affect international food markets and the global food balance.

China is already among the largest emitters of carbon dioxide in the world. Population growth is viewed as one of the decisive factors that will drive future climate change. New research suggests that, in addition to population size, changes in population structure, urbanization, and household size also contribute to climate change. Urbanization leads to a substantial increase in carbon emissions, whereas the aging process leads to a decrease. The net effect of demographic change is to increase projected emissions for China by 45% over time (*42*). However, the demographic impact on climate change should not be overstated, as it accounted for only one-third of the country's emission increase; industrialization, urbanization, and consumption are more important factors determining future carbon emissions in China (*43*).

Demographic changes in China will have important global impacts. Given all of the factors discussed above, a future population decline may be desirable for China. But rapid or even sudden population decline would be disastrous, and it would be very difficult to stop. Maintaining the present low fertility would be worrisome. Overall, it would be rational for China to modify its current population policy and to relax the rigid control on childbearing sooner rather than later, and to allow the TFR to grow and be maintained at around 1.8 in the near future. Then the country's population would decline and its aging process would be slower in the future, which would provide more time and a better social environment for China to cope with future population-related socioeconomic changes. China's population issues should be dealt with in an integrated and balanced way.

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REVIEW

Global Human Capital: Integrating Education and Population

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Almost universally, women with higher levels of education have fewer children. Better education is associated with lower mortality, better health, and different migration patterns. Hence, the global population outlook depends greatly on further progress in education, particularly of young women. By 2050, the highest and lowest education scenarios—assuming identical education-specific fertility rates—result in world population sizes of 8.9 and 10.0 billion, respectively. Better education also matters for human development, including health, economic growth, and democracy. Existing methods of multi-state demography can quantitatively integrate education into standard demographic analysis, thus adding the "quality" dimension.

Human beings have many observable and measurable characteristics that distinguish one individual from another; these characteristics can also be assessed in aggregate and used to distinguish one subgroup of a population from another. Here, we focus on the level of highest educational attainment in age and gender subgroups. In virtually all societies, better educated men and women have lower mortality rates, and their children have better chances of survival (*1*). Almost universally, women with higher levels of education have fewer children, presumably because they want fewer and find better access to birth control (*2*). This effect of education on fertility is particularly strong in countries that still have relatively high overall fertility levels and hence are in the early phases of their demographic transitions (*3*). There are many reasons to assume that these pervasive differentials are directly caused by education, which enhances access to information, changes the motivations for behavior, and empowers people to better pursue their own preferences, although causality can only be proven for specific historical settings (*4*). For the following projections by level of education, it is sufficient to assume that the systematic associations will continue to persist over the coming decades as they have for more than a century for virtually all populations for which data exist.

In demography, the gender of a person is considered a fundamental characteristic because it is essential for studying the process of reproduction. Mortality and migration also show strong variation by gender. Age is another key characteristic of people because it is the main driver of biological maturation in the young, and age also matters for social institutions such as school attendance, labor force entry, and retirement. Because there are distinct patterns of fertility, mortality, and migration with age, gender and age are conventionally considered the two most fundamental demographic dimensions (*5*). However, there are many other biological, social, and economic characteristics of people that demographers are taking into account: These include place of residence (and whether urban or rural), citizenship, marital status, educational attainment level, race, migration status, employment status, income group, and health and disability status.

It has been argued recently that among these, educational attainment level is the single most important source of observable population heterogeneity that should be routinely added to population analyses based on three criteria (*6*, *7*): (i) Its explicit consideration should be feasible in terms of available data and methodology; (ii) it should matter substantially in terms of altering population dynamics; and (iii) it should be of interest in its own right in terms of its social and economic implications. The following sections will address these criteria separately. Such an integration of education can also be interpreted as adding a "quality" dimension to the mere consideration of the quantity of people.

Human capital is usually defined to encompass both the education and health of people. Although health is an important prerequisite for effectively attending school at young age and health matters for economic productivity at adult age, here we will focus primarily on the education component because it can be measured more consistently across countries and because a dynamic new field of analysis has recently developed in the area of demographic education modeling.

