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Wolfgang Lutz, Editor

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Editorial: Human capital research for evidence-based policy

The Wittgenstein Centre has released the most complete state-of-the-art disaggregated population projections ever produced. This important research on human capital, which provides robust empirical evidence for policy-based solutions, is a breakthrough for policymakers and academics worldwide. The cover article of this issue illustrates how population projections by age, sex, and education can become a central element in informing global decision-making bodies about the focus of population policies.

As shown by the Wittgenstein Centre's scientists in the Science article reprinted on pp. 4-5, education plays a central role in determining not only global population dynamics, but also people's vulnerability and resilience to environmental risks. Thus, public investment in universal education should be considered as one of the key priorities of the policies addressing climate change.

Efficiently communicating research results to the policy arena is not an easy task. The development of new data visualization tools can make a huge difference in terms of enhancing the information flow between researchers and policymakers. For example, the latest global international migration figures reconstructed at the Wittgenstein Centre are presented in circular plots for ease of comprehension. This format is set to become the new standard in representing migration data. Another example is the 2014 European Demographic Data Sheet presented for the first time in interactive online format.

More and more in the modern world, scientists are expected to produce policy-relevant research and make the results widely available to the global public. By highlighting the overwhelming power of education as a force of global socioeconomic change and finding new ways of transmitting this knowledge, the Wittgenstein Centre is making its own input into better, evidence-based policies for future sustainable development.

Jesus Crespo Cuaresma

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

World Population and Human Capital in the 21st Century

New book implies need for new population policy rationale

Wittgenstein Centre projections illustrate the importance of national human resource development as a policy that can help achieve sustainable development

World population is still likely to peak during the second half of this century, reaching about 9.4 billion in the 2060-2080 period followed by a slight decline to 9 billion by the end of the century. This is the result of the medium scenario used in a major new international effort to summarize the state of the art of the drivers of future fertility, mortality, migration, and education and translate them into scenarios by age, sex, and seven levels of educational attainment for 175 countries. A large number of international population experts (including 26 lead authors, 46 contributing authors, and over 550 demographic experts around the world who responded to an online questionnaire evaluating alternative arguments relating to future demographic trends) contributed to a 1056-page book, *World Population and Human Capital in the 21st Century*, published recently by Oxford University Press (OUP; see box on p.3).

In terms of total population size these new projections show a medium trajectory for the second half of the century which is lower than that of a recent paper by Gerland et al. (2014) based on the UN (2012) population assessment. This is primarily due to somewhat lower fertility assumptions for some African countries and for China (see reprint of a response Letter in *Science* on p.3) and to the fact that unlike the UN projections, the new projections also explicitly incorporate population heterogeneity by level of education in addition to age and sex. Fertility varies significantly with the level of female education – particularly during the process of demographic transition. Thus, improvements in the education of younger female cohorts in several major African countries since 2000 that are already known about (and are possibly related to the Millennium Development Goals [MDGs]) suggest a near-term decline in fertility. Similarly,

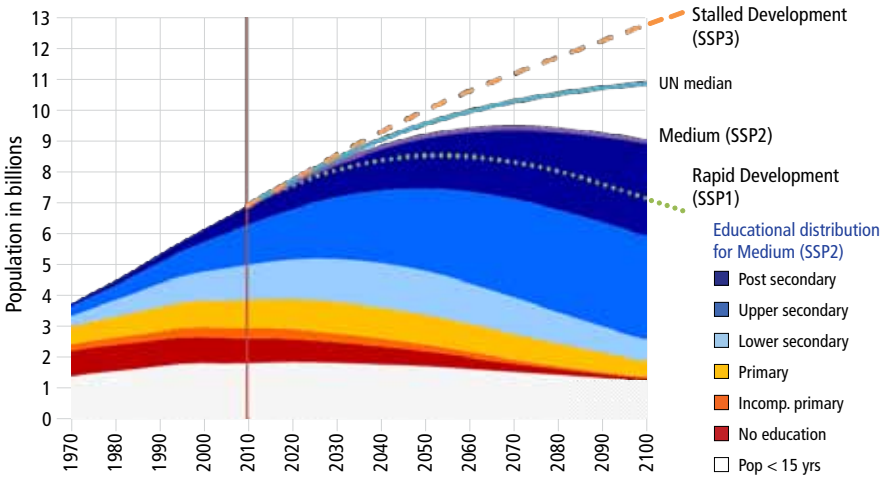

Chart 1. Historical trend and projections according to the medium scenario (SSP2) for the world population by six levels of educational attainment (see color coding). The additional lines superimposed on this graph show the projections of total population size according the stalled development scenario (SSP3), the rapid development scenario (SSP1), and the medium variant of the UN 2012 projection.

the stalled fertility decline around 2000 was associated with a stalled improvement in the education of earlier female cohorts that was a likely consequence of the Structural Adjustment Programs of the 1980s during which education spending was cut drastically. Conventional population projections that differentiate only according to age and sex and are based on statistical extrapolations of aggregate TFRs cannot possibly capture these important discontinuities in the education structure of subsequent female cohorts. This can only be done through the explicit incorporation of education as a third demographic dimension. In addition, the involvement of so many population experts from around the world who contributed to the new book allowed consideration of country-specific factors and knowledge about specific conditions within countries.

The new scenarios

These population projections by age, sex, and level of education also form the "human core" of a new set of global change scenarios developed and used in the context of the Intergovernmental Panel on Climate Change (IPCC) and Integrated Assessment (IA) modeling groups. These are the Representative Concentration Pathways (RCPs) on future climate impacts and the Shared Socioeconomic Pathways (SSPs) on the relationship between climate change, on the one hand, and socioeconomic vulnerabilities, adaptation, and mitigation, on the other.

The scenarios of the Special Report on Emission Scenarios (SRES) published in 2000, which were used prior to the introduction of the RCPs and SSPs, had only total population size and gross domestic product (GDP) as socioeconomic variables, with population largely being relegated to a denominator function for per capita energy and emissions data. The new generation of SSP scenarios is significantly richer in detail about the changing structure of human populations. In particular, the SSPs were designed to capture the socioeconomic challenges associated both with climate change mitigation and adaptation. Following the general SSP storylines about alternative global developments in the 21st century, alternative sets of assumptions on future fertility, mortality, migration, education, and urbanization trajectories were defined and combined with consistent GDP trajectories that also account for the established relationship between human capital and GDP growth. Of the five SSPs, Chart 1 depicts the medium (middle of the road) SSP2, and also SSP1, which describes the case of rapid socioeconomic development, and SSP3, which captures the case of stalled development. As can be seen from Chart 1, the SSP1 to SSP3 range covers a world population size in 2100 from 7 to 12.7 billion.

Implications for population policy priorities

The new OUP book has an Epilogue by Wolfgang Lutz entitled, "With education the future looks different" which highlights many important consequences of explicitly incorporating education in the population outlook. The implications for population policy are covered more comprehensively in a recent paper in *Population and Development Review* (Lutz 2014) entitled "A population policy rationale for the 21st century," which draws rather radical conclusions about the need to redefine population policies when education as a demographic dimension is taken into account.

