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Demography of Aging

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Introduction

From 2010-2015, the annual growth rate of older adults was 3.3 percent globally (United- Nations 2017). As the proportion of the world's population continues to age, the increasing number of older adults in the population presents significant challenges for policy makers in nearly all sectors of society. According to the United Nations *Population Ageing Report 2017*, the global population of adults 60 years and older increased more than two-fold from 382 million in 1980 to 962 million in 2017, and the number is expected to reach nearly 2.1 billion by 2050 (United Nations 2018). While population aging affects nearly every country in the world, the pace of aging has been faster is less developed countries than in developed countries (He, Goodkind, & Kowal 2016).

Demographic changes in fertility, mortality, and to a lesser extent migration, have had profound effects on the age-structure of many societies worldwide. These population trends in global aging require improved data and analyses to assist societies with social and economic shifts in social welfare and health care services, labor markets

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and retirement, technology, housing, transportation, and intergenerational relationships. With an increasingly larger share in the population of aging adults in virtually every country throughout the world, it is imperative that governments design innovative policies specifically aimed at public services to benefit aging individuals and societies.

In our chapter we present an overview of important issues related to global trends in population aging. We organized this review according to five key areas: (1) demographic determinants of global aging; (2) measures and methods; (3) trajectories of population aging; (4) theoretical considerations; and (5) future research directions. We turn now to the first of these topics.

Demographic Determinants of Population Aging

Demographic changes in fertility, mortality, and migration have profound effects on the age-structure of societies. Indeed, the age distribution of a population is determined by the size and history of its birth cohorts, age-specific mortality, and migration rates. Each of these demographic processes contributes significantly to population aging. Research has shown that declines in fertility have been the primary engine behind the growth of older populations in many regions of the world (He et al. 2016). However, global aging can also be attributed to the low levels of mortality which have fueled population aging in many countries, and to a lesser extent, to the age patterns of immigration and emigration. The two main approaches developed by demographers for understanding how population aging occurs are the following: the stable population model, and population projections.

The Stable Population Model

The stable population model is a central tenet of modern demography that is used to examine the structure and growth of population aging. This model has been described in detail elsewhere (Coale, Demeny, & Vaughan 2013; Inaba 2017; Preston, Heuveline, & Guillot 2000; Yusuf, Martins, Swanson, Martins, & Swanson 2014). See also Poston's discussion of the stable population model in Chapter 1 of this *Handbook of Population*.

We begin by introducing important characteristics of this model and then turn to its use in population analysis. First, the stable population model assumes that the age distribution of a closed population remains constant over time. This is determined by:

- a constant number of births every year
- constant age-specific mortality rates, and
- closed migration, i.e., no immigration or emigration

If age-specific fertility and age-specific mortality rates remain constant for a long period of time, and if no migration occurs, then the population becomes stationary with an unchanging age distribution, neither growing nor declining in size. Under these unique conditions, the proportion of the population does not change from one year to the next and has a growth rate of zero. The effects of a change on the age distribution of a population based on birth and death rates are relatively straightforward using the stable population model. As the age distribution in a stable population is mathematically determined by age-specific fertility and age-specific mortality rates, it is possible to estimate the effect of changes in age-specific fertility and/or age-specific mortality rates on the age structures of a stable population.

For instance, under the conditions of no migration, it can be shown that populations with unvarying fertility and mortality patterns will increase, or decrease, in total size at a constant rate, and then acquire an age distribution that does not change over time. However, variation in the age structure of stable populations may arise from differences between the fertility and mortality rates. For example, decreases in fertility rates, without subsequent changes in mortality rates, will inevitably lead to an aging of the population. That is, if the number of annual births in a population is less than the number of annual deaths, then the population will become older. In contrast, an increase in the number of births with a constant mortality schedule in the same population leads to a larger proportion of children, and hence to a younger population.

Comparing the hypothetical consequences of differing fertility levels on stable populations with similar life expectancies highlights the magnitude of fertility change. For example, in a stable population with a life expectancy of 80 years, 7.5 percent of the population will be age 65 and older if the gross reproduction rate (GRR) is 2.0. Conversely the proportion of older adults will increase to 25.9 percent if the GRR decreases to 0.8.

Table 1. Proportion Age 65 and Older in Stable Populations with Various Combinations of Fertility and Mortality.

	Gross reproduction rate					
Life Expectancy	*0.80*	*1.00*	*1.50*	*2.00*	*3.00*	*4.00*
20	.165	.134	.085	.058	.032	.020
30	.178	.142	.087	.055	.031	.019
40	.189	.149	.090	.059	.030	.018
50	.198	.154	.091	.060	.030	.017
60	.201	.156	.092	.059	.029	.017
70	.212	.165	.096	.061	.030	.017
80	.259	.202	.119	.075	.036	.021

Source: Coale, Demeny, and Vaughan 2013

Using data from Table 1, similar comparisons in the age structure of stable populations under differing fertility/mortality combinations can be made. The effects of increasing fertility levels can be seen by looking across the rows in this table. Regardless of mortality, represented here as years of life expectancy, the result of the higher birth rates is evident in the proportional change of the younger population.

However, analyzing the effect of mortality on population aging in a stable population is less clear because the results of variations in mortality patterns depend on the specific ages in which mortality changes occur. For example, an increase in life expectancy in a cohort will not necessarily lead to the aging of a population, and in fact may, counter-intuitively, lead to a younger population. Indeed, the data in Table 1 indicate that increases in life expectancy from 40 to 60 years under a GRR of 3.0 results in a decrease of the proportion of the population age 65 and older. Conversely, an increase in life expectancy from 60 to 80 years under a GRR of 0.8 results in a significant increase in the older population, from 20.1 percent to 25.9 percent.

Direct and indirect effects of variation in mortality levels on population age structure can be viewed under differing scenarios of increasing life expectancy. In the first scenario, increases in life expectancy due solely to low levels of infant mortality result in a younger population. Thus, high survival rates among infants has the same long-term effects on population age structure as high fertility. In contrast, an increase in life expectancy resulting exclusively from lower mortality rates among older adults, i.e., those of the age of 50 and older, would result in increases of the proportion of older adults and ultimately lead to an aging population.

A final scenario worth mentioning is one in which decreases in mortality have no effects at all on the age structure of a population. This is possible, if a stable population experiences equal decreases in mortality rates across all age distributions. Thus, depending on the specific ages in which the mortality changes occur, increases in life expectancy can result in a population becoming younger, in an aging population, or in no change in age composition of a population.

Population Projections

Population projections are estimates of the growth and composition of a population at a future date under a particular set of assumptions. The standard approach to population projections uses a cohort-component method that accounts for the age and sex structure of a population and its demographic processes, i.e., its fertility rate, mortality rate, and rate of net migration, through which populations change over time. The accuracy of population projections depends on how close the actual trends are with respect to the assumptions about future births, deaths, and net migration.

Below we discuss the use of population projections as demographic forecasts to assess determinants of population aging. Specifically, we examine the effects of alternative assumptions of fertility, life expectancy, and net immigration levels on the future age structure of the population of United States. We employ a series of population projections based on three different component assumptions provided by the U.S. Census (Day 1996) to illustrate how population forecasts can further our understanding of the determinants of population aging. For more information, see the discussion of population projections by Morrison, Smith and Bryan in Chapter 31 of this *Handbook of Population*.

