Age Structure

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Abstract

Trends in the age structure of a population should be considered in policy development and planning by governments and private businesses, because demands for goods and services, labor force participation rates, health conditions, and people's behavioral patterns vary substantially with age. Age structure is primarily determined by fertility, mortality, and migration during the last several decades. Most developed and developing countries in the world have experienced notable changes in the age structure due to significant declines in fertility and mortality. Various statistical and mathematical tools have been developed for measuring and analyzing age structure trends and their effects.

The age structure (or age composition) of a population is the pattern of its distribution by age. The age distribution is often shown separately by sex and displayed as the *population pyramid*, in which the sizes of age–sex groups are indicated by horizontal bars arranged from the youngest age-group at the bottom to the oldest age-group at the top. Several examples of population pyramid are in **Figure 1**. The graphs are called population *pyramids* because the graphs often exhibit triangular shapes, partly due to the tendency for the number of survivors to decrease with age and partly due to the increasing size of birth cohort in growing populations. The age structure is *young* if the proportion of younger people is high and that of older people is low (e.g., India, 1980, in **Figure 1(c)**). The age structure is considered *old* if the opposite is true (e.g., Sweden, 2011, in **Figure 1(b)**).

It is crucial to consider current and prospective changes in the age structure when planning government policies and forecasting consumer demand and labor supply for private industries (*see* Age Policy; Population Aging: Economic and Social Consequences). Demands for different types of goods and services vary significantly with age. A large youth population implies high demand for school facilities and teachers. A greater elderly population may mean more needs for nursing homes, medical services, and hospital facilities and a higher amount of pension payments. A society with a rapidly increasing number of people in 20s and early 30s may need to create more employment opportunities and provide new housing.

Furthermore, labor force participation is null or low at both the ends of age spectrum and high in between. If the proportion of the working-age population (between the age when people typically start their first full-time job and the typical retirement age) is decreasing, people in the labor force may have a growing burden of economically supporting those outside it.

Underlying these societal consequences of age structure are age variations in health conditions, behavioral patterns, and socioeconomic characteristics of people (*see* Motivation: Life Course and Sociological Perspectives; Life Course: Sociological Aspects). This is partly because humans experience substantial age-associated physiological changes in their lives (physical development at young ages, sexual maturation, and senescent processes at middle and old ages), and partly because age-related social roles have been built on these biological life history patterns.

Population Dynamics and Age Structure

The age structure is determined primarily by the levels, age patterns, and trends of fertility, mortality, and migration during the past few decades (Coale, 1972). A population with higher fertility tends to have a larger proportion of children, and a population with lower mortality has a higher proportion of people who survive to old ages. In a growing population, the sizes of more recent birth cohorts tend to be larger, producing a young age structure, but a decreasing population tends to have an old age structure.

The migration rate tends to be high among young adults. Thus, usually migration reduces the proportion of young adults in countries that send out migrants, and increases the proportion in countries that receive them. The long-term effects of migration on the age structure are complicated if fertility and mortality patterns of the migrants are considerably different from those of the native population, or if there are significant flows of return migration.

During the last one and a half centuries, the age structure has become older in the majority of countries in the world. Significant population aging started during the first half of the twentieth century in most economically and technologically developed countries, and it started during the second half in many developing countries. Figures 1(a) and 1(b) illustrate the historical age structure changes in Sweden, indicating that the age composition of Sweden is noticeably older in 2011 than in 1900. Figures 1(c) and 1(d) show data from India as an example of a developing country. The relative narrowing of the pyramid base from 1980 to 2011 reflects recent fertility declines in India. The difference in the timing of population aging between developed and developing countries is illustrated in **Figure 2** for Sweden and India.

