Shared Socio-Economic Pathways and Global Income Distribution

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Abstract

New socio-economic pathways have been developed in the context of ongoing work for the Intergovernmental Panel on Climate Change (IPCC), starting with the Fifth Assessment Report (AR5). Economists, part of the Integrated Assessment Modeling Consortium (IAMC) and linked to the IPCC process, have been developing so-called shared socio-economic pathways (or SSPs) that are designed to span the spectrum of potential outcomes for the global economy along two broad axes—relating to the challenges of adaptation and mitigation respectively. Part of the storyline of the SSPs relates to relative developments of per capita incomes, i.e. different assumptions about processes of income convergence and divergence. To date, most of the analysis on income distribution has focused on the across country distribution of global GDP. The main purpose of this paper is to combine the across country analysis with within country assumptions about income distribution and to assess the implications for global and regional income distribution when populations are merged into larger entities. A focus on across country analysis provides a distorted picture of what the current distribution is and how it may evolve. Even in the most optimistic growth scenario, the degree of improvement in the Gini coefficient, one measure of global income distribution, is not nearly so great when taking into consideration within country distribution. This paper provides some insight into global income distribution taking into account differential macro growth rates as well as the changing within-country distribution. The main drivers—GDP and population—are taken from the publicly available database for the five SSP scenarios. The base distribution information is sourced from the World Bank's Povcal website for developing countries and from the OECD for the OECD countries. The available country distributional data is used to calibrate parameterized distribution functions (e.g. log-normal). These latter are projected forward in time with assumptions about their evolution consistent with an interpretation of the SSP storylines. The parameterized distribution functions are then used to construct artificial household distributions for each country. These latter are then pooled in different regional aggregations, including a world aggregation, to assess implications for regional and global income distribution.

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1 Introduction

There has been a lengthy tradition of developing long-term socio-economic scenarios dating at least as far back as Malthus'prediction of eminent doom as population growth was slated to outgrow food production. Since the 1980s, with the inception of the Intergovernmental Panel on Climate Change (IPCC), there has been a more systematic international effort to develop socio-economic scenarios that would inform government and researchers on the potential impacts of population and economic growth on greenhouse gas emissions that could feed in to the growingly more sophisticated long-term climate models—with eventual feedback effect from the climate models back to the economic models.

At the beginning of the work on the recently released Fifth Assessment Report (AR5) of the IPCC, the Integrated Assessment Modeling (IAM) community took it upon itself to develop a new suite of socio-economic scenarios, the now so-called Shared Socio-Economic Pathways or SSPs.[1]

One critical decision taken early on was to separate the development of the SSPs from the development of the climate scenarios, or the so-called representative concentration pathways (RCPs). In the previous community-wide exercise, scenario development was sequenced. In the late 1990's a group of researchers published an IPCC Special Report called *Emissions Scenarios*, IPCC [2000], often referred to as simply the SRES scenarios. These emission scenarios then fed into the various models of future climate (GCMs) to assess the climate impacts of the scenarios. At the start of the development of IPCC's fifth assessment report (AR5) it was felt that the sequential processing was too time consuming and that the climate modelers had sufficient information to develop the climate scenarios that would span the scope of plausible outcomes. The SSPs and RCPs were thus to be developed in parallel with an integration phase to occur at a later stage.

One key factor in the development of the RCPs was that the results from climate models are hard to differentiate in a close range of a certain outcome. The GCM modelers therefore focused on four RCPs that were sufficiently differentiated as measured by radiative forcing. The upper extreme focused on a radiative forcing of $8.5w/m^2$ and the lower extreme at $2.6w/m^2$.[2] Two intermediate scenarios were chosen, RCP4.5

[1] The IAM community eventually morphed into the Integrated Assessment Modeling Consortium (IAMC), `http://www.globalchange.umd.edu/iamc`.
[2] Controversial at the time as few IAMs were able to reach that lower limit.

and RCP6.0. Table 1 presents the CMIP5 ensemble results in terms of temperature change towards the end of the century.[3]

Tab. 1: CMIP5 Global mean surface temperature change (°C) in 2085-2095 relative to 1986-2005.

RCP	5%	17%	50%	83%	95%
RCP2.6	0.18	0.58	0.94	1.53	1.79
RCP4.5	1.06	1.33	1.68	2.29	2.59
RCP6.0	1.51	1.72	2.03	2.92	3.24
RCP8.5	2.63	2.96	3.57	4.45	4.81

The IAM community has spear-headed the quantification of the SSPs, described further below. The first phase of the quantification focused on three elements—demographics, income growth and urbanization. The demographic projections have been provided by the demographics group at the International Institute of Applied Systems Analysis (IIASA) based in Austria.[4]. The demographic projections are highly detailed with indicators on gender, educational levels[5] and for 5-year age cohorts—for most countries. Three research teams worked on the income projections—a group from IIASA, one from the Organization of Economic Cooperation and Development (OECD) and one from the Potsdam Institute for Climate Impact Research (PIK). All three groups harmonized on the common set of IIASA-based demographic projections. The first two groups provide indicators at a country level and cover a large share of global GDP and population. The PIK team focused on an aggregation of the global economy into 32 regions, of which some are countries. The urbanization indicators, also at a country level, have been developed at the National Center for Atmospheric Research (NCAR).[6] Many research teams are currently fleshing out other quantitative aspects of the SSP storylines, for example on trade policies, land-use, agricultural productivity, etc.

The results reported in this paper rely on two sets of projections related to the SSP. The first is the demographic projections—and only total population is used.[7] The second is the GDP projections of the OECD team. The next section describes some of the key features of these two sets of indicators.

The income distribution projections rely on two sets of sources. The World Bank, via its PovcalNet website[8], provides time series data for a large number of developing countries that typically contains at least decile information, as well as more aggregate information such as the Gini coefficient. The OECD maintains a database of income distribution indicators[9] for the OECD countries. These two databases are used to construct a two-parameter distribution for each country—initially using the log-normal distribution function. The two parameters are thus calibrated to the mean and Gini coefficient. The functional distribution is then projected forward with the mean calibrated to the OECD-provided GDP projections and the country specific Gini evolves according to an interpretation of the SSP story lines—improving, deteriorating or no change.

In order to assess global and regional changes in income distribution, an artificial household sample is generated each year and in each country based on income brackets using the cumulative distribution function (CDF). To make the resulting distribution as smooth as possible, income brackets are defined in sizes of $50 each, from 0 to $500,000, for a total of some 10,000 households per country (with one bracket for those earning $500,000 or more).[10] These households can be pooled together as aggregations of 1 or more countries, including the global distribution, from which a number of aggregate indicators and other measures

3 IPCC [2013], Annex II, page 1444.
4 See KC et al. [2010], KC and Lutz [2012], KC and Lutz [2014a] and KC and Lutz [2014b].
5 None, primary, secondary and tertiary.
6 The SSP socio-economic data is available at `https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about#intro`. Additional notes regarding the quantification, notably the underlying methodologies used to develop the quantification is available at `https://secure.iiasa.ac.at/web-apps/ene/SspDb/static/download/ssp_suplementary%20text.pdf`.
7 In related work with a CGE model, other elements of the demographic projections that are used include growth of the working-age population—typically defined as the age group between 15 and 64 years—and the education profiles are used to differentiate the growth rates of skilled and unskilled labor.
8 See `http://iresearch.worldbank.org/PovcalNet/`.
9 See `http://www.oecd.org/social/income-distribution-database.htm`.
10 Incomes are measured in constant $2005 at PPP exchange rates.

can be evaluated.

