Demographic Change and Future Carbon Emissions in China and India

Michael Dalton,[1] Leiwen Jiang,[2] Shonali Pachauri,[3] Brian C. O'Neill[3,2]

[1] U.S. National Oceanic and Atmospheric Administration, Seattle WA, USA.
[2] Brown University, Providence RI, USA.
[3] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

March 16, 2007 Draft
For Presentation at the Population Association of America Annual Meetings
New York, NY

ABSTRACT

This paper investigates whether projected changes in the demographic characteristics of Chinese and Indian households over the next century could have a substantial influence on consumption, economic growth, energy demand, and carbon dioxide emissions. We use new household projections for China and India that model changes in population size, urbanization, and the size and age structure of households over the next 100 years. The initial economic characteristics of different household types, including demand for consumer goods, supplies of labor, and capital, are estimated from household surveys and production data for each country. A global energy-economic growth model simulates economic growth as well as changes in consumption of various goods, direct and indirect energy demand, and carbon emissions over time. Effects of demographic change are compared under different scenarios that include technical change. Results show that explicit consideration of urbanization leads to a substantial increase in projected emissions, while aging leads to a decrease. The net effect of demographic change is to increase projected emissions from China by 45% by the end of the century, and from India, by 15-35%.

1. INTRODUCTION

China and India are the world's population billionaires, both economies are developing rapidly, and China is almost certain to overtake the U.S. as the largest emitter of carbon dioxide in the coming decades. Carbon dioxide (CO_2) is the most important greenhouse gas emitted as a result of human activity, primarily from the burning of fossil fuels (coal, oil, and natural gas) for energy production, with a lesser contribution from deforestation and other land use changes. In this light, the link between household behavior and energy use is a key component of the relationship between population and climate change, and other energy-related environmental impacts such as air quality and natural resource depletion. Households use energy directly for transportation, space heating and cooling, cooking, lighting, and appliances, and they also use it indirectly, by consuming other goods (food, housing, clothing, etc.) that require energy in their production processes.

    Many countries have experienced large shifts in demographic composition over the past century and are expected to continue changing in the future. India and China are no exceptions. In general, households are likely to become older and smaller as populations age and preferences shift away from living with the extended family. Households are also expected to shift from predominantly rural to predominantly urban over the coming decades. Consumption and work

patterns vary substantially across rural and urban households, and the energy studies literature has identified household characteristics as key determinants of direct residential energy demand. For example, households exhibit life cycle patterns in energy use as they age, and household size can affect energy use either because it frequently reflects the age composition within the household (smaller households tend to have a larger fraction of adults) or because there can be economies of scale in consumption at the household level (Schipper, 1996; O'Neill and Chen, 2002). In addition, the relation of a household's urban or rural status to energy use has long been a focus in the energy studies literature, particularly in understanding the transition in rural households from traditional to modern fuels as incomes rise (Jiang and O'Neill, 2004). At the national level, urbanization has been associated with increases in energy use (Parikh and Shukla, 1995).

Therefore, future changes in the composition of populations by household type could substantially affect the outlook for energy demand and its environmental consequences. Climate change is arguably the issue in which such outlooks play the largest role, and indeed, a growing number of models are employed to develop long-term scenarios of future energy use, land use, and greenhouse gas emissions. These emissions scenarios play a key role in projections of future climate change, impacts on society and ecosystems, and the costs of alternative emissions reduction strategies (Nakicenovic et al., 2000; Morita et al., 2001; van Vuuren et al., 2006). Yet most of these models do not consider any demographic characteristics other than population size. Typically models assume a representative household for each region, and this assumption is used to derive aggregate demands for consumption and investment, and supplies of labor and capital. In most of these models, population size is a scale factor, with minor exceptions in cases where population exerts a weak negative effect on output growth, or age structure is taken into account in determining the size of the labor force.

Perhaps surprisingly, no model explicitly considers the potential impact of urbanization on economic growth or commercial energy demand. A few models consider urbanization as a determinant of demand for household biomass energy (Alcamo et al., 1998) or in producing spatial scenarios of future population for use in impact assessment (van Vuuren et al., in press; Gruebler et al., in press). As far as we are aware, there has been only one study that assessed the potential impact of urbanization on economic growth and total energy demand. Imai (2002) used the Edmonds-Reilly model, a partial equilibrium model of global energy supply and demand, to test the impact of changes in labor productivity driven by urbanization. Results indicated that urbanization was comparable to changes in total population size in its effect on emissions. However, that study did not use household level data on differences in economic characteristics between urban and rural households, treated all developing countries as a single region, and the modifications made to the model were not adopted in any further analyses. Thus, a considerable gap remains between treatment of population in energy projection models, and results reported in the energy studies literature.

Our purpose in this paper is to help bridge this gap by examining the potential effect of demographic change, including urbanization, on future energy use and emissions in India and China. This work builds on a recently completed analysis for the U.S. (Dalton et al., 2006) that focused on aging, finding that aging could reduce emissions over the next century by up to one third. Here, we incorporate household level data for China and India into simulations of future demand for fossil fuels, including oil, natural gas, and coal, in order to quantify effects of demographic heterogeneity on future CO_2 emissions. We use the Population-Environment-Technology (PET) model for these simulations, which we recently modified in two principal

ways: first, we replaced the representative household assumption in the original model with a classification of households by age, size, and potentially additional factors, each type with its own demand for consumption goods, propensity to save, stock of assets, labor supply, and other household level variables. Second, we disaggregated the demand framework for consumer goods to include energy intensive commodities such as utilities, fuels and recreation, and less energy intensive goods and services like education, and health (Goulder, 1995). The analysis in this paper, however, limits the number of consumer goods to four: food, energy, transportation, and housing (that includes everything else). Our analysis with the PET model is based on a recent household projection for China and two newly developed household projections for India.

The rest of the paper is organized as follows: the PET model is introduced in Sec. 2. Household and population projections for China, and India, are presented in Sec. 3. Household, production, and energy data are described in Sec. 4. Results are contained in Sec. 5. The paper concludes in Sec. 6 with a discussion of results, comments on the methodology, and ideas for future research.
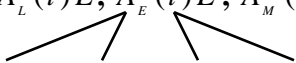
2. POPULATION ENVIRONMENT TECHNOLOGY MODEL

The PET model is a dynamic computable general equilibrium model designed to analyze economic tradeoffs associated with production and use of fossil fuels and associated CO_2 emissions. The model accounts for all fossil-fuel based CO_2 emissions in an economy, and we use it in this paper to analyze how total CO_2 emissions from use of fossil fuels in the Chinese and Indian economies could be influenced by future demographic change. The structure of the PET model is not the focus of this paper, and to save space, we will not describe its details here. For a complete description of the model, readers are referred to the paper available on IIASA's website by Dalton et al. (2006). A schematic diagram of the model is given in Fig. 1.

Fig. 1: Overview of the PET Model. Households demand consumption and investment goods (C and I), and supply capital and labor (K and L). Final good producers supply C, I, and a government good (G). Intermediate goods producers supply energy and materials (E and M). The primary energy producers, which are coal, oil and gas industries, create CO_2 emissions.

3
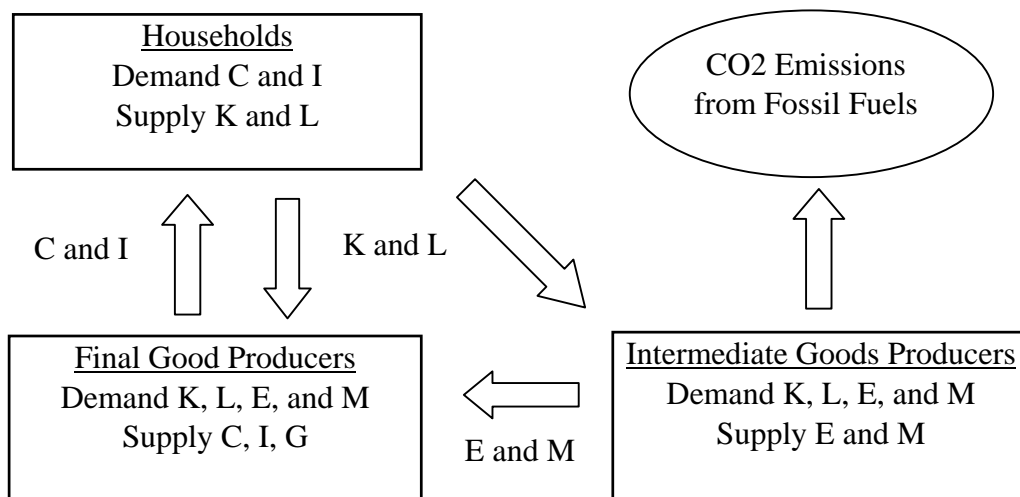
The production component of the model has industries that produce intermediate goods, including energy (E) and materials (M), and final goods of Consumption (C), and investment (I), plus the output of a government sector. Production functions for each industry in the model have a Capital-Labor-Energy-Materials (KLEM) structure. Energy inputs of Oil and Gas, Coal, Electricity, and Refined Petroleum are treated separately in the model. Other intermediate goods are aggregated, and produced by a single Materials industry. Technical change is represented in the PET model using separate productivity coefficients that change exogenously over time, denoted in the following equation by $A_i(t)$:

$$X = f(A_K(t)K, A_L(t)L, A_E(t)E, A_M(t)M).$$

Oil and Gas, Coal, Electricity, Refined Petroleum

This representation allows different patterns of labor, capital, and energy augmenting technical change. While changes in these productivity coefficients are exogenous, the resulting pattern of input use including energy is driven by changes in relative prices, and therefore, endogenous. Thus, economic growth and the carbon intensity of production are endogenous model outputs. Time-paths for different productivity coefficients are set so that outputs including growth of per capita gross domestic product (GDP) and trends in carbon intensities are consistent with a particular scenario. An advantage of this approach is that rates and patterns of technical change can be specified in terms of the PET model's structural parameters rather than using a purely exogenous device, such as an Autonomous Energy Efficiency Improvement (AEEI) parameter.