When measuring education, it is important to distinguish conceptually between education flows and stocks. The flows refer to the process of education, to schooling, or more generally the production of human capital, which may consist of formal and informal education. This process of education is the central focus of pedagogics and education science, in which the usual statistical indicators are school enrollment rates, student-teacher ratios, drop-out rates, and repetition rates. Human capital refers to the stock of educated adult people, which is the result of past education flows for younger adults in the more recent past and for older ones quite some decades ago. This stock is usually measured in terms of the quantity of formal education (highest level of attainment or mean years of schooling), but the quality dimension (the general knowledge and cognitive skills people actually have) and content or direction of education also matter. For countries for which data on cognitive skills of the adult population exist, they have shown to have a significant impact (*8*), but the number of these countries is still very limited. Content of education matters more for higher education than for basic education, in which the main aim is the acquisition of literacy skills and basic numeracy. The quantity of formal education is often measured by the mean years of schooling of the adult population above either the age of 15 or 25 years. This has the advantage of capturing the entire human capital of a population at one point in time in one single number (or two when distinguishing between men and women). However, there is much to be gained from decomposing this highly aggregate indicator into the full distribution of educational attainment categories (and thus capturing the differences in the composition of education stocks across countries and regions) and into different age groups and hence capturing inter-cohort changes that drive many of the consequences of improving human capital on society and economy.

Populations by Age, Sex, and Levels of Education

Consistent time series data on educational attainment that are comparable across a large number of countries are difficult to obtain. Theoretically, the data by age, sex, and level of education should be available from the censuses and many representative surveys. In practice, these data are almost impossible to compare across countries and over time because of differing definitions of education categories despite efforts by the United Nations Educational, Scientific and Cultural Organization to standardize classifications in the form of the ISCED (International Standard Classification of Education) categories. This makes the comprehensive statistical analysis of the various benefits of improvements in educational attainment for societies and economies across the world and over time difficult to calculate precisely. Hence, several groups of scientists have tried indirectly to estimate consistent international time series of human capital data (*9*–*13*). In most cases, this was done by combining information from time series of school enrollment rates with the existing fragmentary information on attainment while trying to iron out national peculiarities. Demographic multi-state models (*14*, *15*) offer an alternative approach that can deal with age- and sex-specific reconstructions and projections of human capital in a unified framework that also considers educational mortality and fertility differentials.

The methods of multi-state population dynamics are a generalization of the conventional cohort-component method of population projection, which only stratifies populations by age and sex. In the multi-state model (also known as multidimensional mathematical demography), additional dimensions are added that subdivide the population into different states that all have their specific fertility, mortality, and migration patterns. The methodology was developed during the 1970s in and around the International Institute for Applied Systems Analysis (IIASA) (*14*, *15*), originating from a geographic perspective in which the states were defined to be regions of a country, with the populations interacting through internal migration. Later, this concept was generalized, and states were defined to include marital status as well as health (such as disabled and non-disabled) (*16*) or different types of households (*17*).

Multi-state methods are particularly appropriate for modeling changes in educational attainment. The model is simplified by the fact that transitions from one state to another only go in one direction (people only move up to higher attainment categories) and that the transitions are concentrated at younger ages. Furthermore, fertility and mortality levels tend to vary greatly and systematically by level of education, and hence, the explicit consideration makes a crucial difference, as discussed below.

In applying these methods for projecting backward (reconstruction) or forward (into the future), one has to have at least one data point for which the size and structure of the population by age, sex, and level of educational attainment is available

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empirically. The empirical data set for each country used here (*13*, *18*) refers to dates around the year 2000. Given this information, the basic idea of projecting is straightforward: Assuming that the educational attainment of a person remains invariant after a certain age, one can derive the proportion of women without any formal education aged 50 to 54 years in 2005 directly from the proportion of women without any formal education aged 45 to 49 years in 2000 and vice versa by considering the mortality and migration rates between those ages. One can make further adjustments for the fact that higher education levels can still change after age 15 and that fertility, mortality, and migration vary by level of education.