2 Shared socio-economic pathways

Climate change is at the heart of the development of the SSPs, even though there initial quantification is largely absent of any climate change considerations. After lengthy discussions, consensus was built around developing the new SSPs along two axes.[11] The first axis would highlight the challenges to adaptation. Moving along the axis would imply increasing adaptation challenges—either because climate impacts were becoming more severe and/or adaptation was difficult because of increasing vulnerability and the lack of economic resources to assist with adaptation. The second axis highlights the challenges to mitigation. Along this axis, challenges to mitigation could be high as radiative forcing becomes high and/or because cleaner technologies are not available—at least not at low cost.

At the core of the quantification of all long-term scenarios are population growth and economic development. The former could encompass its own set of drivers—assumptions about fertility and mortality—and its own set of outcomes, for example age and gender structure. There are other features of population that one may wish to consider in story lines such as spatial distribution, urbanization, education and, linked to economics, occupation.

The economic drivers will be in part linked to demographics—overall population, labor force growth and composition, education levels, etc. The other two major components of economic development include the aggregate level of savings—largely household, but also influenced by fiscal policy and foreign capital flows—and technological developments, for example labor productivity. Outcomes will include a range of socio-economic indicators such as poverty, income distribution (within countries as well as across), and international trade.

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The economic drivers will be in part linked to demographics—overall population, labor force growth and composition, education levels, etc. The other two major components of economic development include the aggregate level of savings—largely household, but also influenced by fiscal policy and foreign capital flows—and technological developments, for example labor productivity. Other factors will influence the patterns of growth, notably the price of energy by source and the availability and cost of news sources of energy. Outcomes will include a range of socio-economic indicators such as poverty, income distribution (within countries as well as across), and international trade. The growth and structure of energy demand will have a large influence on emissions, and thus the importance of new energy technologies.

The storylines discussed below largely focus on only a handful of these elements—population and overall economic development—leaving many of the details to be determined by individual research teams that may focus on one or several of the other connected elements.

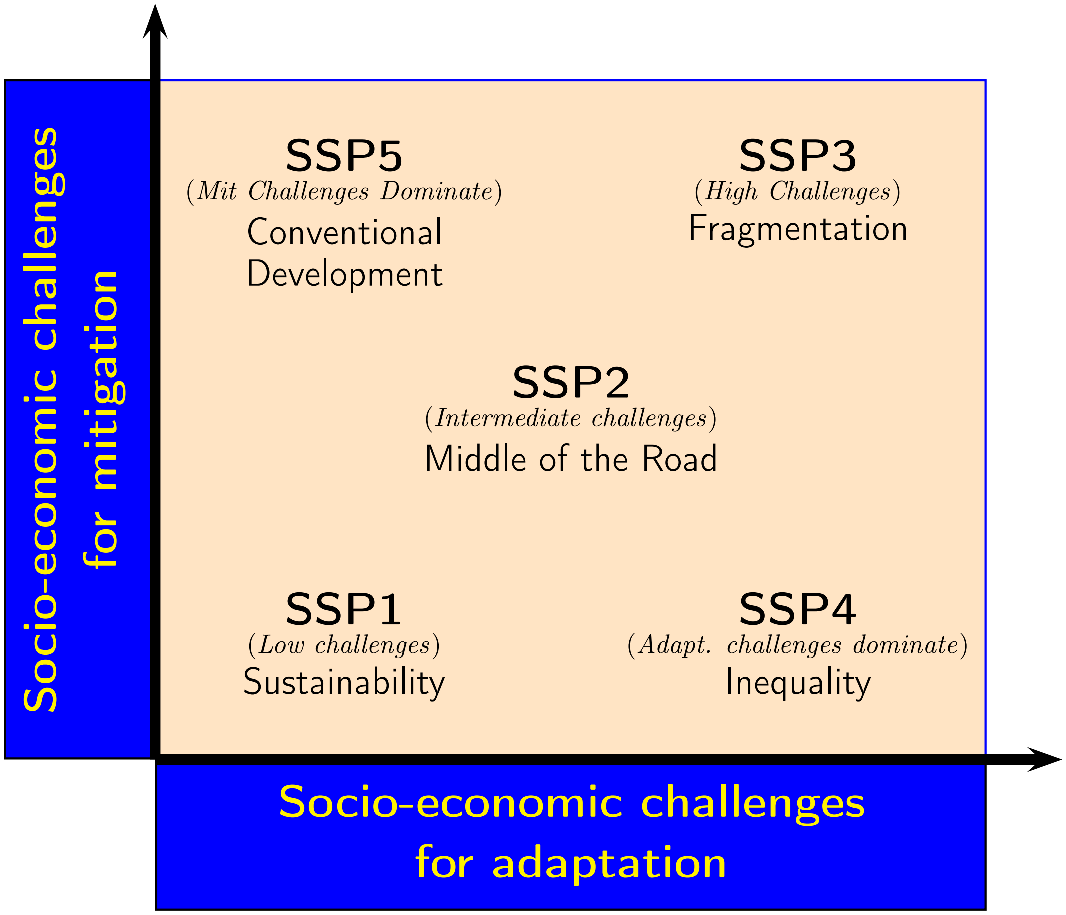
2.1 Storylines

Figure 1 depicts the five broad story lines developed for the SSPs and categorized along the two axes—mitigation and adaptation challenges. Table 2 summarizes the basic story lines for each of the five SSPs.[12] SSP1, SSP2 and SSP3, the SSPs along the diagonal can be viewed as 'high', 'middle of the road' and 'worst' scenarios, where SSP1 has a good balance in terms of income growth with a more environmentally sustainable outcome and SSP3 is on the other side of the spectrum with both poor outcomes in terms of income growth and environmental indicators. SSP5 is characterized by high and relatively equitable GDP growth—using conventional energy technologies—thus high GDP growth is associated with high emissions growth. Adaptation challenges are reduced as growth is relatively evenly spread and thus communities have greater means available to adapt to the high climate signal. SSP4 is an interesting off-diagonal case. It

[11] Background papers on the development of the SSPs include Moss et al. [2010], Kriegler et al. [2010], Arnell et al. [2011], Kriegler et al. [2012], O'Neill and Schweizer [2011], O'Neill et al. [2012], van Vuuren et al. [2012a] and van Vuuren et al. [2012b].

[12] O'Neill et al. [2014] provide a table that indicates possible relations between the SRES and SSP scenarios.

Fig. 1: **Five SSP storylines**



involves a scenario where GDP growth is highly uneven and thus there are significant pockets of poor that have few resources for adaptation. A more concentrated elite have the means to develop energy technologies that facilitate mitigation and thus mitigation challenges are relatively low.

The teams developing the initial quantification of the 5 story lines made their own interpretation of the scenarios and how these would modify the exogenous elements that are inputs into their various modeling frameworks. For the teams focused on economic growth, they took demographic projections as exogenous, though able to use different demographic indicators, such as education levels or the definition of working age population, as they desired.

2.2 Population

World population increased dramatically between 1950 and 2010 from [2.6] billion persons to [7.0] billion persons—largely predicated on rapidly declining mortality rates, somewhat offset by declining fertility rates. The latter are well below replacement rates in many parts of the developed world and part of the developing world, and declining in most countries.[13] The SSPs have vastly different implications for the global population in 2050 and even more so for 2100. Figure (2) shows the different outcomes for the total world population across the five SSPs. Four of the five scenarios have population peaking before the end of the century and then exhibit a decline. SSP2 and SSP4 peak late in the century (respectively 2070 and 2075) at some 38 percent above 2010 levels. SSP1 and SSP5 peak much earlier—towards mid-century—with a rise of around 25 percent relative to 2010—and the a relatively sharp fall. Under SSP1, population in 2100 would return

[13] Downloaded from United Nations Population division website `http://esa.un.org/unpd/wpp/unpp/panel_population.htm`—accessed 15 April 2015.

