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FINAL REPORT

Project Title: Improving Demographic Components of Integrated Assessment Models: The Effect of Changes in Population Composition by Household Characteristics
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Revised Aims:

The overall objective of this project was to improve projections of energy demand and associated greenhouse gas emissions by taking into account demographic factors currently not incorporated in Integrated Assessment Models (IAMs) of global climate change. We proposed to examine the potential magnitude of effects on energy demand of changes in the composition of populations by household characteristics for three countries: the U.S., China, and Indonesia. For each country, we planned to analyze household energy use survey data to estimate relationships between household characteristics and energy use; develop a new set of detailed household projections for each country; and combine these analyses to produce new projections of energy demand illustrating the potential importance of consideration of households.

As work progressed, we adjusted our plans in order to focus more than originally anticipated on methodological development for incorporating demographic change in energy-economic growth components of integrated assessment models. Thus, while we analyzed household energy and consumption data for all three countries, and developed new projections of changes in household living arrangements (including aging) for two of them (U.S. and China), our considerable work on methodological development for incorporating demographic heterogeneity in energy and emissions models was illustrated in new scenarios for one country (the U.S.). We believe this was the appropriate strategy and consistent with our overall objective as it (1) laid the groundwork (in terms of energy and demographic analysis) for all countries, and (2) focused on a single country for the purpose of developing a solid and innovative methodology for accounting for demographic change that can be applied in future work to other regions, and used in other models.

Results:

This project involved the production of long-term household projections, analysis of household energy use data, and development of methodologies for generating scenarios for future household energy demand that draw on results from both of these activities. It includes case studies of the U.S., China, and Indonesia.

Household projections

A major component of the project involved the development of household projections using the ProFamy model. An important weakness of existing work on the potential effect of changes in household size and composition on consumption patterns is that there has been no credible exploration of the scope for change in living arrangements in the future. We produced long-term household projections for both the U.S. (Zeng et al., 2006a; Jiang and O'Neill, 2006) and China (Zeng et al., 2006b), which involved extensive analysis of census data and large survey datasets for both countries, as well as further development of the ProFamy model.

In the US case, the ProFamy model was first modified to differentiate by race, an an initial set of household projections was carried out to test the model for a range of possible future demographic trends (Zeng et al. 2006a). A second set of projections (Jiang and O'Neill, 2006) was carried out to better understand the sensitivity of future outcomes to specific demographic factors such as changes in life expectancy, fertility, and union formation/dissolution (e.g., marriage, divorce, etc.), and also to develop three scenarios aimed at exploring the potential range of population composition by household type, particularly in terms of household size and age composition. We showed that outcomes are most sensitive to changes in fertility rates and union formation and dissolution rates. They are less sensitive to the timing of marriage and childbearing and to changes in life expectancy. We then constructed a set of future scenarios designed to reflect a wide but plausible range of outcomes, including a new set of scenarios for union formation and dissolution rates based on past trends, experience in other countries, and current theory. We found that the percentage of people living in households headed by the elderly may climb from 11% in 2000 to 20-31% in 2050 and 20-39% in 2100, while the average size of households could plausibly be as low as 2.0 or as high as 3.1 by the second half of the century. Our results also include not just average size, but distributions of household by specific sizes so that trends in, for example, 1- and 2-person households can be projected. Taken as a set, the results indicae substantial scope for long-term demographic change, particularly in low population growth scenarios in which aging is more pronounced.

Projections for China were also completed (Zeng et al., 2006b), after overcoming substantial obstacles in obtaining the necessary data and modifying the ProFamy model in order to differentiate between the urban and rural population. Using recent census and survey data mainly collected around the 2000 census, changes in family household size and structure were projected for the period 2000-2050 based on medium assumptions for fertility, mortality, rural-urban migration, marriage, and divorce for rural and urban areas in China. Results indicate the average household size of China decreases from 3.46 persons per household in 2000 to 2.86 in 2020 and 2.69 in 2050. The number of households with at least one elderly (65+) person increases from 24% in 2000 to 45% in 2050. Aging is particularly dramatic in rural areas, emphasizing the importance of distinguishing rural from urban populations in projections for China. As in the U.S., results indicate the scope for substantial demographic change, in this case for urbanization, aging, and changes in household size.

Our work on household projections has led to an unexpected benefit in developing new ideas for alternative household projection models that can be much simpler, yet still retain the major benefit of the ProFamy model: projecting household structure as a function of demographic events such as marriage, divorce, having children, leaving home, etc. The ProFamy model is an excellent basis for the kind of exploratory analysis undertaken in our current work, but produces more detail than necessary and does not run fast enough for use in integrated assessment models for climate change. Our new proposed model is essentially a reduced form version of the

ProFamy model, and produces the type of detailed output necessary for integrated assessment models at much less cost in terms of data requirements and computational speed. The initial idea has been published in Jiang and O'Neill (2004), and an elaborated concept is under review as a funding proposal to NIH.

