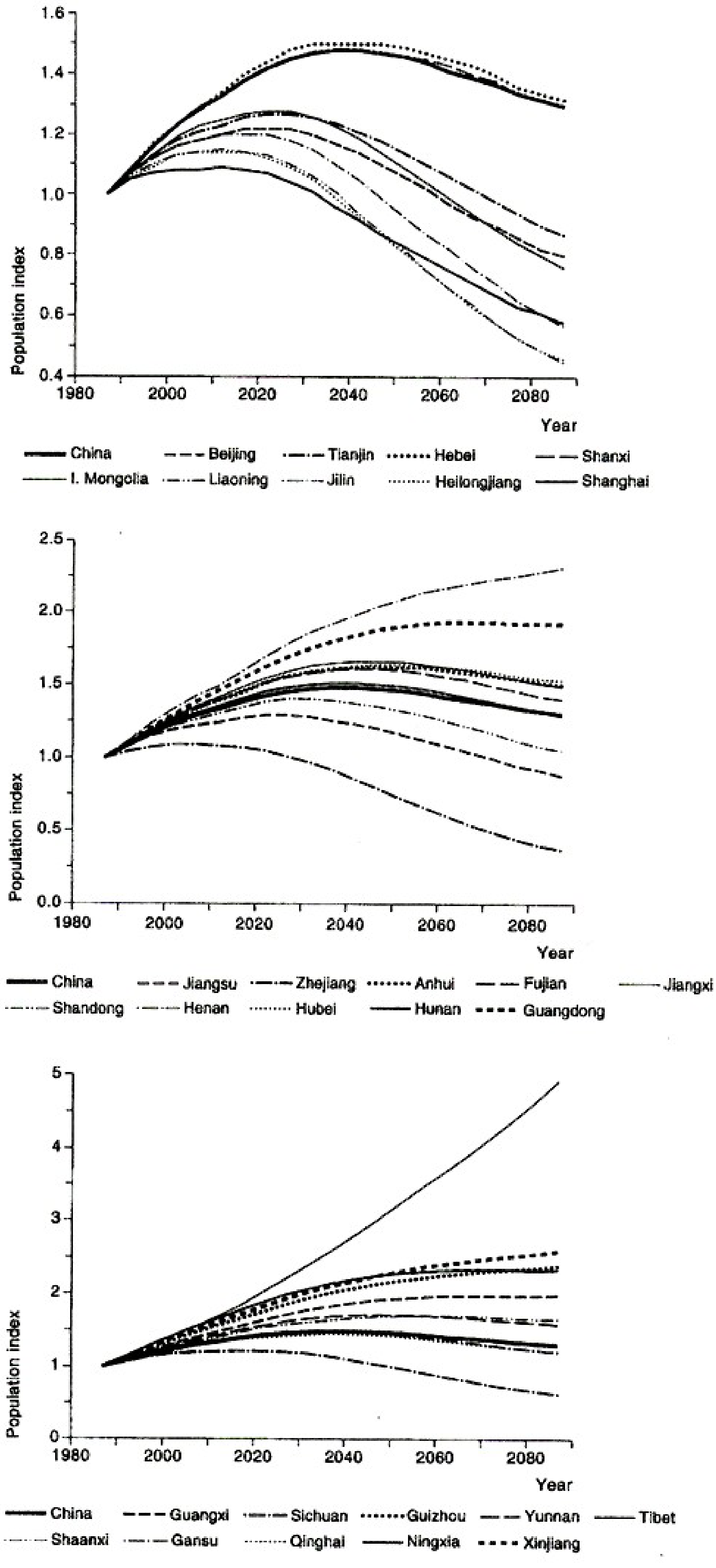


FIGURE 4. Regional population index of projection (A) in China.