The baseline projections presented for this exercise begin in 1995, when approximately 12.8 percent of the U.S. population was aged 65 and older, the total fertility rate (TFR) was 2.06, life expectancy was 75.9 years, and yearly net immigration was 820,000. Applying different assumptions regarding the above components of population change, the U.S. Census Bureau estimated the size and age structure of the population for 2050. Table 2 presents the various assumptions

Table 2. Fertility, Life Expectancy, and Net Migration Assumptions for 1995-2050.

		2050 Level of Assumption		
Item	*1995*	*Low*	*Middle*	*High*
Fertility	2.055	1,910	2,245	2,580
Life Expectancy	75.9	74.8	82.0	89.4
Yearly Net Migration (thousands)	820	300	820	1,370

Source: Day 1996.

Table 3. Alternative Assumptions for Percent of U.S. Population Projected to be Age 65 and Older in 2050

Assumptions[a]	*% 65+*
Middle Series for Fertility, Life Expectancy & Immigration	20.0
Low Fertility, Middle Life Expectancy & Immigration	22.8
High Fertility, Middle Life Expectancy & Immigration	17.6
Low Life Expectancy, Middle Fertility & Immigration	23.3
High Life Expectancy, Middle Fertility & Immigration	16.5
High Immigration, Middle Life Expectancy & Fertility	19.4
Low Immigration, Middle Life Expectancy & Fertility	20.8
Zero Immigration, Middle Life Expectancy & Fertility	22.3

a. See text for description of assumptions
Source: Day 1996.

used for these calculations. Alternative assumptions for the percent of the U.S. population projected to be age 65 and older in 2050 are shown in Table 3.

Following the assumption of the middle series for each component of change, the population aged 65 and older would increase from 12.8 percent in 1995 to approximately 20 percent in 2050. Table 3 further highlights differences in the projected percentage of the population age 65 and older under alternative assumptions. Examining different scenarios in which one of the components of population change follows either a high or a low assumption and the others follow the middle assumption, allows us to isolate the effect of fertility, life expectancy, and net immigration on population aging.

Per our previous discussion on the stable population model, high levels of fertility with unvarying mortality and migration patterns would result in a younger population (17.6 percent age 65 and older), whereas a pattern of low fertility with unvarying mortality and migration levels would result in an older population (22.8 percent age 65 and older). In contrast, projections for alternative mortality assumptions show a larger effect for population aging than alternative fertility assumptions. For instance, low mortality combined with unchanging fertility and net migration patterns would result in the largest projected percentage (23.3 percent) of the population age 65 and older in any of these scenarios, whereas high mortality with constant fertility and net migration patterns results in the smallest percentage of older adults in any scenario (16.5 percent).

It should be noted that differing assumptions regarding immigration patterns have a relatively small effect on the future age distribution of the U.S. population compared to the other demographic processes. Assuming a low or high annual net migration (20.8 percent and 19.4 percent, respectively) results in a less than one percent change from the middle series (20 percent) in the proportion of adults age 65 and older. Moreover, an extreme assumption of zero net migration results in a marginally older population (22.3 percent) in the proportion of adults age 65 and older. Thus, migration is an ineffective demographic mechanism to slow population aging.

Both the stable population model and population projections with alternative assumptions lead to the same basic conclusions regarding the demographic mechanisms of population aging. Decreases in fertility rates lead to an aging population. Conversely, decreases in mortality across all age distributions have relatively little effect on the age structure of a population. However, a decrease in mortality rates among older adults can significantly lead to population aging. Finally, within typical boundaries, net migration has a minimal effect on population aging. The above approaches help us understand past trends in population aging and provide a basis for anticipating how future trends in population aging may occur.

Measures and Methods

Measures of population aging are important because they inform and influence our past, current, and future perceptions of demographic trends. These measures can tell us if population aging will be accompanied by improved health, improved quality of life, and if there are sufficient social and economic resources to sustain major population changes. Below, we discuss five commonly used indicators of population aging, namely, the population pyramid, the dependency ratio, life expectancy, median age, and the aging index. Each indicator has a purpose in describing how a population is aging and can tell us a powerful story about each country's history and future.

Population Pyramids

A population pyramid is a graphical illustration of the age and sex structure of a population. It shows the percentage or number of people in a total population that falls into selected age categories, typically 5-year groupings, and sex categories, male or female. Population pyramids can portray for us many of the past, present, and future demographic trends all in one picture. We can also use population pyramids to analyze the growth, or the decline, of fertility, mortality, and migration in any given population. In addition, the shape of a population pyramid can tell us about the number of people being born, dying, and moving in and out of a location since they affect the relative size of all the age and sex groupings for that population. There are three basic shapes that describe a population structure, namely, the pyramid, i.e., triangular shape; the rectangular shape; and the inverted pyramid shape.

A pyramid-shaped age structure describes a population that is young with higher proportions of children due to high levels of fertility and high levels of mortality. Figure 1 is an example of the pyramid-shaped structure, using age and sex for Angola in 2017. Angola, located in Southern Africa bordering the Atlantic Ocean, has a youthful population with high child mortality rates, the 12th highest in the world, and a fertility rate of more than five children per woman (United Nations 2017). Angola has lived through long periods of political and military instability having gained independence from Portugal in 1975, followed by an eruption of a civil war immediately thereafter that lasted 27 years and ended in 2002 (Tvedten 2018). These events have taken a toll on Angola's people and its economy. The destruction caused by the civil war led to the country's reliance on international, non-governmental organizations for the supply of basic food and medical care, which have not been enough to support the population and its shambled infrastructures (Tvedten 2018). Angola's population has high levels of child malnutrition and low levels of

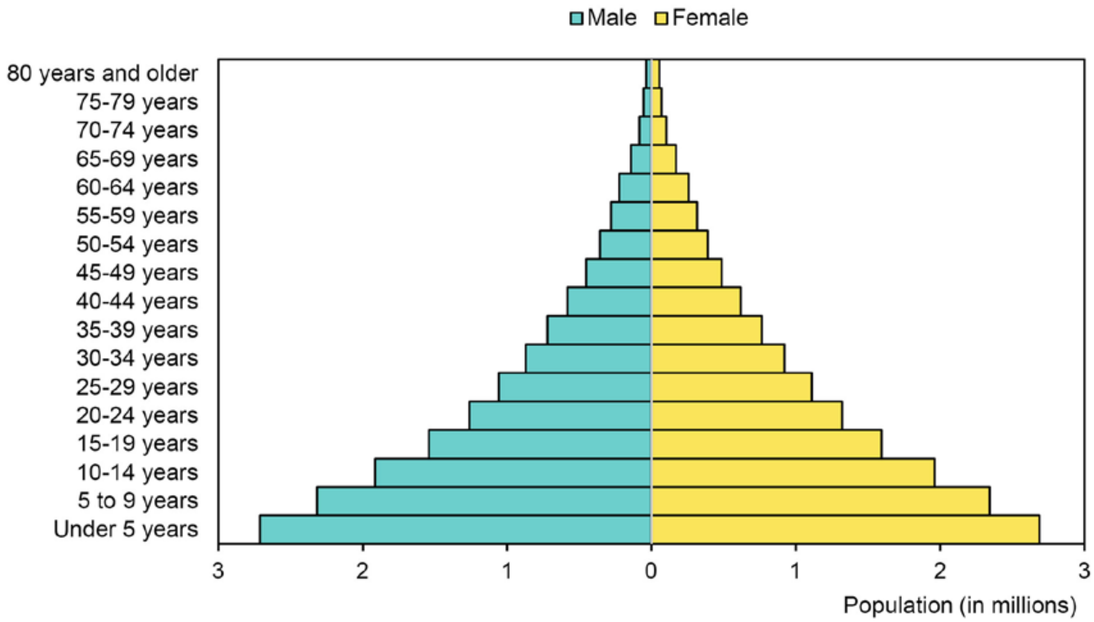

Figure 1. Population Pyramid, Angola, 2017. Source: The World Bank.