While the PET model allows trade, we ignore its effects in this paper to simplify the analysis and to isolate effects of demographic change in a more controlled setting. We recognize that effects of trade are likely to be important, and we are currently working towards a global analysis with trade that is discussed below. However, an initial assessment that treats China and India as closed economies, without the interacting and potentially confounding effects of trade, provides a useful benchmark against which further work can be compared, and still allows an informative comparison of results with and without demographic heterogeneity.

The consumption component of the PET model is based on a population with many households that take prices as given. As discussed below, households are linked through dynastic relationships and are assumed to operate within these dynasties as perfectly cohesive units. Capital accumulation occurs at the dynastic level, and households within a particular dynasty are assumed to follow its savings and consumption rules. Households demand consumer goods, and receive income from supplying capital and labor to producers. Households save by purchasing investment goods. In the model, savings behavior is determined by solving an infinite horizon dynamic optimization problem, under perfect foresight, for each dynasty. The solution to this optimization problem determines the savings rule for the dynasty to which each household belongs. We note that solving a separate dynamic optimization problem for multiple dynasties distinguishes our approach, which is based explicitly on decentralized and forward looking economic behavior, from the more common assumption of a social planner that represents the preferences of a single type of representative household over time. The model treats labor income as exogenous. Capital income is derived from savings decisions that are endogenous, but dependent on an exogenous initial distribution of capital.

Fig. 2: Cohort Structure of Dynasties in the PET Model. Dynasty 1 consists of cohorts 1a-f (boxes). Dynasty 2, consists of cohorts 2a-f (circles). Dynasty 3, consists of cohorts 3a-e (triangles).

cohort: 1a 2a 3a 1b 2b 3b 1c 2c 3c 1d 2d

3d
1e
2e
3e
1f
2f

Age

Year
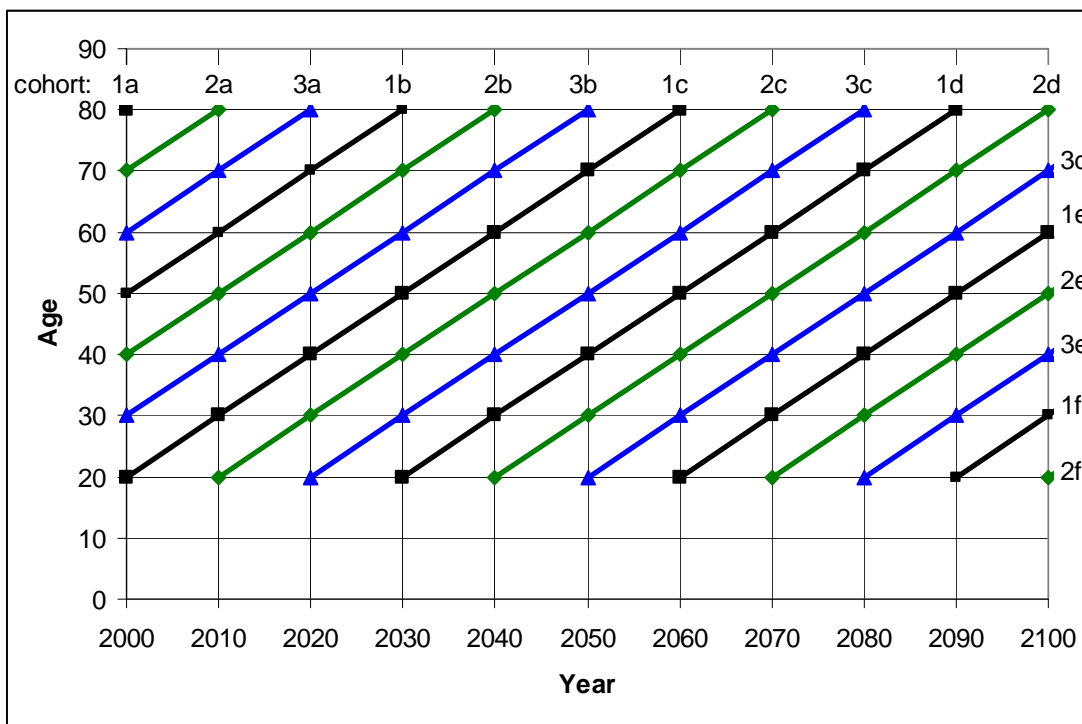
The dynastic structure of the PET model was developed as a means of introducing age heterogeneity into an economic model with forward looking behavior (e.g., perfect foresight). In a dynastic structure, consumption-savings decisions are made in order to maximize the utility of a given cohort's own consumption over its lifetime, as well as the consumption of its children, and of all subsequent generations of descendants. To implement this approach, we first sort households in our household projections into age groups based on decadal intervals so that households headed by, say, individuals younger than 20 years form one group, 20-29 year-olds form another, and so on at 10-year intervals up to the oldest group (90+). The population distribution by household age is used to form a series of cohorts of households of different ages at each point in time (Fig. 2). These age groups are linked together to form three independent dynasties using the mean age of childbearing (~30). For example in the year 2000, households headed by 20, 50, and 80 year-olds are in the same dynasty. In 2010, these household heads have aged by 10 years, and therefore, this dynasty now consists of households headed by 30, 60, and 90 year-olds. This procedure implies age heterogeneity not only across each of the three dynasties, but also within each, since household age distributions change over time based on the projected population size of each household cohort. The age distribution of households in a dynasty at a given point in time affects its total labor supply, through assumed differences in productivity (for the entire household, including children) that are based on average labor income of households by age of the head. We treat the individuals within each age class as identical; this approach is only a modest relaxation of the single dynasty, representative household approach.

Size heterogeneity is introduced by splitting each of the three age-based dynasties into two: one in which middle-aged households (i.e., those with heads aged 30-60) are large (>3 members)

5

and one in which they are small. Younger and older households are not distinguished by size, under the conservative assumption (i.e., by introducing less heterogeneity) that young households do not generally know whether they will turn out to be small or large when middle-aged (and therefore do not yet identify themselves with a particular size dynasty), and households do not know whether they will turn out to be small or large when they are elderly.

Rural/urban heterogeneity is not treated by introducing separate dynasties. We have not yet identified an appropriate dynastic structure for a perfect foresight model with non-zero migration between urban and rural areas. Instead, this heterogeneity is treated within existing dynasties. That is, the changing labor supply over time of a given dynasty is determined not just by the mix of household age and size within a dynasty, but also by proportions of urban and rural in the population as a whole. In fact, it is possible to treat each type of heterogeneity that we consider (age, size, and rural/urban) in the way just described.

Specifically, a single dynasty model can always be defined in which characteristics of the single household representing that dynasty change over time in accordance with the changing composition of the dynasty, where that composition reflects shifts in household age, size, and rural/urban status. Ignoring consumption effects, which we show are relatively small, a single-dynasty approximation of a multi-dynasty model is achieved by scaling labor supply of the single-dynasty at each point in time to match the total labor supplied in the multi-dynasty model. This technique is possible, and valid under assumptions that we make about inelastic labor supply, by interpreting labor supply in terms of efficiency units in the model. What the single-dynasty structure sacrifices are so called general equilibrium effects, transmitted through prices or wages, on household consumption and savings that arise from decisions made simultaneously by other dynasties with different characteristics. Nonetheless, the scaled single-dynasty version of the PET model expresses the first order demographic scale effects implied by aging or size in a multi-dynasty model, and most of the results in this paper are based on a single-dynasty structure. Except where noted, this simplification has negligible effects on results.
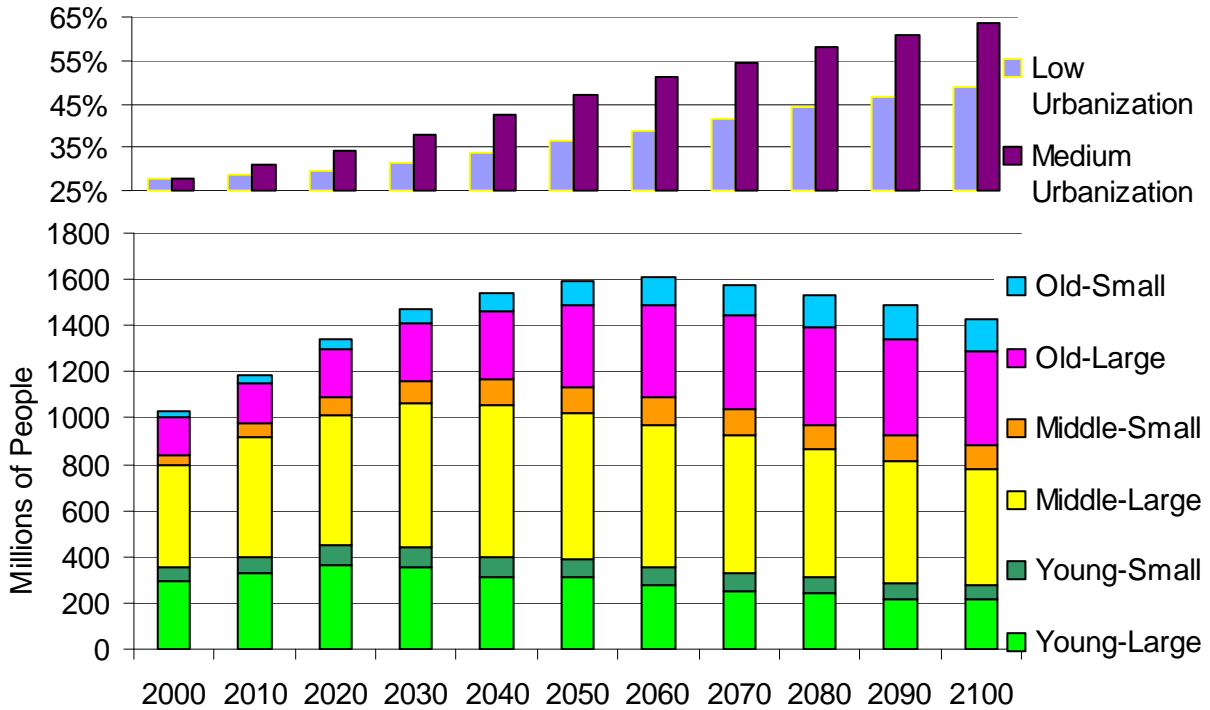
3. HOUSEHOLD AND POPULATION PROJECTIONS

For China, we extended to 2100 household projections made by Zeng et al. (in press) that are based on the most recent data and carried out with the ProFamy model. This model offers advantages over models that rely on headship rate methods, which do not directly provide information for some important household types like size. The ProFamy model projects individuals and households simultaneously to produce a rich set of output for different household types. Zeng et al. (in press) conducted an analysis of current demographic conditions, and recent trends of fertility, life expectancy, general rates and timing of marriage and divorce, children leaving home, etc. for rural and urban households in China. Their projection is based on an assumption that the 1-child policy will be relaxed in the near future. As a result, fertility is assumed to rise from 1.63 to 1.85 by 2035. In addition, life expectancy is assumed to increase from 73 to 80 for females, and 69 to 75 for males. Urbanization levels are assumed to double from about 36.4% in 2000 to 75% in 2050, based on government middle-term plans. Rates of marriage and divorce are held constant. Projections imply that aging will be substantial in China, especially in rural areas. Although fertility in rural areas in China is much higher than in urban areas, aging will be more serious in rural areas because of continuing rural-urban migration of young people. Results from the ProFamy projection for China are presented in Fig. 3.

