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Accounting for household heterogeneity in general equilibrium economic growth models ☆

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ABSTRACT

We describe and evaluate a new method of aggregating heterogeneous households that allows for the representation of changing demographic composition in a multi-sector economic growth model. The method is based on a utility and labor supply calibration that takes into account time variations in demographic characteristics of the population. We test the method using the Population-Environment-Technology (PET) model by comparing energy and emissions projections employing the aggregate representation of households to projections representing different household types explicitly. Results show that the difference between the two approaches in terms of total demand for energy and consumption goods is negligible for a wide range of model parameters. Our approach allows the effects of population aging, urbanization, and other forms of compositional change on energy demand and CO_2 emissions to be estimated and compared in a computationally manageable manner using a representative household under assumptions and functional forms that are standard in economic growth models.

1. Introduction

Quantifying the effect of consumer heterogeneity on aggregate behavior is an important question, addressed in many economic growth studies (see, e.g., Caselli and Ventura, 2000; Krusell and Smith, 2006, for an overview). In contrast, in the field of long-term energy and emissions modeling, the approach has typically been to assume consumers are homogenous; i.e., to treat the whole population as a single representative household with fixed characteristics over time (see, e.g., Manne et al., 1995). More recently, multi-sector growth models typical of this field have begun to explore the effect of heterogeneity, with an initial focus on how changing demographic factors (household age, size, geographical type, etc.) could influence energy use and carbon dioxide emissions (see, e.g., Paltsev et al., 2005; Dalton et al., 2008; O'Neill et al., 2010, and references therein).

Methods for introducing heterogeneity in energy and emissions models are evolving. A direct method of accounting for household heterogeneity is to treat population sub-groups separately. This can be achieved by solving separate optimization problems for several population groups over time. The benefit of the method is that it can explicitly account for time variations in demographic heterogeneity and allows for general equilibrium effects through prices (Dalton et al., 2007, 2008). However, this multiple household type approach is more computationally demanding than and gives up some of the simplicity of the representative household approach.

The aim of this paper is to describe and evaluate a method that combines the benefits of the two approaches by retaining the single representative (infinitely lived) household framework but reflecting underlying heterogeneity and changes in composition through changes over time in parameters describing the economic characteristics of this household. Parameter changes are based on detailed household data, and we show that demand over time in this case is quantitatively close to the total demand that would be obtained from modeling different

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household types separately. This approach captures heterogeneity while remaining computationally manageable and retaining the multi-sector, infinitely lived agent (ILA) structure of models typical of the energy and emissions field.

In other fields, a number of approaches to representing heterogeneity within a dynamic general equilibrium framework have been employed. For example, in one-sector models, several authors have studied functional forms of the individual utility functions that are sufficient for existence of the representative consumer (see, e.g., Caselli and Ventura, 2000). The closed form analytic formulas were then used to analyze distributions of consumption, wealth and income. Rausch and Rutherford (2010) used a representative household, with sequentially recalibrated preferences, to iteratively update the equilibrium prices in a model with many heterogeneous households.

An alternative to ILA models for incorporating demographic projections and distinguishing households by age and type is the overlapping-generation (OLG) models (see the discussion in Dalton et al., 2008). There are a number of numerical methods that show how equilibria in an OLG model with many heterogeneous households can be solved, but so far the studies have been limited to the case of the single production sector (see, e.g., Krusell and Smith, 2006; Fehr et al., 2008; Rausch and Rutherford, 2010). We do not pursue an OLG structure here, given our goal of introducing heterogeneity into the multi-sector, ILA structure typical of energy and emissions models, although as discussed below our formulation shares some features of OLG models.

In multi-sector general equilibrium models, exact aggregation of several household groups into a single representative household that would have the same total demand is possible only under fairly stringent assumptions on the model (see, e.g., Kehoe, 1991). Melnikov et al. (2010) presented a multi-sector model, with both utilities and production functions of Cobb–Douglas type, that allows a closed-form analytical solution. The equilibrium in this model is Pareto efficient, and the solution to the Pareto problem is obtained with the help of dynamic programming. It has been shown that, for each particular good, the preference coefficient of the representative household is equal to the weighted sum of the preference coefficients of heterogeneous households with the Negishi weights expressed as functions of the model parameters.