The international community has just gone through the Cairo+20 process in which the Programme of Action of the International Conference on Population and Development (ICPD) was formally reaffirmed. Twenty years ago an important shift took place away from simply achieving demographic targets toward ensuring human wellbeing and environmental sustainability based on the principles of human rights, dignity, and equality. Revolutionary in 1994, it is still highly relevant today. But it addresses only part of the current population-related concerns. Over the past 20 years in an increasing number of countries, these concerns have been shifting toward the question of population aging and even population shrinkage. Cairo+20 had little to say on these topics.

A new population policy rationale for the 21st century, which is equally valid in countries with high and low fertility levels, is human capital formation. This focuses not only on counting the number of people, but on empowering them through better education and health. Recent demographic research has demonstrated that adding education to the conventional age and gender dimensions in population analysis significantly changes currently dominant population policy rationales:

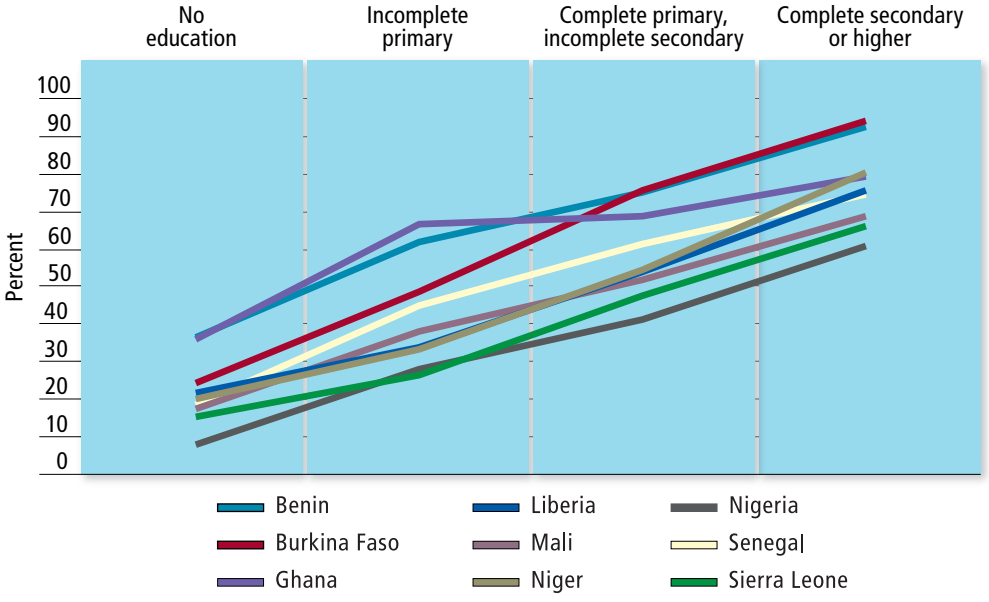

Chart 2. Having ever used contraception by women's educational attainment, DHS data for nine countries in West Africa.

Below replacement-level fertility is desirable: A well-educated and more productive labor force will increase economic growth and thus compensate for decreasing population size. Although many established pension systems need adjustments to cope with population aging, for most countries the socially desirable level of fertility—in terms of maximizing per capita wellbeing—is, in fact, somewhat below replacement level. This has been independently shown by Lee et al (2014) and by Striessnig and Lutz (2013) using different approaches.

The demographic dividend is primarily an education dividend: The apparent association between declining fertility rates and economic growth in many developing countries has frequently been interpreted as resulting from falling youth dependency ratios. New research shows that it is mainly due to improved female education, which results in both lower fertility and increased productivity. This has been shown in Crespo et al. (2013).

Female education is key to lower desired family size and to overcoming the obstacles of the unmet need for contraception: The association of girls' education with greater contraceptive use and lower fertility is very clear, and there is little doubt that one consequence of empowering women through education is higher contraceptive use. Chart 2 illustrates the relationship between female education and contraceptive use for Demographic and Health Surveys (DHS) in West Africa. More educated women want fewer children and are empowered to actually have the number of children they desire by helping them overcome many of the main obstacles to modern contraceptive use such as misinformation on possible side-effects and cultural/familial objections. But investments in female education and in reproductive health services should not be seen as being in competition. Both are needed and, indeed, can be strongly synergistic.

The ICPD Programme of Action rejected quantitative demographic targets and, in a widely applauded move, redirected the population policy focus to human rights, gender equity, and reproductive health. However, it did not set any other meaningful aggregate-level objectives that might replace the dismantled demographic targets. What, then, should the goal of population policies in the 21st century be for high- and low-fertility countries?

Lutz (2014) argues that the primary goal of population policies should be to strengthen the human resource base for national and global sustainable development. This goal is fully consistent with the ICPD goals and also has strong synergies with other internationally agreed development objectives.

This 21st century population policy rationale does not seek to identify any particular population size, growth rate, fertility rate, or age structure as its primary goal. Instead, policies would aim to efficiently and flexibly manage human resources so as to achieve the highest long-term wellbeing for current and future generations, while fully respecting human rights.

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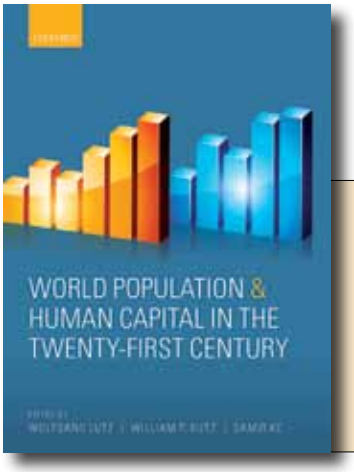

The Executive Summary of the book can be freely downloaded from www.iiasa.ac.at/publication/more_XO-14-031.php

The complete book Lutz, W., Butz, W. P. & KC, S. (Eds.) (2014) *World Population and Human Capital in the 21st Century*. Oxford: Oxford University Press is available for purchase from Oxford University Press: http://ukcatalogue.oup.com/product/9780198703167.do

Country- and region-specific data and projections can also be explored online and free of charge through the Wittgenstein Centre's Data Explorer www.wittgensteincentre.org/dataexplorer/

Reprint from: *Science*, 31 October 2014, Vol 346, Issue 6209)

Population growth: Peak probability

IN THEIR REPORT "World population stabilization unlikely this century" (10 October, p. 234; published online 18 September), P. Gerland *et al.* used a United Nations (UN) 2012 assessment to support their claim that the population will not peak this century, despite our earlier work indicating that it will (*1*–*3*).

The UN assumptions used by Gerland *et al.* are mainly based on statistical extrapolation, whereas our approach is based on substantive reasoning and assessments of alternative arguments (*4*). For example, a changing education structure means that young Nigerian women are more educated than their elders, implying likely near-term fertility declines. The UN assumes constant fertility at 6.0 for 2010 to 2015, but the newest Demographic and Health Survey shows that it has already decreased to 5.5 in 2010 to 2013. The population increase for Nigeria from today's 160 million to 914 million in 2100 expected by the UN is thus unrealistic. For China, the UN assumes that fertility will only increase in the future. We assume, like many Chinese scientists and institutions (*5*), that it will decline and stay low in the coming decades. On balance, we therefore still expect the end of world population growth this century.

Wolfgang Lutz,* William Butz, Samir KC, Warren Sanderson, Sergei Scherbov

World Population Program, International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria.

