**Population Dynamics: a survey of key demographic concepts**
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Demography is the discipline whose primary concern is measuring the size and composition of populations, and the changes in size and composition of populations over time. It is sometimes used to encompass, in addition, the causes and consequences of demographic changes on other important social processes such as economic development. Efforts by states and governments to collect information on population size, composition, and dynamics are millennia old, and were motivated by the need to tax populations, form armies, detect epidemics, form viable political and socio-economic units, and provide adequate social services such as policing, health services, and schools. Demography is no less relevant today. Many of the key challenges of development in Africa and the rest of the world are locked in complex relationships of mutual cause and effect with demographic processes. Some of these challenges include the hurdles to economic development caused by high fertility rates, the need to provide old-age security for aging populations, the impact of HIV/AIDS mortality on the number of prime-aged adults, and the movement of peoples from rural to urban areas within countries or from poorer countries to wealthier ones.

The basic demographic equation says the population of a country in some point in time is by definition equal to its population at some previous point in time, plus the inflow of new people into that population during the interval between those two points in time, minus the outflow of people from that population during that interval. The inflow of new people consists of births and immigrants, while the outflow consists of deaths and emigrants. More precisely:

$$population_{t+1} = population_t + (births_t + immigration_t) - (deaths_t + emigration_t)$$

which can be rewritten as

$$population_{t+1} = population_t + (births_t - deaths_t) + (immigration_t - emigration_t)$$
$$population_{t+1} = population_t + natural\ increase_t + net\ migration_t$$

where

$$natural\ increase_t = births_t - deaths_t$$
$$net\ migration_t = immigration_t - emigration_t$$

All the major demographic concepts are revolve around the basic concepts in the basic demographic equation: births or fertility, death or mortality, and migration, as well as particular ways of disaggregating populations: by gender, age, urbanity or rurality. This framework paper will discuss each of these major concepts of fertility, mortality, and migration, providing a history of demographic research on each topic, the major theories, and research frontier.

This fundamental equation of demography shows that populations are dynamic, that is, that they change over time. They may grow bigger or smaller, younger or older, more concentrated in cities or certain regions, and they may even change in the relative presence of men and women. Most of these changes are driven by three fundamental demographic processes: people being born (fertility), people moving (migration), and people dying (mortality).

Where possible, definitions are obtained from UN World Population Prospects (UN 2005).

1. Concepts related to population size and trends:

*Population size* – the de facto population in a country, area or region

*Population density* – population per square kilometer

*Population growth rate* -Average exponential rate of growth of the population over a given period. It is calculated as ln(Pt/P0)/t where t is the length of the period. It is expressed as a percentage.

The *rate of natural increase* or *rate of intrinsic growth* is simply the difference in births and deaths. It is a measure of how population size changes occur from within, that is, ignoring the impact of migration, and focusing only on births and deaths.

The world population stood at 6.5 billion in the year 2005, which is about 4 billion more than it stood in 1950, and is projected to grow to 9 billion in the year 2050.

TABLE I.1. POPULATION, BY DEVELOPMENT GROUP AND MAJOR AREA, ESTIMATES AND MEDIUM VARIANT, 1950, 2005 AND 2050

| | *Population (millions)* | | | *Percentage distribution* | | |
|---|---|---|---|---|---|---|
| *Development group or major area* | *1950* | *2005* | *2050* | *1950* | *2005* | *2050* |
| World | 2 519 | 6 465 | 9 076 | 100.0 | 100.0 | 100.0 |
| More developed regions | 813 | 1 211 | 1 236 | 32.3 | 18.7 | 13.6 |
| Less developed regions | 1 707 | 5 253 | 7 840 | 67.7 | 81.3 | 86.4 |
| Least developed countries | 201 | 759 | 1 735 | 8.0 | 11.7 | 19.1 |
| Other less developed countries | 1 506 | 4 494 | 6 104 | 59.8 | 69.5 | 67.3 |
| Africa | 224 | 906 | 1 937 | 8.9 | 14.0 | 21.3 |
| Asia | 1 396 | 3 905 | 5 217 | 55.4 | 60.4 | 57.5 |
| Europe | 547 | 728 | 653 | 21.7 | 11.3 | 7.2 |
| Latin America and the Caribbean | 167 | 561 | 783 | 6.6 | 8.7 | 8.6 |
| Northern America | 172 | 331 | 438 | 6.8 | 5.1 | 4.8 |
| Oceania | 13 | 33 | 48 | 0.5 | 0.5 | 0.5 |