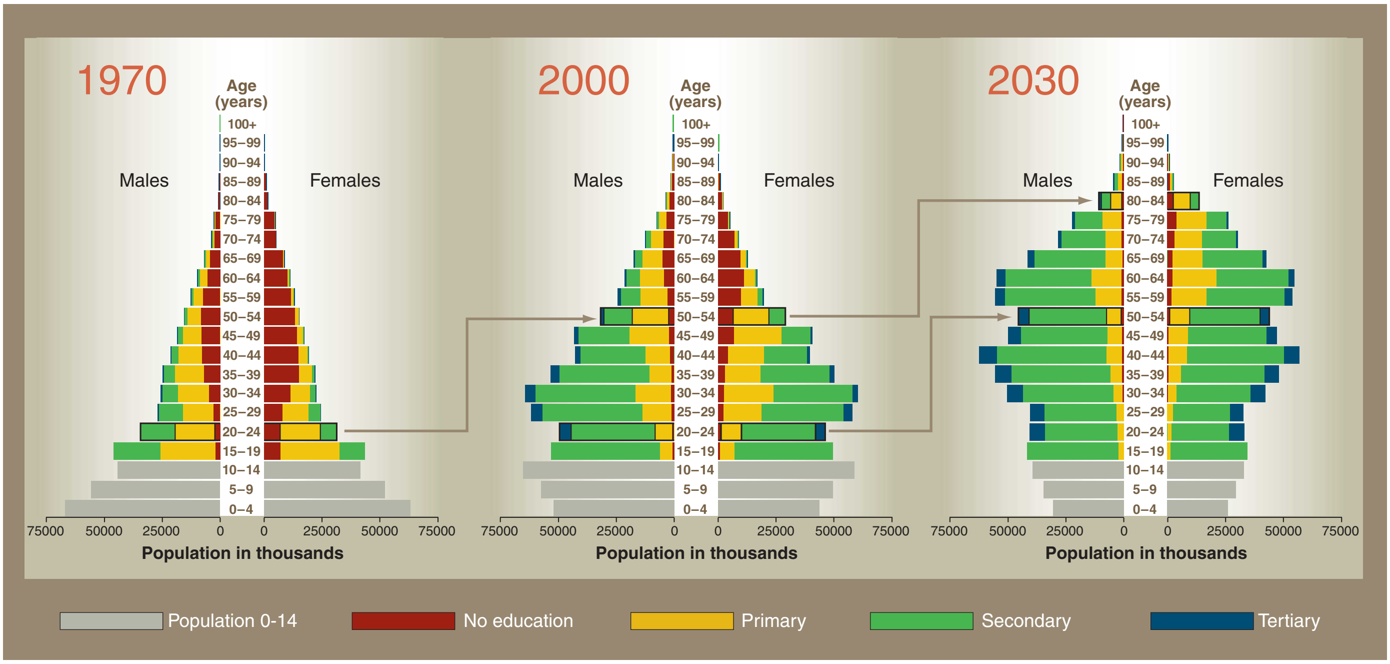

Fig. 1. Age and education pyramids for China in 1970, 2000, and 2030. Colors indicate highest level of educational attainment. Children aged 0 to 14 are marked in gray. Sources are (*13*, *18*).

Explore pyramids for more countries at www.scim.ag/phYT60

This dynamic is illustrated in Fig. 1 with the example of China, which is not only the world's most populous country but also experienced one of the most rapid fertility declines together with a phenomenal education expansion. The analysis begins with the age and education pyramid for 2000. Red indicates the number of men and women without any formal education. They still form a majority among the elderly population. Orange indicates persons with some primary education; green indicates persons who have completed junior secondary, and dark blue indicates a completed tertiary education. The figure also shows that today, younger cohorts are much better educated than their elders. Reconstructing the education structure for the year 1970 follows the above-described procedure along cohort lines: Those aged 50 to 54 years in 2000 were aged 20 to 24 years in 1970. The same procedure is applied for forecasting, in which the cohort aged 20 to 24 years in 2000 will be aged 50 to 54 years in 2030 and will essentially maintain its proportions with primary and secondary education. Only the tertiary category may still be joined by some after the age of 20 to 24 years. This figure also illustrates that much of the future improvement in the educational attainment of the adult population is already embedded in today's education structure. Future changes in school enrollment rates will only make a difference for younger cohorts.