6

Fig. 3: Chinese Population by Age, Size, and %Urban (Note: Large >3; Young < 40; Old > 60).
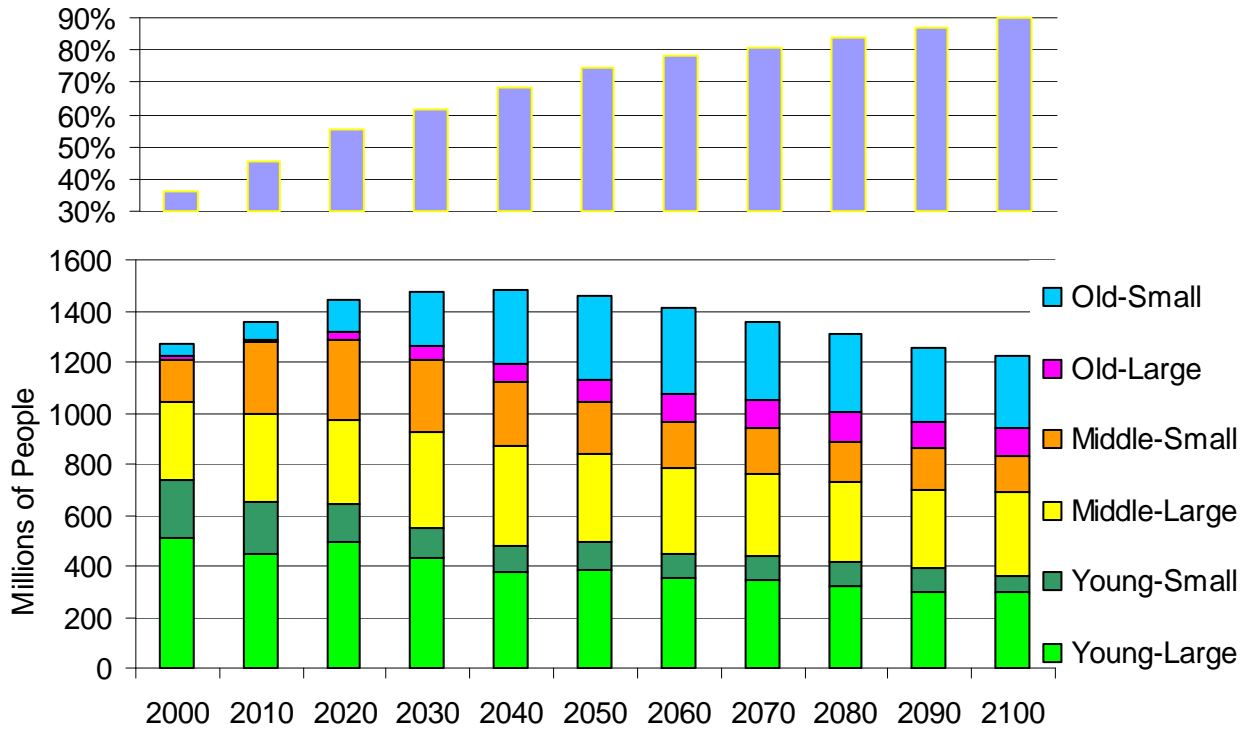
Fig. 4: Indian Population by Age, Size, and %Urban (Large >3; Young < 40; Old > 60).

We are in the process of developing ProFamy household projections for India. In the meantime, we have produced household projections based on a constant headship rate approach. We first produced a population and urbanization projection and then combined it with household age- and size-specific headship rates held constant at their current levels. The population projection used a multi-state model to project the Indian population by rural and urban status over the period 2001-2100. We derived benchmark population data from the Indian 2001 Census, corrected for age misreporting using the Whipple Index and other indirect estimation methods. We obtained age specific fertility rates and constructed life tables for rural and urban populations using data from the Census of India's Sample Registration System (SRS) Statistical Report 2001. From the 2001 Census, we obtained the number of rural to urban migrants in the most recent year before the census and used the Rogers-Castro model migration schedules to derive rural-urban migration transition rates. We formulated scenarios on the future changes of fertility and mortality that are roughly consistent with projections by major international and Indian institutions. We assume that fertility declines from 3.1 to 1.85 in 2050, and then, is constant. Life expectancy over this period increases from 64 to 78 for females, and from 62 to 75 for males.

We developed two scenarios of future urbanization, based on assumed changes in rural-urban migration rates. In the first, we assume that the current rural-urban migration rate is twice as large as the most recent estimate (which is uncertain), and that future rates increase by 2% per year, while the urban-rural migration rate is kept constant. Urbanization in the first scenario is close to the UN Urbanization Prospects 2004 revision, and to an extension of that scenario developed at IIASA (Gruebler et al., 2007). On that basis, we call it a medium scenario. In the second scenario, we assume a 1% annual increase in the rural-urban migration rate for the entire projection period, and the urban-rural migration rate is held constant. This assumption produces an urbanization level of just above 35% by 2050, and above 45% by 2100. We consider this assumption to be a low scenario, based on a comparison to the historical experience of countries after they passed the urbanization level India is currently experiencing. Results of both projections for India are presented in Fig. 4.

To project future population distribution by size and age of householders, we first obtained age- and size-specific headship rates for rural and urban households separately from India's 1999-2000 National Household Survey data. By combining rural/urban age- and size-specific headship rates with rural/urban population projection results, we estimate the population distribution by size and age of householders to obtain a household projection using a constant age- and size specific headship model. To make the implied total population size in the household projection consistent with the total population in the population projection, we adjusted the population in the household projection by proportionately changing the number of people in the largest household categories (7+), a practice common in constant headship rate projections.

4. HOUSEHOLD AND PRODUCTION DATA

Income and Expenditures from Chinese and Indian Household Surveys

To calibrate each dynasty in the PET model, we use data from household surveys in China and India to derive weighted mean per capita labor supply, initial capital holdings, and expenditure shares for consumer goods that change over time to reflect the changing demographic composition.
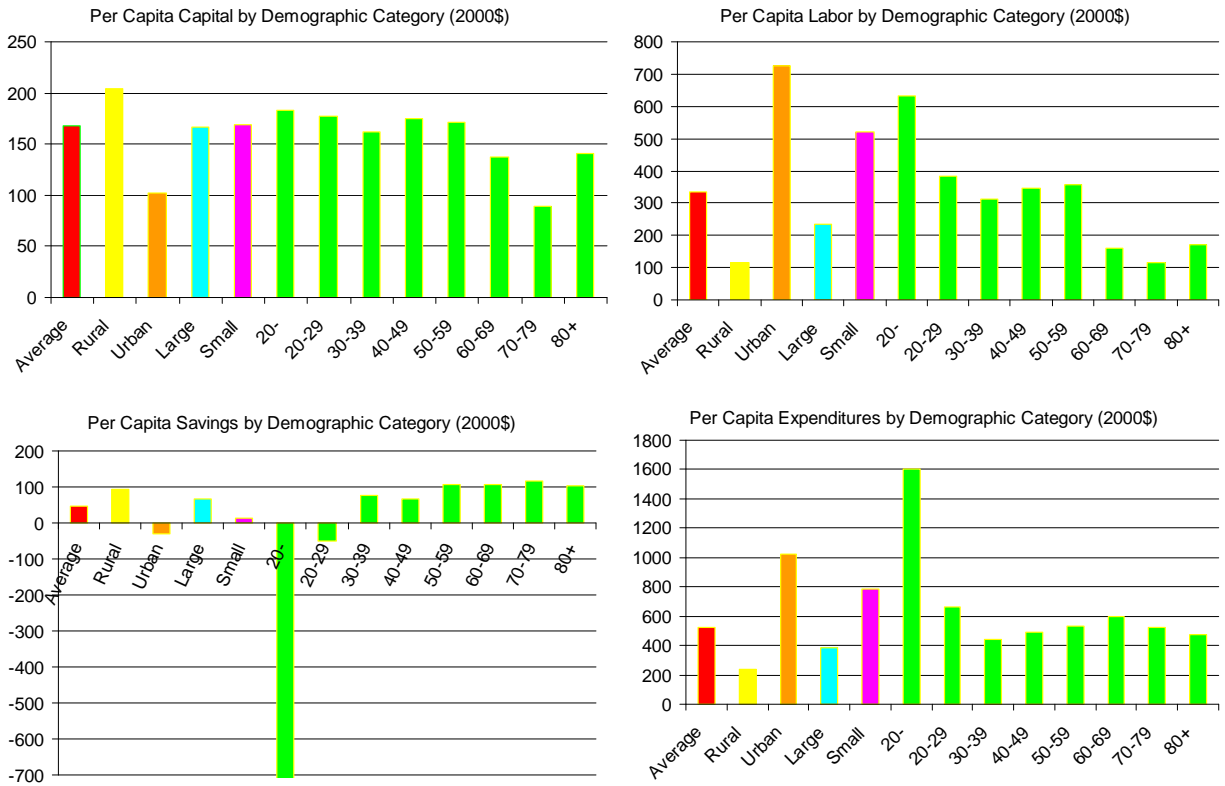
For China, data from the National Socio-Economic Household Survey, 2003 are used to establish a benchmark for the PET model. Results from the Chinese household surveys for per capita income and expenditures are presented in Fig. 5, and expenditure shares in Fig. 6. The China National Household Survey is among the most comprehensive social and economic surveys undertaken by China's National Bureau of Statistics, mainly providing information on income, expenditure, consumption, production and other activities of rural and urban residents. The Rural and Urban Social and Economic Survey Organization, part of the National Bureau of Statistics, conducts separate surveys for rural and urban areas. About 68,000 rural households and 37,000 urban households were randomly selected, using a three-stage stratified and systematic sampling method, to be representative at both national and provincial levels. The households selected for the survey were requested to record all their daily social and economic activities.