As can be observed from Table 1.1 from UNWPP (2005), Africa is the fastest growing region of the world, with its population more than tripling between 1950 and 2005, and projected to more than double from 2005 to 2050. Each 50 year period since 1950 sees Africa's share of the world population increase by about 5 percentage points from about 9% in 1950 to 15% today, to about 20% in 2050. However Southern Africa itself is expected to have either population declines or only slight increases, primarily because of the HIV epidemic. For example, only Namibia is

expected to experience substantial population growth because of its high fertility. South Africa, which has the largest population in Southern Africa will only grow by 3% over the period 2005 to 2050, Botswana and Lesotho are expected to have population declines of 6% and 11% respectively, and Swaziland is expected to have population declines till 2030, and population increases till 2050 which will only be sufficient to make it return to its 2005 population.

Throughout most of human history, population growth was probably very low, and it was probably not until the 17th and 18th centuries that annual growth rates reached about 0.5%, where it stayed until the turn of the 20th century. However, improvements in health particularly among the young, to be discussed in more detail below, led to a reduction in deaths, which caused global population growth rates to rise until they peaked at about 2% from 1965-1970. But subsequent declines in fertility have caused population growth rates to decline considerably. Today, global population growth is around 1.2%, and in the medium variant projection of the UN, is projected to return to the very long run historical levels of 0.5%. As UNWPP (2005) states, "The rapid [population] growth of the twentieth century may come to be seen as an extraordinary but historically isolated phenomenon."

One of the most fundamental questions in the long history of thought in development is whether population growth was a threat to economic development, a fear that reached its height a few decades ago when "population explosion" led to fears of mass starvation and famines. The idea that population growth was a threat to development received its earliest important articulation from Malthus (1798):

"Taking the population of the world at any number, a thousand millions, for instance...the human species would increase in the ratio of 1, 2, 4, 8, 16, 32, 64, 128, 256, 516, etc. and subsistence as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, etc. In two centuries and a quarter the population would be to the means of subsistence as 512 to 10; in three centuries as 4096 to 13, and in two thousand years the difference would be incalculable."

Thus progress in food production is always threatened by population pressure. And although agricultural innovations and discoveries of new resources may cause improvements in standards of living, these can only be temporary. Rising prosperity sets in motion more rapid population growth, which drags living standards back to subsistence levels. Malthusian pessimism was reawakened in the 60s, as exemplified by Ehrlich (1968): "The battle...is over. In the 1970s hundreds of millions of people are going to starve to death."

The later half of the 20th century has proved alarmist versions of pessimism to be wrong. At a global level, these have been periods of rapid population growth AND rapid economic growth. In the past few decades, world per capita incomes have increased by about 2/3rds and the world population has grown by over two billion (Bloom, Canning, and Sevilla 2002). Famines have occurred but Ehrlich's "hundreds of millions" of people have not starved. Technological progress, in both agriculture and industry, has been more rapid than at any other time in human history. There have been equally dramatic social and institutional innovations, in the

ways people work, the standard of their education and health, and the extent to which they participate in the political process. Rather than being constrained by fixed resources, the world sees the prices of raw materials in long-term decline; inflation (for the moment at least) quite low; and some parts of the economy becoming 'dematerialized' as the knowledge revolution kicks in.

While alarmist accounts seem largely and appropriately discredited, there remain more sober and carefully reasoned accounts of why large populations and high population growth pose challenges for development. One focuses on the possible effect of population growth in "diluting" a society's material resources, which have to be spread out over more people. In the canonical Solow (1957) model of economic growth, which remains the foundation of the modern economics profession's view of the relationship between population growth and economic welfare, population growth lowers levels of per capital consumption because productive resources need to be spread out over a larger number of people, lowering each person's stock of productive resources, and therefore that person's product and well-being. Another strand focuses on the possible effect of population growth in "diluting" a society's human capital. Larger population growth invariably occurs through growing numbers of dependent children that jeopardize society's and households' capacities to invest sufficiently in their nutrition, health, and education (Becker and Lewis 1973). In both cases of dilution of physical and human capital, economic growth is threatened, and the likelihood of poverty rises.

