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# Methods for including income distribution in global CGE models for long-term climate change research

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ABSTRACT

The consequences of climate policy and the impacts of climate change vary among different types of households depending on their income level, expenditure pattern, and other socioeconomic characteristics. Global economy-environment models that are used to assess climate change issues traditionally do not distinguish households by income or other attributes. To facilitate progress in this area, we review and assess literature on methods to include household heterogeneity in global long-term Computable General Equilibrium (CGE) models. We distinguish among three categories of approaches: 1) the explicit modeling of multiple household types within the CGE framework, 2) micro-simulation modeling, and 3) direct modeling of income distribution. For each of these approaches we describe the method, key assumptions, limitations and several prominent examples from the literature. Moreover, we discuss data needs, including the contents of household survey data, their availability and processing. We conclude with an overview of what each method could provide for global, long-term climate-related research.



## 1. Introduction

The success of climate change policies is not only about how much climate damages they avoid and how much they impact the whole economy but also on how costs and benefits of climate change mitigation actions are distributed among households. Indeed both the consequences of climate policy and the impacts of climate change vary between different types of households, and then winners and losers should be clearly identified in order to compensate the latter and make the policy acceptable. For instance, Hertel et al. (2010) found considerable differences between household groups for the poverty effects of crop yield changes due to climate change, driven mostly by differences in earnings and ownership structure of agricultural households. Rausch et al. (2011) found that welfare implications of a carbon tax vary between households at different income- and education levels and across ethnic groups in the United States, due to differences in occupation, and income and expenditure patterns. Hallegatte et al. (2014) recently developed a framework that identifies the channels through which households may escape or fall into poverty and how these channels relate to climate change: prices, assets, productivity and opportunities. Climate impacts and greenhouse gas (GHG) mitigation impacts each of these channels differently, and all of these channels are macro-economically linked. Global long-term general equilibrium models are useful tools to consistently analyse future developments of these channels at the global level and consistently link the macro-economic implications from changes in prices, assets, productivity and opportunities. However, analyzing the implications of climate change for poverty and income distribution requires that such models explicitly represent different household groups.

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Although country level applications of CGE models often include some degree of heterogeneous households, global economy-environment models that are used to assess climate change issues typically do not distinguish household groups by income or other attributes. Recently, a few partial equilibrium models that focus on the energy system and greenhouse gas emission mitigation have introduced sub-regional distributions of households (for an overview see Krey, 2014). Some of these studies defined a small set of household types according to a combination of income and urban-rural status (Ekholm et al., 2010; van Ruijven et al., 2011). These models were used to analyze the implications of future changes in urbanization (Krey et al., 2012), income distribution (van Ruijven et al., 2011) or access to energy for energy use and emissions (Pachauri et al., 2013) and whether consequences of mitigation policies differ across household types (Daioglou et al., 2012). Other studies used a global general equilibrium model, and characterized a representative household on the basis of underlying changes in age, household size, or urban-rural status, to analyze the effect of demographic change on economic growth, energy use and emissions (Dalton et al., 2008; Melnikov et al., 2012; O'Neill et al., 2010). Some studies have used global general equilibrium models to analyze the impacts of climate change on different household groups by extending the number household types for several countries (Bouet et al., 2013) or by performing a sequential microsimulation for a number of countries (Ahmed et al., 2011; Hertel et al., 2010). Another part of the literature applied non-CGE tools to analyze national level impacts of GHG mitigation policies (Blonz et al., 2010; Büchs et al., 2011; Jorgenson et al., 2011; Parry and Williams, 2010; Rao, 2013).

So far, analyses of long-term impacts of climate change seldom include changes in income distribution (van Ruijven et al., 2014), though this might change in the near future as the new scenarios framework provides new handles for including this aspect of socioeconomic vulnerability. As part of the process to develop new scenarios for global climate change research (Kriegler et al., 2012; Moss et al., 2010; van Vuuren et al., 2012) an effort is underway to enrich the recently developed Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2014; O'Neill et al., in press) with projections of changes in income distribution. On top of projections of demographic change (KC. and Lutz, in press), urbanization (Jiang and O'Neill, in press) and GDP (Dellink et al., in press; Crespo Cuaresma, in press; Leimbach et al., in press). Several existing methods, such as those described by Bussolo et al. (2010); Hughes et al. (2009); Kemp-Benedict (2011) and Van der Mensbrugghe (2015) are being applied to develop poverty and income distribution projection that are consistent with the SSPs.