Mother's Education Is Key

A great deal of research has focused on substantiating the independent and causal relationship between maternal schooling and child health (*19*, *20*). Reviews of surveys and census data from developing countries (*21*, *22*) and econometric analyses of cross-country macro-data have confirmed women's education as the most important determinant of child mortality, in which estimates show that each additional year of schooling is associated with a 5 to 7% reduction in child death. (*22*, *23*).

A systematic assessment for a large number of developing countries using recent DHS (Demographic and Health Survey) micro-level data finds that almost universally, a mother's education is more important for child survival than is household income and wealth. This finding has major implications for setting policy priorities because whether the emphasis is put primarily on girls' education or on household income generation makes a big difference.

The magnitude of empirically measured child mortality differentials in a selection of developing countries is shown in Table 1. The indicators for the <5-years mortality rate and the total fertility rate are compiled from DHS (*24*) for the most recent surveys (after 2004). The <5-years mortality rate is high in many African countries, especially among the children of uneducated mothers. The worst situation is in Mali and Niger. In every country, the mortality rates are lower for better educated mothers. In some countries, primary education is already associated with much lower child mortality (such as in Nigeria and Bolivia); in others, the decisive difference only comes with secondary education (such as in Liberia and Uganda).

In terms of fertility—measured as the number of live births per woman—the educational differentials are equally pervasive. Although fertility rates have seen strong declines in most of Asia and Latin America, in sub-Saharan Africa there is still an average of five children per woman, with countries such as Niger as high as seven children per woman. In virtually every society, better educated women have lower fertility than do less educated women. At one extreme is Ethiopia, where uneducated women have on average more than six children, whereas those with secondary education have two children on average. Better educated women have lower desired family sizes because they tend to face higher opportunity costs and tend to put more emphasis on the "quality" of lives of their children (*25*). Empirical studies show that better educated women consistently want fewer children, have greater autonomy in reproductive decision-making, more knowledge about and access to contraception, and are more motivated to use contraception because of the higher opportunity costs of unplanned childbearing (*2*, *26*).

Female Education and Population Growth

Because female education is associated with lower fertility at the individual level, populations with higher proportions of better educated women have lower overall birth rates. Because this factor by far outweighs the higher child survival rates, it will lead to a reduction in the population growth rates. For this reason, universal secondary female education—in addition to its many other positive implications—has been suggested as an effective way to lower the world's population growth (*27*).

This effect of education on future population growth is illustrated numerically in Table 2 through the comparison of different education scenarios for individual countries and world regions through 2050 (*18*, *28*). Table 2 lists four alternative education scenarios that are based on identical sets of education-specific fertility, mortality, and migration rates; they differ in terms of their assumptions about future school enrollment rates. The fast track (FT) scenario is extremely ambitious; it assumes that all countries expand their school system at the fastest possible rate, which would be comparable with best performers in the past such as Singapore and South Korea (*29*, *30*). The global education trend (GET) scenario is more moderately optimistic and assumes that countries will follow the average path of school expansion that other countries already somewhat further advanced in this process have experienced. The constant enrollment rate (CER) scenario assumes that countries only keep the proportions of cohorts attending school constant at current levels. The most pessimistic scenario, constant enrollment numbers (CEN), assumes that no more schools at all are being built and that the absolute number of students is kept constant, which under conditions of population growth means declining enrollment rates. The resulting global population projections by level of education on the basis of these four alternative education scenarios is shown in Fig. 2.

When interpreting the results of the comparison of these scenarios, it needs to be kept in mind that the effect of better education on population growth will take a long time, primarily because of two factors: If more girls are entering primary education tomorrow, the main effect on fertility will only be some 15 or more years later, when these young women are in their prime child-bearing ages; once fertility rates fall, this will not translate right away into falling absolute numbers of births because of the great momentum of more young women moving into reproductive ages as a consequence of past high fertility. Even in the unlikely case of instant replacement-level fertility, young populations would continue to grow substantially for decades. For these reasons, the differences among

Table 1. Less-than-5-years mortality rate and total fertility rate for selected countries for recent years (later than 2004) by level of education of mothers. Source of data is (*24*).

