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Income projections for climate change research: A framework based on human capital dynamics☆

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ABSTRACT

The quantitative assessment of the global effects of climate change requires the construction of income projections spanning large time horizons. Exploiting the robust link between educational attainment, age structure dynamics and economic growth, we use population projections by age, sex and educational attainment to obtain income per capita paths to the year 2100 for 144 countries. Such a framework offers a powerful, consistent methodology which can be used to study the future environmental challenges and to address potential policy reactions.

1. Introduction

The development of socio-economic projection scenarios plays a central role in the assessment of climate change impacts, as well as in the design of policy responses. Scenario building facilitates the interdisciplinary research efforts that appear necessary for understanding the feedback mechanisms between climate impacts and socio-economic conditions. Recent proposals for climate research projection scenarios build on defining matrix structures where the interplay of climate signals and socio-economic developments is explicitly emphasized (see for example Van Vuuren et al., 2012 or Kriegler et al., 2012). To the extent that they are a central determinant of adaptation and mitigation, income developments appear as a particularly important component of such projection exercises, as highlighted in Van Vuuren et al. (2014) and O'Neill et al. (2014) for the case of the recent Shared Socioeconomic Pathways (SSPs).

The aim of this paper is to present a modelling framework to create scenarios for GDP and GDP per capita that can be used as an input in integrated assessment modelling and other climate research applications which require income per capita projections in the very long run. Our projection model has several advantages that make it particularly well suited to serve as an instrument in climate change impact assessments at the global level. On the one hand, its underlying structure, based on a standard macroeconomic production function with labour input differentiated by age and education attainment level, is simple and easy to communicate. On the other hand, since the GDP projections are driven by human capital dynamics (defined as the change of population by sex, age and educational attainment), the specification proposed can be combined with the population projections developed in the context of the SSPs by Samir and Lutz (2014) in a straightforward manner. In addition to the population projection input, the model is calibrated by setting assumptions on physical capital investment, cross-sectional convergence and the developments in technological progress which are not related to human capital. The combination of the income projection method presented in this contribution with the population projection instruments described in Samir et al. (2010) and used in Samir and Lutz (2014) constitutes a self-contained and comprehensive framework to develop quantitative scenarios for assessing long-run environmental challenges. As such, it is thus designed to serve as a quantitative tool for assessing climate research questions related to the interplay of climate and socioeconomic systems. Furthermore, the relative simplicity of the approach makes it particularly suited to be adapted to other applications in social and environmental sciences.

From a theoretical point of view, the modelling strategy behind the projection exercise proposed in this paper builds upon a broad

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literature which emphasizes the role of human capital as a driver of economic growth (see for example Miller, 1967 for a discussion on the role of education as a driver of economic growth in the history of economic thought). Early econometric contributions assessing the link between educational attainment and economic growth using large samples of countries tend to treat human capital as a standard input of production (see Mankiw et al., 1992) whose accumulation affects income per capita in a similar fashion as physical capital accumulation does in earlier exogenous models of economic growth. The effect of education on labour productivity, a robust empirical stylized fact at the microeconomic level, justifies such an approach. Moving away from such an interpretation as a production factor, several contributions recognize the central role played by the stock of human capital (as opposed to the rate of accumulation) as a catalyst of technological innovation and foreign technology adoption (see Nelson and Phelps, 1966; Benhabib and Spiegel, 1994). In terms of model specification, such a generalization of the theoretical setting leads to empirical specifications where the stock of human capital and its interaction with the distance to the global technological frontier are used as explanatory covariates in addition to human capital accumulation variables.

In spite of the empirical evidence supporting the link between education and income at the macroeconomic level, very few contributions have used education as a basis for long-run out-of-sample economic growth projections. The lack of comparable data on educational attainment projections for broad sets of countries explains, at least partly, this gap in the literature. The information contained in age-structured population projections, which are available globally, has however been utilized to construct income forecasts (see Bloom et al., 2007 or Lindh and Malmberg, 2007). Recently, the availability of new global data of population by age, sex and educational attainment (see Lutz et al., 2007) has enabled the integration of these branches of the literature and the investigation of the effect that the distribution of education across age groups exerts on economic growth. The results in Lutz et al. (2008) or Crespo Cuaresma and Mishra (2011) show that income growth differences across countries and over time can be better predicted if the age dimension of human capital is incorporated in the modelling framework.