The population aging was due to considerable declines in mortality and fertility. This international demographic trend is called the *demographic transition*, which accompanied the industrialization of economy and related social changes. The age structure of developed countries, where the demographic

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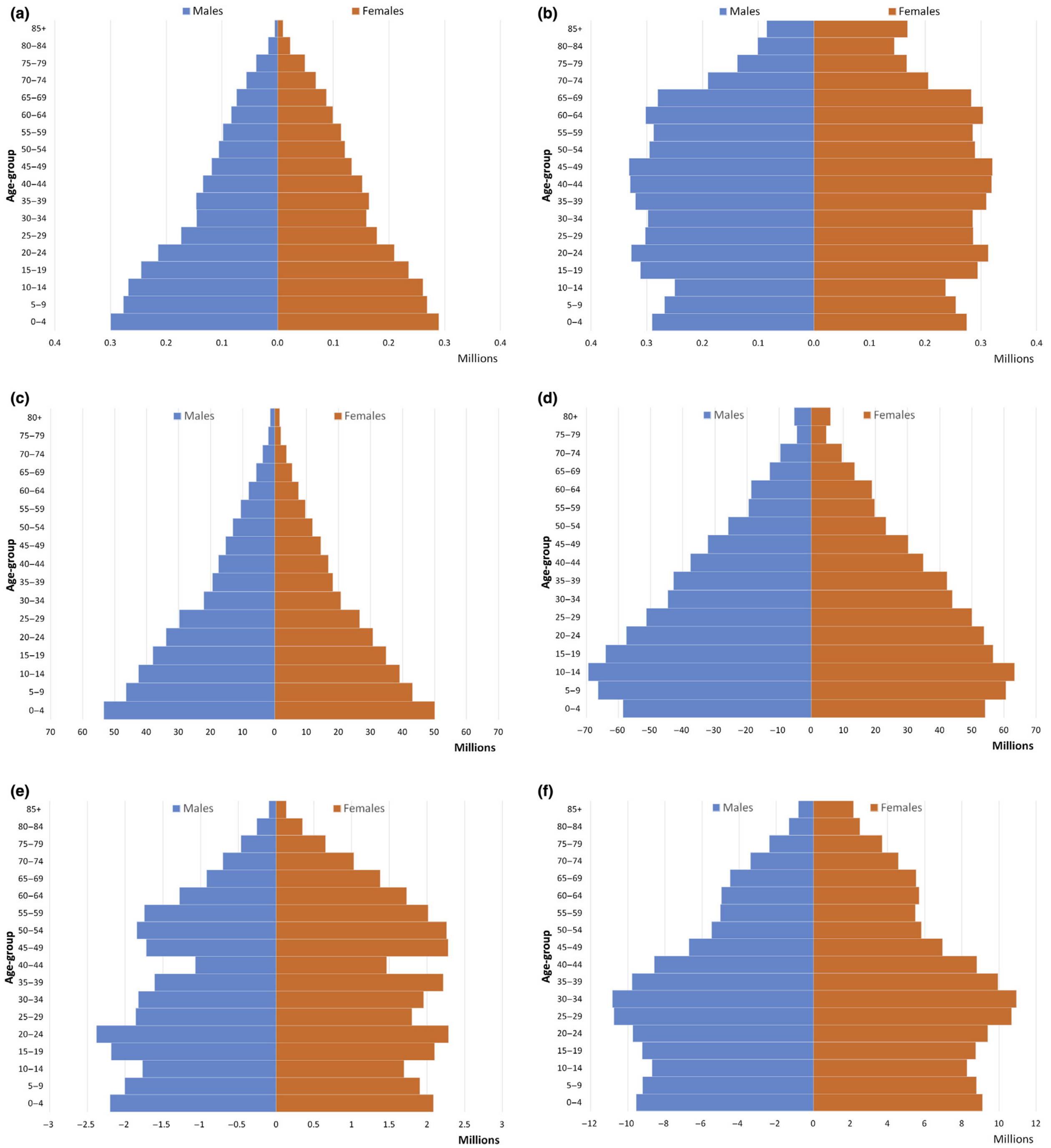

Figure 1 Selected population pyramids: (a) Sweden, 1900; (b) Sweden, 2011; (c) India, 1980; (d) India, 2011; (e) West Germany, 1960; (f) The United States, 1990.
Sources: Sweden, 1900 and 2011; West Germany, 1960; USA., 1990. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at http://www.mortality.org (data downloaded on 02.04.14.); India, 1980: United Nations (2012). World Population Prospects: The 2012 Revision; India, 2011: Office of the Registrar General and Census Commissioner. Census of India 2011. Available at http://censusindia.gov.in.

transition started earlier, is significantly older than that of developing countries. (For example, compare the population pyramids of Sweden, 2011, in **Figure 1(b)**, and India, 2011, in **Figure 1(d)**.)