Tab. 2: SSP story lines

SSP	Challenges	Illustrative starting points for narratives
SSP1	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.
SSP2	Moderate	An intermediate case between SSP1 and SSP3—perhaps can be viewed as business-as-usual.
SSP3	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.
SSP4	High for adaptation, low for mitigation	A mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most to global emissions. However, in other regions development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.
SSP5	High for mitigation, low for adaptation	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.

Source: Adapted from O'Neill et al. [2014].

to the 2010 level and continue declining in the 22^{nd} century. SSP5 would see a more modest decline with population 8 percent above the 2010 level in 2100. SSP3, by design, is a high population growth scenario. Under SSP3, population would climb to nearly 13 billion persons globally, an increment of some 84 percent relative to 2010, and with no signs of peaking.

The range of differences across the scenarios clearly widens over time. In 2050, the range between the low and high lines is around 1.5 billion. The range jumps to 5.8 billion in 2100.

Scenarios SSP2 and SSP4, and even more so SSP1 or SSP5, would be a sharp break from long-term world population trends, over the last two centuries that has seen rapid growth. Though individual countries, and more frequently local communities, have witnessed declining populations, the world has never experienced large scale declines in population and the social and economic adjustments this may portend. In the long-run, the world may stabilize at some sustainable population level with (nearly) constant age cohort proportions. However, in the transition to such a steady-state, countries are likely to observe sharp changes in these proportions, for example rapidly rising shares of elderly relative to labor force size and the economic impacts of these changes are likely to be important.

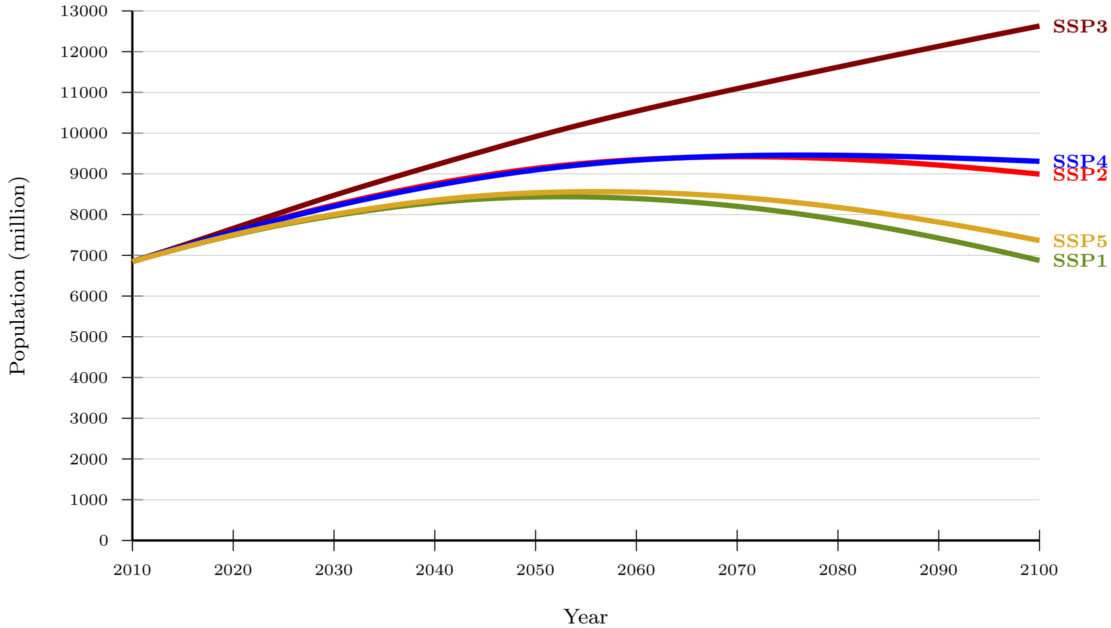
The global composition of population will vary according to SSPs.[14] In all cases, the East Asia and Pacific region sees a decline in its share of global population–from a level of near 30 percent in 2010 to somewhere around 23 percent in 2050 and closer to 15 percent in 2100. South Asia's share varies within a much narrower band around 25 percent in 2010 and staying close to that share in 2050. There is somewhat greater variation in 2100, with the share rising to 30 percent under SSP3. The share of global population remains relatively constant for Middle East and North Africa and Latin America and Caribbean—the former at

[14] The data described below is available from the author and is calculated from the IIASA-based demographic profiles for the SSPs.

roughly 5 percent and the latter at around 8 percent and dropping modestly under all scenarios save SSP3. Europe and Central Asia would witness a relatively sharp fall in its share of global population under all scenarios. On the other hand, Sub-Sarahan Africa would see the largest rise under all scenarios. In 2050, at a minimum, its share would rise from a 2010 level of around 13 percent to 18 percent (SSP5) and as high as 23 percent under SSP4. By 2100, its share of global population could reach close to 40 percent under SSP4—and clustered around 25 percent undert the other scenarios, i.e. a near doubling of its global share. The population share of the high-income economies is highly variegated under the various scenarios—particularly in 2100. From an initial level of around 18 percent, its share in 2050 could range from 12 percent (SSP3) to 18!percent (SSP5). The range in 2100 is much greater—between 7 percent (SSP3) and 27 percent (SSP5).

In terms of absolute numbers, the countries anticipated to see the highest growth would be India, Nigeria, Pakistan, the United States, the D.R. Congo, Ethiopia, Uganda and Tanzania—though with different implications in 2050 compared with 2100. India for example would witness an additional 300 to 750 million persons in 2050 under all scenarios, however with a lower population level in 2100 relative to 2010 under three of the SSPs. On the other hand, under SSP3 India's population would increase by some 1.4 billion in 2100. Countries in Sub-Saharan Africa could be subject to some very sizable population increases—particularly in 2100. Under SSP3 and SSP4, Nigeria's population would be nearly 700 million greater in 2100 compared to 2010. Even relatively small countries such as Ethiopia and Uganda would see increases of some 200 million persons by 2100. The United States is an interesting high-income country. Under SSP5, with high and relatively equitable growth—its population in 2100 would increase by some 400 million persons, more than a doubling of current levels.