*Corresponding author. E-mail: lutz@iiasa.ac.at

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ENVIRONMENT AND DEVELOPMENT

Universal education is key to enhanced climate adaptation

Fund more educators rather than just engineers

By **Wolfgang Lutz, Raya Muttarak, Erich Striessnig***

Over the coming years, enormous amounts of money will likely be spent on adaptation to climate change. The international community recently made pledges of up to $100 billion per year by 2020 for the Green Climate Fund. Judging from such climate finance to date, funding for large projects overwhelmingly goes to engineers to build seawalls, dams, or irrigation systems (*1*). But with specific projections of future changes in climate in specific locations still highly uncertain, such heavy concrete (in both meanings) and immobile investments that can lock countries into certain paths may not be the best way to go (*2*). Our new study suggests that it may be efficient and effective to give part of this fund to educators rather than engineers. Public investment in universal education in poor countries in the near future should be seen as a top priority for enhancing societies' adaptive capacity vis-à-vis future climate change.

POLICY

Recent research suggests that general empowerment of populations through universal primary and secondary education is not only essential to poverty alleviation and economic growth but also to reducing vulnerability to natural disasters (*3*, *4*). It is not unreasonable to assume that factors that helped reduce vulnerability to floods, tropical storms, and droughts over the past decades will help reduce future vulnerability to climate change. We present findings from the most comprehensive global-level assessment of the effects of education on disaster fatalities (measured as the logged number of deaths per million of population) from hydro-meteorological hazards that are likely to be intensified by climate change, e.g., floods, droughts, storms, and extreme temperatures. The data cover 167 countries for the period 1970 to 2010. Data on disasters come from the Emergency Events Database (EM-DAT), which provides the best available information on the number of disasters and reported fatalities from around the world (*5*).

EDUCATE FEMALES, REDUCE FATALITIES. Because the literature on disaster vulnerability has conventionally emphasized economic growth while disregarding education, our statistical analysis focuses on the relative assessment of these two factors as measured by Gross Domestic Product (GDP) per capita and the proportion of women aged 20 to 39 with at least junior secondary education. The latter was shown to be a good indicator for recent improvements in human capital in other contexts (*3*).

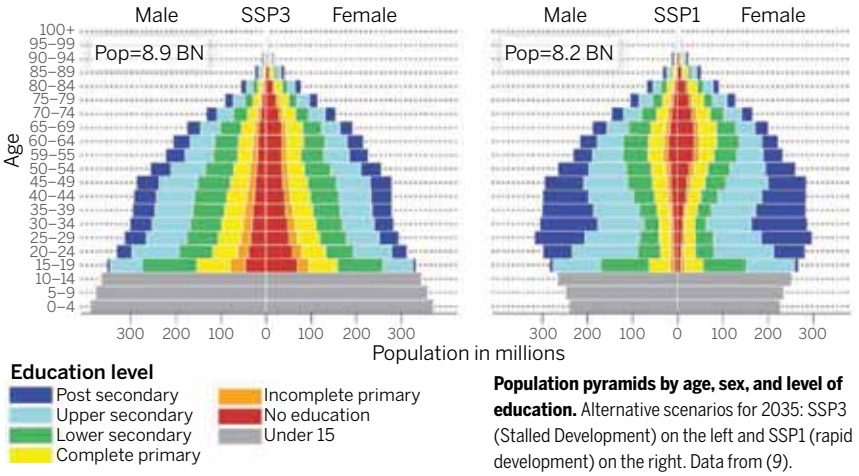
To account for differences in the frequency of natural hazards experienced and size of the countries affected, we include as controls the number of registered disasters per population, total arable land area, a dummy variable for being landlocked, the recent rate of population growth to capture stress on infrastructure, and 43 regional fixed effects for countries with comparable settings and climate zones. As documented in the supplementary materials (SM) (table S1 and sensitivity analysis in table S2 and fig. S1), several alternative model specifications combined with different estimation techniques resulted in very consistent findings: When estimating the relative effects of income and education in the same models, GDP per capita turns out to be insignificant, whereas female education is highly significant across all models with the expected negative sign. Hence, this empirical analysis of national-level time series clearly indicates that female education is indeed strongly associated with a reduction in disaster fatalities.

Assuming that this robust association between education and lower mortality risk from natural disasters will continue in the future, we present alternative scenarios for future disaster-related fatalities as a function of alternative future education and population trends. When studying the effects of improvements in school enrollment on the human capital stock of the adult population, it is essential to account for significant inertia in the process of human capital formation. Because primary and junior secondary education tend to happen almost exclusively during childhood, it will take several decades until an expansion of education among children translates into higher human capital for men and women around age 50. This process of human capital formation along cohort lines can be appropriately modeled using the tools of multidimensional demography (*6*).

This approach has recently been applied to produce a new set of SSP (Shared Socioeconomic Pathways) scenarios for the international integrated assessment and vulnerability, risk, and adaptation research communities replacing the older Special Report on Emissions Scenarios which contained only total population size and GDP as socioeconomic variables (*7*). The SSPs were defined to address simultaneously the socioeconomic challenges to climate change mitigation and adaptation (*8*). Besides many

*Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID/ÖAW, WU), Austria. All authors contributed equally and are listed in alphabetic order. *E-mail: striess@iiasa.ac.at*

Projecting the population by level of education



Population pyramids by age, sex, and level of education. Alternative scenarios for 2035: SSP3 (Stalled Development) on the left and SSP1 (rapid development) on the right. Data from (*9*).

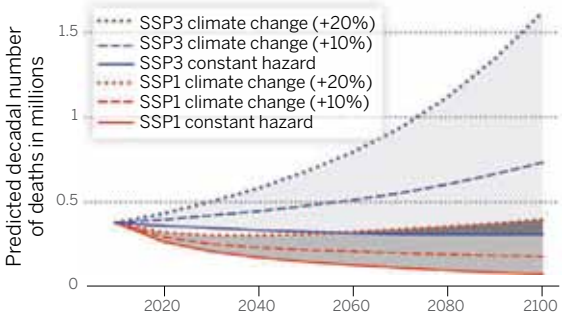
(Reprint from: *Science*, 28 November 2014, Vol 346, Issue 6213)

other economic and technological variables, alternative population scenarios by age, sex, and seven levels of educational attainment for all countries form the "human core" of the full SSPs (*9*). SSP1 illustrates the case of rapid social development in all parts of the world associated with rapidly expanding education (see the first chart). SSP2 is the middle-of-the-road scenario where current development trends continue while SSP3 anticipates a fragmented world with stalled socioeconomic development. The figure also illustrates the great inertia of progress in improving educational attainment where, by 2035, the differences between the scenarios are only evident for the younger cohorts.

The results of combining the estimated coefficients (table S1) with two contrasting SSP scenarios (SSP1 and SSP3) for the rest of the century are shown in the second chart. We did this by taking the time-varying population and education variables from the respective SSPs. Different assumptions were made for the frequency of disasters representing possible greater future hazards. The solid lines in the second chart show the hypothetical case of constant hazard (i.e., no climate change). Under SSP1, this results in a significant decline of disaster deaths because of underlying progress in educational expansion. If we assume stalled development, which also implies higher fertility and thus higher population size, we observe almost no change under SSP3. The dashed lines assume an increase in the number of hydro-meteorological extreme events of on average 10% per decade (Climate Change +10%). Although there is still a slight reduction in future disaster deaths for SSP1, we observe a strong increase according to SSP3. The more extreme assumption of the hazard increasing on average by 20% per decade (Climate Change +20%; dotted line) leads to an increase in future disaster deaths in the longer run for all SSPs, although to different degrees.