Country	Period*	Less-than-5-years child mortality* (per thousand live births)				Total fertility rate (number of live births per woman)			
		No education	Primary	Secondary or higher	Overall	No education	Primary	Secondary or higher	Overall
Bangladesh	2007	93	73	52	74	3.0	2.9	2.5	2.7
Benin	2006	143	121	78	136	6.4	5.2	3.7	5.7
Bolivia	2008	134	87	44	76	6.1	4.7	2.6	3.5
Cambodia	2005	136	107	53	106	4.3	3.5	2.6	3.4
Congo (Brazzaville)	2005	202	134	101	123	6.2	6.3	4.0	4.8
Congo DR	2007	209	158	112	155	7.1	7.1	5.0	6.3
Egypt	2008	44	38	26	33	3.4	3.2	3.0	3.0
Ethiopia	2005	139	111	54	132	6.1	5.1	2.0	5.4
Ghana	2008	103	88	67	85	6.0	4.9	3.0	4.0
Guatemala	2008	65	40	20	45	5.2	3.8	2.3	3.6
Guinea	2005	194	172	92	188	6.2	5.1	3.3	5.7
Haiti	2005–2006	123	97	65	102	5.9	4.3	2.4	3.9
Honduras	2005–2006	55	40	20	37	4.9	3.8	2.2	3.3
India	2005–2006	106	78	49	85	3.6	2.6	2.1	2.7
Indonesia	2007	94	60	38	51	2.4	2.8	2.6	2.6
Liberia	2009	164	162	131	158	7.1	6.2	3.9	5.9
Mali	2006	223	176	102	215	7.0	6.3	3.8	6.6
Nepal	2006	93	67	32	79	3.9	2.8	2.2	3.1
Nicaragua	2006	67	40	26	41	4.4	3.2	2.0	2.7
Niger	2006	222	209	92	218	7.2	7.0	4.8	7.0
Nigeria	2008	210	159	107	171	7.3	6.5	4.2	5.7
Pakistan	2006–2007	102	85	62	93	4.8	4.0	2.8	4.1
Philippines	2008	136	47	30	37	4.5	4.5	3.0	3.3
Rwanda	2007–2008	174	127	43	135	6.1	5.7	3.8	5.5
Senegal	2008–2009	112	74	33	100	5.6	4.5	3.1	4.9
Sierra Leone	2008	170	187	130	168	5.8	5.1	3.1	5.1
Swaziland	2006–2007	150	106	95	106	4.9	4.5	3.4	3.9
Uganda	2006	164	145	91	144	7.7	7.2	4.4	6.7
Zambia	2007	144	146	105	137	8.2	7.1	3.9	6.2

*Less-than-5-years child mortality refers to the period of 10 years prior.

scenarios listed in Table 2 for the year 2050 show only the beginning of the effects, with more substantial impacts embedded for the longer-term future. By 2050, the impact of different education scenarios under otherwise identical education-specific conditions on world population size is already very strong: Population size in the FT scenario will be over 1 billion people lower than under the CEN scenario. This implies that alternative education trajectories alone will already, over the next 40 years, make a difference in global population size that is bigger than the entire African population today, or three times the current U.S. population. This effect is strongest for countries with currently high fertility rates and high education differentials. In Kenya, for example, the population would increase from 31 million in 2000 to 84 to 85 million in 2050 under the optimistic scenarios (FT and GET) but increase to an incredible 114 million if no new schools are built (CEN). The difference between these extreme scenarios is 30 million—about the size of Kenya's total population in 2000.

These results are likely to be an underestimate of the effect of education on population growth because it only considers the individual-level effects and not the community-level effects of spillover, normative change, and better availability of reproductive health services in communities with better educated women. Particularly in countries that have experienced the most rapid voluntary fertility declines—such as Iran, Mauritius, and South Korea—these community-level effects were highly relevant (*31*, *32*). A multilevel analysis of 22 countries in sub-Saharan Africa shows that an additional fertility decline of up to one child per woman is attributable to the aggregate-level effect of female education on top of the individual-level effects (*33*).