However while pessimism has centered around the idea that population "dilutes" either natural resources, physical capital, or human capital, a rival optimist view has focused on the potential positive impact that population growth might have on ideas, innovation, and technology. Optimism has an older and equally venerably lineage as pessimism. As early as 1682, William Petty argued that larger populations meant more innovation

"As for the Arts of Delight and Ornament, they are best promoted by the greatest number of emulators. And it is more likely that one ingenious curious man may rather be found among 4 million than 400 persons....And for the propagation and improvement of useful learning, the same may be said....(1682/1899, p. 474, quoted in Simon, 1986)"

More recently, optimist views have been expressed by Simon Kuznets (1967) and Julian Simon (1981), who argue that population increases serve to augment the stock of human ingenuity, allow economies of scale. Boserup (1981) argues that population growth creates pressures on resources, but thereby stimulate innovations to counteract these pressures. Thus innovation is borne of adversity.

2. Concepts related to population composition:

2.1. Gender

*Population sex ratio* is the number of males per 100 females in the population

*Sex ratio at birth* is the number of male births per female birth

According to Sen (1990), the ratio of women to men in the population is about 1.05 in the developed world, but as low as 0.95 in some parts of the developing world, particularly in South and West Asia and China. This simple statistic raises profound issues that need to be understood. At birth, males always tend to outnumber females by about 1.05 male births for every female birth. However, after birth, biology always seems to advantage women. As Sen (1990) says "Considerable research has shown that if men and women receive similar nutritional and medical attention and general health care, women tend to live noticeably longer than men. Women seem to be, on the whole, more resistant to disease and in general hardier than men, an advantage they enjoy not only after they are forty years old but also at the beginning of life, especially during the months immediately following birth, and even in the womb. When given the same care as males, females tend to have better survival rates than males." The fact that the ratio is so low in part of Asia led Sen to theorize that women are dying sooner because of social gender bias in the allocation of resources such as food, health care, and social services. This gender bias is not exclusively a function of poverty. Sub-Saharan Africa, which is the poorest continent, has a relatively healthy female to male ratio of 1.02. And in India, some of the wealthiest states have low ratios and some of the poorest states have high ratios. Estimating how many women ought to have been alive in such gender biased societies by using the female to male ratio of 1.05, Sen estimated that there are 100 million "missing women." About a decade after, however, Oster (2005) proposed that hepatitis B may account for about 45% of the missing women problem, so that gender bias cannot provide a full account of the problem, and that disease epidemiology is an important component of it. Pregnant women with hepatitis B, for reasons not yet fully understood, are far more likely to give birth to boys than girls: the sex ratio at birth is 1.5 boys per girl. Hepatitis B is also prevalent among the countries in which there seems to be missing women.

### 2.2. Age

The sizes of the different age groups in a population is critical. This is because people of different ages have different socio-economic functions in a population. The young have to be fed, clothed, housed, schooled, and cared for health-wise. They are net consumers of resources, in that they usually consume more resources than they produce through their work. Adults, on the other hand, are net producers of resources, and are the primary age group upon which society relies for productive economic activity. It is the surplus of their economic product over and above their own consumption that is allocated for the consumption needs of the young and the elderly. And in old age, a final reversal takes place. The elderly, like the young, return to being net consumers of resources. The old either live off their savings from their adult lives, or are dependent on state- or family-provided support.

Recent work in demographic economics has reawakened interest in population age structure and its relevance for policy. This work has centered around the theory of the *demographic transition.* This theory claims that pre-modern societies experience simultaneously high levels of

mortality and fertility, which jointly produce a relatively stable population size with low average age. A *mortality transition* then occurs, coincident with modernization and improvements in public health and nutrition, through which mortality rates decline, especially among children, causing rapid population growth and a decline in the average age of the population. With a lag of variable lengths across countries, the mortality transition thereafter causes the emergence of a *fertility transition*, which occurs as fertility decreases in response to mortality reductions. This decline in fertility creates a baby boom generation whose movement through the population age structure has excited development theorists for their potential to facilitate economic growth. After both mortality and fertility transitions have taken place, population dynamics restabilize at low fertility and mortality rates, and older populations.

The demographic transition creates a baby boom generation that winds its way through a population's age distribution. When this baby boom generation is young, it raises the youth dependency burden of a population, which may depress savings and therefore economic growth (Coale and Hoover 1958), and poses challenges associated with investing in the health and education of the young. When this baby boom generation reaches working age, it creates special opportunities for growth—called the *demographic dividend*—in the form of extra labor supply, higher savings, and higher human capital (Bloom, Canning, and Sevilla 2002). And when this baby boom generation ages, it creates special challenges in the form of greater social security, health, and pension demands. These issues are discussed more fully in a subsequent framework paper.