Using a global dataset that spans the last four decades, in this contribution we estimate econometric models which capture the different aspects of the link between human capital and income growth highlighted in the literature. We combine such an estimated model with the projections of population by age, sex and educational attainment developed by Samir and Lutz (2014) for practically all countries of the world to the year 2100. These population projections, in turn, have been designed to mimic the different qualitative scenarios (SSPs) which serve as a unifying frame in order to assess the impacts of climate change and the role played by adaptation and mitigation policies in counteracting its negative consequences.

The choice of a specification for the aim of projecting income per capita over very long horizons encounters a trade-off between expanding the model to include the manifold of factors affecting income and incorporating the uncertainty about the future trajectories of such determinants over the projection horizon. By concentrating on human capital dynamics, the model chosen tries to strike a balance between these two forces. Although the modelling framework employed in the projection exercise abstracts from some important economic growth determinants, comparable specifications to the one used in this contribution have been often used in other studies (see Benhabib and Spiegel, 1994, 2005; Lutz et al., 2008 or Barro and Lee, 2013, just to name a few). The modelling approach has the advantage of using as an input education-structured population data, whose persistent dynamics allow for relatively precise and well understood projections. This contribution is framed in the context of research efforts aimed at providing economic growth projections for climate research based on the SSP storylines, thus complementing the reference projections provided by Chateau et al. (2014) for use in integrated assessment models (see also Leimbach et al., 2014 for an alternative complementary approach based on GDP aggregated at the level of world regions).

The paper is organized as follows. Section 2 presents the econometric model used to obtain the projections of GDP per capita. Section 3 summarizes the set of assumptions implied by each one of the SSPs, which define our projection scenarios. Section 4 presents the results of the income projection exercise, concentrating on the dynamics of world GDP per capita and the characteristics of each scenario in terms of the distribution of income per capita across countries. Finally, Section 5 concludes.

2. The modelling framework: education, age structure and economic growth

The income projection model is based on a simple aggregate production function with heterogeneous labour input, which is differentiated by educational attainment (no education, primary, secondary and tertiary) and age group (younger and older workers, defined by a cut-off age of 35 years),

$$Y_{it} = A_{it}K_{it}^{\alpha}\prod_{j=0}^{3}\prod_{k=1}^{2}L_{i,jkt}^{\beta_{jk}} \qquad (1)$$

where Y_{it} is total output in country i at time t, A_{it} refers to total factor productivity (TFP), K_{it} denotes the capital stock and $L_{i,jkt}$ corresponds to the labour input in age group k (k=1,2 denoting the younger and older age group) with educational attainment j (from j=0 no education to j=3 some tertiary education level attained). Given the high correlation in the within-country dynamics of educational attainment by age group, there is a trade-off between using a low aggregation level in the age dimension and obtaining precise estimates of the model parameters. The potential multicollinearity problem caused by the co-movement of population by educational attainment calls therefore for the use of a small group of age groups in the specification of the economic growth regressions. The results in Lutz et al. (2008) indicate that the use of two broad age groups appears sufficient to explain global economic growth trends once the education dimension is added to the model. Given the persistence of population dynamics, the results of the estimation and projection exercise are not strongly affected by changing the age threshold that defines the older and younger group within the interval (30,45). We also performed a principal components analysis exercise on the education data by age group which confirmed that the average level of education and the difference between older and younger age groups appears sufficient to summarize the variation of each one of the human capital variables over time and across countries.

Such a specification as the one given by Eq. (1) implies that the growth rate of total output depends on the growth rate of each one of the factors of production (TFP, the capital stock and each one of the population groups by age and educational attainment level),

$$\Delta\log Y_{it} = \Delta\log A_{it} + \alpha\Delta\log K_{it} + \sum_{j=0}^{3}\sum_{k=1}^{2}\beta_{jk}\Delta\log L_{i,jkt} \qquad (2)$$

In addition, in the spirit of the Nelson–Phelps paradigm (see Nelson and Phelps, 1966; Benhabib and Spiegel, 1994), we assume that the growth rate of total factor productivity depends on three different factors:

(i) the distance to the technology frontier (as approximated by the average income per capita level of the country), which reflects (conditional) income convergence dynamics,