COGNITIVE CAPACITY, SOCIAL SPILLOVER. Our macrolevel finding that education reduces disaster-related mortality is consistent with evidence from recent empirical studies for different parts of the world and at different levels of analysis (from individual-, household-, and community-level to global-level data). These studies demonstrate that education contributes to vulnerability reduction and adaptive capacity enhancement in the predisaster phase and during disaster events and the disaster aftermath [for review, see (*2*)].

Expanded education limits deaths



Predicted decadal number of disaster deaths (in millions). Difference in deaths resulting from estimated education and population effects according to the contrasting scenarios SSP1 and SSP3 to 2100. See SM for details.

Before a disaster, disaster mitigation efforts like living in low-risk areas or undertaking disaster preparedness measures, such as stockpiling emergency supplies, are found to be greater among more highly educated individuals and households (*10*). Similarly, loss of life, injury, morbidity, and physical damage from natural disasters were reported to be lower in communities and countries with a higher proportion of populations with at least a junior secondary education (*11*). The better educated were also found to cope better with both income loss and the psychological impacts of natural disasters (*12*). Most of these studies explicitly compare the effects of education to those of household income with education consistently emerging as more important. Given such systematically strong associations and a sound causal narrative described below, there is firm ground to assume functional causality of the effects of education on reducing vulnerability. This implies that a continuation of this association in the future can be reasonably assumed.

One important mechanism through which education influences human well-being is neurocognitive development. Learning basic literacy, numeracy, and abstraction skills enhances cognitive capacities through raising the efficiency of individuals' cognitive processes and logical reasoning (*13*). Accordingly, because preventive action is initiated by stressors, such as perception of risk, followed by assessments of one's ability to respond to the threat, the more educated tend to have greater risk awareness because of better understanding of the consequences of their actions, e.g., as found in the case of smoking and cancer prevention (*14*). In addition to these individual-level effects, there are also spillover effects of education at the community level as is evident for the effect of female education on lowering infant mortality (*15*). Opportunities of social interaction with more-educated members may speed up the diffusion of information and knowledge, or access to institutions that favor disaster risk reduction.

Of course, in our study the association between educational level and disaster vulnerability has only been estimated on the basis of the past 40 years and can change in the longer-term future because of all kinds of uncertainties. Instead of assuming different percentage changes in the hazard as we did, more differentiated global climate models could be applied. But our calculations show a clear picture of the strong effects of empowerment through education on reducing disaster vulnerability and enhancing adaptive capacity to climate change, which is unlikely to change when using more sophisticated models. Accordingly, given uncertainty about the precise manifestations of climate change in specific areas, it seems beneficial to increase general flexibility and enhance human and social capital in order to empower populations to better and more flexibly cope with climate change in a way best for their long-term benefit. ■

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/346/6213/1061/suppl/DC1

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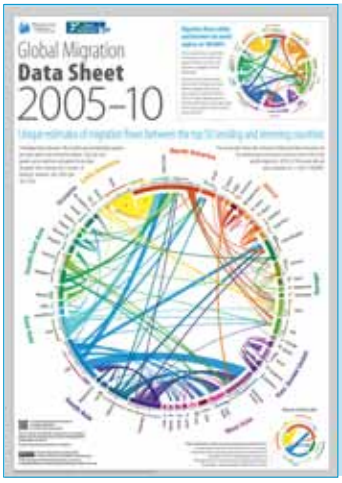

The Global Flow of People

The first edition of the Global Migration Data Sheet presents new estimates of migration flows between 196 countries over the period 2005-2010. The Data Sheet has been developed by Nikola Sander, Guy J Abel, and Ramon Bauer of the Wittgenstein Centre for Demography and Global Human Capital.

At www.global-migration.info everyone can explore migration flow estimates between and within regions for five-year periods from 1999 to 2010 in interactive format. The circular migration plots have been done by the authors together with Null2 Berlin. A PDF version of the Data Sheet can also be downloaded from this website.

Quantifying Global International Migration Flows

Guy J. Abel* and Nikola Sander*†

Widely available data on the number of people living outside of their country of birth do not adequately capture contemporary intensities and patterns of global migration flows. We present data on bilateral flows between 196 countries from 1990 through 2010 that provide a comprehensive view of international migration flows. Our data suggest a stable intensity of global 5-year migration flows at ~0.6% of world population since 1995. In addition, the results aid the interpretation of trends and patterns of migration flows to and from individual countries by placing them in a regional or global context. We estimate the largest movements to occur between South and West Asia, from Latin to North America, and within Africa.

Existing data on global bilateral migration flows are incomplete and incomparable because of national statistical agencies not measuring migration or variation in the way migration flows are defined (*1*–*3*). Stock data, measured at a given point in time as the number of people living in a country other than the one in which they were born, are more widely available and far easier to measure across countries than are flow data capturing movements over a period of time. This is especially true in regions where the collection of demographic data are less reliable. However, flow data are essential for understanding contemporary trends in international migration and for determining relationships. The discrepancies between the demand for flow data and the availability of migrant stock data have hindered theoretical development and have led to conjectures concerning increases in the overall volume of global migration (*4*, *5*) and shifts in spatial patterns (*6*).

The demand for bilateral migration flow data that can be the basis for robust comparisons has led researchers to develop indirect estimates. These have been limited to European data, in which flow statistics are plentiful, and have required model-based methods to harmonize reported flows and impute missing data (*7*–*9*). Outside of Europe, global bilateral migrant stock data that capture the size of foreign-born populations in each country—thus potentially allowing indirect estimations of flows—have only recently become available (*10*, *11*).

Here, we present a set of global bilateral migration flows estimated from sequential stock tables published by the United Nations (U.N.) for 1990, 2000, and 2010 (*11*). The data are primarily based on place-of-birth responses to census questions, details collected from population registers, and refugee statistics. First, we generated mid-decadal stock tables for the years 1995 and 2005 using a procedure similar to that used by the U.N. to align census and survey data to the beginning year of each decade (*11*). To quantify the global flow of people over 5-year periods, we then obtained maximum likelihood estimates for the number of movements required to meet the changes over time in migrant stock data, using an iterative proportional fitting algorithm (*12*). A detailed

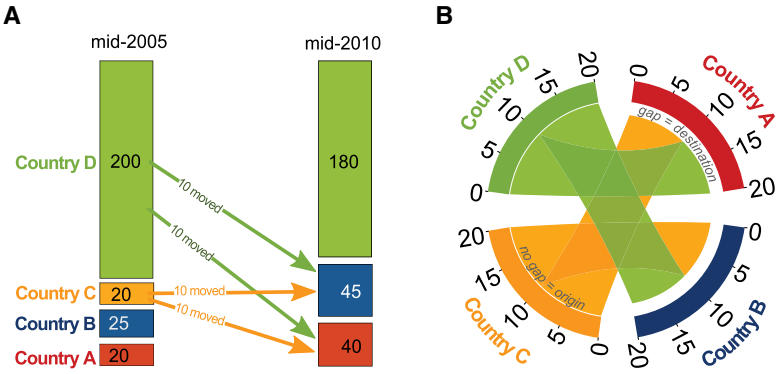

Fig. 1. Linking migrant flow to stock data and visualizing flows via circular plots. (A) The simplified example illustrates our method for estimating 5-year migration flows from changes in stock data between mid-2005 and mid-2010 (details are available in the supplementary materials). The number of people born in Country D and living in Country D (green field) decreased from 200 in 2005 to 180 in 2010. The number of people born in D and living in Country A (red field) increased from 20 to 40, and the number of people living in Country B (blue field) also increased from 25 to 45, but the number living in Country C (yellow field) decreased from 20 to 0. To match these differences in migrant stock data, our model provides an estimate of 20 people moving out of Country C, of whom 10 moved to A and 10 to B, and another 20 people moving out of Country D, with 10 moving to A and 10 to B. **(B)** The circular plot visualizes the migrant flows estimated in the hypothetical example. The origins and destinations of migrants (Countries A to D) are each assigned a color and represented by the circle's segments. The direction of the flow is encoded by both the origin country's color and a gap between the flow and the destination country's segment. The volume of movement is indicated by the width of the flow. Because the flow width is nonlinearly adapted to the curvature, it corresponds to the flow size only at the beginning and end points. Tick marks on the circle segments show the number of migrants (inflows and outflows).

Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID/ÖAW, WU), Vienna Institute of Demography (Austrian Academy of Sciences), Wohllebengasse 12-14, Vienna, 1040, Austria.

*These authors contributed equally to this work.
†Corresponding author. E-mail: nikola.sander@oeaw.ac.at

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discussion of the input data and estimation methodology can be found in the supplementary materials and (*13*). Our methodology to obtain bilateral flows with a simplified example of changes in stock tables for people born in a hypothetical country is illustrated in Fig. 1A. We produced a comparable set of global migration flows by simultaneously replicating the birthplace-specific estimation procedure for all 196 countries and accounting for changes in populations from births and deaths. Refugee movements are included in our estimates when they are taken into account in the U.N. stock data.

Our bilateral flow estimates capture the number of people who change their country of residence over 5-year intervals, similar to transitions measured over fixed intervals that are recorded by population censuses (*14*). The net migration totals calculated from our bilateral flow tables match the 5-year net migration data in the U.N. World Population Prospects. A robust comparison with existing bilateral flow estimates for Europe (*7*–*9*) is prejudiced by migration being measured as the annual number of movements rather than only a transition over a 5-year period. As the ratio of movements to transitions differs across countries, depending on the amount of multiple and return moves, there is no simple algebraic solution to convert from one definition to the other (*15*).

Migrant stock data compare country of birth with country of residence so as to give an estimate of lifetime migration. Compared with our 5-year flow measurement, the longer observation interval provides less detail on the timing of the move (*15*, *16*). Using stock data as a proxy measure for contemporary flows is potentially misleading in the sense that the relative size of immigrant populations does not necessarily correspond to that of migrant flows.

The visualization of global migration flows allows for the visual quantification of directional gross migration flows and the identification of their spatial patterns. Using Circos, a software package widely used in genetics (*17*), we created circular migration plots (Fig. 1B) to illustrate the complex and dynamic nature of migration. The circular migration plots in Fig. 2 give a snapshot of our flow estimates in 1990 to 1995 and 2005 to 2010 (top) as compared with the U.N. sequential migrant stocks in 1990 and 2010 (bottom), which our estimates are based on (*11*). Designations of "more developed," "less developed," and "least developed" were according to the U.N. Population Division (*11*). The patterns of flows during the 1990 to 1995 period are noticeably different from those of the migrant stock data of 1990. Differences between flows and stocks at this aggregated level were not tested with *t* test because such significance tests neglect the array of assumptions behind the estimation model and complexities in the underlying data, and a more fully fledged model-building exercise is beyond the scope of the paper. Fig. 2A depicts a 13% lower share of migration within the developed world and a 6% lower share from the least to less developed world, whereas the share of migration between the least developed countries is 7% higher in comparison with that in Fig. 2C. These differences might reflect sudden changes in the global migration regime driven by the fall of the Iron Curtain and armed conflicts in Asia and Africa. The stock data do not capture these fluctuations in contemporary patterns of movement. The patterns shown in Fig. 2, B and D, are much more similar because migration flows appear to have followed long-term trends captured by stock data.

Contrary to common belief (*4*–*6*), our data (Fig. 3) do not indicate a continuous increase in migration flows over the past two decades, neither in absolute or relative terms. According to our estimates, the volume of global migration flows declined from 41.4 million (0.75% of world population) during 1990 to 1995, to 34.2 million (0.57% of world population) during 1995 to 2000. A substantial part of the fall might be accounted for by ceasing of cross-border movements triggered by the violent conflicts in Rwanda and the ending of the Soviet-installed Najibullah regime in Afghanistan. The number of global movements increased by 5.7 million between 1995–2000 and 2000–2005, and by 1.6 million between 2000–2005 and 2005–2010, whereas the percentage of the world population moving over 5-year periods has been relatively stable since 1995.

The size of migration flows within and between 15 world regions in 2005 to 2010 (estimates are in database S1) is shown in Fig. 4. Several migration patterns shown in Fig. 4 are broadly in line with previous assessments based on global stock data (*11*) and flow data for selected countries published by the U.N. (*3*, *4*, *18*, *19*). Earlier observations

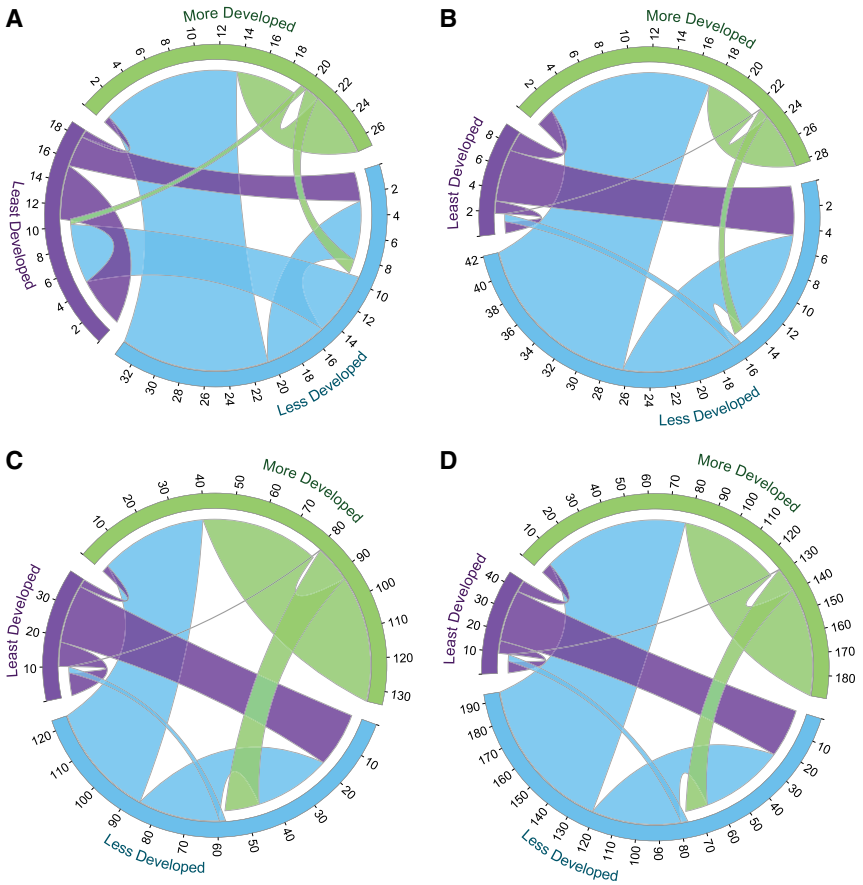

Fig. 2. Comparing estimated migrant flows to stocks in early 1990s and late 2000s. Migration flows between more developed (green), less developed (blue), and least developed (purple) countries. (**A**) Flows during 1990 to 1995. (**B**) Flows during 2005 to 2010. (**C**) Stock data from 1990. (**D**) Stock data from 2010. Tick marks on the circle segments show the number of migrants (inflows and outflows) in millions.