#### 2.2.1. Median age

Age that divides the population in two parts of equal size, that is, there are as many persons with ages above the median as there are with ages below the median.

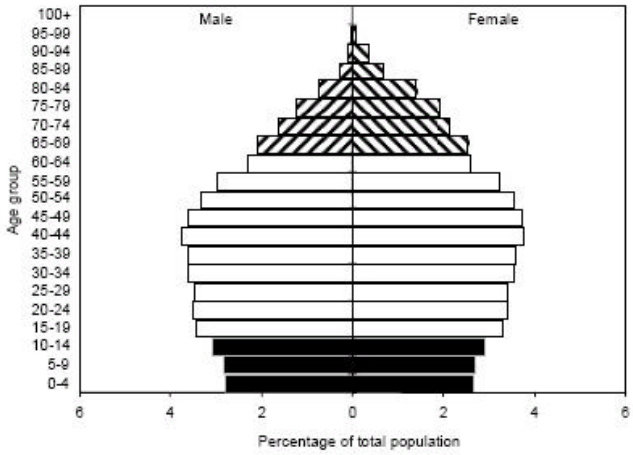
#### 2.2.2. Youth dependency ratio
#### 2.2.3. Old age dependency ratio
#### 2.2.4. Total dependency ratio

The *total dependency ratio* is the ratio of the sum of the population aged 0-14 and that aged 65+ to the population aged 15-64. The *youth dependency ratio* is the ratio of the population aged 0-14 to the population aged 15-64. The *old-age dependency ratio* is the ratio of the population aged 65 years or over to the population aged 15-64. All ratios are presented as number of dependants per 100 persons of working age (15-64).

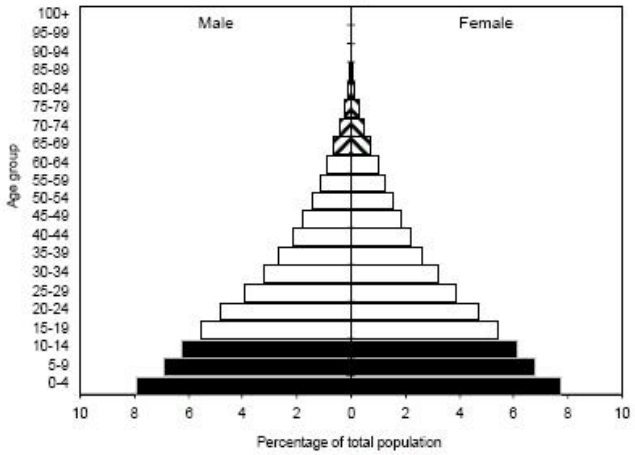
The age structure of populations is often described graphically through *population age pyramids* such as the following, excerpted from UN (2005)

**Figure II.1. Population pyramids, by development group, 2005**

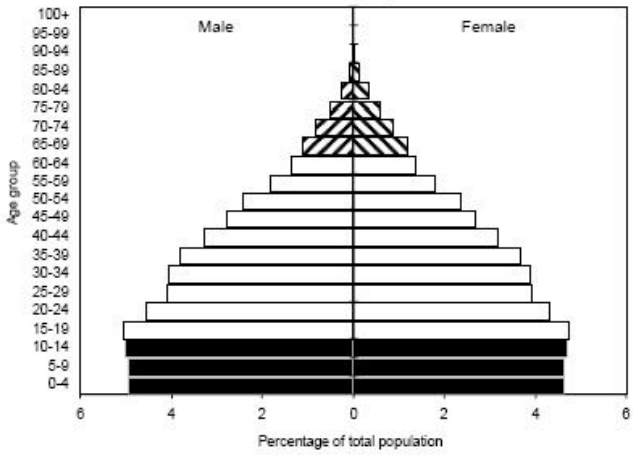
*A. More developed regions*




*B. Least developed countries*




*C. Other less developed countries*



These age pyramids reflect the differences in the extent to which the developed and less developed countries have undergone the demographic transition. As can be seen, the low levels of fertility and mortality in developed countries are reflected in a pyramid which is fatter around the ages 40 and up. In contrast, less developed countries which still have high fertility rates still have very young age structures.

2.3. Urban/rural
*Urban population*-population living in areas classified as urban
*Rural population*- population living in areas classified as rural

3. Concepts related to births and fertility

The *crude birth rate* is the number of births over a given period divided by the person-years lived by the population over that period. It is expressed as number of births per 1,000 population.