Until recently, the major driving force of age structure changes in the demographic transition was fertility declines (Coale, 1972) (*see* Fertility Theory). Although the significant mortality decline started before the significant fertility decline in the majority of countries, the age structure of some populations became younger in early phases of mortality decline, as the pronounced reduction of infant and child mortality increased the number of young children. The decline in the

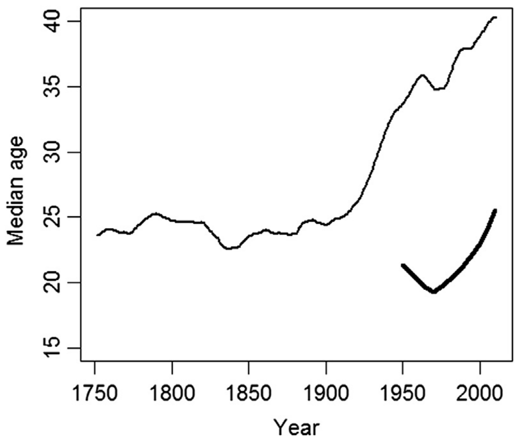

Figure 2 Trends in the median age of population for India, 1950–2010 (thick line) and Sweden, 1751–2011 (thin line).
Source: India: United Nations (2012). World Population Prospects: The 2012 Revision; Sweden: *Human Mortality Database*. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at http://www.mortality.org (data downloaded on 02.04.14.)

Table 1 Estimated summary indicators[a] of age structure for selected countries[b], 2010

	Median age	*C(0–19)*	*C(65+)*	*Age-dependency ratio*
Kenya	18.5	53.1	2.6	125.7
India	25.5	39.9	5.1	81.8
Brazil	29.0	33.9	6.9	68.9
Sweden	40.7	23.4	18.2	71.2
Japan	44.9	18.0	23.0	69.5

[a]C(0–19) is the proportion (in %) of population aged under 20 and C(65+) is the proportion of population aged 20 and over.
[b]Countries are listed in the ascending order of median age.
Source: United Nations (2012). World Population Prospects: The 2012 Revision.

median age of India's population in the 1950s and 1960s, seen in Figure 2, may be due to the decrease in youth mortality. However, during the last few decades, reductions of old-age mortality in many developed countries had strong impacts on population aging (Horiuchi, 1991; Preston et al., 1989; Preston and Stokes, 2012; Vaupel and Jeune, 1995).

The age structure may also show significant fluctuations in cohort size, reflecting temporary changes in fertility, mortality, or migration. Events such as famine, drought, epidemic, and war often reduce fertility and disproportionately increase death rates for infants and young children, producing relatively small cohorts who were born during or immediately before the catastrophic period. Wars may also cause considerable attrition of cohorts deeply involved in combat. Figure 1(e) shows the population pyramid for West Germany, 1960, in which the proportions aged 40–44 and 10–14, born during the World Wars I and II, are substantially small. Also the male cohorts aged 35–54 were noticeably smaller than their female counterparts, reflecting gender differences in mortality of young adults during World War II.

Temporary rises in fertility (baby booms) also produce significant cohort size variations. In Figure 1(f), the relatively high proportion of population aged 25–44 in the United States, 1990, is due to the baby boom after World War II. Such cohort size variations may be echoed among later cohorts. For example, Figure 1(f) shows that under 15 years of age, the size of younger cohort is larger, probably because cohort size variations among the baby boom cohorts were repeated by those among their children, though with some diminution.