immunization, which inevitably contribute to excess child mortality (Agadjanian & Prata 2003). Angola also faces a high burden of such communicable diseases as malaria, tuberculosis, onchocerciasis, respiratory diseases, diarrhea, and HIV/AIDS, which are among the leading causes of death in Angola (Rosário, Costa, Francisco, & Brito 2017; Rosário et al. 2016). These ongoing issues, without significant intervention, will inevitably keep Angola's population young.

In contrast to Angola's pyramidal age structure, the population pyramid for the United States in 2017 has a more rectangular shape (see Figure 2) with about similar numbers or percentages of people in each age group, apart from the oldest age groups, where the bulk of mortality occurs. This rectangular shape is indicative of United States as a population with a low total fertility rate of 1.8 children per woman, and low mortality. In other words, the U.S. is an aging population (United Nations 2017). One of the most important features of the United States 356 population pyramid is the effect that the "baby boom" generation, i.e., the large number of people born between 1946 and 1964 after World War II, has had on the older population structure. The baby boom bulge seen in Figure 2 in the 50 to 70-year age range has been moving up the population pyramid in past decades,

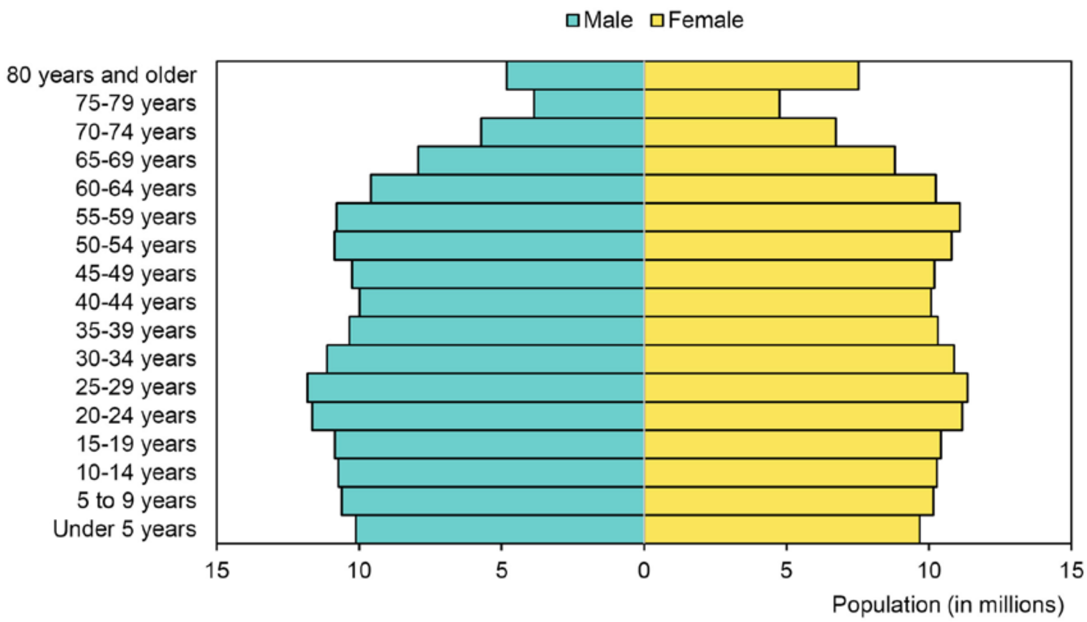

Figure 2. Population Pyramid, United States, 2017. Source: The World Bank.

leaving the lower part of the working-age population and the base narrower. It is also important to note that the top of the pyramid is skewed to the right, with more women surviving to older ages than men. This is reflective of the mortality trend in the U.S. and most everywhere that women live longer than men (Vaupel, 2010). The U.S. population pyramid also reveals that the United States has experienced a recent decline in fertility, since there is an appreciable deficit in the child age groups. Based on this 2017 population pyramid, we can predict that the United States will have a larger proportion of older adults than younger adults in the coming decades. If fertility rates continue to drop, it will also contribute to rapid population aging. These factors are of major concern for government and policy makers amid talks concerning the nation's ability to support the fast-growing older adult population. One of the major consequences of population aging is the reduction of the working age population that contributes to the support systems of an aging population. However, increasing the size of the working age population through international migration can offset declines in the working age population and offset the effects of overall aging of a population (United Nations 2001).

For example, the role of international migration to countries such as the United States, Canada, and Australia has kept the population relatively young because of high rates of youthful immigration. The

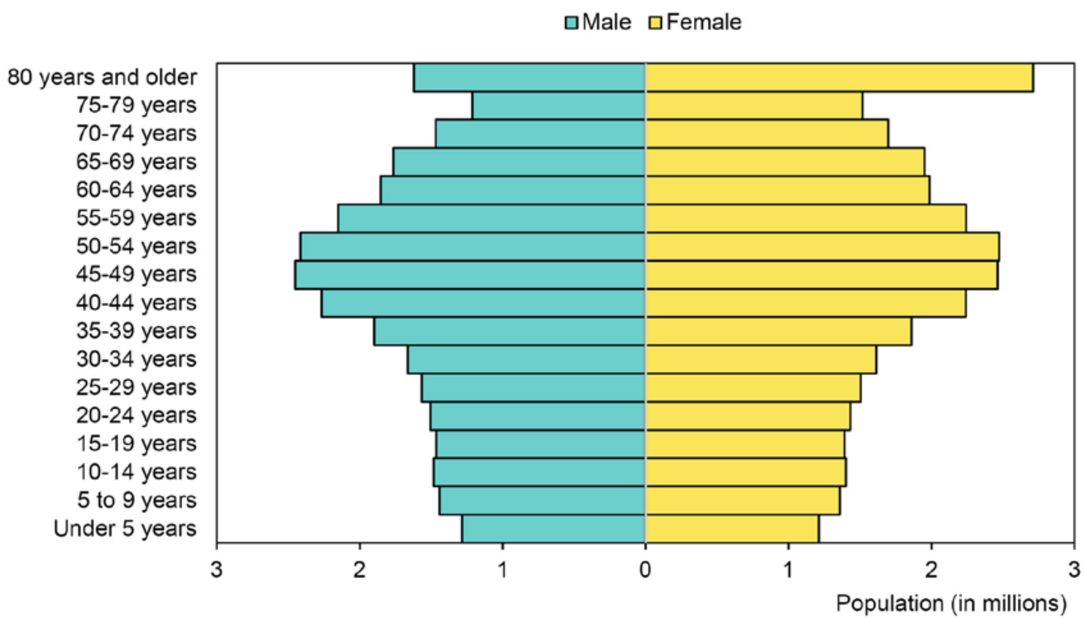

Figure 3. Population Pyramid, Italy, 2017. Source: The World Bank.

immigration of young workers not only contributes to population growth, but also helps support the increasing number of older adults through tax revenues. It must be noted that while international migration may be seen as a solution to population aging, it cannot reverse long-term trends in population decline since the number of immigrants would need to be very large (Skeldon 2013).