The interaction between education and population growth goes both ways. The discussion of the CEN scenario already showed that under conditions of high population growth because of high birth rates, the increase in the school-age population is such that even maintaining the current school enrollment rates can be an uphill battle. In several African countries during the 1980s, the proportions of young cohorts in school actually declined, presumably because of the combined effects of economic and political problems and very rapid population growth, resulting in an increase in the school-age population. The stall of fertility decline that was observed in some African countries around 2000 is partly associated with this stall in education of the relevant female cohorts. Although female education is an important force toward lowering fertility, rapid growth in the number of children in a society in which total resources do not grow at the same pace is an obstacle in the expansion of education. For this reason, from a policy perspective it is most effective to try to increase female education and improve access to family planning programs at the same time.

Human Capital and Human Development

Education matters greatly for almost every aspect of progress in human development. The empowering function of education is considered a major goal in its own right. The Human Development Index, one of the most widely used indicators of desirable social and economic progress, consists of three components: one that measures progress in education itself and two that capture progress in health and material well-being (*34*). There is reason to assume that these latter two aspects are to some extent driven by progress in the education of the population, and that indeed human capital may be viewed as the root cause of human development (*28*). The human capital data that are differentiated by age and sex helped to shed some light on this assertion.

In economics, it has been assumed for a long time that education has an important positive effect not only on individual earnings but also on aggregate-level economic growth (*35*, *36*). Although the empirical evidence is unambiguous for individual-level earnings, the statistical evidence for economic growth has been rather weak until recently. The reasons for this unsatisfactory situation can be found in the lack of precision of the education data used and more specifically in the lack of explicit consideration of the age structure of human capital (*10*–*12*, *30*). As can be seen from the example of China in Fig. 1, the most frequently used indicator of human capital in economic growth regressions—the mean years of schooling of the entire adult population above the age of 25—averages over age cohorts with very different levels of education, including the highly educated young cohorts as well as the poorly educated older ones. In recent analyses that explicitly consider the age structure of human capital, economic growth is fastest when the better educated young cohorts enter young adulthood. This pattern is most clearly visible for the Asian tiger states, where the inter-cohort improvements in education were dramatic. At the global level, the age-specific human capital indicators statistically and unambiguously confirm the key role of human capital in economic growth (*30*).

Education is also one of the most important determinants of adult health and mortality. Large numbers of studies have established significant education gradients in mortality in different parts of the world despite marked contextual differences (*1*, *37*). Even more dramatic are the education differentials with respect to disability at older ages. A recent global-level study on the basis of the World Health Survey found that almost universally, better educated men and women at a given age have a much lower level of self-reported disability [limitations in activities of daily living (ADL)] than do the less educated (*1*). Viewing this fact together with the above-described education projections entirely changes our outlook on