Measurement of Age Structure

Age structure can be considered as a pattern of C_is, where C_i is the proportion of the population that falls in age-group $i (i = 1, 2, \ldots, n$ and $\sum_{i=1}^{n} C_i = 1)$. With age as a continuous variable x, age distribution can also be represented as the density function $c(x)$ for the proportional distribution of population by age. Then the proportion of population that falls in the age interval between a and b is expressed as $\int_a^b c(x)\mathrm{d}x$, and $\int_0^\infty c(x)\mathrm{d}x = 1$.

Common summary measures of age structure include the mean age of population, median age of population, proportion of population at young ages (e.g., under age 20), and proportion of population at old ages (e.g., age 65 and above). The age-dependency ratio is the ratio of the population outside the working-age range to the population in the age range. The working-age range is defined as ages between x_1 and x_2 (usually including x_1 but excluding x_2), where x_1 is a typical age at the start of the first full-time employment and x_2 is the typical age of retirement. Since multiples of 5 are preferred, 15 and 20 are widely used for x_1 and 60 or 65 for x_2. The ratio is usually multiplied by 100. It is used as a measure of effects of the age structure on the extent to which people in labor force have to economically support those outside labor force. Also used are the child-dependency ratio, which is the ratio of the population under x_1 to the population between x_1 and x_2, and the old-age dependency ratio, which is the ratio of the population aged x_2 and above to the population between x_1 and x_2 (for a more detailed explanation of measures of age structure, see Hobbs, 2004).

Table 1 shows the median age of a population, proportion under age 20, proportion aged 65 and over, and age-dependency ratio (using 20–64 as the working age) for five selected countries that have different age structures. Kenya has the youngest age distribution among the three developing countries, followed by India and Brazil. The differential age structures of the three countries reflect different timings of their demographic transitions. As for the two developed countries, Sweden started its demographic transition much earlier than Japan, but now the age structure of Japan is older than that of Sweden, because of the steep declines in fertility and mortality in Japan during the last few decades. The age-dependency ratios of Brazil, Sweden, and Japan are fairly close, indicating that populations with different age structures could have similar age-dependency ratios, if the sum of the proportion under the working-age range and proportion above it happen to be close among those countries. Overall, Table 1 suggests that currently there are very large variations in age structure among countries in the world.

The direction and pattern of age structure changes in a population are indicated by the profile of age-specific

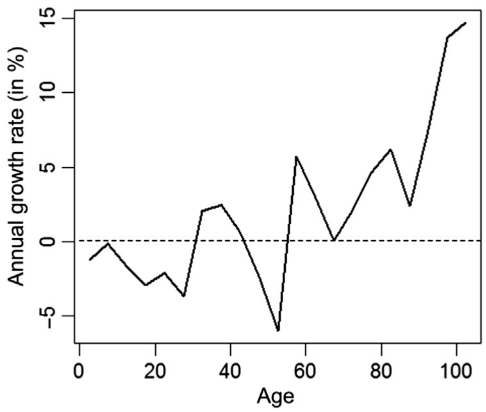

Figure 3 Annual rate of population growth by age for Japan, 2010. Population size estimates by 5-year age-groups were used, and geometric rates of change in percent were computed. The dashed line indicates the growth rate of total population. Source: Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at http://www.mortality.org (data downloaded on 02.04.14.).

growth rates for the population (Horiuchi and Preston, 1988). For example, Figure 3 shows that although the total population size of Japan remained nearly constant during 2010, the population under age 30 decreased and the population aged 55 and over increased. In particular, the population aged 95 and over grew by about 15% in the year. The proportions of age-groups with higher growth rates than that of the total population increase, and those of age-groups with lower growth rates decrease. Thus, the large age variations of population growth in Figure 3 suggest that the age structure of the population of Japan was changing fairly rapidly in 2010.

