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The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100

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ABSTRACT

This paper applies the methods of multi-dimensional mathematical demography to project national populations based on alternative assumptions on future, fertility, mortality, migration and educational transitions that correspond to the five shared socioeconomic pathways (SSP) storylines. In doing so it goes a significant step beyond past population scenarios in the IPCC context which considered only total population size. By differentiating the human population not only by age and sex—as is conventionally done in demographic projections—but also by different levels of educational attainment the most fundamental aspects of human development and social change are being explicitly addressed through modeling the changing composition of populations by these three important individual characteristics. The scenarios have been defined in a collaborative effort of the international Integrated Assessment Modeling community with the medium scenario following that of a major new effort by the Wittgenstein Centre for Demography and Global Human Capital (IIASA, OEAW, WU) involving over 550 experts from around the world. As a result, in terms of total world population size the trajectories resulting from the five SSPs stay very close to each other until around 2030 and by the middle of the century already a visible differentiation appears with the range between the highest (SSP3) and the lowest (SSP1) trajectories spanning 1.5 billion. The range opens up much more with the SSP3 reaching 12.6 billion in 2100 and SSP1 falling to 6.9 billion which is lower than today's world population.

1. Introduction

The number of human beings on this planet has changed greatly over the past millennia and was in many aspects linked to changes in the natural environment—both in terms of being driven by changes in the environment and also of inducing such changes—as well as the evolution of technologies and human cultures. It is estimated that from the appearance of modern Homo sapiens some 200,000 years ago in Africa until around 35,000 years ago the total world population was well under one million and our species was seriously threatened by extinction (Biraben, 2002). Only after the Neolithic revolution which introduced agriculture the world population surpassed 100 million roughly 7000 years ago. But it was only in the 19th century that population growth really started to take off in the now industrialized countries as a consequence of a decline in death rates which was the result of better nutrition, improvements in hygiene and public fresh water supply and other advances in early preventive medicine. Right after the end of World War II death rates then started to fall precipitously in almost all parts of the world which at this time was also the result of modern medicine including the invention of antibiotics. But for several decades birth rates remained very high (and in some cases even increased due to a better health status of women) since high fertility norms had been deeply imbedded in most traditional cultures and religions and such norms tend to change only slowly. As a consequence, world population size started to "explode" from 2.5 billion in 1950 to somewhat above 7 billion today. But over the past decades birth rates have also started to decline in many parts of the world—most dramatically in populous East Asia—giving rise to the expectation that over the course of the 21st century there is a high probability that world population will reach a peak and then start to decline (Lutz et al., 2001).

The scientific discipline of demography has a rather elaborate and powerful toolbox for studying population dynamics and produces detailed population projections according to different assumptions about the future trend in fertility, mortality,

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migration and other drivers of changing population composition. While population growth has been a topic of scientific enquiry and discussion for centuries and at least since Thomas Malthus entered the field of structured quantitative analysis, early population projections only applied an assumed growth rate to the population total. Only after World War II it became standard to produce projections that explicitly consider the age- and sex-structure of the population (the so-called cohort component method). Hajnal (1955) provides a good overview of these early population projections. Between 1951 and 2011, the UN published 22 sets of estimates (past and current conditions) and projections (future) for all countries and territories of the world. Before 1978 these projections were revised approximately every 5 years; since then new revisions (called assessments and published in their World Population Prospects series) have been made every 2 years. So far the UN assessments have provided projections by age and sex for a medium scenario, and alternative scenarios that are based on alternative fertility assumptions combined with identical mortality and migration assumptions.