To facilitate progress in the modeling of household heterogeneity within the context of long-term global studies, this paper provides an overview of the different methods that exist for general equilibrium models to include income distribution. Most of these methods have been developed in the context of development economics and within this field several overviews exist (Ahmed and O' Donoghue, 2007; Bourguignon and Bussolo, 2013; Savard, 2003). However, most applications of these methods in the literature use static CGE models and analyze short-term poverty impacts of development-related policy shocks. Hence, these models do not have to account for several factors that are relevant for long-term projections and climate change issues, such as changes in population structure (age, urbanization, education). In this paper, we will expand on the existing reviews by adding examples that focus on the longer-term and on climate-related applications. We will describe a range of methods available with particular emphasis on their suitability for use with global long-term Computable General Equilibrium (CGE) frameworks.

In this paper, Section 2 introduces different aspects of household heterogeneity in CGE models and the existing approaches to analyze this. Section 3 discusses the explicit modeling of multi-household CGE models, Section 4 describes micro-simulation approaches and Section 5 focuses on direct modeling of income distribution. For each of these approaches we present a description of the basic method, the key assumptions and limitations and several prominent examples from the literature. Section 6 describes the combination of these methodologies in hybrid approaches. Section 7 discusses data availability and processing and Section 8 discusses and concludes this paper.

## 2. Approaches to modeling income distribution within CGE frameworks

In many global CGE models, all households within a country or other model region are aggregated into a single representative household (Fig. 2). This representative household is endowed with labor and

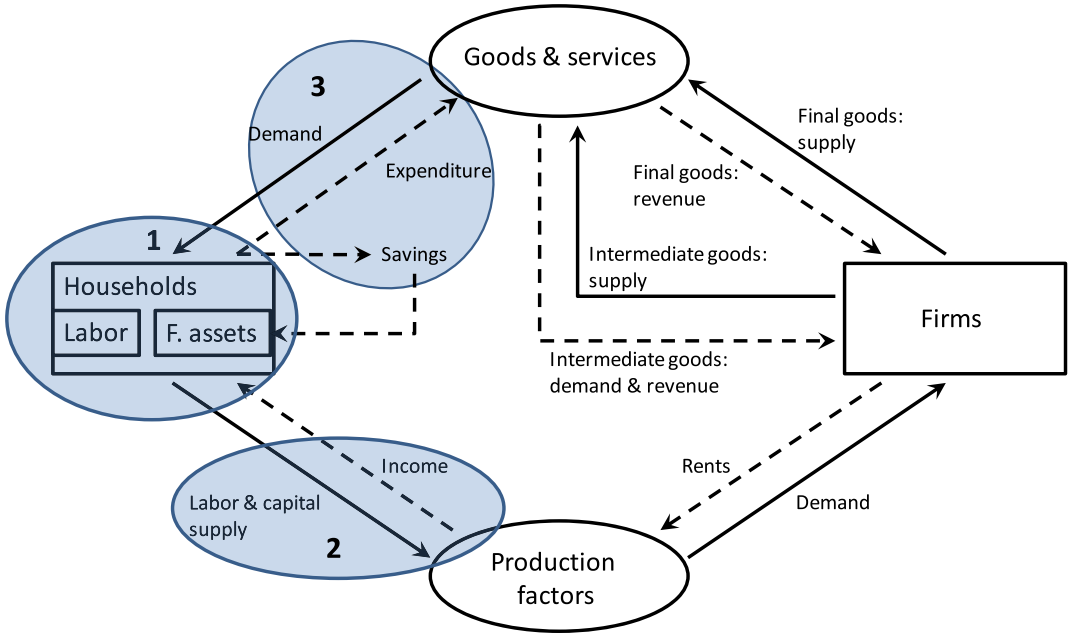


**Fig. 1.** Schematic representation of the flows (white circles and arrows) in a basic CGE model between the stocks of firms and households (rectangles). Households provide production factors (labor and capital) to firms and firms provide goods and services to each other and to households. The dashed arrows indicate monetary flows (income, expenditure, revenue, rents); the solid arrows indicate flows of products/factors in the opposite direction. Shaded circles indicate the three different aspects of household heterogeneity in CGE models indicated by Bertola et al. (2006).