It should be noted that some demographic data on age must be used with caution because self-reported ages in populations with low literacy rates may not be accurate (Hobbs, 2004). Particular attention should be given to ages of old persons and old decedents in historical demographic data collected in those days and data from current developing countries, partly because older cohorts tend to have higher illiteracy rates in many countries, and partly because age inaccuracy tends to produce larger biases in statistics on older adults (Preston et al., 1996).

Age-Standardization

The incidence of various events (such as marriage, childbearing, and death) is strongly associated with age. The crude rate of such an event, usually computed as the ratio of the number of the events in a year to the total midyear population, could be significantly affected by the age structure of the population. Thus, for comparing the rate among populations, it should be adjusted for age structure differences.

For example, the crude death rate (CDR) is the ratio of the number of deaths in a year to the total midyear population, usually multiplied by 1000. CDR is strongly affected by age structure, because it is the sum of age-specific death rates weighted by the proportion of the population in that age-group:

$$\mathrm{CDR} = \frac{D}{N} = \sum_{i=1}^{n} \frac{D_i}{N_i} \cdot \frac{N_i}{N} = \sum_{i=1}^{n} M_i C_i \qquad [1]$$

where D is the total number of deaths in the year, N is the midyear total population, n is the number of age-groups, D_i is the number of deaths in age-group i, N_i is the population of age-group i, M_i is the death rate of age-group i, and C_i is the proportion of total population that belongs to age-group i. Thus, the CDR tends to be high not only in populations with high age-specific death rates but also in populations in which a large proportion of the population belongs to age-groups that have relatively high death rates (e.g., old age-groups).

A widely used method to adjust per capita rates for age structure is age-standardization. The age-standardized death rate (ASDR) for a population is obtained by selecting an actual or hypothetical population as the 'standard' and assuming that the study population has the age structure of the standard population: the ASDR for population j is computed by

$$\mathrm{ASDR}^j = \sum_{i=1}^{n} M_i^j \cdot C_i^s \qquad [2]$$

where M_i^j is the death rate of age-group i in population j and C_i^s is the proportion of total population that belongs to age-group i in the standard population. If the ASDR is calculated for a number of populations using the same standard population, their differences in the ASDR are due to their differences in age-specific death rates only, and completely independent of their differences in age structure. The selection of a different standard does not change ASDR differences significantly unless the age pattern of mortality differs considerably among the study populations. This method is applicable to incidence rates of other age-associated events such as childbearing and migration, as well as proportions of the population with age-related characteristics such as marital status, labor force participation, and morbidity due to a particular disease. (For a more thorough explanation of age-standardization, see Section 2.2 of Preston et al., 2001).

Mathematical Expressions of Age Structure

Relationships between the age structure and demographic rates can be mathematically formulated (Bennett and Horiuchi, 1981; Preston and Coale, 1982) (*see* Population Dynamics: Theory of Nonstable Populations). The density function for population age distribution can be expressed as

$$c(a) = b e^{-\int_0^a r(x)\mathrm{d}x} p(a) e^{\int_0^a \lambda(x)\mathrm{d}x} \qquad [3]$$

where b is the crude birth rate, $r(x)$ is the population growth rate at age x, $p(a)$ is the proportion surviving from birth to age a in the period life table, and $\lambda(x)$ is the rate of net migration (immigration minus emigration) at age x. Note that this is a relation between the age structure and demographic rates observed in the same period.

It may seem puzzling that the current age structure, which primarily resulted from population dynamics in the *recent past*, can be solely determined by *current* demographic rates. This paradoxical relationship can be understood by recognizing the role of age-specific growth rates in the equation. Age-specific growth rates reflect effects of past demographic changes on the current age structure (Horiuchi and Preston, 1988): the growth rate of population at age a and time t, $r(a, t)$, can be decomposed into the growth rate of the number of births, and cumulated changes in age-specific death rates and age-specific rates of net migration that the cohort aged a at time t has previously experienced:

$$r(a,t) = r_B(t-a) - \int_0^a \frac{\partial \mu(x,u)}{\partial u} dx + \int_0^a \frac{\partial \lambda(x,u)}{\partial u} dx \quad [4]$$

where $r_B(t)$ is the growth rate of the number of births at time t, $\mu(a, t)$ and $\lambda(a, t)$ are the instantaneous age-specific death rate and instantaneous rate of net migration, respectively, at age a and time t, and the derivatives are assessed at $u = t - a + x$.