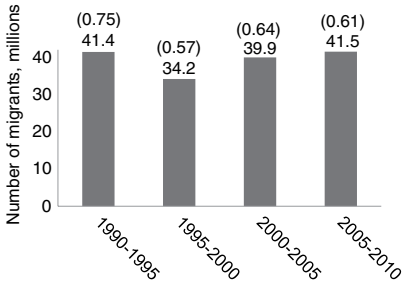

Fig. 3. The global number of international movements between 196 countries in four quinquennial periods, 1990 to 2010. Percentages (shown in parentheses) are calculated by using the world population at the beginning of the period.

include the attractiveness of North America as a migrant destination, the substantial movements from South Asia to the Gulf states in Western Asia, the diverse movements within and between the European regions, and the general tendency for more developed regions to record net migration gains, whereas the less developed countries in Asia, Africa, and Latin America sent more migrants than they received from 2005 to 2010.

A global comparison of migration flows based on our estimates extends these earlier observations and uncovers three striking features of the global migration system. First, African migrants from sub-Saharan Africa (who represent the vast majority of African migrants) appear to have moved predominantly within the African continent. From 2005 to 2010, an estimated 665,000 migrants moved within Eastern Africa, and 1 million people moved within Western Africa. Our data indicate that it is the movements between the member countries of the West African Economic and Monetary Union—especially Ivory Coast, Burkina Faso, and Guinea-Bissau—that drive this pattern (database S2). In contrast, the biggest flow from Western Africa to another continent comprised 277,000 people moving to Western Europe.

Second, migration flows originating in Asia and Latin America tended to be much more spatially focused than were flows out of Europe. Emigrants from South Asia and South-East Asia tend to migrate to Western Asia, North America, and to a lesser degree, Europe. Migrants from Latin America move almost exclusively to North America and Southern Europe. In contrast, migration to and from Europe is characterized by a much more diverse set of flows to and from almost all other regions in the world.

Third, although the largest flows occurred within or to neighboring regions, the plot depicts numerous flows that go through the center of the circle. These long-distance flows are effective in redistributing population to countries with higher income levels, whereas the return flows are negligible.

Will strong population growth in sub-Saharan Africa lead to mass migration from lower-income countries in Africa to higher-income countries in Europe and North America over the coming decades? Our findings provide evidence for a stable intensity of global migration flows and a concentration of African migration within the continent, with only a small percentage moving to the more developed countries in 1990 to 2010. Therefore, it seems unlikely that if these observed trends persist, emigration from Africa will play a key role in shaping global migration patterns in the future. Nevertheless, human capital and demographic trends create a considerable potential for change in the global migration system. If, for example, future population growth in sub-Saharan Africa were to be paralleled by a commensurate expansion in education, the growth of a more skilled workforce may lead to an increase in skilled migration from Africa to the more developed world.

In quantifying global migration flows, our data provide a better basis for analyses of the spatial structure of international migration flows that extend beyond the discipline's theoretical and methodological boundaries. A better understating of the causes and consequences behind current migration patterns may allow for a more informed speculation on future trends.

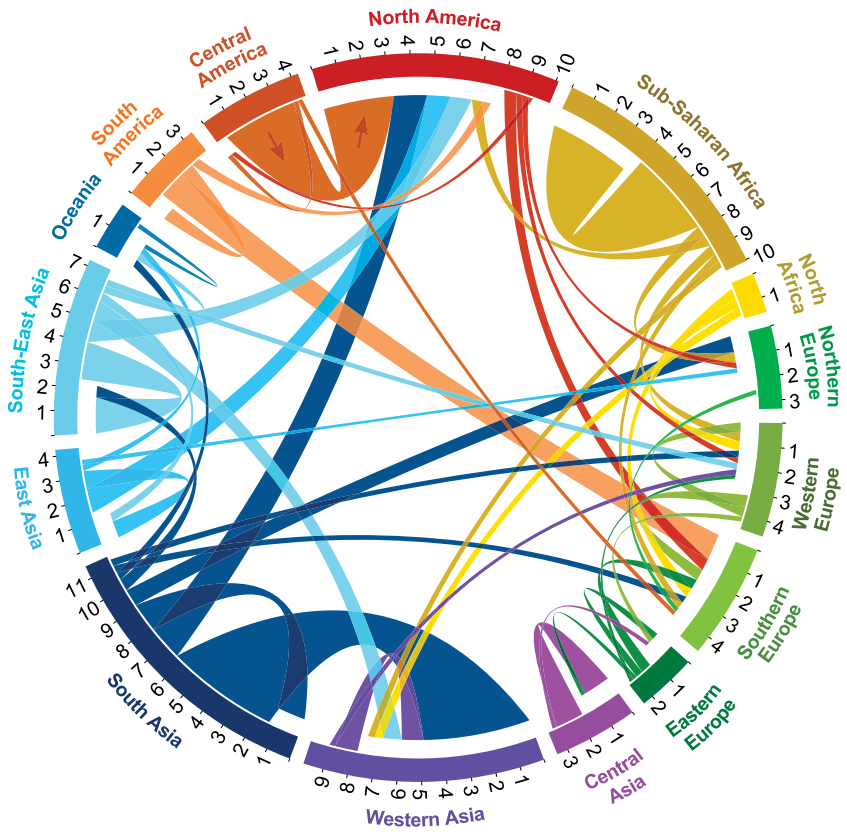

Fig. 4. Circular plot of migration flows between and within world regions during 2005 to 2010. Tick marks show the number of migrants (inflows and outflows) in millions. Only flows containing at least 170,000 migrants are shown.

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Supplementary Materials

www.sciencemag.org/content/343/6178/1520/suppl/DC1
Materials and Methods
Tables S1 to S5
References (*20–26*)
Databases S1 and S2

18 November 2013; accepted 28 February 2014
10.1126/science.1248676

Wittgenstein Centre's 2014 Conferences

Demographic Differential Vulnerability to Natural Disasters in the Context of Climate Change Adaptation

3 days, 9 sessions, 1 roundtable discussion, 40 participants at the seminar co-organized with the IUSSP Panel on Climate Change in Kao Lak, Phang Nga, 23-25 April 2014.

Forty researchers from different disciplines discussed how insights into the effects of demographic and socioeconomic differentials can assist the international risk, vulnerability, and climate change community.

Conference participants stressed that vulnerability to natural hazards depends not only on where you are (exposure) but also who you are. Within the same community or households, the impacts of natural disasters are not distributed evenly among demographic groups. While people have adapted to the changing environment throughout the human history, the capacity to adapt varies with demographic characteristics. Stakeholders who participated in the roundtable discussion pointed out that they need scientific evidence from demographic experts in order to implement disaster risk reduction measures that take account of population change in their community.

The seminar was also the concluding meeting of an ERC (European Research Council) Advanced Investigator Grant awarded to World Population Program director Wolfgang Lutz in 2008 on the topic of "Forecasting societies' adaptive capacity to climate change."