The *net reproduction rate* is the average number of daughters a hypothetical cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates and the mortality rates of a given period. It is expressed as number of daughters per woman. It can also be interpreted as the average number of surviving daughters a woman would bear over the course of her lifetime, taking into account female mortality risks from birth through the end of the reproductive period. When the NRR is greater than one, then an average woman is replaced by more than one daughter, and implies that a population has an intrinsic tendency to grow. When NRR is less than one, women are not sufficiently replaced and a population has an intrinsic tendency to decline. And when NRR is one, then a population has neither an intrinsic tendency to grow or decline.

The *total fertility rate* (TFR) is the average number of children a hypothetical cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality. It is expressed as children per woman.

*Replacement fertility* is a TFR of 2.1, which is the number of live births required to numerically replace a child's parents, with the excess 0.1 percentage point to allow for the probability that children might die.

Sometimes, TFR is contrasted with the *completed* or *cohort fertility rate* or CFR which is the actual average number of children born to a particular cohort of women. By definition, the CFR cannot be computed until a particular cohort finishes its childbearing years, and so it is rarely explicitly computed and is usually approximated by TFR.

The *fertility transition* is the process whereby a country, after experiencing historically high and stable levels of TFR above 6 children per woman perhaps for centuries, begins a transition, usually lasting a few decades, in which fertility declines rapidly resulting in levels of TFR below 3, and sometime below replacement. The causes of the fertility transition remain unsettled and are discussed more fully in a subsequent framework paper.

*Population momentum* refers to the impact that the size of the reproductive age cohort in a population has on the size of the cohort of infant and children of that population. The size of the birth cohort is a function of two things, the number of children per reproductive age woman, and the number of reproductive age women. Thus, a population that has a large cohort of reproductive age women will tend, all else equal, to produce larger cohorts of young children, who will in turn when they reach reproductive age, produce their own larger cohorts of young children.

4. Concepts related to deaths and mortality

The *crude death rate* is the number of deaths over a given period divided by the person-years lived by the population over that period. It is expressed as number of deaths per 1,000 population.

*Life expectancy* is the average number of years of life expected by a hypothetical cohort of individuals who would be subject during all their lives to the mortality rates of a given period. It is expressed as years.

Some important notation:
$e_x$ is the number of additional years of life that can be expected for a person of age *x*. For example, $e_0$ is life expectancy at birth, $e_{60}$ is the life expectancy at age 60.
${}_xq_y$ is the mortality risk between the ages of *y* and *y*+*x*. For example, the *adult mortality rate*, which is the probability that a 15 year old will die before reaching the age of 60 is denoted by ${}_{45}q_{15}$; the *child mortality rate*, which is the risk of dying before the age of 5 is ${}_5q_0$; and the *infant mortality rate*, which is the risk of dying before the age of 1, is ${}_1q_0$.

The *adult survival rate* is the probability that a 15 year old will reach the age of 60 alive, and is given by 1 minus the adult mortality rate or $1-{}_{45}q_{15}$.

A *cohort* is a group of people in a population that are connected by some event. For example, a *birth cohort* is a group of people who are born in the same year. A population's 1970 birth cohort consists of all people in the population who were born in 1970. A *baby boom cohort* refers to those members of a population who were born subsequent to the mortality transition and prior to the fertility transition. This baby boom cohort is larger than the birth cohorts that preceded the mortality transition, and the birth cohorts that succeeded the fertility transition.

*Population aging* is the process whereby the median age of the population rises. It happens as a result of the demographic transition. In the initial stages of the mortality transition, reductions in mortality disproportionately occur among the young, thus lowering the age of the population. However, as the mortality transition progresses, mortality among adults and the elderly decline significantly as well. Thus as the youth cohort ages, it can also expect to live longer since it experiences lower adult and elderly mortality, contributing to population aging. Furthermore, as the fertility transition starts, the number of young people in the population declines, further contributing to population aging.

The *rate of natural increase*, defined above, is also equal to the crude birth rate minus the crude death rate.

5. Concepts related to migration

> The *net migration rate* is the number of immigrants minus the number of emigrants over a period, divided by the person-years lived by the population of the receiving country over that period. It is expressed as net number of migrants per 1,000 population.
>
> The *net number of migrants* is the number of immigrants minus the number of emigrants. It is expressed as thousands.