For India, data from the National Sample Survey Organisation's Household Consumer Expenditure Schedule of Round 55 for the year 1999-2000 are used to estimate consumption differences across households at a disaggregate level (NSSO, 2002). Results from the Indian household surveys for per capita income and expenditures are presented in Fig. 7, and expenditure shares in Fig. 8. The NSSO surveys are canvassed through the interview method across the entire country, involving separate and comprehensive coverage of rural and urban areas, with the exception of some very remote and interior places. For the 55th Round, the survey was administered between July 1999 and June 2000 to 120,310 households. Household consumption in the survey includes goods and services acquired through (a) purchases in the market, (b) receipts in exchange of goods and services, (c) subsistence production, and (d) transfer receipts such as gifts and loans. To minimize recall errors, a very detailed item classification is adopted by the NSSO to collect information, including 190 items of food and beverages, 25 items of clothing and footwear, 20 items of educational and medicinal expenses, 66 items of durable goods, and about 111 miscellaneous goods and services that include fuels and electricity. Data pertaining to the 30-day recall on all food items, fuel and light, and miscellaneous goods and services, are used here. For other types of consumption (mainly durables), data pertaining to the 365-day recall are used.

Since the Indian household surveys do not include information on income, we use data from the Social Accounting Matrix (SAM) for India for the year 2002-03 (Pradhan et al., 2006), which provides information on labor and capital income for rural and urban households. Income flows among different demographic groups within rural and urban areas are not represented in the SAM. Therefore, a separate survey on household savings and investment behavior in India (Pradhan et al., 2003) was used to derive income-expenditure ratios for rural and urban households that differ by size, and age of the household head. Finally, total rural and urban labor incomes from the SAM were divided among the different demographic groups within the rural and urban sectors in proportion to the total number of workers in each household head age category, derived from the Census of India in 2001.

Labor supply under different demographic configurations of the PET model plays a key role in our analysis. To calculate labor supply in the model, per capita labor supply of each age or size group is multiplied by the population living in households of different ages, based on the decadal intervals described above (the 3-way classification used in the figures, of young, middle-aged, and old, is only for the purpose of presentation). The sum of these products determines total labor supply of each dynasty. For each dynasty, the ratio of total labor supply over the dynasty's total population size at a point in time determines its mean per capita labor supply.
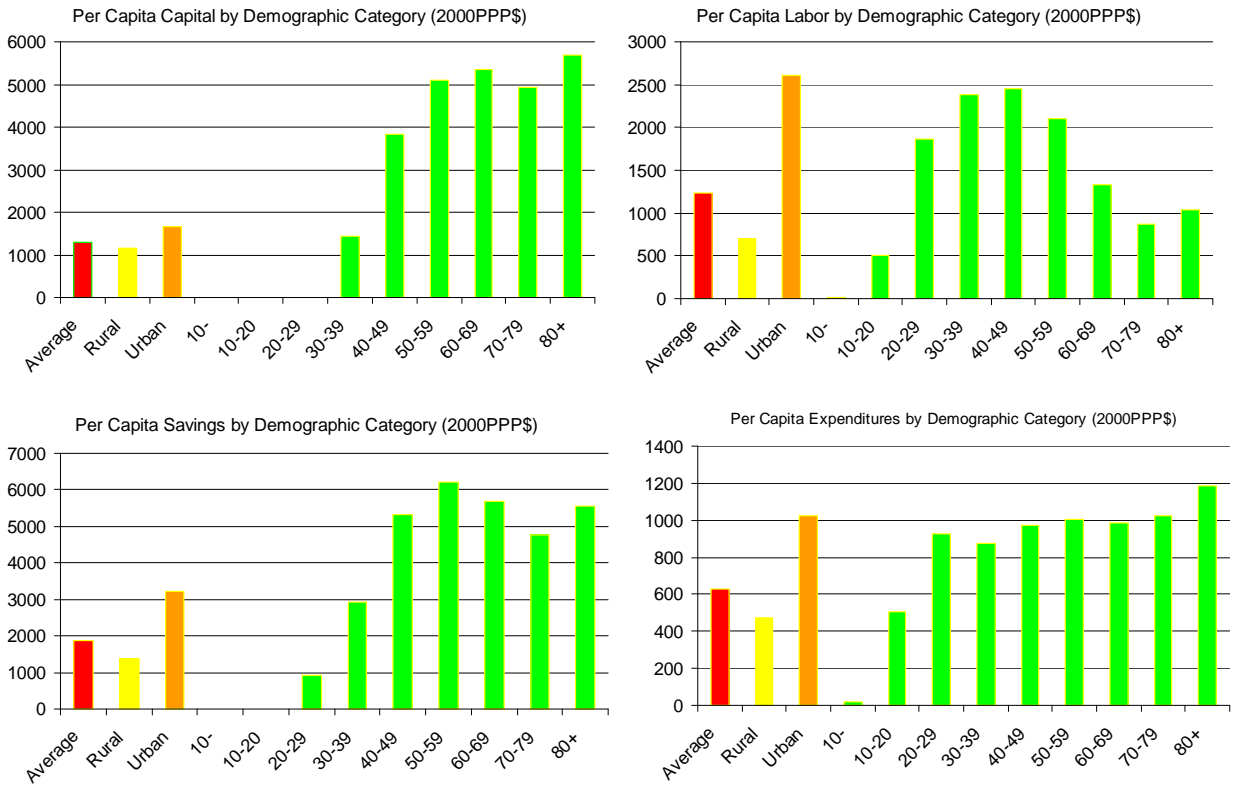
Fig. 5: Chinese Households' Per Capita Capital, Labor, Savings, and Consumption Expenditures.
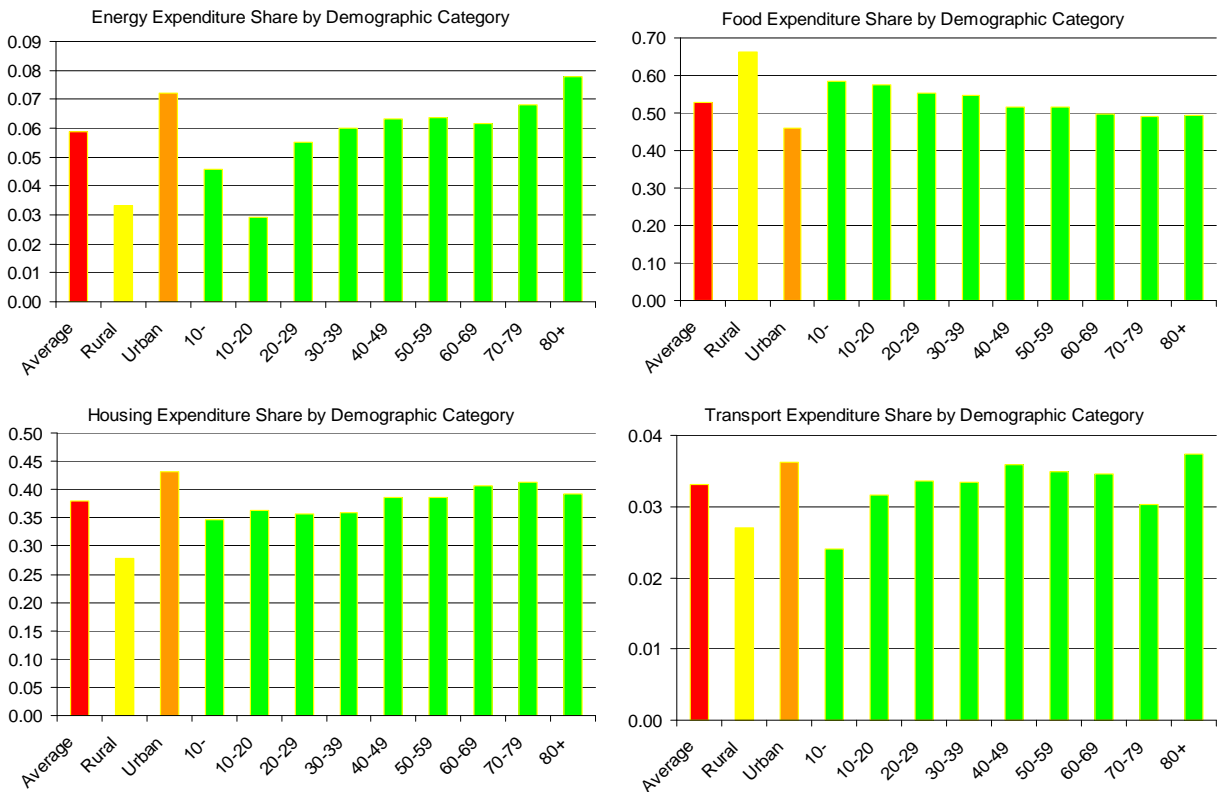
Per Capita Capital by Demographic Category (2000$)

Per Capita Labor by Demographic Category (2000$)

Per Capita Savings by Demographic Category (2000$)

Per Capita Expenditures by Demographic Category (2000$)

Fig. 6: Chinese Households' Expenditures on Energy, Food, Housing/Services, and Transport.

Energy Expenditure Share by Demographic Category

Food Expenditure Share by Demographic Category

Housing Expenditure Share by Demographic Category

Transport Expenditure Share by Demographic Category

Fig. 7: Indian Households' Per Capita Capital, Labor, Savings, and Consumption Expenditures.