Fig. 2: **World population across the different SSPs**

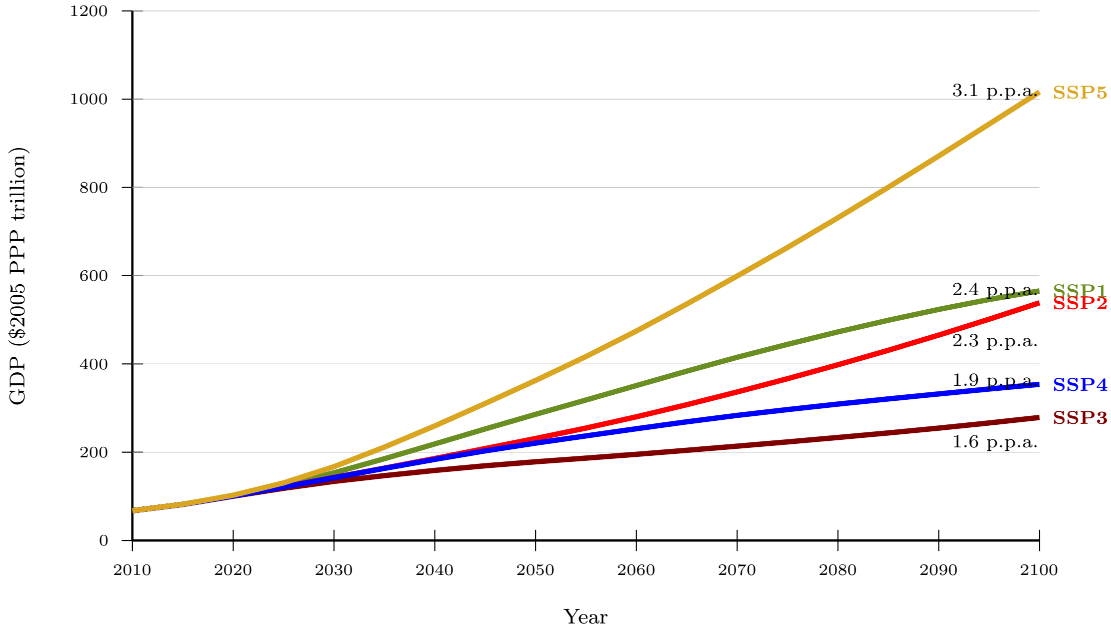


Given this paper's objectives, little more will be described regarding the population prokections. Of course, there is significantly more that can be deduced from the demographic projections including the more structural details that cover gender, age distribution and education levels. Given the purposes of this paper

2.3 Income

This section describes the income profiles under the 5 SSPs using the OECD's GDP projections. Figure 3 traces the evolution of global GDP under the five scenarios—with the levels expressed in constant $2005 at PPP exchange rates. From a level of around $67 trillion in 2010, the global economy in 2100 would range from a low of only $280 trillion under SSP3, to a high of over $1,000 trillion under SSP5. The average growth rate over the 9 decades varies from a low of 1.6 percent per annum to nearly double at 3.1 percent per annum. Similar to the population trends, there is some clustering at the global level, though of different SSPs, with SSP3 and SSP4 quite close together and SSP1 and SSP2 with rather similar shape.

Fig. 3: **World GDP across the different SSPs**

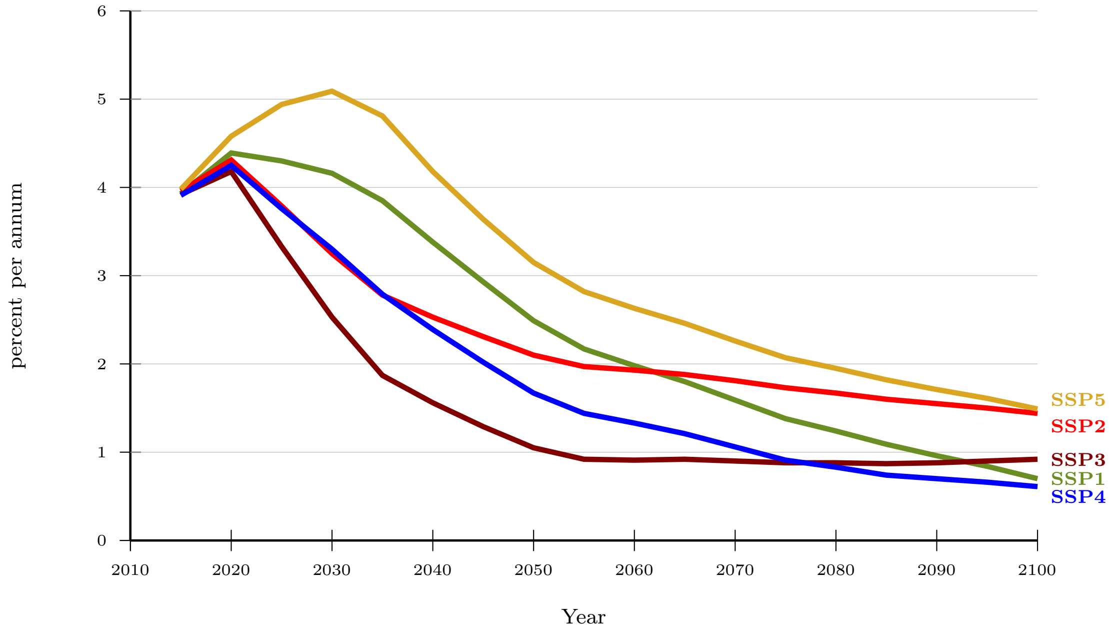


The GDP growth profiles (figure 4) suggest quite a bit of catch-up in incomes over the first half of the century with a marked deceleration in the second half. Under SSP5, global GDP growth would peak at some 5 percent in the 2030's. For the other SSP's, the peak in growth rates occurs earlier with a sharp drop in growth for SSP3 by 2050 and a stable rate of about 1 percent throughout the second-half of the century.

Under all scenarios there is a sharp rotation of output from high-income countries towards developing countries. In 2010, the high-income countries had a 57 percent share of global output. By 2050 this falls to between 30 and 38 percent, depending on the SSPs with the lowest shares under SSP1 and SSP5. By 2100, the share falls to a range of 23 to 36 percent—with the lower percentages for SSP1, SSP2 and SSP3 and the higher ranges for SSP4 and SSP5.

Partly driven by high population growth rates, the share of South Asia and Sub-Saharan Africa in global GDP in 2100 rise significantly, up to 21 percent under SSP2 for South Asia from 7 percent in 2010, and up to 22 percent in Sub-Saharan Africa from 3 percent in 2010. The other developing regions see some variation from their initial shares depending on SSPs, but they remain in a relatively narrow range.

Fig. 4: **Growth rate of world GDP across the different SSPs**



The global GDP trends imply potentially significant increases in per capita incomes. Average per capita income in 2010[15] was approximately $10,000 (in constant $2005 at PPP exchange rates). Under SSP5, this could rise to some $140,000 in 2100 or to only a dismal $22,000 under SSP3. SSP1 would see a rise to some $84,000, well above all other scenarios with the exception of SSP5, and with presumably improved environmental indicators relative to the latter.

Table 3 provides a quick snapshot of the equity implications of the SSP scenarios. The table provides the average regional per capita income relative to the average per capita income in high-income countries. For all developing regions in 2010, this so-called parity index was 16, i.e. each dollar earned in high-income countries translates to an average of 16 cents in developing countries. Under SSP1 and SSP5, the parity index would rise to over 70, i.e. a fairly substantial convergence in incomes at this level of aggregation and broadly shared over the large developing regions. Even South Asia and Sub-Saharan Africa that start from a very low level exhibit significant catch-up, and the better performers, East Asia and Pacific and Latin America and Caribbean would be close to converging. SSP3 and SSP4 are at the opposite spectrum, with the parity index only improving to around 25 or 26 for developing countries in aggregate—and even the better performing regions have incomes that lag behind the high-income countries by around one-half or more.

Tab. 3: Income parity index in 2100, income relative to high-income countries

Region	**2010**	**SSP1**	**SSP2**	**SSP3**	**SSP4**	**SSP5**
East Asia & Pacific	18	85	73	43	53	89
South Asia	8	68	50	19	24	73
Europe & Central Asia	27	72	68	44	54	76
Middle East & North Africa	20	65	57	32	33	71
Sub-Saharan Africa	6	68	47	17	8	74
Latin America & Caribbean	30	83	70	37	49	88
All developing economies	16	73	57	26	25	78

In the absence of information on within country income distribution, it is nonetheless possible to assess global income distribution based on the SSP trends for population and GDP assuming perfect within country income distribution, i.e. each person receives the some income within a country. Figure 5 replicates a similar calculation in Chateau et al. [2012] that also provides significantly more information on the methodology underlying the OECD SSP GDP projections. The figure reiterates some of the points made above. SSP1 and SSP5 reflect very positive outcomes in terms of global equality with the Gini coefficient at the global level dropping from 55 in 2010 to around 10 by the end of the century in both cases. SSP4 reflects the worst outcome for the Gini coefficient. SSP3 is somewhat better, but to some extent reflects the poor growth prospects for a broad share of the global population with relative convergence in incomes at a low level.