Seminar presentations are downloadable at www.iiasa.ac.at/news/IUSSP15.

All presentations can also be watched online: www.iiasa.ac.at/video/IUSSP15. ■

Higher education, mobility, and migration in and out of Africa

The international conference of the same name was organized by the Wittgenstein Centre in June 2014 to provide an opportunity for scientists from Africa and Europe to exchange relevant research findings.

Higher education is central to fostering socioeconomic development. It is particularly important in Africa which is the only macro-region in the South where per capita income, despite some economic growth, has declined in recent years because of extremely high birth rates. African governments recognize the importance of education for socioeconomic development and also increasingly invest in higher education. However, a rapid expansion of universities, especially private ones, is increasingly difficult because of the shortage of university teachers. As a consequence, the quality of education could suffer. The employment of university graduates is also a problem, given the weak development of modern industrial and service sectors. Closely related to this is the issue of emigration of graduates (brain drain) toward Europe and America.

From 19-21 June 2014 the international conference "Higher education, mobility and migration in and out of Africa (HEMMA)" took place at the Wittgenstein Centre. Thirty-four scientists from four European and eleven African countries came to Vienna to discuss issues related to the development, quality, and outcomes of higher education and university teaching and research in Africa from a comparative perspective, with a specific focus on relations between Africa and Europe. The conference also provided a forum for African and European social scientists to exchange relevant research findings across continents.

Please go to the conference Web page www.oeaw.ac.at/vid/hemma for more information on the program and specific presentations. ■

Studying population aging with redefined age

Around 100 demographers and sociologists from different parts of the world discussed new approaches to understanding and interpreting population aging on 3-5 December 2014 in Vienna at the international conference, New Measures of Age and Ageing.

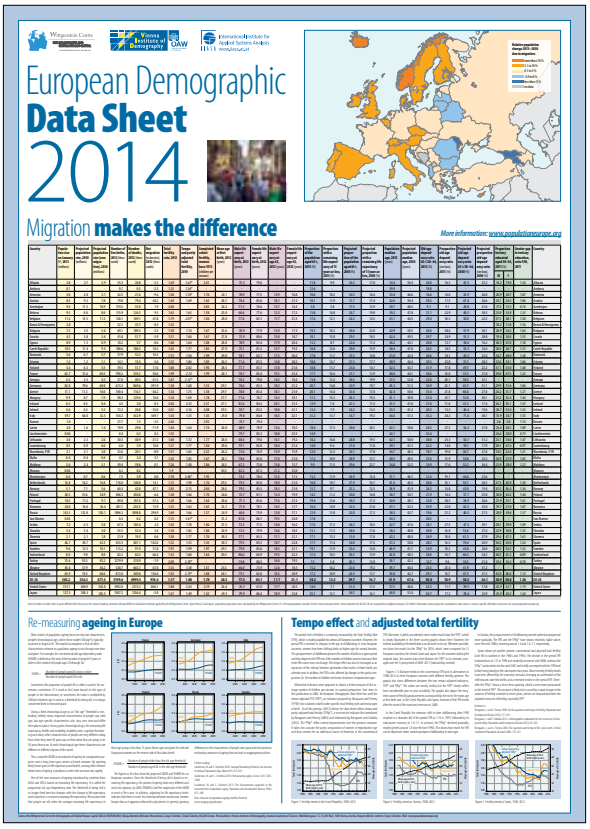
In Europe and other developed regions of the world, life expectancy has increased significantly in recent decades, and continues to increase. Numerous challenges are caused by population aging. The crisis in the health care, social support, and pension systems, for example, is widely discussed in the media, at international high-level events, and in the offices of the policymakers. The alarmist character of many media and political statements due to most studies of population aging focusing on only one characteristic of people: their chronological age. The implicit assumption is that other characteristics relevant to population aging do not change across time and place. But clearly, they do. As people live longer, they also stay healthier longer. Because of education changes and scientific advances, human populations can grow in productivity, creativity, and remaining life expectancy, as they grow older chronologically.

For the three days of the New Measures of Age and Ageing conference, scientists from all over the world presented and discussed new ways of measuring aging in a multidimensional way: based on a set of different characteristics, including cognitive abilities, self-reported physical conditions, biomarkers, etc. The economic and policy implications of these new ways of interpreting age and aging were also considered. Several case studies – contextualizing new measures of aging in South-East Asia, the northern Atlantic region, Russia, and Serbia - were presented at the conference.

Selected conference contributions will be published in the Vienna Yearbook of Population Research 2016.

Conference presentations can be viewed at www.oeaw.ac.at/vid/newage. ■

European Demographic Data Sheet 2014



The latest Data Sheet features the relative population change 2013–2030 due to migration for 49 European countries.

The European Demographic Data Sheet is produced every two years by the Wittgenstein Centre for Demography and Global Human Capital — a collaboration of the International Institute for Applied Systems Analysis, the Austrian Academy of Sciences, and the Vienna University of Economics and Business. The Data Sheet i) presents the most recent demographic data and population projections for 49 European countries, the USA, and Japan, and ii) highlights population aging, using traditional and prospective measures, as well as fertility, taking into account tempo effects. The new issue also provides data on gender differences in education.

The thematic focus of this year's issue is population migration and its impact on current and future population change. The European Demographic Data Sheet 2014 also provides information on female advantage and the reversed gender gap in tertiary education in Europe. A multidimensional projection model was used to assess the future composition of the population by age, sex, and four levels of educational attainment.

For the first time the 2014 European Data Sheet is presented on the dedicated Web site www.PopulationEurope.org in a more interactive and content-rich manner. It allows users to search and sort the main table and download the data from the embedded maps and graphs.

The Data Sheet poster can be downloaded from the Web site in PDF format, or a hard copy can be ordered from Lisa.Janisch@oeaw.ac.at.

Project update

The ERC-funded project Fertility, Reproduction, and Population Change in 21st Century Europe (EURREP)

The project team led by Tomáš Sobotka studies changes in fertility rates, fertility intentions, and ideals, and their underlying drivers. Particular attention is paid to the relationship between education and fertility. Although the project mostly focuses on Europe, it also examines other countries with low fertility rates, including the United States, Japan, Korea, and Brazil.

The EURREP project strongly contributes to data availability by collecting, standardizing, and publishing a wide range of data on historical and recent fertility. This includes two interrelated open-access databases, the Human Fertility Database (HFD, www.humanfertility.org) and the Human Fertility Collection (HFC, www.fertilitydata.org), developed as a joint activity of the Max Planck Institute for Demographic Research in Rostock and the Vienna Institute of Demography/ Wittgenstein Centre.

Based on the census and large-scale sample data, the project has also started developing the open-access Cohort Fertility and Education (CFE) database (www.cfe-database.org). This was launched in June 2014 and provides internationally comparable indicators of cohort fertility by level of education in countries with below- and around-replacement fertility levels. For the moment, data is available for 10 European countries: Austria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Spain, and Switzerland – and South Korea. More countries, including Germany, will follow in 2015. The database focuses on women and men who have (almost) completed their family building (i.e. those aged 40 and over at the time of the census). The following standardized indicators are available: completed cohort fertility rate (CFR), CFR by birth order, share of women (men) by number of children ever born, and parity progression ratios (PPR). These are all stratified by level of education, and, if possible, by country of birth or citizenship. Further, the user can download the input data, which include absolute numbers of women (and men, if available) by birth cohort and level of education. All indicators can be visualized on interactive graphs, which can be printed or downloaded in several formats. The database also contains details about methodology and basic information about available data, education categories, and important data issues for every country included.