Migration is driven primarily by differences between countries and the desire of people to take advantage of these differences to improve their lives. The most important of these are differences in income, technology, and age structure. As Pritchett (2003) states, in the early nineteenth century, the world was almost uniformly poor, and material well-being did not much vary across political boundaries, but today these variations are vast:

> Bourguignon and Morrison (2002) estimate that in 1820 only about ten percent of the differences in incomes among all individuals in the world was due to differences in average incomes across countries. This has shown a steady increase and today over 60 percent of the inequality in the world today is because of differences in incomes across countries.

In addition, the wage gaps that gave rise to the era of great migration from Europe to the lands of recent settlement in the late nineteenth century seem small relative to the wage gaps that currently exist between migration partners:

> The wage ratios between Japan and Vietnam (9.1) or the UK and Kenya (7.2) or the USA and Guatemala (6.1) are substantially larger today than the historical ratios between the mass senders and the USA (Ireland, 2.3, Sweden 4.1).

The traditional theory of economic growth (Solow, 1956) predicted convergence, that is, that poor countries will tend to grow faster than rich countries and catch up with them. This would

reduce the wage and income gaps and therefore migration pressures. Yet this has not occurred. Rather, Pritchett (1997) argues that convergence only occurs among the developed countries, and that divergence is at least as good an explanation of the differences in economic performance between developed and developing countries, and within the developing countries themselves. The persistence of wage and income gaps implies that economic incentives for migration are likely to remain high.

The second important difference is technological. Developed country workforces are more educated and have higher human capital than those of developing countries, reflecting the greater role of human capital in their technologies. Such workforces have little incentive to perform low-skilled work such as housekeeping or cleaning services, the harvesting of agricultural crops, low-skilled services such as security or taxi driving, or even teaching at public schools. These goods and services have two additional characteristics. They are non-tradable (that is they have to be produced locally because you cannot import a clean bathroom) and possibilities for substitution of inputs in their production is low (there are limits to replacing low-skilled service workers with, say, machines). Developed country demand for low-skilled migrant workers exists because some goods and services consumed by developed country populations have these three characteristics: intensiveness in the use of low-skilled workers, non-tradability, and difficulty of substitution.

A final difference is demographic. We are coming to understand that there is an intimate relationship between the age structure of a population and its migration flows. Two mechanisms are important (Hatton and Williamson, 2003). First, migration propensities are especially high among young adults. Second, populations with a large share of elderly require the inflow of adult migrants to prevent rising dependency ratios and support pay-as-you-go welfare systems. Labour immigration of particular occupational categories such as nurses, doctors, and caregivers, also satisfies the growing health services needs of aging populations. Because the demographic transition occurred first among the developed countries, and only afterwards among the developing countries, the elderly-rich phase of the former is coinciding with the adult-rich phase of the latter. The pull from the developed countries is coinciding with the push from the developing countries. While we might expect age structures across countries to converge over the course of the twenty-first century, reducing the demographic pressures for migration (Malmberg, 2004), these demographic disparities are likely to exist for at least a few decades more.

Between 1975 and 2000, the number of international migrants, defined by the UN as persons living outside their country of birth or citizenship, doubled to 175 million (Martin, 2004). It is not easy to predict what the future of migration will be. Some trends, including job outsourcing, trade liberalization, and age structure convergence across countries, might reduce migration pressures. Yet, on the whole, the disparities in income, technology, and age structure are likely to remain with us for at least the next few decades, and technological and cost barriers to movement are likely to continue to decline, so it is likely that pressures for migration will remain high, at least over the next half century.

As UNWPP (2005) notes, most of international migration in Africa occurs across countries within Africa, and therefore shows up in country-level data, but not continent level data. The most important migratory outflows from Africa are from Northern Africa to Europe and to Western Asian oil producers, as well as from sub-Saharan Africa to Europe, Australia, Canada, and the US.

6. Projections, data, models

Demographic data are critical to understanding societies and designing policies, and yet the considerable difficulties and obstacles to producing high quality demographic data are frequently underestimated. The data underlying demographic systems are often collected from three sources (Population Reference Bureau 2004). Censuses count the number, age, and sex of all persons within well-defined areas and time-periods. Civil and vital statistic systems count the number, age, and sex of all persons born, dying, married, and divorced within a population on an ongoing basis. Surveys collect other demographically relevant information, including educational attainment, household structure, and measures of socio-economic status.