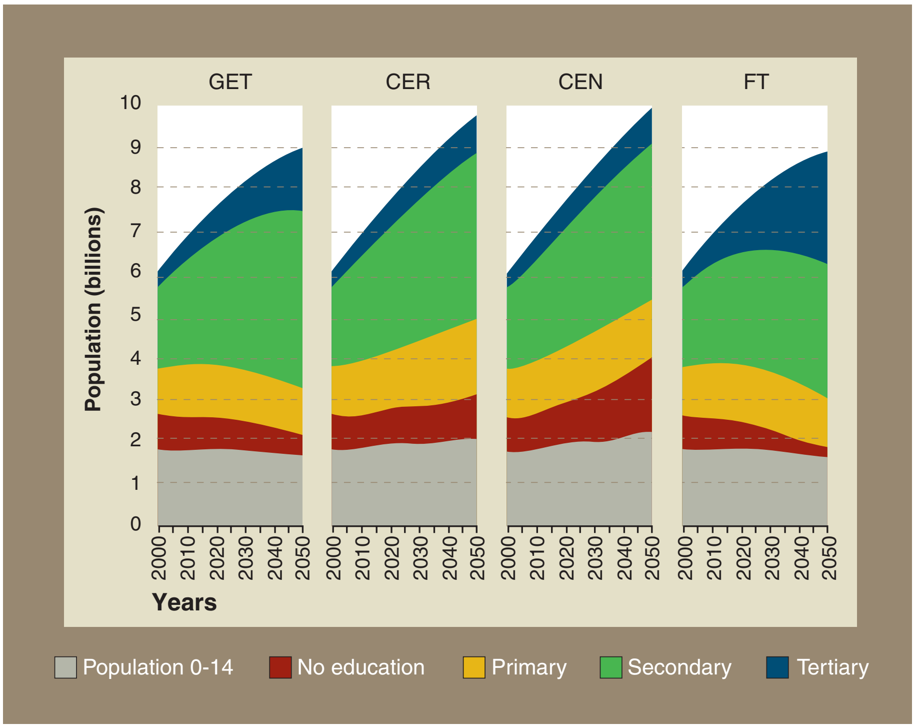

Fig. 2. World population by level of educational attainment projected to 2050 on the basis of four different education scenarios. Source for base year is (*39*) and for the scenarios is (*18*).

Table 2. Population sizes (in millions) in world, regions, and selected countries in 2000 and 2050 according to four scenarios. Source for base year is (*39*) and for scenarios is (*18*).

	2000	2050			
	(Base year)	FT	GET	CER	CEN
World	6115	8885	8954	9728	9977
Africa	819	1871	1998	2236	2393
Asia	3698	5102	5046	5487	5560
Latin America and Caribbean	521	718	729	809	835
Ethiopia	66	153	174	203	214
India	1043	1580	1614	1732	1789
Kenya	31	84	85	100	114
Nigeria	125	275	289	319	340
Pakistan	148	328	335	353	360
Uganda	24	89	91	105	116

the prevalence of disability in the future. If the focus is only on age and sex, then the observed pattern of increased disability at higher ages, together with the projection that there will be more elderly in the future, results in quite dramatic forecasts of future numbers of persons with severe disabilities. If education is also factored in, the picture looks less dramatic. In most countries, the elderly of the future will be better educated than the elderly of today. Assuming that the better educated at any age have substantially lower disability rates, this improving education factor may partly or even fully compensate for the aging factor (*1*, *29*). But because there are still many unknowns, these interactions between education and health are an important field for more research.

Education matters greatly for many further issues than disability, longevity, and economic well-being. At the individual level, better educated people are doing better along almost any dimension, ranging from mental health to the ability to recover from shocks to lower unemployment. At the aggregate level, systems of governance and democracy have been shown to be closely related to a society's level of education (*38*). It has been shown that the age structure of human capital and, in particular, the time when large cohorts of better educated men and women enter the young adult ages play a key role in the transitions of societies into modern democracies (*31*). Large cohorts of young adults (sometimes called the "youth bulge") who are also better educated but cannot match their higher aspirations with the realities under an oppressive regime present a major force toward change. This picture fits well to the recent events in the Arab world (*31*).

Because most populations of the world have seen increases in school enrollment rates among the younger cohorts over the past years, the young are generally better educated than the old. This fact implies that much improvement in the average education of the future adult population is already assured as these better educated cohorts move up the age pyramid. This can be seen in Fig. 2, in which—depending on the scenario—much of the expected population increase will be for people with secondary and tertiary education. In view of the many positive implications of secondary and tertiary education, this is good news, but the full effects will only come to fruition in the developing world if strong further investments in education are being made.

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PERSPECTIVE

Cities, Productivity, and Quality of Life

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Technological changes and improved electronic communications seem, paradoxically, to be making cities more, rather than less, important. There is a strong correlation between urbanization and economic development across countries, and within-country evidence suggests that productivity rises in dense agglomerations. But urban economic advantages are often offset by the perennial urban curses of crime, congestion and contagious disease. The past history of the developed world suggests that these problems require more capable governments that use a combination of economic and engineering solutions. Though the scope of urban challenges can make remaining rural seem attractive, agrarian poverty has typically also been quite costly.

The tight correlation between urbanization and economic development throughout the world reflects a global transition from poverty to prosperity. However, urban density also brings enormous challenges, including crime, congestion, and contagious disease, and these