We shall see below that the assumption of perfect within country distribution seriously obscures the true evolution of global income distribution.

[15] Measured as global GDP divided by global population.

Fig. 5: **Global Gini trends assuming perfect within country distribution**

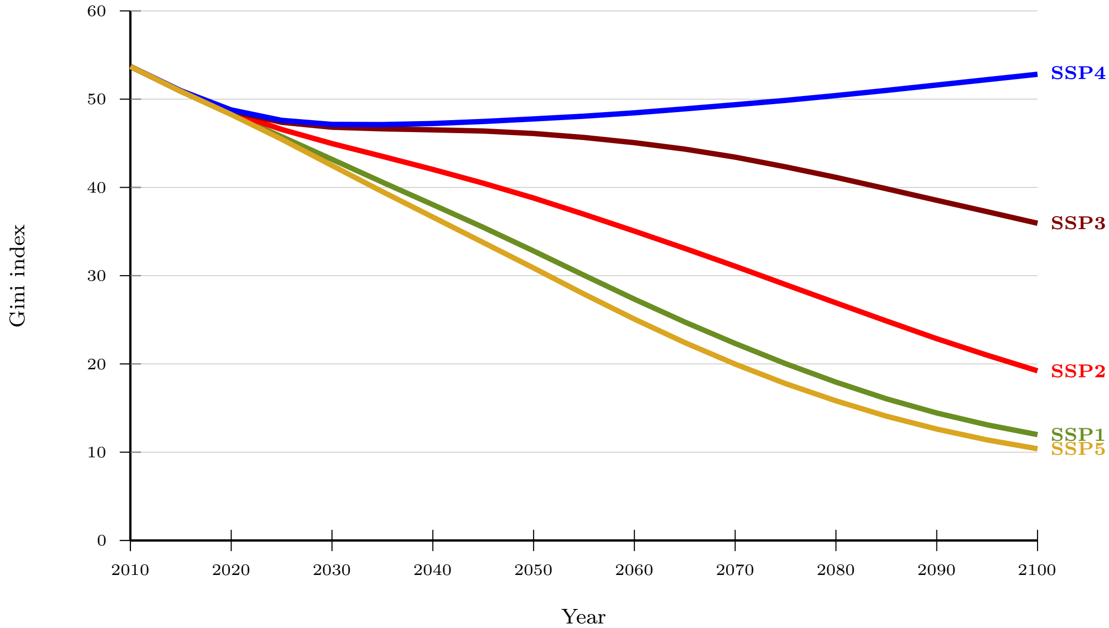


Table 4 summarizes the population and GDP trends for the 5 SSPs. There is no doubt that at the world level SSP1 and SSP5 dominate the other three in terms of desirability and the major difference between these two are income versus environmental trade-offs. The SSP3 and SSP4 worlds would leave a large proportion of the world's population living in very poor conditions and also facing potentially dire environmental impacts. While not delving into the political economy aspects that also underlie the SSPs, the weakness of institutions and global governance is likely to exacerbate the socio-economic aspects of SSP3 and SSP4 through a greater level of civil conflict, stress over limited resources and a higher level of internal and international migration.

Tab. 4: Summary of global population and income trends

SSP	Population	GDP
SSP1	Low	Moderate
SSP2	Moderate	Moderate
SSP3	High	Low
SSP4	Moderate	Low
SSP5	Low	High

3 Current income distribution

The World Bank and the OECD provide partial indicators of income distribution at the global level.[16]

The World Bank data is sourced from its database of household surveys that is increasing in country coverage as well as providing time series of surveys. The World Bank Povcal methodology uses the aggregated data—in decile form for example—to estimate parameterized Lorenz curves. The two functional forms are known as the generalized quadratic and beta and both are three-parameter distributions.[17] For the analysis herein, only the reported Gini coefficient is being used to calibrate the log-normal distribution function, which is a two-parameter functional form.[18]

The OECD data is less elaborate than the World Bank's as it provides only summary measures of income distribution. The Gini index is available for all OECD countries—both pre- and post-tax. The post-tax Gini was chosen for the analysis described below.

For the OECD countries, the Gini index varies from around 50 for Chile to the mid-20s for the Nordic countries and some of the transition economies.

The Gini distribution for developing countries, available from the World Bank, has a wider dispersion across countries. A the high-end, with an index of 65 are countries such as Equatorial Guinea, South Africa and Namibia. At the lower end are many former centrally planned economies such as Ethiopia, Tajikistan, Ukraine and Belarus, with Gini indices centered around 30.

[TODO: Describe more fully the available Ginis]

4 Methodology

The basic methodology involves growing each country's population and GDP according to the 5 SSP scenarios—starting in 2010— and to make specific assumptions on the shape of the Lorenz curve over time. The parameterized Lorenz curve for each country and time period is used to generate an artificial distribution of households using population and average GDP per capita as inputs. The income spectrum is split into income brackets of fixed size, which have been fixed at $50, from $0 to $500,000. This leads

[16] The World Bank data is available at `http://iresearch.worldbank.org/PovcalNet/index.htm?0,3`. The OECD data can be downloaded from `http://www.oecd-ilibrary.org/social-issues-migration-health/data/oecd-social-and-welfare-statistics/income-distribution_data-00654-en`.

[17] See Datt [1998] for further elaboration.

[18] The next iteration will explore other functional forms, including the two used by the World Bank. One concern in the use of these functional forms is there ability to capture appropriately the tails of the distribution—both for estimating the incidence of poverty and to measure the degree of wealth concentration.

to 10,000 household groups per country, plus a residual group that includes all persons with an income of \$500,000 and above.[19] Thus for each country we have the 10,001 groupings of household that contain the number of persons in each grouping as well as the average income in the group. We can pool the households of one or more countries into a regional grouping, from which it is possible to derive a number of indicators related to income distribution such as deciles, number of persons in certain income ranges (e.g. the middle class), the incidence of poverty, the Gini index and other aggregate indicators of inequality. The grouping of all countries represents the world.

5 Income distribution and the SSPs

5.1 Assumptions about within country distribution

The paper is an exploration of potential findings from changing income distribution as defined by the given population and GDP profiles and assumptions about changes in the within country income distribution. Table 5 provides one interpretation of the SSP story lines and their translation into changes in within country income distribution. The assumption under SSP1 is that within country distribution improves in all regions. SSP3 is the polar opposite with income distribution worsening in all regions. SSP2 represents the status quo. SSP4 has income inequality deteriorating in the poorest countries, but the status quo in the upper-middle and high-income regions. SSP5 complements to some extent SSP1, with broad improvements in all regions, but the status quo in high-income countries. For the moment, the interpretation of the arrows is simple. Improving equality reflects a decline in the Gini of 10 percent between 2010 and 2100. A deterioration translates into a 10 percent increase the Gini index over the same period.