Equation [3] is a generalization of the age structure equation in stable populations (Doublin and Lotka, 1925; Lotka, 1998; originally 1939) (*see* Population Dynamics: Theory of Stable Populations, Population Dynamics: Classical Applications of Stable Population Theory). Consider a population in which the growth rate and age structure have been changing up to a certain point of time t. It can be shown that if the population is closed to migration and its age-specific birth rates and age-specific death rates remain unchanged after time t, the population will eventually become a stable population, in which the population growth rate and age structure remain constant over time. Simulations suggest that if the initial age structure of a human population is far from stable, it takes about a century or a little more for the population to become close to stability, but a few centuries to become almost exactly stable.

In a stable population, the density of age distribution at age a is given by

$$c(a) = be^{-ra}p(a) \quad [5]$$

where b is the CDR, r is the growth rate of total population, and $p(a)$ is the proportion surviving from birth to age a, which is determined by age-specific death rates between ages 0 and a. In a stable population, these demographic measures are constant over time.

Equation [3] is used for demographic estimation from incomplete data (e.g., Bennett and Horiuchi, 1981; Preston and Bennett, 1983), eqn [4] is used for analyzing past changes in population growth and age structure (Horiuchi, 1991, 1995), and eqn [5] is used for demographic estimation from data on age distributions of historical populations before the demographic transition and populations in developing countries that are in early stages of demographic transition (United Nations, 1983: Chapter 7).

Age Structure and Population Growth

The age structure has strong effects on the increase or decrease of total population size in the immediate and near future. Even if several populations have the same size and same age schedules of fertility and mortality, a population with a higher proportion of population at peak childbearing ages (usually late 20s) is likely to have a greater number of births in the next several years, and a population with a higher proportion of children tends to have a greater number of births a few decades later when those children reach peak childbearing ages.

An indicator of the extent to which the age structure is conducive to population growth is the ratio of the size of stable equivalent (Keyfitz, 1969), denoted by Q, to the actual population size, N. The stable equivalent is a hypothetical quantity computed assuming that the age schedules of fertility and mortality at t_1 remain unchanged in the future and the population is closed to migration after t_1. Then the population would converge to stability at some time in the future, denoted here by t_2. The stable equivalent at t_1 is given by

$$Q(t_1) = N(t_2) \cdot e^{-r(t_2 - t_1)} \quad [6]$$

where $N(t_2)$ is the size of the population at t_2. If the ratio of stable equivalent to actual population size at t_1, $Q(t_1)/N(t_1)$, is greater than 1, the population size would increase between t_1 and t_2 at the rates that are higher than the stable population growth rate r, due to the positive effects of age structure on population growth.

Another indicator is the population momentum, which is based on the hypothetical scenario that the fertility at t_1 instantly changes to the replacement level and then the age schedules of fertility and mortality remain unchanged, and there is no in- or out-migration (*see* Population Dynamics: Momentum of Population Growth). The population would eventually become a stationary population, which is a stable population the size of which remains constant ($r = 0$) over time. The population momentum is usually measured as the ratio of the size of the stationary population to the size of population immediately before the start of the replacement-level fertility (Keyfitz, 1971). The ratio may substantially deviate from 1, which indicates that even with the replacement-level fertility, the population may continue to significantly increase or decrease for some length of time, because the population increase or decrease in the near future has already been built in the age structure.

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See also: Age Policy; Age Stratification; Age, Sociology of; Fertility Theory; Life Course: Sociological Aspects; Period and Cohort Analysis in Demography; Population Aging: Economic and Social Consequences; Population Dynamics: Momentum of Population Growth; Population Dynamics: Theory of Nonstable Populations; Second Demographic Transition.

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