Per Capita Capital by Demographic Category (2000PPP$)

Per Capita Labor by Demographic Category (2000PPP$)

Per Capita Savings by Demographic Category (2000PPP$)

Per Capita Expenditures by Demographic Category (2000PPP$)

Fig. 8: Indian Households' Expenditures on Energy, Food, Housing/Services, and Transport.

Energy Expenditure Share by Demographic Category

Food Expenditure Share by Demographic Category

Housing Expenditure Share by Demographic Category

Transport Expenditure Share by Demographic Category

11

Information from the household surveys implies a distribution of labor among households and dynasties, which is applied to the aggregate amount of labor from the production data for each country. In other words, labor is distributed among dynasties according to the household surveys, but in each case, the aggregate labor supply is consistent with the production data. Similarly, an initial capital stock for each dynasty is determined using the distribution of capital estimated from the household surveys, applied to the aggregate stock of capital from the production data. However unlike labor, capital accumulation is endogenous in the PET model, and effects of its initial distribution are transitory. Dynamic paths for expenditure shares are derived from the household projections based on a weighted average of the households in each dynasty. In this way, the household projections are used to determine the changing composition of the population across household types within each dynasty.

Production and Energy Data for India

In India, the Central Statistical Organisation (CSO) has the responsibility for preparing the economy-wide input-output (IO) transactions tables for India every five years in accordance with the basic principles specified by the United Nations System of National Accounts. The Commodity by Commodity tables for the year 1998-99 (CSO 2005), the most recent set published by the CSO, at a detailed 115 sector level of aggregation are used to calibrate the PET model's production functions. In addition to economic data included in the IO tables, data on energy transactions in the economy in physical units are also required, for the energy balancing of these tables. This is not a trivial requirement, as energy data in India are published by a number of different departmental bodies and are available mostly in an aggregated form. However, the use of information on physical energy flows, in conjunction with the monetary IO data, is necessary to maintain energy balances in the PET model.

The energy balance for India in the base year, 2000, is constructed using data from various sources, including several ministerial publications, such as Coal Statistics (GoI, 2000), Petroleum and Natural Gas Statistics (GoI, 2000), Energy Statistics (CSO, 2000), the statistical yearbook titled "Energy" (CMIE, 2005), Electricity Statistics (CEA, 2000), and The Energy and Resources Institute's energy database (TERI, 2003). For non-commercial biomass energy flows, data estimates from the Regional Wood Energy Development Programme in Asia (RWEDP) of the FAO (FAO, 1997) are the primary source, but in addition, these estimates are cross-checked with other published estimates, such as those by Ravindranath and Hall (1995), and the Planning Commission (PC, 1999). Carbon emissions factors for oil and gas in India are derived from the Intergovernmental Panel on Climate Change (IPCC) default values. For coal, a weighted average was calculated using emissions factors for different types of coal and lignite, available from India's National Communication (NATCOM) to the UN Framework Convention on Climate Change (UNFCC), and base year energy data on production of lignite and coal from India's Ministry of Coal.

The procedure for energy balancing the IO tables is similar to that used for the Second Generation Model (SGM), described in Sands and Fawcett (2005). As a first step, both the IO table and the energy balance account for India are aggregated across production sectors to match the PET model's format. In the next step, a hybrid table is constructed by substituting physical energy flows from the energy balance for the monetary values in the energy rows of the IO table. Thus, the table is transformed from purely value terms to a combination of energy units (joules) in the energy rows, and currency units (Rupees or dollars) in the non-energy rows. A set of linear

equations, one for each industry, equate value of output with the total value of inputs. The solution to these equations determines a set of prices that rebalance the table. Finally, a new energy rebalanced IO table is created by multiplying all quantities with the newly determined prices. The rebalanced table represents all IO transactions within the economy, is consistent with the physical energy flows between sectors in the base year, and has the property that value added and final demand components (i.e., GDP) are unchanged from the original IO table. Finally, data from the SAM and the IO tables are converted to base year (2000) values using ratios of nominal GDP from the National Accounts Statistics (CSO 2005). The 2000 base year Indian currency values are then converted to 2000 PPP Dollars using the Purchasing Power Parity (PPP) exchange rates published in the Penn World Tables 6.2 (Heston et al., 2006).

Production and Energy Data for China

A similar level of detailed statistics and national data are used for calibration of the Chinese economy in the PET model, but detailed documentation is not presently available. The source of production statistics is the Chinese IO table from 2002 (NBS, 2006). The physical energy transactions data used to energy balance the IO table are from the China Energy Statistical Yearbook (NBS, 2004). Carbon emissions factors are derived from the IPCC default values for oil and gas, and for coal, from the China Energy Statistical Yearbook (NBS, 2004).

5. RESULTS

Simulations with the PET model that include economic effects of changes in age, size, and urbanization are reported in this section. We produced three groups of results. The first group assumes no technical change – and therefore no growth in per capita GDP – in order to isolate the relevant demographic effects, such as the decrease in labor supply, that are associated with population aging. The second and third groups include a particular set of assumptions for technical change based on a mid-range scenario (B2) from the IPCC Special Report on Emissions (SRES), as updated by researchers in the Greenhouse Gas Initiative (GGI) at IIASA (Riahi et al., 2007). This scenario is based on a narrative storyline of future socio-economic development that is assumed to be consistent with moderate rates of population and economic growth. IIASA's B2 scenario over the next few decades is close to a continuation of conditions that actually existed for economic growth and CO2 emissions in China and India through 2003, and roughly, the decade prior. Thus, we use this scenario as a medium case, or continuation of the status quo, to judge the importance of demographic heterogeneity. Our household projections are consistent with this storyline.

In the second and third groups of simulations, we tune the PET model's productivity growth rates, which are associated with exogenous technical change, to match the B2 scenario for China and India in two key dimensions. The first is to match the B2 average growth rate in per capita GDP over the period 2000-2100. Matching this per capita value allows us to use our population projection, while keeping the assumed underlying average rate of productivity growth the same as B2. The second feature of B2 that we match in the PET model is the average rate of change in carbon intensity over the period 2000-2100, measured in tons of CO2 emitted per real dollar of GDP. Tuning the PET model in these two dimensions implies that the average rate of change in per capita CO2 emissions is also the same as B2.

The two groups of results based on the B2 scenario differ in precisely how each group is matched with the PET model. In one group, we match per capita GDP and carbon intensity only with the representative household version of the model (i.e., without demographic heterogeneity), which determines a pair of parameter values for growth rates in the PET model, one for labor productivity and the other for energy. This same pair of values is used in versions of the model that represent demographic change. In this way, we estimate the degree to which demographic compositional change leads to differences in GDP and CO2 emissions relative to a model that does not include such changes. In the other group, we use only the energy productivity growth rate from the representative household version of B2, and adjust labor productivity in versions of the model that represent demographic heterogeneity so that, overall, average GDP growth is the same in each case. This set of results is aimed at exploring a situation in which quantitative assumptions about GDP growth are part of the scenario to be replicated. We then examine whether demographic change induces any effects on emissions, net of the first order GDP effects, and in particular, whether it implies different growth rates for labor productivity. Differences in labor productivity may be important for interpreting the conditions necessary to produce a certain scenario outcome.

While other types of model output are available, results in this section address primarily the main topic of the paper, effects on CO2 emissions from demographic change. We also report effects on GDP and the two main sources of household income, capital and labor. In addition, results in this section consider effects on energy production, in physical units. Recall these are obtained from the energy balance, and used with carbon emissions factors in the model to calculate both direct and indirect CO2 emissions.

The main results are presented in the series of figures that follow: per capita labor income, and capital accumulation, with different levels of demographic heterogeneity are presented without technical change in the PET model for China in Fig. 9, and for India in Fig. 10. Because technical change is absent, effects in this pair of figures, which are discussed with the other figures in the next section, are due purely to changes in the age and size composition of households in China, and the age composition of households in India. Results in Fig. 9 show the six age-size structured dynasties in the model for China, and those in Fig. 10 show the three age structured dynasties in the model for India. Results for the representative household configuration of the model are included in each figure for comparison. The corresponding results, under no technical change, for CO2 emissions and GDP are presented in Fig. 11 for China, and Fig. 12 for India. The other figures include effects of technical change. Results for CO2 emissions and GDP in Fig. 13 and Fig. 14, for China and India, respectively, come from the energy and labor productivity growth rates in the representative household version of B2. Results for CO2 emissions and GDP in Fig. 15 and Fig. 16, for China and India, respectively, come from the set of simulations that use energy productivity growth rates from the representative household version of B2, but adjust labor productivity such that average GDP growth is the same for each version of the model. Next, Fig. 17 and Fig. 18, for China and India, respectively, show energy production in physical units with the energy and labor productivity growth rates used in the representative household version of B2. Recall that energy production in the PET model includes primary fossil fuels, Oil and Gas, and Coal, which are more carbon intensive, and secondary energy industries, Electricity and Refined Petroleum, which are less. Finally, Tab. 1 and Tab. 2 summarize assumptions in the B2 scenario, and give numbers for the energy and labor productivity growth rates that correspond to these assumptions which are used in different versions of the model.