Tab. 5: Within-country assumptions on changes in income inequality

Region	**SSP1**	**SSP2**	**SSP3**	**SSP4**	**SSP5**
Low-income	↗	⟶	↘	↘	↗
Lower middle-income	↗	⟶	↘	↘	↗
Upper middle-income	↗	⟶	↘	⟶	↗
High-income	↗	⟶	↘	⟶	⟶

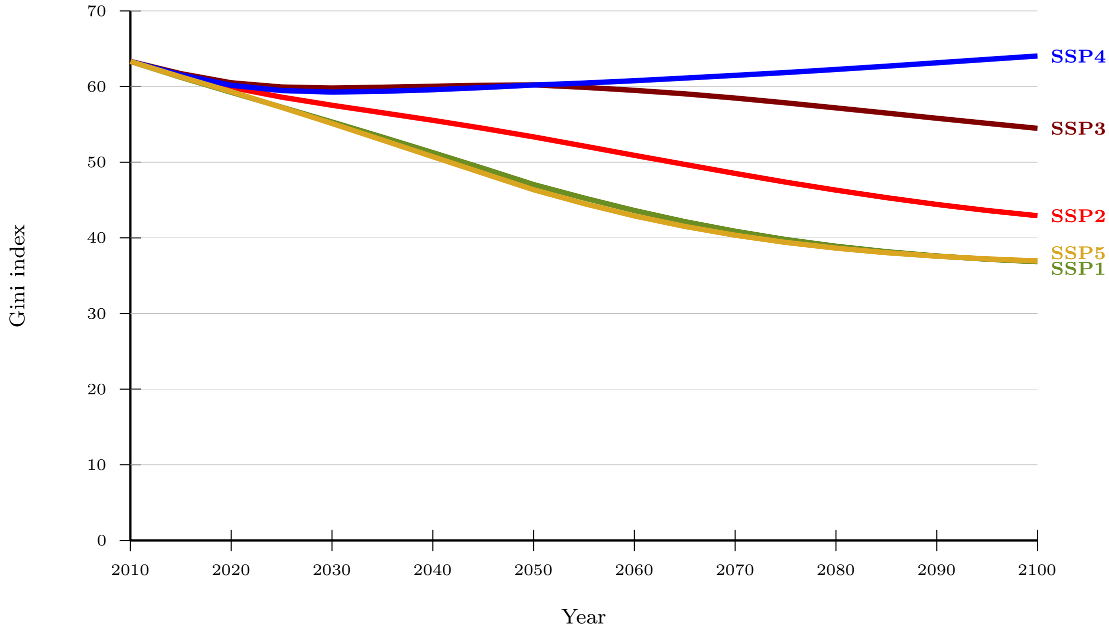
Note: A rising arrow indicates improving equality, i.e. Gini declines.

5.2 Impacts on inequality and distribution

Figure 6 represents the key finding from this study. The relatively rapid income growth in the first few decades leads to an improvement in the global Gini under all scenarios. The resulting stagnation in developing countries, particularly in SSP4, leads to a gently sloping rise so that by 2100, the world income distribution, as summarized by the Gini index is roughly where it started, though dips again slightly for SSP3 as stagnation takes hold in high-income countries as well. The trends for SSP1 and SSP5 line up almost perfectly. The global Gini under these more optimistic scenarios appears to flatten out at a level of around 38. The business-as-usual SSP2 scenario shows a steady decline to reach a level of around 42 with a continuing declining trend.

[19] Greater details on the methodology are elaborated in the Annex.

Fig. 6: **Global Gini trends including assumptions of within-country distribution**



How important are the assumptions on within-country distributional changes to the overall picture? The analysis was re-computed assuming a constant within-country Gini for all countries. At the global level, this had relatively modest impact. In the case of SSP1, the Gini is 40.5 under the latter assumption, compared to 36.8 using the story line assumption, i.e. a difference of 3.7 percentage points. It makes somewhat less of a difference for SSP5, with a difference of 2.8 percentage points. This is roughly the same difference for SSP3, but in the opposite direction. Finally, it makes almost no difference for SSP4.

Table 6 shows the Gini coefficient in 2010 and 2100 for broad regional groupings. There are significant differences in 2010 and not surprisingly the Gini for all regions pooled together is significantly higher than the indices for the individual regions. For high-income countries, the evolution of the Gini index stays in a relatively narrow band. Starting from 36.4 it reaches 40 under the worst case scenario, SSP3. Under SSP1, the Giniindex drops to 31.4. Most of the movement occurs before 2050. For developing countries, the range is very high. Starting from 53.3, the Gini would rise to 64 under the worst case scenario (SSP4), or could drop to around 37 under more optimistic scenarios such as SSP1 and SSP5. It appears that much of the action is occurring in the lower middle-income countries.

[NEED TO FILL IN MORE DETAIL AND EXPLANATION]

Tab. 6: Regional Gini index in 2010 and 2100

Region	2010	SSP1	SSP2	SSP3	SSP4	SSP5
Low-income	43.1	36.3	40.4	45.0	46.5	36.2
Lower middle-income	38.4	34.7	38.3	43.5	56.6	34.6
Upper middle-income	46.8	41.0	46.0	51.5	46.9	40.7
All developing countries	53.3	37.4	42.6	51.0	63.6	37.2
High-income countries	36.4	31.4	35.0	40.1	35.4	34.7
World total	63.3	36.8	42.9	54.5	64.0	37.0

Tables 7 and 8 provide the distribution of global income by broad income groups. If we set the poverty line at $2,000 per annum, the percent below this line in 2010 is 27.5. Across the SSPs, this drops to near zero in SSP1, SSP2 and SSP3, but is persistent in the other 2 scenarios, particularly SSP4, which translates into some 735 million persons still living with $2,000 per year or less. The near poor, defined as those earning between $2,000 and $10,000 per year represents the bulk of persons in 2010, nearly 47 percent of the world's population. This group would also nearly disappear under scenarios SSP1, SSP2 and SSP5, but would still be a very significant group under SSP3 and SSP4. Defining middle income as those with incomes between $10,000 and $100,000 per year, this group represents about 25 percent of total population in 2010 and its share rises significantly under all scenarios—lowest in fact under the high-growth SSP5 scenario—as many graduate to upper income status. Accepting this definition of the middle class, it will increase from 1.7 billion in 2010 to anywhere from 3.2 billion under SSP5 to 7.3 billion under SSP2. The upper income group would also see an even more impressive jump under all scenarios, though particularly SSP5, in which case it would represent 56 percent of the population or some 4.1 billion persons.

[TO DO–More regional differentiation, look more carefully at the definition of income classes, focus on the tails—poverty in 2010 is low compared to the WB definition and high income seems to be underreported.]

6 Conclusion

The core SSPs, in the absence of policies, project radically different futures, but not implausible, nor inconsistent with what we have observed over the last 100 years, taking the economic progress in East Asia as a prominent example, but also the persistence of significant pockets of poverty. As research teams continue to interpret the SPP story lines, for example policy choices, technology, consumer preferences, a more nuanced view of the evolution of the distribution of income will emerge and could alter the rather mechanical, although potentially rich, exercise of this study. The core SSPs are not an end in themselves either. They will be coupled with so-called shared policy assumptions (SPAs) that will govern policies to limit climate change within each one of the SSPs.