Difficulties related to such data sources are many. In the first place, many developing countries do not have the resources, infrastructure, manpower, or expertise to conduct such data collection efforts. Thus countries may hold censuses infrequently, or may not have comprehensive vital registration systems, so that one or more of these three traditional data sources is not available. According to the UN, two countries do not have census or demographic data sources after 1975, 13 countries do not have such data after 1985, 32 countries do not have data after 1995, and about 121 countries have data after 1995 (United Nations 2005). Some progress has been made in the past few decades with respect to data collection in developing countries. This has occurred through the increasing collaboration and sharing of expertise between the United Nations' Statistics Division and developing countries' census and statistics offices. However where such fundamental census data are missing, the UN must resort to indirect estimation techniques, in extreme cases making inferences using data not on the countries themselves but from adjacent countries facing roughly the same demographic and socio-economic realities.

Demographic data collection in the developing countries has also been advanced by the Measure DHS (Demographic and Health Surveys) project which has since the mid-1980s conducted demographic surveys in over 200 surveys in 75 developing countries by drawing large nationally representative samples of reproductive age women to obtain data on fertility, family planning, maternal and child health, child mortality, and more recently data on topics such as HIV/AIDS, anemia, and violence against women. The success of the DHS is reflected in a relatively high percentage of countries having relatively recent information on both fertility and child mortality. The UN (2005) estimates that 178 out of 192 countries had post-1995 data on fertility--including coverage of about 81% of African populations—and 186 countries had post-1995 data on child mortality.

The most serious data shortfalls are in the area of adult mortality and international migration. The UN (2005) estimates that adult mortality data were lacking or of insufficient quality over 91% of Africa on a population basis. This means that UN estimates of life expectancy at birth should not be interpreted as being based on real data on age specific mortality rates through the full life cycle, but rather on the basis of child and infant mortality data supplemented by demographic modeling techniques and data from model life tables. The scarcity of adult mortality data is made especially acute by the HIV/AIDS epidemic, wars and strife, and accidents and injuries which all have profound effects on adult mortality, particularly in Africa. The second area of data collection concern is international migration where collection efforts are widely seen as inadequate. In practice, estimates of net international migration are obtained as residuals: they are measured so as to make measures of population change and rates of natural increase consistent across periods.

Data availability is only one challenge. Even when data sources exist, their quality can be suspect. Censuses may undercount some hard to reach populations, such as groups living in remote areas. People may have poor recall of their own or their family members' ages or birthdays. Many births and deaths may occur without being recorded in vital registration systems. People may have imperfect recall about their or their family members' educational attainments, and they may not have an incentive to accurately report measures of their socio-economic status. When data is scarce, they must often be interpolated or extrapolated from existing datasources using demographic models. When multiple data sources exist, as for example when a civil and vital registration system and a DHS survey yield conflicting estimates of fertility or child mortality, such discrepancies must be reconciled. And finally, data must be rendered comparable across countries.

The major sources of publicly accessible and cross-country comparable data include the United Nations Statistics Division's Demographic Yearbook which has been published annually since 1948, the United Nations Population Division's biennial World Population Prospects which includes demographic data from 1950 onwards and predictions of demographic trends till 2050, the United Nations Statistics Division's Population and vital statistics report issued quarterly, and the Population Reference Bureau's World Population Data Sheet.

Though historical data on demographic processes are of great importance for policy planners, projections into the future are perhaps equally so. Each of the three fundamental concepts in the demographic equation, fertility, mortality, and migration, is projected forward by the UN for a period of a half century.

With respect to fertility projections, the UN divides countries into three categories. High fertility countries are those which, by 2005 had experienced little or no fertility decline, i.e. those that had not yet begun what is called the *fertility transition*. Medium fertility countries were those that had started their fertility transition by 2005 but whose fertility rates remained above 2.1. Low fertility countries are those whose fertility levels were below 2.1 in the year 2005.

In the long-run, the UN assumes that all countries will converge to a fertility rate of 1.85, though the three different groups of countries will achieve that rate on different time scales.

Each country's transition to the assumed long-run fertility rate is estimated using demographic models of fertility change over time which were developed using the historical experience of countries that underwent their fertility transitions from 1950 to 2000. That historical experience suggests that the transition begins slowly--usually with fertility rates above 5--then accelerates as fertility falls below five, and then slows down again towards the end of the transition. This basic assumption is embodied in a demographic model that can be used to predict fertility trends in all countries on the basis of past and present fertility rates. Thus the UN projects that high fertility countries will not begin their fertility transitions until the year 2010, and will not reach the long-run fertility rate of 1.85 until 2083 at the earliest and perhaps not until after 2100. Medium fertility countries, on the other hand, are expected to reach their long-run fertility rate of 1.85 in between 40 to 60 years from now.