Fig. 9: Per Capita Labor and Capital in China under No Technical Change, with Representative Households (R) and 3 Large, and 3 Small, Dynasties (D1 has the cohort of 20 year-olds in 2000, D2 starts with 30 year-olds, and D3 starts with 40 year-olds).
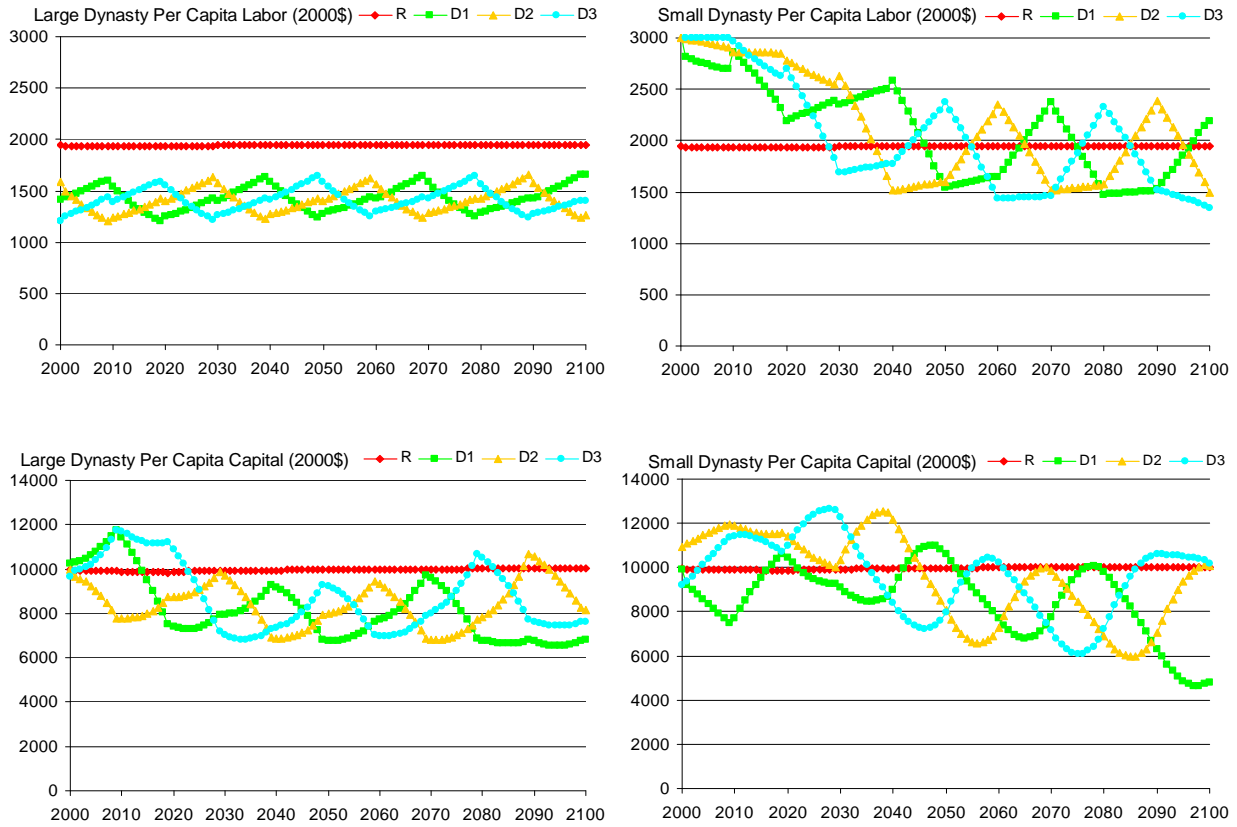

Fig. 10: Per Capita Labor and Capital in India under No Technical Change, with Representative Households (R) and 3 Age-Structured Dynasties (D1 has the cohort of 20 year-olds in 2000, D2 starts with 30 year-olds, and D3 starts with 40 year-olds).

15
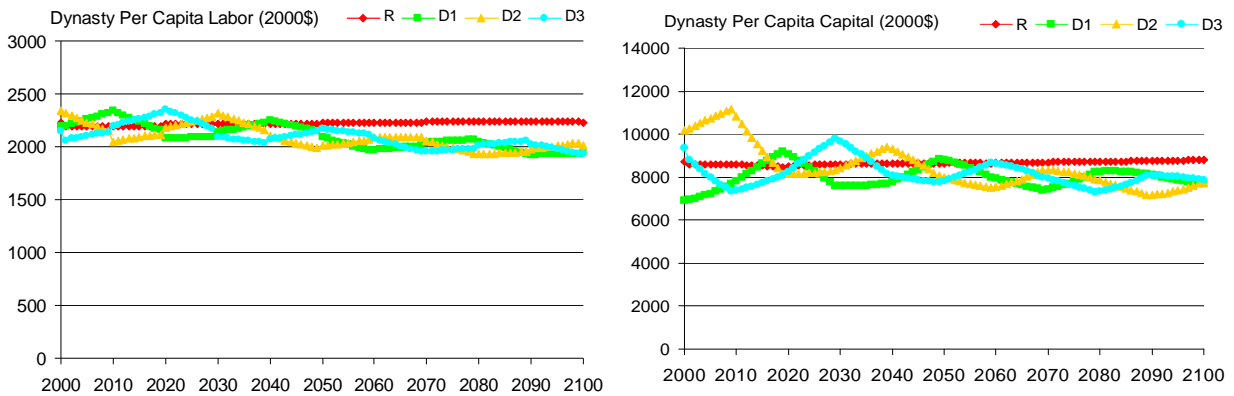
Fig. 11: CO2 Emissions and GDP in China under No Technical Change, with Representative Households (R), Aging (A), Age and Size (A-S), and with Urbanization (A-S-U).
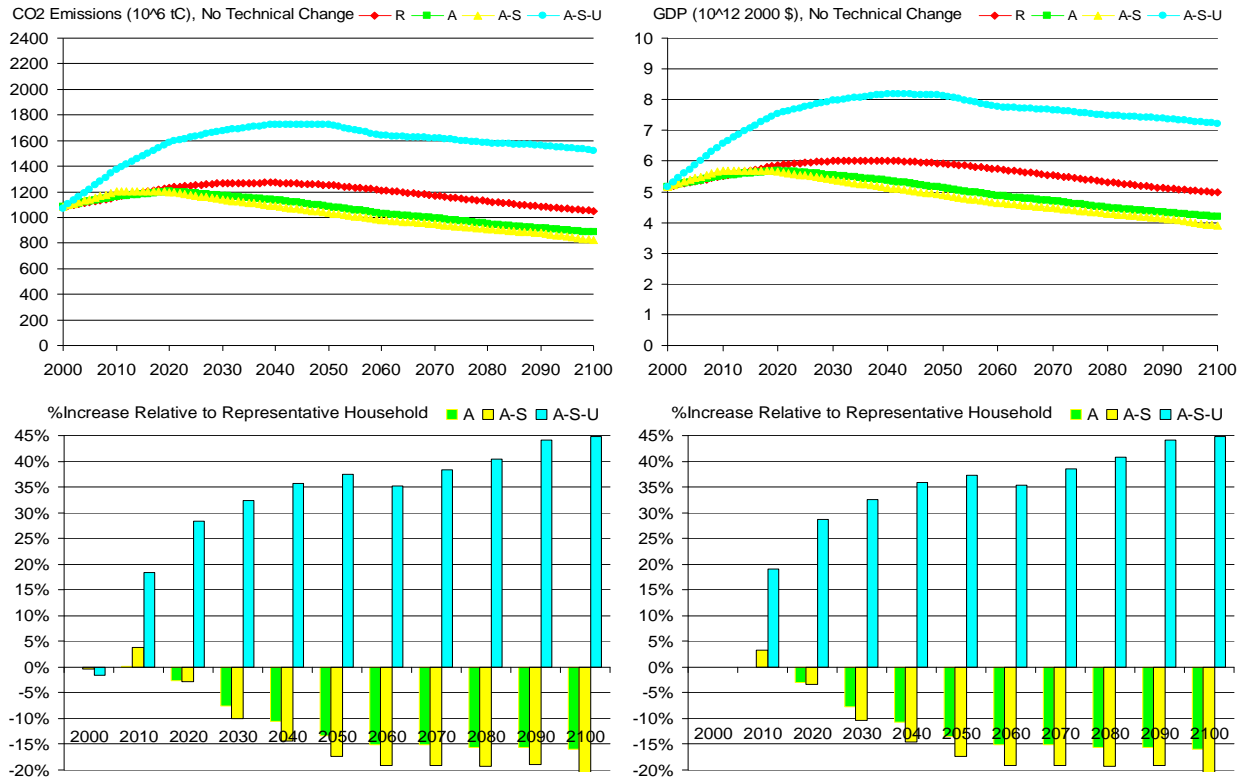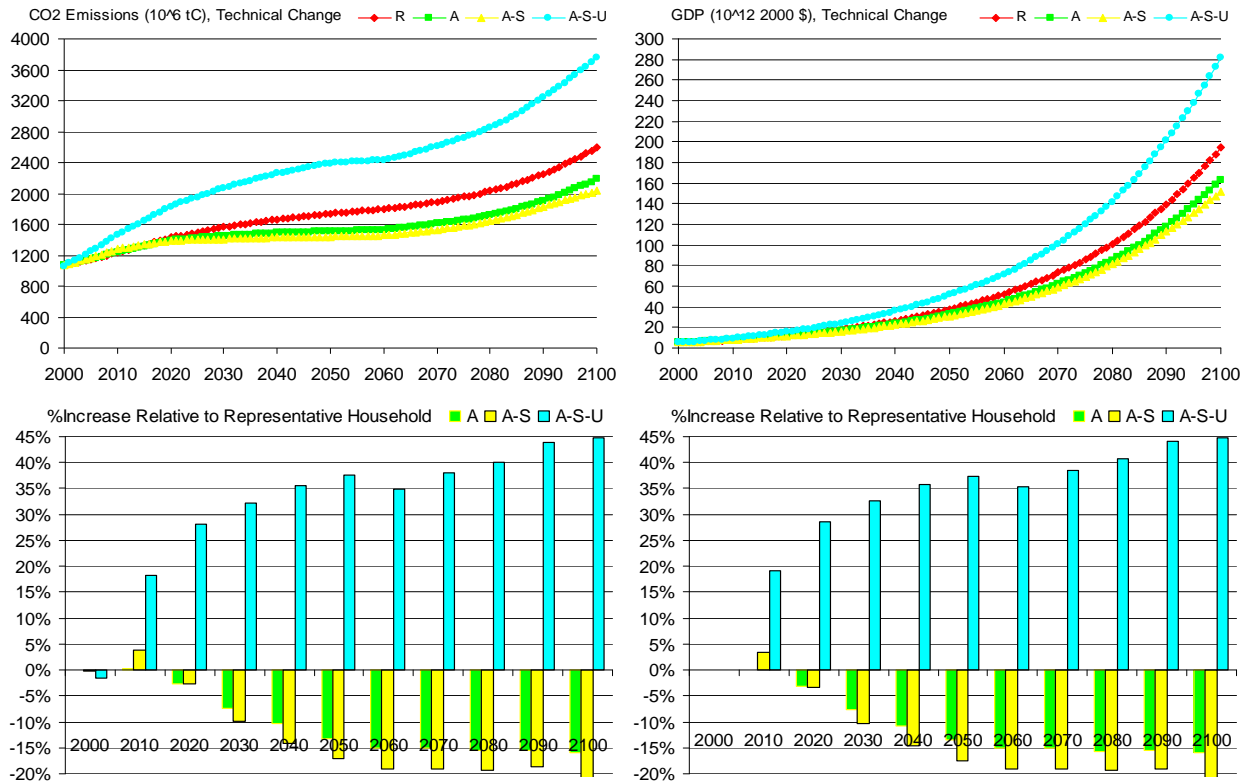