Tab. 7: Distribution of global population by income bracket, percent

Income bracket	2010	SSP1	SSP2	SSP3	SSP4	SSP5
<500	3.8	0.0	0.0	0.1	0.5	0.0
500<x<1K	7.3	0.0	0.0	0.6	1.7	0.0
1K<x<2K	16.4	0.0	0.1	2.5	5.7	0.0
2K<x<5K	29.7	0.1	0.7	13.8	17.8	0.0
5K<x<10K	16.9	0.6	3.2	24.3	16.3	0.1
10K<x<15K	7.3	1.5	5.6	16.5	8.2	0.3
15K<x<30K	10.4	10.5	22.3	22.5	14.1	2.9
30K<x<100K	7.7	60.9	53.4	17.0	25.6	40.9
100K<x<250K	0.4	24.1	13.4	2.5	8.9	44.9
250K<x<500K	0.0	2.1	1.3	0.2	1.1	9.5
>500K	0.0	0.2	0.1	0.0	0.1	1.3

Tab. 8: Distribution of global population by income bracket, levels in millions

Income bracket	2010	SSP1	SSP2	SSP3	SSP4	SSP5
<500	262	0	0	18	44	0
500<x<1K	498	0	1	75	162	0
1K<x<2K	1,121	0	5	315	529	0
2K<x<5K	2,037	6	61	1,745	1,656	2
5K<x<10K	1,159	41	286	3,064	1,518	10
10K<x<15K	500	101	500	2,081	768	24
15K<x<30K	713	720	2,009	2,843	1,308	212
30K<x<100K	527	4,188	4,802	2,148	2,378	3,008
100K<x<250K	29	1,657	1,201	311	827	3,307
250K<x<500K	1	148	115	28	106	703
>500K	0	12	12	3	12	98
Total	6,847	6,874	8,993	12,630	9,307	7,363

Next steps include refining the methodology, with a focus on the tails of the distribution functions, refining the country and SSP-specific story lines in terms of the evolution of income distribution and couple this work with structural models of income distribution—such as dynamic computable general equilibrium (CGE) models where the interplay between the growth of skills, labor market segmentation (rural vs. urban) and the functional distribution of factor remuneration play a significant role in determining distributional outcomes. Piketty [2014] has shown how important historically the latter has been and it is likely to play a key role in the future. How robust are his conclusions in a multi-sector, multi-regional and multi-factor framework? If they are robust, what policies can be implemented to improve distributional outcomes, and what are the tradeoffs?

A Methodology

A numerically generated income distribution is created for each country for each year of analysis for each one of the SSPs. The numerically generated income distribution depends on a parameterized distribution function that is calibrated in some base year and whose parameters evolve along some given exogenous path.

A.1 The log-normal distribution

The log-normal distribution is characterized by its standard deviation that has a one-to-one correspondence with the Gini coefficient. The log-normal distribution assumes that the (natural) log of the random variable behaves as a normal random variable, thus if $X \sim N(\mu_x, \sigma_x)$, then $Y(= e^X) \sim LN(\mu_y, \sigma_y)$. The following relations can be derived between Y and X (Aitchison and Brown [1957]):

$$\mu_x = \log(\mu_y) - \frac{\sigma_x^2}{2} \iff \mu_y = e^{\mu_x + \frac{1}{2}\sigma_x^2} \tag{1}$$

$$\sigma_x^2 = log\left[1 + \left(\frac{\sigma_y}{\mu_y}\right)^2\right] \iff \sigma_y^2 = \mu_y^2\left(e^{\sigma_x^2} - 1\right) \tag{2}$$

It should be noted that if we define the coefficient of variation of Y by:

$$\eta_y = \frac{\sigma_y}{\mu_y} \tag{3}$$

then we also have that the coefficient of variation satisfies the following:

$$\eta_y^2 = \left(\frac{\sigma_y}{\mu_y}\right)^2 = e^{\sigma_x^2} - 1 \iff \sigma_x = \sqrt{\eta_y^2 + 1} \tag{4}$$

Given an estimate of the Gini coefficient, G, it is possible to calibrate the standard deviation (of X). The following relationship holds between G and σ_x (see Aitchison and Brown [1957]):

$$G = 2\Phi\left(\frac{\sigma_x}{\sqrt{2}}; 0, 1\right) - 1 \iff \sigma_x = \sqrt{2}\Phi^{-1}\left(\frac{G+1}{2}; 0, 1\right) \tag{5}$$

where Φ is the normal cumulative distribution function (CDF) (with mean 0 and standard deviation 1) and Φ^{-1} is the inverse normal cumulative distribution function (with mean 0 and standard deviation of 1).

The SSP data provides population and GDP (or GDP per capita) for each country, each available year and each SSP. Income is measured in constant \$2005 at purchase power parity (PPP) exchange rates. Let μ_c^y represent the per capita GDP for country c for a given year and scenario. The starting point for generating the numerical distribution are the following relations:

$$\sigma_c^x = \sqrt{2}\Phi^{-1}\left(\frac{G_c+1}{2}; 0, 1\right)$$
$$\mu_c^x = \log(\mu_c^y) - 0.5(\sigma_c^x)^2$$

Assume there are $n+1$ income brackets defined by y_i. The cumulative population for the first n brackets is defined by:

$$P_{c,i} = \int_0^{\ln(y_i)} \phi\left(\frac{x - \mu_c^x}{\sigma_c^x}; 0, 1\right) dx = \Phi\left(\frac{\log(y_i) - \mu_c^x}{\sigma_c^x}; 0, 1\right)$$

where P_i is the percent of the population with income per capita less than or equal to y_i and ϕ is the normal probability density function (PDF). P_{n+1} is set to 1. The number $p_{n+1} = P_{n+1} - P_n$ represents the percent of the population above the top bracket given by y_n. For example, if the brackets are defined in increments of \$500 and bracket y_n is set to \$500,000, there will be a total of 1001 income brackets and p_{n+1} represents the percent of the population with income of \$500,000 or more.

The cumulative income distribution is calculated using the following formula, which represents the Lorenz curve for the log-normal distribution:

$$L_{c,i} = \Phi\left(\Phi^{-1}\left(P_{c,i};0,1\right) - \sigma_c^x;0,1\right)$$

The latter can be calculated from the following that defines the Lorenz curve:

$$L(P(y)) = \frac{1}{\mu_y}\int_0^y zf(z \mid \mu_y, \sigma_y^2)dz$$

where $f(z \mid \mu_y, \sigma_y^2)$ is the PDF of the log-normal distribution function. Aitchison and Brown define the moment distribution function of the log-normal distribution as:

$$M_j(y \mid \mu_y, \sigma_y) = \frac{1}{\lambda_j}\int_0^y z^j f(z \mid \mu_y, \sigma_y^2)dz$$

where λ_j is the jth moment about the origin and defined as:

$$\lambda_j = \int_0^\infty z^j f(y \mid \mu_y, \sigma_y^2)dz = e^{j\mu_y + \frac{1}{2}j^2\sigma_x^2}$$

The first moment is of course the distribution mean, i.e. μ_y. One of the features of the log-normal distribution is that the jth moment distribution function is linked directly to the log-normal distribution by the following expression:

$$M_j(y \mid \mu_x, \sigma_x) = \int_0^y f(z \mid \mu_y + j\sigma_y^2, \sigma_y^2)dz$$

The Lorenz curve is linked to the first moment distribution:

$$L(P(x)) = \frac{1}{\mu_x}\int_0^y zf(y \mid \mu_y, \sigma_y^2)dz = M_1(y \mid \mu_y, \sigma_y)$$

And from the previous expression, it follows that:

$$M_1(y \mid \mu_y, \sigma_y) = \int_0^y f(z \mid \mu_y + \sigma_y^2, \sigma_y^2)dz$$

This last expression can be linked to the standard normal distribution, similar to the original log-normal function with a mean of μ_x, where the mean is displaced by σ_y, thus the Lorenz curve expression is:

$$L(P(y)) = \Phi\left(\Phi^{-1}\left(P(y) - \sigma_x;0,1\right);0,1\right)$$

The Lorenz curve calculations are done for the first n income brackets and L_{n+1} is set to 1. The percent levels by bracket—both population and income—are derived from the standard cumulation formulas:

$$p_{c,i} = P_{c,i} - P_{c,i-1}$$
$$l_{c,i} = L_{c,i} - L_{c,i-1}$$

with the levels for the initial bracket set to the respective cumulative level. The actual levels—population, income per capita and total income—can be derived from the following formulas:

$$Pop_{c,i} = p_{c,i}TPOP_c$$
$$YPC_{c,i} = \mu_c^y \frac{l_{c,i}}{p_{c,i}}$$
$$Y_{c,i} = YPC_{c,i}Pop_{c,i}$$

where $TPOP$ represents total population in country c.