Energy analysis

Our energy analysis results for the U.S., China, and Indonesia have yielded several insights directly applicable to integrated assessment modeling. For example, in our analysis of household-level energy consumption data for the U.S., we established the existence of differential patterns of energy consumption by end use and demographic characteristics of households in cross sectional data (O'Neill and Chen, 2002), and identified a substantial influence of some demographic factors, particularly household size, on historical energy use. This work supports the hypothesis that future shifts in demographic composition are important to account for in integrated assessment modeling. We extended that work to look in more detail at energy use patterns, an effort that involved putting together an extensive data set of household energy surveys, locating difficult-to-obtain RECS (Residential Energy Consumption Survey, administered by the EIA) data sets from the 1970s and 1980s, an early precursor to the RECS administered in 1973 and 1975, and transportation data sets from the NPTS (National Personal Transportation Survey) from 1979 and 1990. Many of the datasets existed only on mainframe tapes that turned out to be defective, and we worked with a third party contractor to recover the files.

This work has shown that while total household energy consumption tends to rise with age of the householder and then remain constant at older ages, this relationship is dominated by a particular end use: space heat. Energy consumed for hot water heat and appliance use follows a different pattern of rising and then falling with age. This may have interesting consequences for the effect of demographics on demand for particular fuels, which varies considerably by end use. It also implies that if IAMs are to improve their accounting for demographic heterogeneity, careful attention will need to be given to the way consumption goods are aggregated in the demand system. Lumping together goods with different patterns of use by household types will hide the effects of heterogeneity.

In addition, we examined cohort patterns of consumption by end use to explore hypotheses about the causes of energy use patterns over the lifespan. We found that the relationship between energy use and age of the householder reflects physical size of housing units. For example, while cross sectional analysis indicates a decline in living area (i.e., the physical size of a housing unit) with age of the householder, our analysis reveals that this is largely a cohort effect. Within cohorts, the mean size of housing units peaks when householders are middle aged, and does not decline substantially thereafter. Peak housing unit size, an important determinant of energy demand, has been increasing over time. Thus a future increase in potential demand may be locked in due to large housing unit sizes in middle-aged cohorts and persistence in preferences for housing unit size.

We also focused particular attention on the fast growing transportation sector. We carried out and age-period-cohort (APC) analysis using 5 cross-sectional RTECS survey datasets and constructing pseudo-panel data by grouping observations together into "cohorts" of households by age of the householder. First, we estimated the cohort-specific effects of income and household demographic characteristics on household vehicle miles of travel (VMT) in each period. In a second step, we decomposed the coefficients from this model into age, period, and cohort effects by regressing mean VMT for each household type (defined by demographic and income characteristics) on mean age of householder within a cohort across all periods, assuming a linear or quadratic functional form for age. Results support the presence of cohort and period effects for certain household types: one- or two-adult households without children exhibit cohort effects: householders born in the late 1940s and 1950s (i.e., baby boomers) drive more than other cohorts, net of income effects. In contrast, two-adult households with children (and higher incomes) exhibit a cohort effect in the opposite direction, with older cohorts driving less than others. We made initial steps toward incorporating these results into a projection framework driven by exogenous household projections, and assumptions regarding income growth and changes in income distribution.

In our analysis of China, we obtained nationally representative household energy consumption data from separate rural and urban surveys and have published the first analyses we are aware of based on such national datasets. In our rural analysis (Jiang and O'Neill, 2004), we explored patterns of residential energy use in rural China within the conceptual framework of the energy transition. We find that residential energy consumption varies tremendously across geographic regions due to disparities of access to different energy sources, prices, climate, income, and urbanization level. Per capita energy use varies widely by province and region, with no clear relationship to income. In a regression analysis, we find that household demographic characteristics, in particular household size, have important impacts on residential energy use, suggesting that IAMs that incorporate this effect, combined with the household projections discussed above, could lead to substantial aggregate effects on energy demand in the future at household size shifts to smaller households.

In addition, aggregate time series data show that the transition from biomass to modern commercial sources is still at an early stage, and our cross-sectional survey data suggest that incomes may have to rise substantially in order for absolute biomass use to fall. The conceptual model of the energy transition asserts that the process of economic development is generally accompanied by a shift within developing country households toward increasing use of modern fuels, and decreasing reliance on biomass, even in the absence of policies explicitly aimed at achieving this outcome. We find that energy use patterns as a function of net income, rather than total expenditure (as used in many analyses), are more consistent with the energy transition model in rural China.