A society with an inverted population pyramid has a larger proportion of older adults than younger people to support them, which fundamentally alters the structure of the nation's economy. Figure 3 shows an inverted population pyramid age structure, using age and sex data for Italy in 2017. Italy is a country with a very high life expectancy of 82.7 years and a profoundly low total fertility rate of 1.35 births per woman (United Nations 2017). These characteristics of Italy are reflected in its population pyramid. On the top panel of Figure 3, there is a pronounced peak in the 40 to 60-year age range, with an aging population approaching the top tier. This peak is followed by appreciable declines through the younger age groups, denoting the long-run persistence of low fertility. This means that much of the future workforce in Italy will be composed of senior citizens, which may potentially have serious economic repercussions owing to the declining physical capacity in an older workforce. These population trends pose significant social and economic challenges transitioning from a child-centered society to an older adult-centered society, especially if a nation does not have the policy and tax resources to address these rapid changes.

As just illustrated, population pyramids are a useful resource and can provide an illustrative visual of a population's past, current, and future demographic trends. The shape of a population pyramid effectively communicates whether a population is young or old, and it can shed light on the extent of development and other aspects of the population. For more information and other examples, see Poston's discussion of population pyramids in Chapter 1 of this *Handbook of Population.*

Dependency Ratios

The dependency ratio is a summary measure of age composition. It represents the proportion of a population that falls in the age categories that are traditionally thought to be economically dependent. The ratios are based on a division of three age groups: children (0-14 years), the working age population (15-64 years), and the older population (65 years and older). Although this measure is standard in many demographic indicators of population aging, there are definitional variations on who is considered to be a dependent. For example, traditional measures of dependency do not take into account societies in which persons enter the workforce before age 15, and/or those who stay working beyond age 65 years. Changing the lower or upper limit of these working ages can affect the dependency ratios appreciably. Nonetheless, dependency ratios are a useful tool for examining the potential number of persons available to support each older or younger person.

The young, or youth, dependency ratio represents the number of children per 100 workers. Similarly, the old age, or aged, dependency ratio is the number of people aged 65 and older per 100 workers. The sum of the young and old dependency ratios equals the total dependency ratio, i.e., the ratio of dependent people, young and old, per 100 persons in the working ages. With respect to aging, this measure provides a straightforward way for comparing the relative number of older people in various populations across time periods. These numbers can be used to determine different patterns of demand on social and economic resources such as the allocation of tax dollars, health care, caregiving, and the educational system.

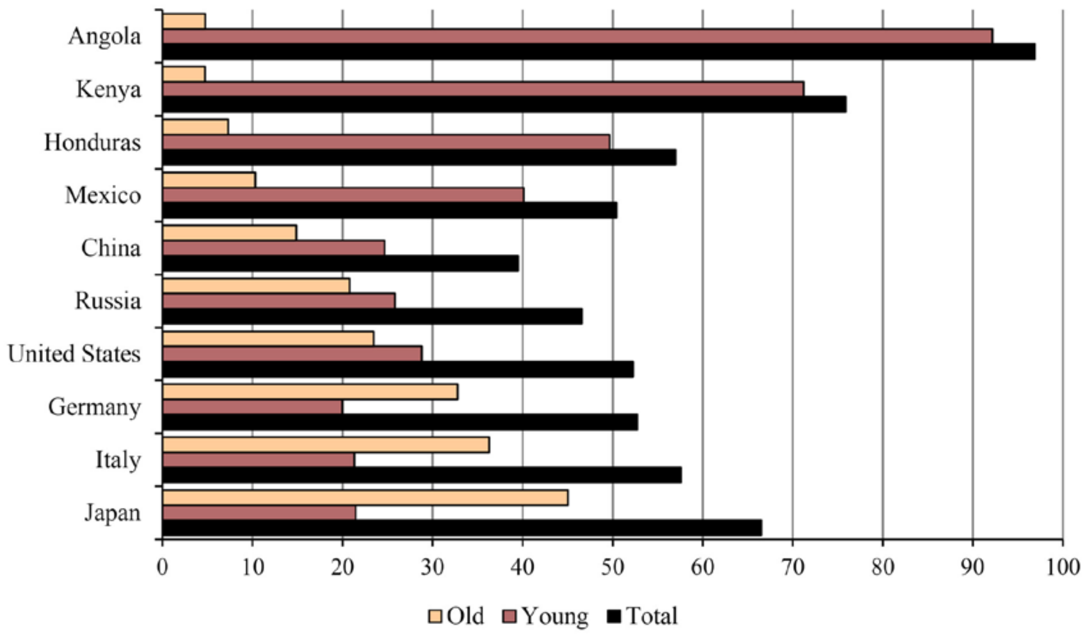

Figure 4. Dependency and Support Ratios, 2017. Source: The World Bank.

Figure 4 shows the young, old, and total dependency ratios for selected countries in Africa, Asia, Europe, and North America. Among the countries shown, the country with the highest total dependency ratio is Angola, which has 97 children and older adults for every 100 working-age citizens. In contrast, the country with the lowest dependency ratio is China, which has 40 children and older adults for every 100 working-age citizens. Countries such as the United States, Japan, and Germany have ratios in between. With continued interest in the aging population, there are stark differences in the old-age dependency ratio by country that deserve closer examination. For instance, Japan has the highest old-age dependency ratio in the world, meaning that Japan has a very large proportion of its population that is retired. This affects the demand for economic, medical, and long-term care services, both formal and informal. Italy and Germany also face similar issues related to a high old-age dependency ratio that will demand the need to reevaluate welfare strategies and health care for the elderly.

Life Expectancy

Life expectancy is often used as an indicator of the quality of life, health, and social development of a population. Life expectancy is closely linked to health conditions, which are an integral part of development in a country. Life expectancy refers to the average length of time to be lived by a group of people born in the same year, assuming that age-specific mortality levels remain constant. Life expectancy is calculated from actual mortality data in a single year and describes what would happen to a hypothetical group if they moved through their lives experiencing the mortality rates observed for the country in any given year. Table 4 shows the life expectancies of selected countries classified in 2015 as high-income, middle-income, and low-income. It is probably not surprising that the high-income countries shown in the table, namely, Japan, Italy, and the United States, have the highest life expectancies compared to the middle- and low-income countries. Women in Japan have the highest life expectancy in the world at 87 years. The high life expectancies observed among the high-income countries are reflected in their success of handling

Table 4. Life Expectancies Among High-, Middle-, and Low-Income Countries.

	Life Expectancy at Birth, 2015[a]		*Life Expectancy at Age 65, 2010-2015*[b]	
	Men	*Women*	*Men*	*Women*
High Income				
Italy	80.3	84.9	18.6	22.0
Japan	80.8	87.0	19.0	23.9
United States	76.3	81.2	18.0	20.6
Middle Income				
Brazil	71.6	78.9	16.3	19.5
Mexico	74.5	79.4	17.9	19.7
Russia	65.9	76.7	12.9	17.1
Low Income				
Afghanistan	62.0	64.6	12.2	13.4
Ethiopia	63.2	66.9	13.8	14.9
Uganda	57.4	61.8	13.2	14.3

a. *Source*: The World Bank;
b. *Source*: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision

noncommunicable diseases since fewer men and women are dying before their 60th birthday from heart disease and stroke (World Health Organization 2014).