The World Bank started to produce independent population projections in 1978. These were always meant primarily for internal use in the Bank's development planning and were published as part of the World Development Report series. After 1984, the World Bank projections were revised approximately every 2 years and in most cases only one updated variant was published but with a long time horizon to 2150. Around 1995, the World Bank stopped publishing separate projections but presumably continued to use them for internal purposes for a number of years. The Washington-based Population Reference Bureau (PRB) publishes independent world population projections (population size only and a single scenario) every year as part of its annual World Population DataSheet. The US Census Bureau (USCB) also produces single scenario projections for all countries in the world since 1985 with a varying time horizon. The World Population Program of the International Institute for Applied Systems Analysis (IIASA) based outside Vienna (Austria) began producing global population projections at the level of 13 world regions in 1994. One of the purposes was to produce population projections as part of the Special Report on Emissions Scenarios (SRES)(Nakicenovic et al., 2000) that underlie the global emission scenarios used by the Intergovernmental Panel for Climate Change (IPCC). This was followed by three rounds of probabilistic projections at the level of 13 world regions (Lutz et al., 2008b, 2001, 1997).

2. Key dimensions considered in population projections

For most users of population projections clearly the most important piece of information is the future total size of the population. For this reason population size was the only demographic/social variable considered in the SRES scenarios complemented only by GDP per capita as an economic variable. Hence, for many practical purposes population size served primarily the function of a scaling factor in the calculation of per capita indicators.

There are two important reasons for population projections to go beyond the consideration of population size alone, one methodological and the other substantive. Human populations are not homogeneous and this heterogeneity greatly matters for the likely future growth of the population. Populations that are selective in a way that they have only a small proportion of women or more elderly people than young adults are likely to have lower birth rates than population of comparable size but with a larger proportion of women in reproductive age. In this sense future population growth is a direct function of the age- and sex-structure of the population and for this reason all modern population projections do explicitly incorporate these two sources of population heterogeneity and define their assumptions in the form of age-specific fertility, mortality and migrations rates.

The age- and sex-composition of the population is also of interest in its own right. Population aging is considered a highly important socioeconomic issue which can only be quantitatively addressed if the age-structure of populations is explicitly incorporated in the projection model. But the same is true for other highly relevant individual characteristics such as level of education and rural/urban place of residence. Both are of dual significance: They are important sources of population heterogeneity, influencing its dynamics, and their changing composition in the population is directly relevant for anticipating socioeconomic challenges for mitigation as well as adaptation to unavoidable climate change. In this paper we will explicitly address the changing educational structure of populations while the following paper will deal with the modeling of urbanization (Jiang and O'Neill, in press).

The methods of multi-dimensional population dynamics are able to deal with populations that are stratified by further demographic dimensions in addition to age and sex. The International Institute for Applied Systems Analysis (IIASA)—where these methods were originally developed during the 1970s—has recently applied them to produce reconstructions and projections of populations by age, sex and level of educational attainment for most countries in the world (KC et al., 2010; Lutz et al., 2007). Like age and sex, education is also an important source of population heterogeneity and bears a significant weight of its own. Almost universally more educated people have lower mortality, and there is sufficient evidence that this is a real effect and not just owing to selectivity. Lutz and Skirbekk (2013) discuss the issue of causality in the effects of education and bring together many studies based on natural experiments, instrumental variable models and other approaches that clearly demonstrate that this almost universal association is not a spurious effect. They coin the notion of "functional causality" to indicate that—while it is nearly impossible to proof causality for all times and all different cultural settings—there are good reasons to assume that the effect of education on lowering mortality and fertility can indeed be assumed to hold over the projection period cover here. Finally, it needs to be stressed that the indicator of highest educational attainment that is being used here as the indicator of choice for all countries is only a proxy for skills and human capital. It does not include the quality dimension of education (because empirical data on this tend to be limited to rich countries) nor does it cover informal education which also contributes to human capital and for which even less reliable statistical information exists. In this sense the choice of educational attainment distribution was primarily driven by pragmatic considerations as the only indicator available in a rather consistent way for almost all countries of the world. While the baseline data distinguish between six educational attainment categories and the multi-dimensional projections have been carried out for these six categories, for the purpose of this paper we collapse them into four categories for the ease of presentations (for more information about the base line data and assumptions see KC et al., 2013).

The empirical data show that, in virtually all populations—and in particular those that are still in the process of demographic transition—more educated women have lower fertility. These educational differentials can be very significant. The Demographic and Health Survey for Ethiopia, for instance, shows that women without any formal education have on average six children,