Fig. 12: CO2 Emissions and GDP in India under No Technical Change with Representative Households (R), Aging (A), with Low Urbanization (Lo-AU), and Medium Urbanization (AU).
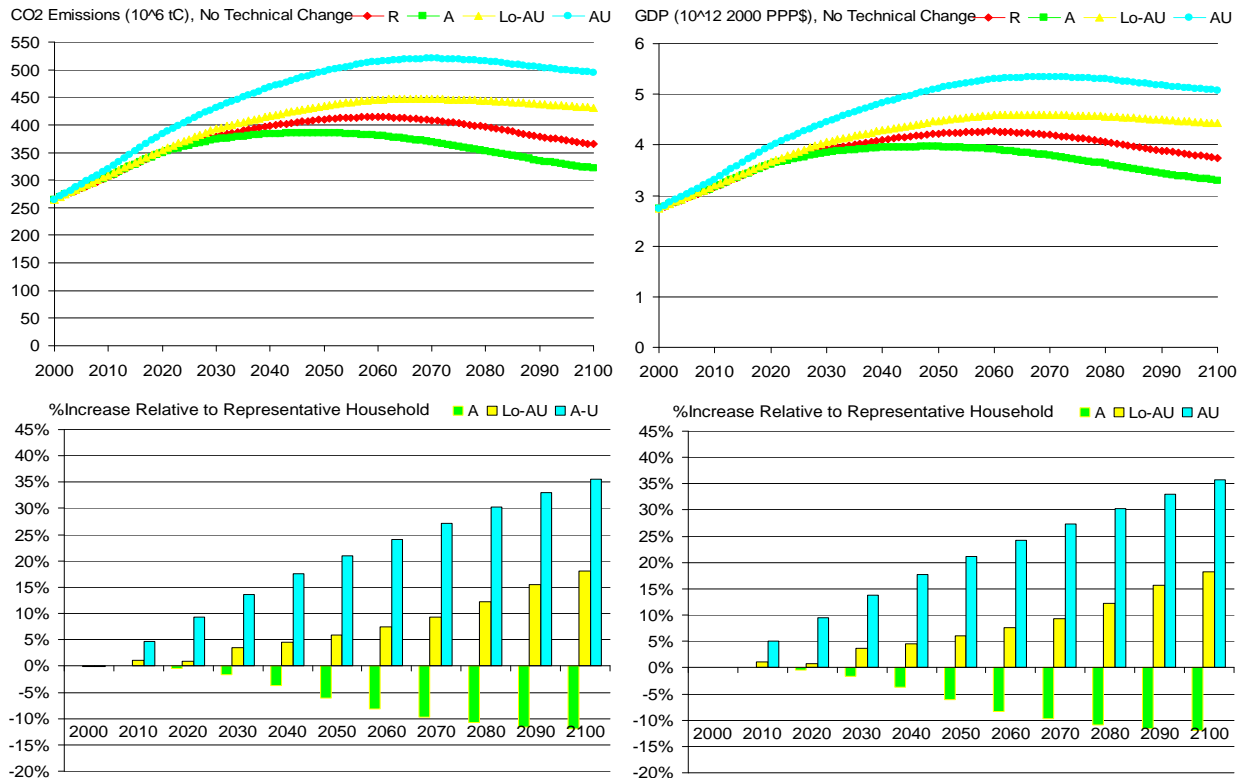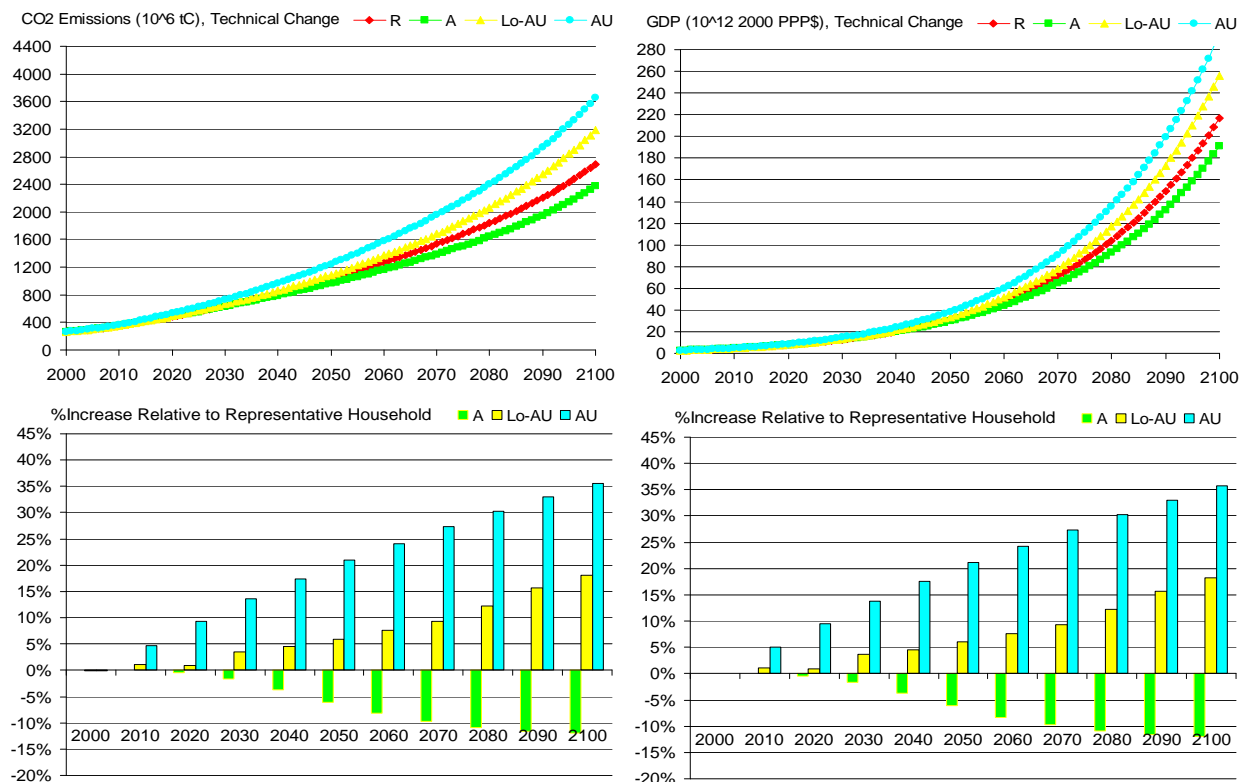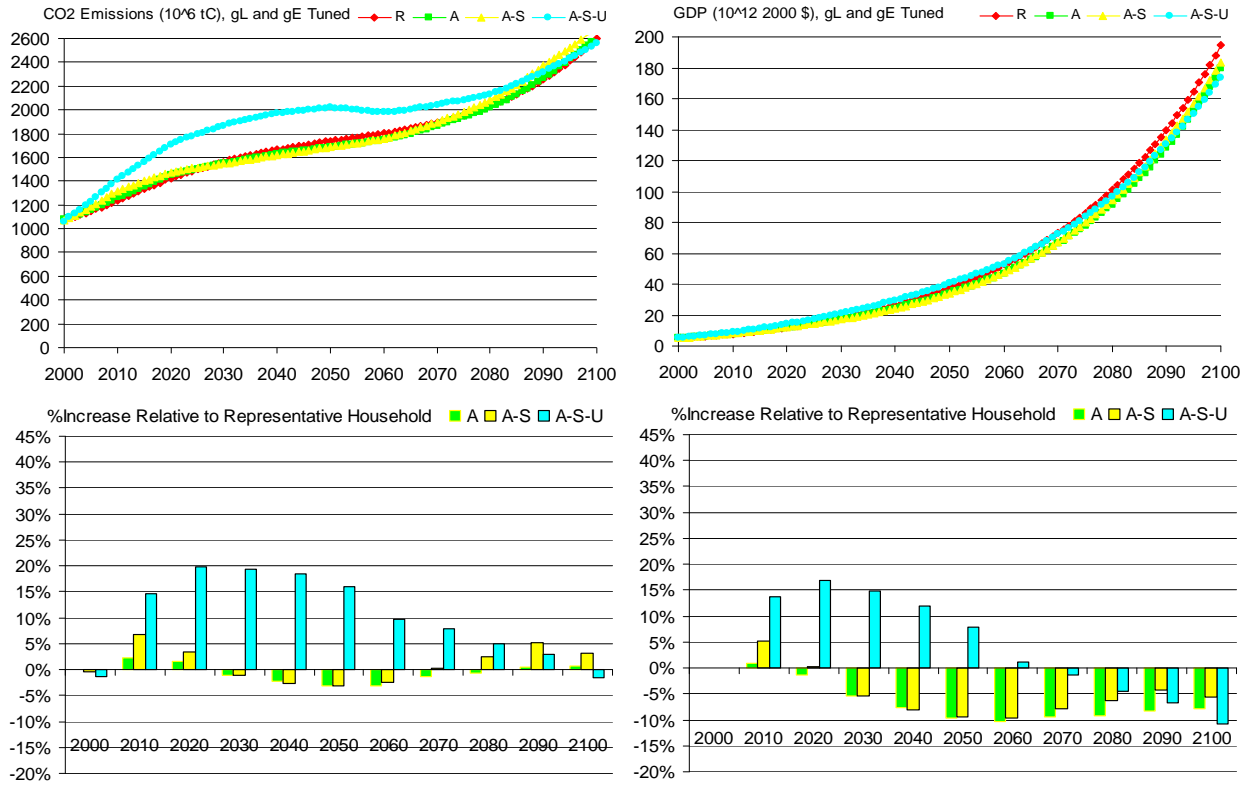
Fig. 13: CO2 Emissions and GDP in China under Technical Change with Representative Households (R), Aging (A), Age and Size (A-S), and with Urbanization (A-S-U).