At the other end of the scale, low-income countries, such as Uganda, have lower life expectancies than the high-income countries. In Uganda, for example, their high infant mortality rates contribute to keeping the population younger (Daumerie & Madsen, 2010).

Since we are interested in aging populations, we also included in Table 4 a measure of population aging such as life expectancy at age 65, which is the average number of years that a person at age 65 can be expected to live, assuming that age-specific mortality levels remain constant. This indicator can help governments make informed decisions about retirement age, benefits, and health care costs. As observed earlier with life expectancy at birth, high-income countries have the highest life expectancies at age 65, with women in Japan having the longest life expectancy at age 65, of 23.9 more years. This means that women in Japan who reach the age of 65 can be expected, on average, to live an additional 23.9 years, that is, they will live until approximately age 89. Note that life expectancy at age 65 is larger than that observed for life expectancy at birth. In the case of women in Japan, their life expectancy at birth is 87 years, while their life expectancy at age 65 is approximately 89 years. This is due to selective mortality. That is, life expectancy for individuals at age 65 is conditional on their survival to age 65 and does not account for mortality for those younger than age 65.

With the steady increase of life expectancy around the world, and the growing proportion of the older population, there is also a need to capture the quality and quantity of the remaining years lived. Healthy life expectancy is one such measure that captures both the quality and quantity of remaining years lived by dividing life expectancy into life spent in different states of health. Healthy life expectancy refers to the number of years that an individual may expect to live in a healthy state, i.e., living without disability or morbidity. This is calculated using the Sullivan method (Sullivan 1971), also known as Sullivan health expectancy, which integrates age-specific data on the prevalence of the population in healthy and unhealthy states, with age-specific mortality information. Sullivan health expectancies have been used to provide results for populations from over 50 countries worldwide (Jagger & Robine 2011).

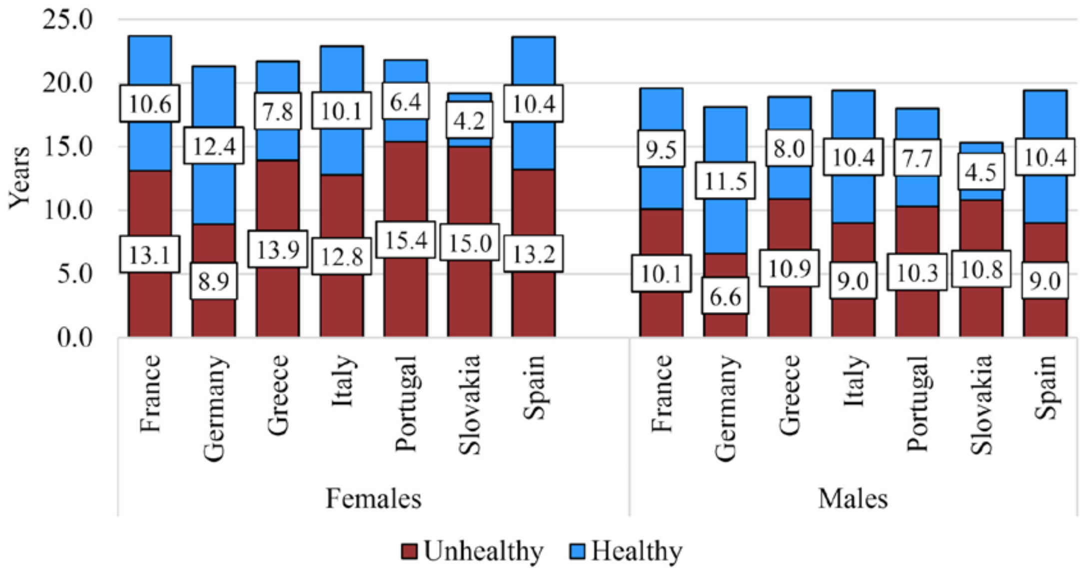

Figure 5. Healthy Life Years and Life Expectancy at Age 65, 2016. Source: Eurostat (2018). http://ec.europa.eu/eurostat/en/web/products-datasets/-/TEPSR_SP320

Figure 5 provides Sullivan health expectancy data at age 65 for selected countries in Europe, by sex, in 2016. The figure shows the total life expectancy at age 65 divided into healthy and unhealthy states. For example, females in France have a life expectancy at age 65 of 23.7 years. Out of those 23.7 years, they can expect, on average, to spend 10.6 years of their total life expectancy at age 65 in a healthy state. To gain a more impactful meaning of these numbers, we take the healthy life expectancy value for a country and divide it by the total life expectancy value for the country to obtain a proportion that an individual can expect to live in a healthy state. In the case of France, we divide 10.6 into 23.7, for a ratio of 0.45, which represents the proportion of remaining life after age 65 spent in good health. Thus, at age 65 French women can expect to spend 45 percent of their remaining life in a healthy state. In contrast, Slovakian women at age 65 can expect to spend 22 percent of their remaining life in a healthy state. These percentages are useful in making cross-population comparisons. Comparing women in France and Slovakia, we can say that Slovakians are spending a lower proportion of their life after age 65 in a healthy state compared to the French.

Table 5. Median age, 2017.

	Total	*Male*	*Female*
Japan	47.3	46.0	48.7
Italy	45.5	44.4	46.5
Germany	47.1	46.0	48.2
United States	38.1	36.8	39.4
Russia	39.6	36.6	42.5
China	37.4	36.5	38.4
Mexico	28.3	27.2	29.4
Honduras	23.0	22.6	23.3
Kenya	19.7	19.6	19.9
Angola	15.9	15.4	16.3

Source: The World Factbook, Central Intelligence Agency, United States.

Median Age

The median age of a population is a measure of central tendency that divides a population into two age groups of the same size, such that one-half the total population is younger than the median age, and the other one-half is older. The median is the midpoint separating these two halves. The median age is a useful measure of undertaking cross-population comparisons when age distributions are not symmetrical because the median is less affected by outliers and skewed data. However, a major limitation of median age data is that they do not give details of the age distribution. Table 5 shows a range of median ages for selected countries. As most indicators in this chapter have shown, Japan is the oldest country in the world and has a median age of 47.3 years. Angola, among the youngest countries in the world, has a much lower median age of 15.9 years.

Aging Index

The aging index is the number of persons 60 years old or older per one-hundred persons under age 15. This measure is a straightforward indicator of the relative number of older persons in a population for every 100 children. In 2000, a few countries such as Japan, Germany, and Italy had aging indexes above 100 (Gavrilov & Heuveline 2003). By 2030, however, it is expected that all developed countries will have aging indexes above 100 (Kinsella & Phillips 2005), with some countries, such as Japan, having an aging index exceeding 200 (Gavrilov & Heuveline 2003). Conversely, in developing countries, aging indexes are much lower since their 363 populations are much younger. The aging index is a telling measure of the challenges societies face in their allocation of resources to support an increasingly aging population.