As stated previously, due to the scarcity of adult mortality data, historical data on life expectancy constructed primarily from data on infant and child mortality supplemented by demographic modeling that employs model life tables. The UN's life expectancy projections assume that life expectancy will continue to improve across all countries generally, continuing the rather remarkable reductions in mortality that the world has experienced over the past two centuries. Just as cross-country variations in fertility rationalize disaggregating countries into three groups, variations in mortality experience have rationalized distinguishing between 5 different rates of improvement in life expectancy from 1950 to 2000 ranging from the very fast (reflecting rates of life expectancy growth in the 90$^{th}$ percentile of cross-country performance), fast (75$^{th}$ percentile), medium (50$^{th}$ percentile), slow (25$^{th}$ percentile), and very slow (10$^{th}$ percentile). All these five regimes, however, share the feature that low life expectancies are associated with slow life expectancy growth similar to the historical experience of countries prior to their demographic transitions, with life expectancy growth increasing during the early stages of the demographic transition as life expectancy reaches the years 50 to 60, and slower life expectancy growth thereafter.

The major exception to the general assumed trend in increasing life expectancy arises due to the impact of the HIV/AIDS epidemic on population-level mortality. The UN explicitly makes special population projections for the almost 60 countries with population HIV prevalence rates of at least 1%, as well as such as the United States, Brazil, India, and China where the combination of low prevalence but large populations results in large numbers of individuals with HIV. Contributing to the need for explicit consideration and modeling of the HIV epidemic is the fact that the vast majority of AIDS mortality occurs among adults. Not only does this mortality strike at the population age group on whose mortality the data is most scarce, it also pushes the age structure of mortality in these populations away from the standard pattern of high mortality at the early and later ages and low mortality in the prime adult years that is most often reflected in standard model life tables.

The distinctive dynamics created by the HIV/AIDS epidemic leads the UN to model two separate mortality processes: the mortality caused by the epidemic itself and the mortality that occurs in the non-infected population, the latter referred to as "background mortality."

Modeling the mortality caused by the epidemic requires, as its first step, estimates of annual HIV incidence rates, that is, the probability that an uninfected individual will be infected within the timespan of one year. This number is usually obtained from HIV status data among pregnant women attending antenatal clinics (ANCs). Though there are well known obstacles to extrapolating such incidence and prevalence numbers to non-pregnant women and to men, the relative paucity of population-level data usually leads the UN to assume that these ANC data are broadly representative of HIV incidence and prevalence among women in general and among men. Future projected trends in the epidemic are derived using data that are fed into a software package called the Epidemiological Program Package (EPP) (Ghys et. al. 2004). This software treats a national epidemic as a combination of sub-epidemics (e.g. urban epidemics and rural epidemics), each of which can be modeled using a simple epidemic model created by the UNAIDS Reference Group on Estimates, Modeling, and Projections. This model asks for some data inputs from the user—specifically population sizes and ANC prevalence rates, though more recently input data can include ART coverage rates and survival rates--and then uses these inputs to estimate four quantities: the fraction of individuals who entered the at risk population at age 15 at the start of the epidemic, the probability that an interaction between an uninfected and infected individual will result in a new infection, the recruitment of people into the at risk population, and the year that the epidemic started. This model can then take these parameter estimates and data, and then use them to derive future projections of the annual number of adults living with HIV, the number of susceptibles and non-susceptibles, the number of new infections, and the number of deaths.

Projections of international migration are even more difficult because of the scarcity of migration data, the volatility of population flows, and their sensitivity to regional and national variations in socio-economic and political forces. The UN, in making its projections, distinguishes between international migration and movement of refugees, and makes separate assumptions for each of these components. Refugees are generally assumed to return to their home countries within 5 to 10 years. With regard to international migration, it is simply assumed that in general, if a country has stable patterns of migration flows, that those patterns would simply continue. Of the world's countries, about 15 do not have a history of significant inflows and outflows of persons, and so have projected net migration levels of zero. About 10 countries do not have international movement of persons other than because of refugee movements, and for these countries, net migration is projected to fall to zero sometime between 2005 and 2025. Of the remaining 167 countries, projected net migration is assumed to follow historical patterns relatively unchanged.

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