With functional forms of preferences and technologies that are conventionally used in energy economics, closed-form solutions in a multi-sector computable general equilibrium (CGE) model are unavailable. Moreover, the preference coefficients of the heterogeneous households themselves are calculated from the data and depend on a particular calibration method. Therefore, we turn to approximate methods of calculating the parameters of the representative household.

The primary novel contribution of this paper is to describe and evaluate an approximate solution for transitional dynamics in a multi-sector, ILA model with many heterogeneous consumers. We show that the approximate solution is computationally manageable and numerically very close to the solution of the model with multiple household groups for aggregate variables such as energy demand and GDP.

To illustrate the proposed method, a one-region version of the Population-Environment-Technology (PET) model (Dalton and Goulder, 2001; Dalton et al., 2007, 2008) is used (model code and all input and output files for this paper are available at http://www.cgd.ucar.edu/ccr/boneill/). As is typical of the energy economics models, it has a multi-sector production side with a disaggregated energy sector. The use of the time-dependent representative consumer in the PET model significantly reduces the computational time, compared to several heterogeneous groups model, especially in multi-regional models that take into account international trade (O'Neill et al., 2010).

In the PET model, the disaggregation of the population into separate age groups accounts for the fact that households will make savings and consumption decisions based on forward looking behavior over their life cycle, and the life cycle of their children. Therefore, the population is disaggregated not by age groups *per se*, but by dynasties; i.e., groups that contain households of a given age today and that track those households, and the households of their children, as they age over time (for details see Dalton et al., 2008). Thus, the model with multiple dynasties has a structure that shares features of the ILA and OLG approaches. The numerical procedure used in the PET model is similar in style to the procedure used in the OLG model of Auerbach and Kotlikoff (1987); i.e. it employs a variation of the algorithm by Fair and Taylor (1983).

Within the multiple dynasties approach, households can affect energy use either directly through their consumption patterns or indirectly through their effects on economic growth in ways that up until now have not been explicitly accounted for in other energy-economics models. The direct effect on emissions is represented by disaggregating household consumption for each household type into several categories of goods so that shifts in the composition of the population by household type produce shifts in the aggregate mix of goods demanded. Because different goods have different energy intensities of production, these shifts can lead to changes in energy use. To represent indirect effects on energy use through economic growth, the PET model explicitly accounts for the effect of population growth on economic growth rates, age structure changes on labor supply, urbanization on labor productivity, and anticipated demographic change (and its economic effects) on savings and consumption behavior (O'Neill et al., 2010).

The plan of the paper is as follows. In Section 2, we start with reviewing the conventional calibration of preference coefficients and labor supply to the benchmark data in a CGE model. Next this approach is extended to the case with possible time variations in household characteristics (see also the discussion in Creedy and Guest, 2008). The "expected" consumption shares and labor productivities are calculated based on the projected population values (for an alternative method of calculating time-varying consumption shares of the representative household, as a function of *per capita* income with regression-based coefficients, see Paltsev et al., 2005).

Household aggregation in the PET model is presented in Section 3, preceded by a brief overview of the model. Then the aggregation of heterogeneous households into a *single dynasty* with homogeneous characteristics (representative household) is compared against the aggregation to *multiple dynasties* with heterogeneous characteristics. A detailed description of the PET model, used in this study, is given in Appendix A.

2. Methods of aggregation in CGE models

The Cobb–Douglas general equilibrium model of Melnikov et al. (2010) gives a useful example where the Negishi approach (see, e.g., Kehoe, 1991) yields a closed-form solution. However, even in models with *constant elasticity of substitution* (CES) functions, the system of equations that describes the competitive equilibrium for the representative consumer cannot be solved analytically. Therefore, in CGE models, the representative consumer is created using an approximate aggregation based on the input data.

In subsection 1, we recall the conventional method of constructing the representative consumer with fixed consumption preferences, which consists of calibrating preference coefficients to the benchmark consumption shares. In the following subsections, we extend this approach to models with heterogeneous consumer groups that may have different labor supply, capital income and consumer preferences. Based on this method, we take into account time variations in labor supply and consumer preferences.

2.1. Calibration of CES utility to the benchmark data

In this subsection, we consider a non-stationary CGE model with heterogeneous consumers having CES utilities. The whole population