Trajectories of Population Aging

Demographic Transition

The classical model of the demographic, or epidemiological, transition refers to the process in which a population characterized by high fertility and mortality transitions into a population with low fertility and low mortality. The demographic transition is one of the most important historical changes that have affected both the population growth rate and the age structure of a country.

According to Omran's (1971) epidemiological transition model, there are three key stages of transition. The first stage, called the "age of pestilence and famine," is characterized by populations having high and fluctuating mortality rates among children and adults because of infectious and deficiency diseases. Throughout this stage, populations have variable life expectancy with a low average life span (about 20 to 40 years). Further, the population's age structure is young with a pyramid shape that consists of a larger proportion of children at the base and very few older people at the top, due to high rates of mortality and fertility. Consequently, natural increase, i.e., births minus deaths, is low, and population growth is slow.

The second stage, called the "age of receding pandemics," is marked by high rates of fertility, declining mortality rates, and population growth because populations experience improvements in nutrition, hygiene, sanitation, social programs and medical technologies that reduce the incidence of infectious and deficiency diseases. Average life expectancy also increases in this stage. This transition is accompanied by a shift in the population age distribution, as infectious and deficiency diseases decline, and deaths from chronic degenerative diseases increase at older ages. The population age structure, however, remains young, but there is an increasing proportion of older adults as mortality rates decrease and lifespan increases.

In the third stage, called the "age of degenerative and man-made diseases," noncommunicable diseases, also known as chronic diseases, become the primary cause of death for the populations. Infectious and deficiency diseases become rare or nonexistent at this point. This stage is characterized by low and stable rates of infant mortality and increased survival into adulthood and old age. Average life expectancy becomes much higher and tends to be greater than 50 years of age. The population age structure also starts to become older, an important determinant of population aging.

Although Omran proposed three key stages, some demographers and epidemiologists have suggested that there is a fourth stage, "the age of delayed degenerative diseases" stage, in which prosperity and medicine are contributing factors to the postponement of senescence, or delay in aging (Olshansky & Ault 1986; Vaupel 2010). In this stage, death rates fall across the age range, showing a survival curve that becomes more "rectangular" in shape since the distribution of deaths have shifted to the right and become more compressed (Wilmoth 2000). Other characteristics in this stage include low mortality and low fertility rates, a flattening of population growth, and an age structure that becomes old.

The demographic transition reflects differential risks of cause-specific mortality that explain the persistent disparities in the pace of improvements in survival across the world's populations. For example, countries that have reduced the risk of childhood death from infectious and deficiency diseases have achieved more rapid gains in longevity and advanced 365 further though their demographic transition compared to countries that continue to face large burdens from infectious and deficiency diseases.

Global Population Aging

Globally, the number of older adults aged 60 and older is growing faster than the numbers of people in any other age group. In 2015, there were 48 percent more people aged 60 years and older worldwide than there were in 2000. And by 2050, the number of older adults is expected to more than triple since 2000 (United Nations 2015). In contrast, the number of children, i.e., persons under age 10, and adolescents and youth, i.e., persons aged 10-24 years, is projected to change by 11 percent from 2000 to 2050 (United Nations 2015). The

Table 6. Percent of Population Over Age 60 years and 80 years for the World, Development Groups, Regions, and Income Groups, 2000, 2015, 2030, and 2050.

	60+				*80+*			
Area	*2000*	*2015*	*2030*	*2050*	*2000*	*2015*	*2030*	*2050*
World	9.9	12.3	16.5	21.5	1.2	1.7	2.4	4.5
Development Groups								
More Developed regions	19.5	23.9	29.2	32.8	3.1	4.7	6.6	9.9
Less Developed regions	8.0	10.7	15.9	22.7	0.7	1.2	1.8	4.4
Least Developed regions	5.1	5.5	6.7	9.8	0.4	0.5	0.6	1.1
Regions								
Africa	5.2	5.4	6.3	8.9	0.4	0.5	0.6	0.9
Asia	8.6	11.6	17.2	24.6	0.8	1.4	2.1	4.9
Europe	20.3	23.9	29.6	34.2	2.9	4.7	6.3	10.1
Latin America and the Caribbean	8.1	11.2	16.8	25.5	1.0	1.6	2.6	5.7
Oceania	13.4	16.5	20.2	23.3	2.2	2.9	4.3	6.4
North America	16.2	20.8	26.4	28.3	3.2	3.8	5.6	8.6
Income Groups								
High-Income Countries	18.0	22.1	27.7	31.9	2.9	4.3	6.2	9.6
Upper-Middle-Income Countries	9.2	13.4	21.2	30.5	0.9	1.6	2.6	7.0
Lower-Middle-Income Countries	6.9	8.1	11.2	16.5	0.6	0.8	1.1	2.3
Low-Income Countries	5.0	5.2	5.8	8.3	0.3	0.4	0.5	0.8

Source: United Nations (2015). *World Population Prospects: The 2015 Revision.*

number of adults (aged 25- 59 years), however, is growing faster than the number of children, but not as fast as the older adult population aged 60 and older. In 2015, there were 29 percent more adults than there were in 2000; and by 2050, the number of adults is projected to increase by 62 percent (United Nations 2015). Although the global trends are alarming, the pace of these trends has not been shared uniformly across the world. A distinct feature of global population aging is its uneven speed across world regions and development levels.

The data in Table 6 show the percentage of older adults aged over 60 years and 80 years for the world, development groups, regions, and income groups in 2000, 2015, 2030, and 2050. The data for 2015 are based on estimates from national census and surveys, and the data for 2030 and 2050 are projections based on certain assumptions regarding future demographic behavior. We selected these particular populations to illustrate the diversity in patterns of population aging. The percentage of adults aged 80 years and older is included in this table 366 because of the growing interest of social and health policy researchers of the "oldest-old" population.

The first comparison in Table 6 is between the more developed regions, i.e., Europe, Northern America, Australia, New Zealand, and Japan, the less developed regions, i.e., Africa, much of Asia, Latin America and the Caribbean, and the group of least developed regions, i.e., which refers to much of Africa (United Nations 2015). In general, countries in the “more developed” regions have higher standards of living, higher levels of income, higher life expectancy, and lower birth rates than countries in the “less and least developed” regions. Although there is a stark divide among world societies, it is clear that these characteristics influence differences in population aging. Between 2000 and 2050, population aging is expected to progress much more rapidly in the more developed areas than in the less and least developed areas. In 2000, the percent over age 60 in developed regions was 19.5 compared to 8.0 in the less developed regions, and 5.1 in the least developed regions (United Nations 2015). Between 2000 and 2050, it is anticipated that the proportion of older adults will nearly double in developed regions, to 32.8 percent, and nearly triple in the less developed regions, to 22.7 percent, and nearly double in the least developed regions, to 9.8 percent (United Nations 2015). In the next comparison, we document further variation within both the more and less developed regions.