Though this is the generic procedure, in fact there are a few modifications that are implemented. First, all population levels are rounded to the nearest unit. Due to this, there will be many brackets with 0 population, and this could lead to some potentially large under-counting of population and incomes. For income brackets at the lower end, they are summed together till the cumulative total is 1 or more. For income brackets at the top end, the last bracket is typically larger than 1 because it encompasses all the population above the top bracket, but it may be preceded by a number of brackets with 0 population.

The last bracket therefore is the sum over all preceding brackets from the last bracket with a (rounded) population that exceeds 1. The resulting population levels (all integer numbers) range from the first bracket where (rounded) population exceeds 1 to the last bracket which sums over all brackets from the last with a positive (rounded) population to the initial last bracket. This means that the brackets individually are no longer comparable across countries. For example, the USA bracket for $250, may include all persons with incomes of $250 or less, whereas for Tanzania, it may only include those that earn between $200 and $250 (where $50 is the standard bracket size). Similarly, the $250,000 bracket for Sri Lanka could include all persons with incomes of $250,000 or more, but for Germany, may simply include persons with incomes between $249,950 and $250,000. This does not affect subsequent calculations as these are based on average per capita incomes within each bracket and they do not rely on the homogeneity of brackets.

A.2 Vectorization

The previous section described how 'households' are generated given each country's income and some notion of its distribution. The households are then stacked in a single vector that will have the length of $(n+1).NC$ where $(n+1)$ represents the number of income brackets, i.e. households, and NC is the total number of countries. With the current data, there are 169 countries and assuming the full default size of brackets, the number of households globally is around 1.7 million, though there could be fewer given the adjustments described above to delete brackets with fewer than 1 persons.

After vectorization of the individual country surveys, the global distribution is ranked by per capita income levels providing the relevant sorted global vectors for p, P, l and L, i.e. the population distribution and cumulative distribution and the income distribution and cumulative income distribution. A number of statistics can then be derived at either the country or regional level. The overall distribution index, as measured by the Gini index is provided by:

$$G = 1 - \sum_{i=1}^{N} p_i(2L_i - l_i) \tag{6}$$

The median income is based on the income bracket, im, that has the cumulative population distribution closest to 50 percent:

$$im = \{i \mid \min(|P_i - 0.5|)\} \tag{7}$$

The median income is then defined as the per capita income of that bracket:

$$Median = YPC_{im} \tag{8}$$

The average income of the bottom half of the distribution is then calculated as:

$$\mu^L = \frac{\sum_{i=1}^{im} Pop_i\, YPC_i}{\sum_{i=1}^{im} Pop_i} \tag{9}$$

While Gini is an index of overall income distribution, Wolfson (Wolfson [1994]) introduces a so-called *polarization* index that measures

> the extent to which the society is divided into the "haves" and "have-nots." Roughly speaking, distribution A is said to be more polarized B than if the incomes in A tend to be more bimodal, in that there are more poor and rich, but fewer people in the middle (Ravallion and Chen [1997])

Wolfson defines the polarization index as:

$$Polar = \frac{2(2T - G)}{mtan}$$

where T is "the vertical distance between the Lorenz curve and the 45-degree line at the 50th percentile" (Wolfson [1994]) and is equal to $0.5 - L(0.5)$. $L(0.5)$ represents the cumulative income (in percent) of the bottom half of the population. This can be converted to the mean income of the bottom half of the population by the formula $\mu^L = \mu L(0.5)/0.5$ or $L(0.5) = 0.5\mu^L/\mu$. Wolfson defines $mtan$ as the tangent of the Lorenz curve at the 50th population percentile and it is equal to $Median/\mu$. Defining $\mu^* = \mu(1-G)$ as in Ravallion and Chen [1997] that call the distribution corrected mean income, the polarization index is defined as:

$$Polar = \frac{2(\mu^* - \mu^L)}{Median} \tag{10}$$

Another measure of inequality is known as the Generalized Entropy and defined by the following formula:

$$GE(\alpha) = \frac{1}{\alpha(\alpha-1)}\left[\frac{\sum_i Pop_i\left(\frac{YPC_i}{\mu}\right)^\alpha}{\sum_i Pop_i} - 1\right] \tag{11}$$

where α is often given the values of 0, 1 and 2:

$$GE(0) = \frac{\sum_i Pop_i \log\left(\frac{\mu}{YPC_i}\right)}{\sum_i Pop_i}$$

$$GE(1) = \frac{\sum_i Pop_i \frac{YPC_i}{\mu} \log\left(\frac{YPC_i}{\mu}\right)}{\sum_i Pop_i}$$

$$GE(2) = \tfrac{1}{2}\left[\frac{\sum_i Pop_i\left(\frac{YPC_i}{\mu}\right)^2}{\sum_i Pop_i} - 1\right]$$

The sums are over all relevant income brackets. If the relevant population percentages sum to 1, then the population weights can be replaced with p and the denominator (calculating the population total) can be dropped. GE(0) is sometimes referred to as the mean log deviation measure (or MLD) and also known as Theil's L-index. GE(1) is often referred to as Theil's T-index.

Poverty measures rely on an assumption of a poverty line, for example \$1/day or \$2/day. Let z represent the poverty line. A class of poverty measures, known as the Foster-Greer-Thorbecke, or FGT index (Foster et al. [1984]), is succinctly described by the following formula:

$$FGT(\alpha) = \frac{\sum_{i\in\{i|\, YPC_i \le z\}} Pop_i\left(1 - \frac{YPC_i}{z}\right)^\alpha}{\sum_i Pop_i} \tag{12}$$

The sum in the numerator is over all income brackets where the average income is less than or equal to the poverty line z. The population weights can be replaced by the population share, p, if they sum to 1 over the relevant population. In this case, the denominator can be dropped.

The most common values for α are 0, 1 and 2. $FGT(0)$ represents the headcount index, H, i.e. the percent of the population that has an income below the poverty line. $FGT(1)$ represents the so-called poverty gap index, PG. This index takes into account the average distance of the poor from the poverty line. If two countries have identical headcount indices, the country with the greater poverty gap has a greater proportion of its population further away from the poverty line. $FGT(2)$ puts more weight on the poorest of the poor and thus captures the severity of poverty. The common poverty measures, H and PG, fail to conform with some intuitively appealing axioms that poverty measures should have (see Zheng [1997]). The Watts index (described in Zheng [1997] and used in Ravallion and Chen [2003]) does conform to some of the core axioms and is defined as:

$$W = \frac{\sum_{i \in \{i | YPC_i \leq z\}} Pop_i log\left(\frac{z}{YPC_i}\right)}{\sum_i Pop_i} \tag{13}$$

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