Recent publications:

1. Sobotka, Tomáš and Éva Beaujouan. 2014. "Two is best? The persistence of a two-child family ideal in Europe", *Population and Development Review* 40(3): 391-419
2. Brzozowska, Zuzanna. 2014. "Fertility and education in Poland during state socialism", *Demographic Research* 31(12).
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Further information:

www.eurrep.org; www.cfe-database.org.

Strategic Plan for 2015-2017

Wittgenstein Centre's Research Focus: The Demography of Global Human Capital

The scientific goal of the Wittgenstein Centre for Demography and Global Human Capital research is to significantly advance the global frontier in modeling and understanding the drivers and consequences of changing population structures around the world – past, present, and likely future. The Centre's strategic scientific priorities for the coming years explicitly address multiple dimensions of population structures that go beyond the conventional analysis by age and sex. They focus particularly on the roles of human capital formation and global population aging and on the interactions of these trends with the social, economic, and natural environment. The Wittgenstein Centre's scientists will continue to use the rich methodological toolbox of demography and in particular the methods of multi-dimensional population dynamics to quantitatively address the "quality dimension" of changing human populations. The strategic focus that incorporates this dimension into the study of population trends, including their drivers and consequences, around the world can be structured into four broad research themes and ten research areas (Chart 1).

Because of the strong interactions and interdependencies of the individual components, the whole research endeavor is clearly more than the sum of its parts. Different themes and areas jointly address an ambitious research agenda. Only together can they achieve the goal of advancing a new social science paradigm that will introduce the quality dimension into population analysis in a coherent and convincing manner while facilitating the multi-dimensional modeling of the key interactions in the development of human societies.

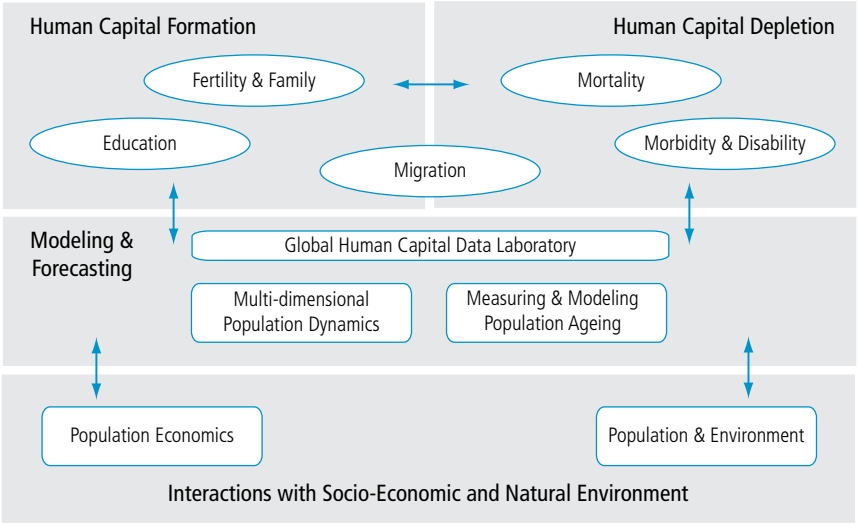

Chart 1. Wittgenstein Centre's Research Themes and Areas

Global Human Capital Data Sheet 2015

The Global Human Capital Data Sheet 2015 presents new population projections by age, sex, and level of educational attainment for the world.

Based on the latest data and analyses, which were presented and discussed in a recent book entitled *World Population & Global Human Capital in the 21st Century*, published by Oxford University Press, this data sheet illustrates that investments in human capital, especially (female) education, are critical for global sustainable development. The new population projections are presented by age, sex, and level of educational attainment for the world, world regions, and 195 individual countries (24 countries with limited education data) with a time horizon to 2060.

Three scenarios of possible development used in this data sheet show how alternative policies of education expansion, mainly through their effect on the future educational attainment of young women, can significantly influence the medium- to long-term future paths of population growth for individual countries and the world as a whole.

The data are presented in an extensive table and a number of illustrative charts and population pyramids.

The Data Sheet can be downloaded from the IIASA World Population Program's web-page:
www.iiasa.ac.at/POP/DataSheets

A hard copy can be requested from Katja Scherbov at scherb@iiasa.ac.at

Postdoctoral demographic research at IIASA

Every year IIASA provides full funding for several postdoctoral researchers. The World Population Program (POP) is looking for strong candidates interested in conducting their own research on different aspects of human capital under the supervision of, and in collaboration with, prominent POP scientists. Postdoctoral positions of up to 2 years' duration can begin within 6 months of selection.

Candidates should have their PhD at the time of taking up the appointment. They are expected to have a proven record of research accomplishments and a solid working knowledge of English. Preference will be given to applicants who are nationals of countries where IIASA has a National Member Organization and who have held a doctoral degree for less than 5 years at the application deadline.

More information on the postdoctoral program including application details can be found at www.iiasa.ac.at/postdocs. Application deadlines are 1 April 2015 and 1 April 2016.

If you have general questions on the postdoctoral program please contact YSSP & Postdoc Coordinator Tanja Huber (huber@iiasa.ac.at). For specific questions on demographic research proposals, please refer to Valeria Bordone of POP (bordone@iiasa.ac.at).

Save the date: 9 September 2015

Symposium celebrating the 40th anniversary of the establishment of the Vienna Institute of Demography (VID) of the Austrian Academy of Sciences and Opening of the new VID premises on the new campus of WU (Vienna University of Economics and Business) in the Prater. In addition to the festive event there will be an international symposium organized by the Wittgenstein Centre for Demography and Global Human Capital (VID/ÖAW, WU, IIASA) relating population analysis to the Sustainable Development Goals which will be established by the United Nations General Assembly the following week.

More information about the symposium will be communicated in due course.

Call for papers

Wittgenstein Centre International Conference on Education and Reproduction in Low-fertility Settings
Vienna, 2-4 December 2015

Vienna Institute of Demography (VID), Austrian Academy of Sciences/Wittgenstein Centre for Population and Global Human Capital (WIC) are organizing this conference to investigate aggregate and individual links, as well as causal mechanisms, between level of education and reproductive behavior among women and men. The discussion will cover countries, regions, and populations with below-replacement or around-replacement fertility. Empirical and theoretical contributions examining the relationship between education and union formation, fertility, and reproductive behavior are welcome. The authors of the papers selected for the conference will be invited to submit their manuscripts to the special issue of the *Vienna Yearbook of Population Research* (2017) which will be devoted to the topic of the conference.

Organizers: Tomáš Sobotka, Éva Beaujouan, Wolfgang Lutz, and Maria Rita Testa

Please submit your one-page abstract to conference.vid@oeaw.ac.at by 30 June 2015 .

Authors of successful submissions will be informed by 3 September 2015.

More information can be found at www.oeaw.ac.at/vid/edurep.

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IIASA
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, Austria
Telephone: (+43 2236) 807 0
Fax: (+43 2236) 71 313
Web: www.iiasa.ac.at
E-mail: popinfo@iiasa.ac.at

Managing Editor: Tatyana Haplichnik
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