The pattern of population aging is very similar in Asia and Latin America and the Caribbean over the 50 years between 2000 and 2050. In both regions, the percentage of adults aged 60 was modest in 2000, but extremely rapid aging is projected to occur over the subsequent 50 years as the percentage of the population over age 60 years nearly triples (United Nations 2015). The primary reason for anticipating rapid population aging after 2000 is the sharp decline in birth rates that began in the last three decades of the 20th century in these regions. In the 1960s, the total fertility rate (TFR) was above 6 children per woman in two-thirds of the countries in Latin America and the Caribbean, but by 2000-2005, the TFR in the region was estimated at 2.6 children per woman (United Nations 2015). Similarly, in Asia, the total fertility rate in the 1960-1965 period was about 6 children per woman and 2.4 by 2000-2005 (United Nations 2015). Africa, in contrast, has yet to experience population aging with only 5.2 percent of its population over age 60 years in 2000 (United Nations 2015). Birth rates in most of Africa remained high by world standards throughout the 20th century, and life expectancy has increased slowly compared to Asia and Latin America. Due to the HIV/AIDS epidemic in the 1990s, some African countries have experienced large declines in life expectancy, and for the continent as a whole, life expectancy was lower in 2000 than in 1990. However, some of the greatest gains in life expectancy between 2000 and 2015 were experienced in Africa due to improvements in child survival and access to antiretrovirals for the treatments of HIV. These demographic trends suggest that Africa will experience its demographic transition within the 21st century, with the TFR perhaps declining to 2.9 by 2050-2055. Under this scenario, the percentage of older adults in Africa's population will nearly double between 2000 and 2050, from 5.2 to 8.9 (United Nations 2015). However, the population of Africa in 2050 would still be younger than the population of the more developed regions was in 2000.

In both Europe and North America, older adults constitute a large share of the population. In both regions in 2015, one in five persons was aged 60 years and older (United Nations 2015). This is projected to continue to rise such that, in 2050, older adults will account for one in three people (United Nations 2015). Europe is projected to have the oldest population of any region in the coming decades (United Nations 2015). These population trends are not new in these regions. In fact, these regions have been aging for decades, with some countries in these regions aging for over a century. While declining fertility has been a significant factor for population aging for these regions, population aging is also a result of extended longevity. In both Europe and North America, living to age 60 or age 80 is no longer a rarity. However, increasing longevity has led to new challenges such as the health and disability patterns of older populations, the economic resources available to older adults, and health care costs, to name only a few.

The last comparison in Table 6 is between income groups. Older adults comprised 22.1 percent of the population of high-income countries in 2015, 13.4 percent of upper-middle-income countries, 8.1 percent of lower-middle-income countries, and 5.2 percent of low-income countries. Across income groups, older adults are projected to increase significantly by 2050. Older adults will comprise 31.9 percent of the population of high-income countries in 2050, 30.5 percent of upper-middle-income countries, 16.5 percent of lower-middle-income countries, and 8.3 percent of low-income countries (United Nations 2015).

Theoretical Issues

Migration and Population Aging

Patterns of migration, i.e., in-migration and out-migration, may not necessarily be drivers of change in the age structure of a population. For example, if there was no variation in the age of the migrants, and they had fertility and mortality profiles similar to those of the receiving population, then in-migration would only affect the size of the population. However, migration is an important factor in population aging for some countries (Sudharsanan & Bloom 2018). Immigration may contribute to the decline of population aging, i.e. in Canada and Europe, because immigrants tend to be younger and have higher fertility than the receiving population. In contrast, emigration of working-age adults may contribute to increases in population aging as older adults tend to migrate less than younger adults. Population aging may also be accelerated by immigration of retirees from other nations and the return migration of older emigrants as observed in some Caribbean countries (Gavrilov & Heuveline 2003). Despite the age selectivity of immigrants, the effects of migration on population aging are generally larger on the age composition of smaller populations due to a higher proportion of immigrants. Additional insights about the association between migration patterns and population aging can be attained by considering two scenarios, namely, the effects of internal migration in the United States on regional differences in age distribution; and replacement migration in developed countries as a solution to population aging.

Migration and Population Aging in the United States

In 2010, 40.3 million adults or 13 percent of the population in the United States was aged 65 and older (West, Cole, Goodkind, & He 2014). Geographically, 11 states had over one million adults aged 65 and older. However, states with the largest number of older adults are not necessarily those with the highest percentages of elderly. For instance, the state of California had the greatest number of older adults, but it is ranked 46th among the 50 states and District of Columbia with regard to the percentage of its older population. Conversely. West Virginia had the second highest percentage of older adults, yet is ranked 35th in terms of population 65 and older.

The percentage of the state population of age 65+ and old varied among the states from a high of 17.3 percent in Florida to a low of 7.7 percent in Alaska (West et al. 2014). Differences in the percentage of older adults in these extremes are mainly attributable to in-migration patterns. Florida is a desirable retirement destination which may attract a disproportionate number of older adults. Conversely, Alaska, historically, has attracted a disproportionate number of young adults for college, military, and employment (Alaska Department of Labor and Workforce Development 2015). In addition to Florida and West Virginia, Maine, and Pennsylvania were the only other states with 15 percent or more of their populations aged 65 and older. In contrast, Colorado, Georgia, Texas, and Utah comprised the remaining states with older populations under 11 percent. Furthermore, Alaska, Nevada, Idaho, Colorado, Arizona, Georgia, Utah, and South Carolina in the West and South regions experienced the fastest growth rates, from 30.2 percent to 53.9 percent, between 2000 and 2010. Conversely, North Dakota, Iowa, Massachusetts, Nebraska, Kansas, New York, New Jersey, and Pennsylvania all experienced a relatively low growth of under 7 percent of their older populations, and Rhode Island and the District of Columbia experienced declines.

Following the above patterns, one might ask what accounts for the growth or decline of older populations by state and region. The answer to the question is that older adults are less likely to move than their younger counterparts. Indeed, research shows that adults aged 65 and older are three times less likely to be mobile than adults aged 18-64 (Ihrke, Faber, & Koerber 2011). While residential mobility at older ages is not uncommon, relocation is more prevalent among adults who are retired, in poor health, have higher levels of income/wealth, and reside in urban areas (Cagney & Cornwell 2018; Sergeant & Ekerdt 2008; Taylor, Morin, Cohn, & Wang 2008). Older adults who do move disproportionately tend to do so within their state and tend to "age in place" (Cagney & Cornwell 2018), while a disproportionate number of younger people move out. As migration characteristics largely depend on age, those states, or regions, in which out-migration exceeds in-migration over a continual period will tend to have older populations. In recent decades, the Northeast and Midwest regions of the United States have experienced significant net out-migration which has resulted in a large growth in the percentage of the population aged 65 and older. Conversely, regions in the South, with the exception of

Florida, and the West, have experienced significant net in-migration which has resulted in younger populations.

Replacement Migration.

As we have noted above, immigration tends to have a smaller effect on the age structure of a population. However, from a demographic point of view, it is a useful exercise to examine for developed countries the volume of in-migration that would be required to offset population decline and population aging resulting from low rates of fertility and mortality. Focusing on these population trends, the United Nations (2001) provided this information for eight countries, namely, France, Germany, Italy, Japan, Republic of Korea, Russian Federation, United Kingdom and United States, and for two regions, namely, Europe and the European Union. The title of the U.N. publication is "Replacement Migration: Is it a Solution to Declining and Ageing Populations?"