For Indonesia we have obtained income and expenditure data from large (>40,000 households) nationally representative surveys that have been collected every three years since 1980. The data show that the use of electricity has spread rapidly and the use of LPG has begun to increase, while the use of firewood peaked in 1990 and has since declined, along with charcoal and kerosene. This pattern is consistent with the conceptual model of the energy transition. We completed a regression analysis estimating income elasticities of budget shares for various fuels and various household types. Results show that demographic characteristics (particularly household size and urban/rural status) are important determinants of amount and type of energy used (Chen and Pitt, in preparation). On the other hand, since population composition did not change significantly over the past 20 years, demographic trends does not have a large effect on changes in total energy use. Interestingly, we found that non-income preferences explain a large fraction of observed changes in demand. Our hypothesis is that the change in preferences reflects changes in the context in which decisions are made, particularly those related to urbanization and access to different fuels, and particularly electricity. This result strongly suggests that scenarios of future use must include some explicit accounting for changes in access – and not just income, prices, and demographics – in order to credibly simulate household fuel use decisions.

Methodological development for scenario generation

We developed a new method for accounting for demographic heterogeneity in energy-economic growth models (typical components of integrated assessment models). In work also supported by funding from the EPA, we developed a "multiple dynasty" structure that shares features of Infinitely Lived Agent (ILA) and Overlapping Generations (OLG) models. In our work we used the Population-Environment-Technology (PET) model originally developed by Larry Goulder and Mike Dalton at Stanford University. The original PET model, like many growth models used in the IAM field, has an ILA structure with perfect foresight. Any disaggregation of the population into separate age groups therefore must account 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. Thus we disaggregate the population 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. Development and testing of this approach took a considerable amount of time and effort.

We then used the results of our new household projections for the US to construct "cohorts" of households, where household age is defined by the age of the household head. Household cohorts from the ProFamy model are grouped into three infinitely lived dynasties in the PET model. Each dynasty contains households separated in age by the average length of a generation, taken to be thirty-years. For example, today's eighty-year-old, fifty-year-old, and twenty-year-old households are grouped in a single dynasty, based on the assumption that the younger households are, on average, descendents of the older households.

We use the PET model to estimate effects of population aging by comparing emissions baselines from simulations with age-specific heterogeneity to baselines without aging and a representative household (Dalton et al., 2006). To isolate demographic effects, the first set of simulations does not include technical change. We found that age-specific heterogeneity in labor income reduces CO2 emissions by 11%, 18%, and 37% per year by 2100 in the high, medium, and low population scenarios, respectively. In our reference case, a labor scale effect accounts for about 85% of these reductions, and the other 15% is from capital dynamics and general equilibrium effects. A second set of simulations compares emissions baselines with population aging to a representative household in the presence of technical change. Assumptions about technical change are based on the SRES A1 Scenario for OECD countries. The most interesting result is that effects of aging on emissions are as large, or larger, than effects of technology in some cases. The main trade-off in this result is the amount of aging in the household projections, on the one hand, and the nature of the technical change on the other.

We believe this work has established a sound new methodology for incorporating demographic heterogeneity into integrated assessment models, and illustrated that at least in the case of the U.S., and considering only the effects of aging, demographic change can have a substantial influence on energy use and emissions outcomes in the long run, in one case exceeding a one-third reduction in emissions.

Papers and other products delivered:

Papers published or submitted:

Dalton, M.G., O'Neill, B.C., Fuernkranz-Prskawetz, A., Jiang, L., and J. Pitkin. 2006. Population aging and future carbon emissions in the United States. In press, *Energy Economics.*

Jiang, L. and O'Neill, B.C. 2006. Impacts of demographic events on U.S. household change. Interim Report IR-06-022. Laxenburg, Austria: IIASA. Submitted to *Population and Development Review*.

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Jiang, L. and B.C. O'Neill. 2004b. The energy transition in rural China, *International Journal of Global Energy Issues,* 21 (1/2), 2-26.

O'Neill, B.C. and B. Chen. 2002. Demographic determinants of household energy use in the United States. In *Methods of Population-Environment Analysis, A Supplement to Population and Development Review* 28, 53-88.

Zeng, Y., Land, K., Wang, Z., and Gu, D. 2006a. U.S. family household momentum and dynamics: an extension and application of the ProFamy method. *Population Research and Policy Review* 25: 1–41

Zeng, Y., Wang, Z., Jiang, L., Danan, G. 2006b. Projection of family households and elderly living arrangement in the context of rapid population aging in China – A demographic window of opportunity until 2030 and serious challenges thereafter. In press, *Genus*.

Draft manuscripts

Chen, J. and Pitt, M. Household energy use in Indonesia: demographic influences and patterns of change over two decades. Draft manuscript, to be submitted to the *Energy Journal*.

Jiang, L. Residential energy use in urban China. In preparation.

Desai, M. and O'Neill, B.C. Sources of change in the demand for energy by Indonesian households: 1980-1999. Draft manuscript, to be submitted to *Energy Policy*.