The motivating factor behind this report was the potential increased burden placed on working age adults, i.e., those aged 15 to 64 years old, to support the older population, i.e., those aged 65 and older. The population indicator of interest was the potential support ratio (PSR). The PSR is defined as the ratio of population aged 15-64 years to the population aged 65 years and older. (Also, see Poston's discussion of the PSR in Chapter 1 of this *Handbook*.) The basic question involved the association between PSRs in 2050 and alternative scenarios according to the annual number of net migrants entering each selected country or region between 1995 and 2050. Therefore, the analysis compared the age distribution PSRs resulting from various population projections based on alternative assumptions of net immigration.

Table 7 summarizes the results of alternative population projections for Japan, the United States, and the European Union. Baseline information on PSRs in 1950 and 1995 are provided for each country and region in addition to selected outcomes of four alternative projections in 2050. Each estimate is based on the fertility and mortality assumptions behind the medium variant of the standard United Nations population projections. The four alternatives for migration are: 1) medium variant projection; 2) zero migration after 1995; 3) migration required to maintain PSR of 3.0 before 2050; 4) migration required to maintain PSR at 2000 level. The outcomes for each projection are: 1)

Table 7. Population Data and Indexes for Japan, European Union, and the United States in 2050 Under Alternative Demographic Scenarios.

Country and Indicator	*1950*	*2000*	*2050*			
			Proj. 1[e]	*Proj. 2*[f]	*Proj. 3*[g]	*Proj. 4*[h]
Japan						
1. PSR[a]	12.1	4	1.7	1.7	3.0	4.8
2. Average Immigration[b]			0	0	1,897	10,471
3. % Immigration[c]			0	0	54.2	87.2
4. Population Increase[d]			0.83	0.83	1.81	6.46
European Union						
1. PSR[a]	7.0	4.1	2.0	1.9	3.0	4.3
2. Average Immigration[b]			270	0	3,073	13,480
3. % Immigration[c]			6.2	0	40.2	74.7
4. Population Increase[d]			0.88	0.83	1.39	3.27
United States						
1. PSR[a]	7.8	5.3	2.8	2.6	3.0	5.2
2. Average Immigration[b]			760	0	816	10,777
3. % Immigration[c]			16.8	0	17.4	72.7
4. Population Increase[d]			1.25	1.04	1.26	3.83

a. PSR = Potential Support Ratio (pop. 15-64/pop. 65+).
b. Average Immigration = Average annual volume of immigration in 1000s, 2000- 2050.
c. % Immigration = Percent of population composed of post-2000 immigrants and their descendants.
d. Population Increase = Ratio of total population to total population in 2000.
e. Projection 1 - Median variant
f. Projection 2 - Median variant, except zero migration
g. Projection 3 - Maintain PSR of 3.0
h. Projection 4 - Maintain PST existing in 1995
Source: United Nations 2000.

PSR in 2050; 2) average annual number of immigrants between 2000 and 2050; 3) percent of the 2050 population composed of post-2000 immigrants and their descendants; and 4) the ratio of the total population in 2050 to total population in 2000.

In Japan, the PSR declined from 12.1 to 4.0 between 1950 and 2000 and is projected to further decline to 1.7 in 2050 under the medium variant projection assumption. Under the assumption of zero migration, the medium projection results in a 2050 population that is approximately 20 percent smaller than the 2000 population and is unaffected by immigrants from other countries. However, if Japan were to use immigration to maintain a PSR of 3.0 in 2050, they would need to admit an average of 1.9 million immigrants per year until 2050. The fourth scenario, maintaining the same PSR as 1995, demonstrates that a policy aimed at countering population aging through international immigration is highly improbable. Attempts to prevent population aging after 1995 through replacement migration would lead to a 2050 population that would be approximately eight times larger than the 1995 population, and one in which 87.2 percent were migrants or their descendants.

Results for the United States and the European Union are also presented in Table 7. In both analyses, it is astonishing what little difference the effect of projected immigration has on population aging compared to that of zero migration. Similar to Japan, the volume of future immigration required by the United States and the European Union to prevent population aging after 1995 is considered to be unrealistic. The consequence of attempting to stop population aging via immigration would result in an increase in population density of migrants and their descendants which would likely transform the culture of the receiving area, a result which is clearly unacceptable give the current political climate towards immigration. As populations cannot grow indefinitely at a rapid pace, this solution would only postpone the ultimate need to adapt to the inevitable aging of the population. The medium projection indicates a PSR of 2.8 in 2050 for the United States. As the U.S. is expected to sustain near replacement fertility levels over the twenty-first century, maintaining a PSR of 3.0 would only require an average immigration level 20 percent greater than the expected one. Conversely, in order to keep the PSR constant at 3.0, the European Union would require an annual level of immigration 3 times greater than that occurring in 2000.

Challenges due to declining and aging populations have led to the question of whether replacement migration can be used as a solution to offset population aging. However, efforts to use replacement migration are unlikely to gain significant political support owing to the backlash in many countries regarding the increasing of the immigrant populations. Significantly increasing the proportion of immigrants in developed countries would surely generate concerns about environmental consequences and cultural challenges (Grant 2001; Meyerson 2001). Moreover, the magnitude of sustained migration required to significantly alter future patterns of population aging is not only staggering but also most unrealistic.

Future Research Directions

The demography of aging is the analysis of the changes experienced by individuals and societies as they age over time (Weir, Waite, Wong, & Freedman 2018). Since the last edition of this *Handbook of Population* was published in 2005, there have been great advances in the collection of international and longitudinal data sets that focus on aging. These include the development of harmonized international studies which use socio-demographic, economic, and health measures on individuals and households that are comparable to the Health and Retirement Study (HRS) in the United States. Some of these international data sets include the Mexican Health and Aging Study (MHAS), the Costa Rican Longevity and Healthy Aging Study (CRELES), the English Longitudinal Study of Aging (ELSA), the Survey of Health and Retirement in Europe (SHARE), the Irish Longitudinal Study on Ageing (TILDA), the Korean Longitudinal Study of Aging (KLoSA), the Indonesian Family Life Survey (IFLS), the Japanese Study of Aging and Retirement (JSTAR), the Chinese Health and Retirement Longitudinal Study (CHARLS), and the Longitudinal Aging Study in India (LASI). These longitudinal data sets include large cohorts of older adults that have allowed multidisciplinary researchers to conduct cross-national comparisons to expand the understanding of the social, economic, political, and health implications of population aging across the world. Some of the more recent developments across these data sets include measures of social networks, sexuality, biological and functional measures of health, and genetics that better describe the specific challenges and underlying mechanisms of aging faced by individuals. Another advancement is that it is possible to combine these survey data with administrative/medical records that provide a more comprehensive picture of aging and health than researchers have been able to develop previously. These data linkages combine self-reports and objective historical measures to create a rich source of individual information on health care use, health conditions, life events, and medical expenditures, which will invariably be important for public policy makers in trying to address the challenges of population aging.

The collection of population studies and innovative measures in aging research from different regions around the world, particularly developing nations, provides new opportunities for collaborative work across disciplines. Historically, social scientists have focused on individual domains specific to their field: demographers on population trajectories; economists on occupation, retirement, and pension; epidemiologists on health-related factors; and sociologists on family dynamics. However, each of these domains is associated with the others and cannot be fully understood without the recognition that aging is a multi-faceted process.

Therefore, multidisciplinary approaches aimed at the development of theoretical advances informed by innovative technological methods and measures can lead to better informed policy recommendations for dealing with population aging. In our opinion, this is one of the important and policy-relevant foci for future research in the demography of aging.

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