Fig. 14: CO2 Emissions and GDP in India under Technical Change with Representative Households (R), Aging (A), with Low Urbanization (Lo-AU), and Medium Urbanization (AU).

Fig. 15: CO2 Emissions and GDP in China with Representative Households (R), Aging (A), Age and Size (A-S), and Urbanization (A-S-U) Tuned Separately to the B2 Scenario.


Fig. 16: CO2 Emissions and GDP in India with Representative Households (R), Aging (A), Low Urbanization (Lo-AU), and Medium Urbanization (AU) Tuned Separately to the B2 Scenario.
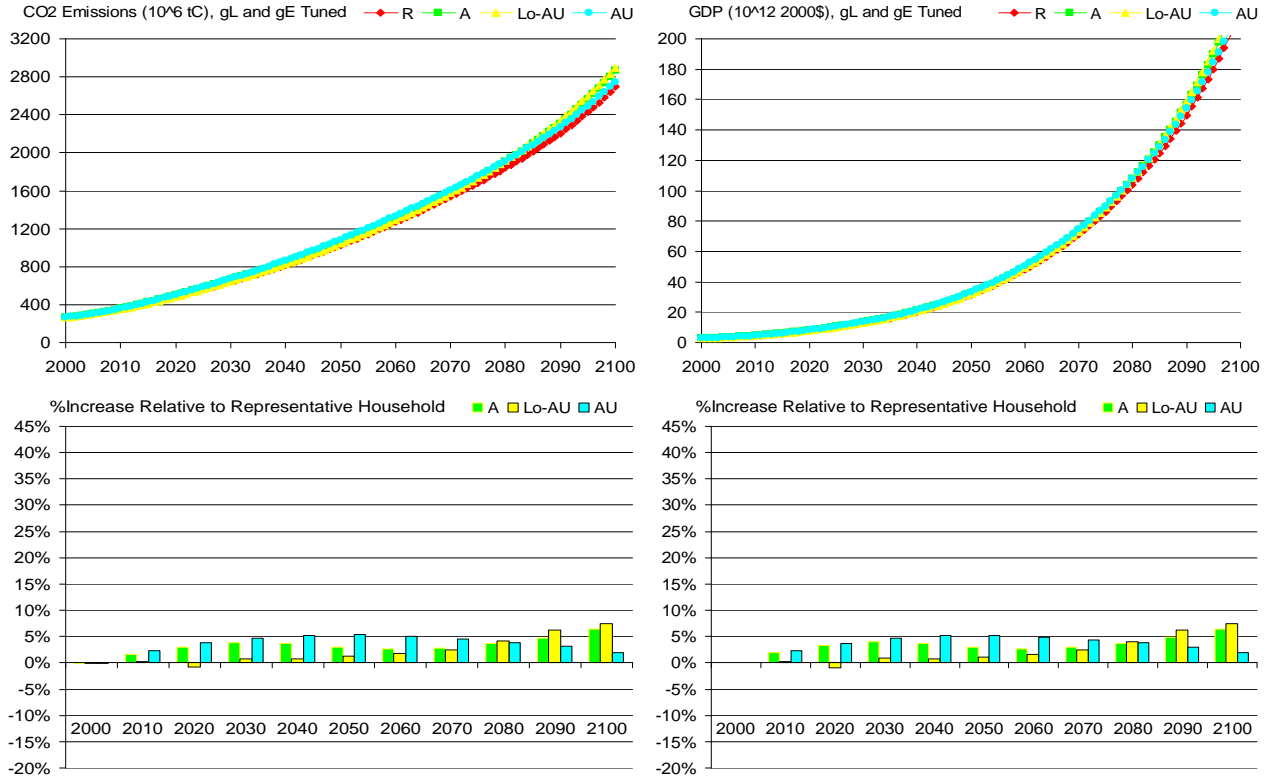
Fig. 17: Energy Production in China (in PJ) under B2 Representative Household Productivity with Representative Households (R), Aging (A), Age and Size (AS), and Urbanization (ASU).
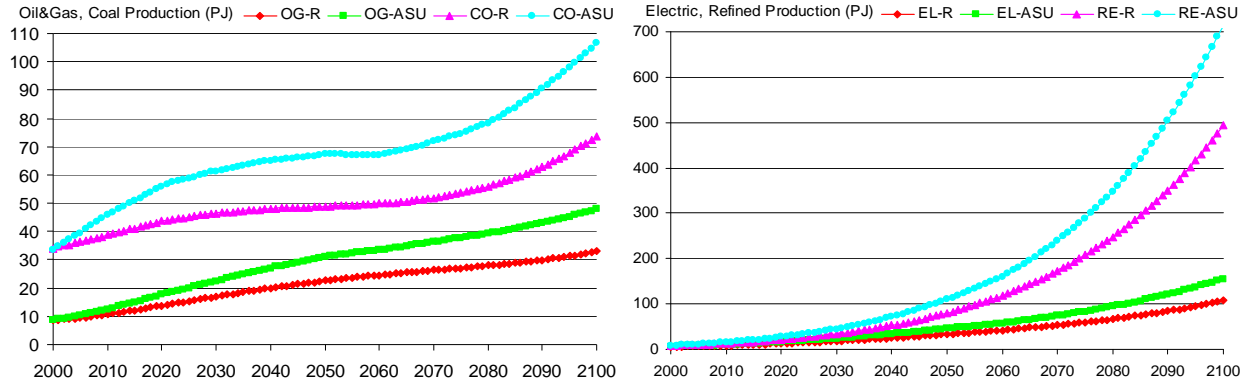
Fig. 18: Energy Production in India (in PJ) under B2 Representative Household Productivity with Representative Households (R), Aging (A), Age and Size (AS), and Urbanization (ASU).
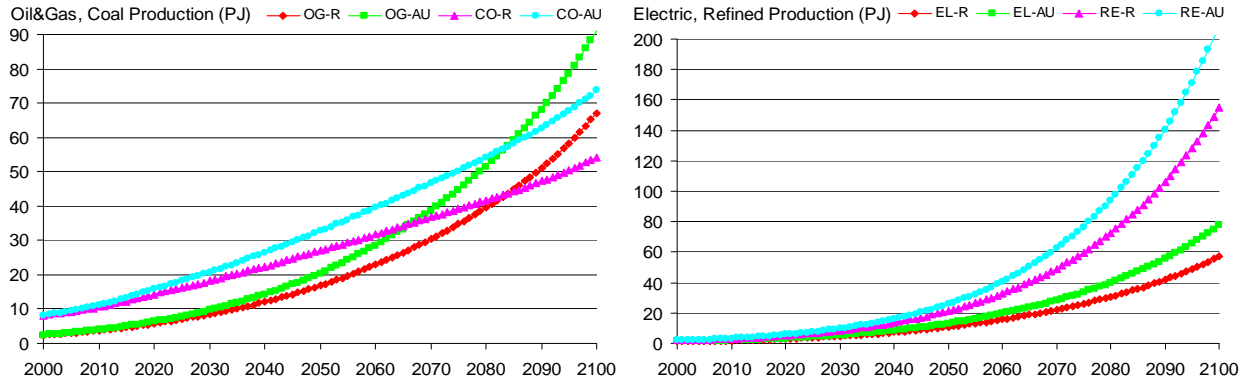
Tab. 1: Energy (g_E) and Labor (g_L) Productivity Growth Rates in the PET Model for China that Match IIASA's B2 Scenario. The average annual growth rate in per capita GDP is 3.7%, and carbon intensity in Centrally Planned Asia falls by 2.6% per year.

	Representative HH	Age	Age-Size	Age-Size-Urban
g_E	2.4%	2.3%	2.4%	2.4%
g_L	3.6%	3.7%	3.8%	3.1%

Tab. 2: Energy (g_E) and Labor (g_L) Productivity Growth Rates in the PET Model for India that Match IIASA's B2 Scenario. The average annual growth rate in per capita GDP is 4.2%, and carbon intensity in South Asia falls by 2.0% per year.

	Representative HH	Age	Age-Lo-Urban	Age-Urban
g_E	1.8%	1.8%	1.8%	1.8%
g_L	4.2%	4.3%	4.0%	3.8%

6. DISCUSSION

Explanation and Overview of Results

First, we simulated a world with no technical change to isolate demographic effects on economic growth, energy demand, and emissions. For this case, the results in Fig. 11 and Fig. 12 show that the net effect of aging, changes in household size, and urbanization in China will increase emissions, relative to the model without demographic effects, by around 15% in the first decade, 35% by mid-century, and 45% by 2100. The independent effects of urbanization in the model are even larger, since the combined effect of aging and changes in household size is to reduce emissions by 20% in the long run. In other words, urbanization alone is projected to have a huge positive effect on emissions of perhaps 65% per year by the second half of the century, everything else equal. Results of this magnitude are based on a moderate demographic scenario for China. More rapid aging and urbanization are possible, and would have correspondingly larger effects.

Results for India are also large. The effect of population aging on emissions reaches over minus 10%. We have not conducted simulations with differences in household size in India yet, but in addition to aging, we did conduct simulations using low and medium urbanization assumptions. For these, the model estimates that emissions will be larger by 15-35% respectively compared to the model without demographic heterogeneity. A comparison of labor and capital income in the models for China and India shows that important demographic effects appear to be transmitted through differences in household size. For example, most of the negative effects of aging on per capita labor income occur in small Chinese households, which are seen in Fig. 9 to influence the wealth of large households, as they smooth consumption in response to the general increase in labor scarcity. In comparison, India has weaker composition effects, which may be an artifact of the projection methodology. In particular, our household projections for India are currently based on the assumption of constant headship rates, which limits the amount of demographic change that we can represent. As a result, percentage changes due to urbanization in India exhibit a nearly linear increase in Fig. 12, while the corresponding effects in Fig. 11 for China based on the ProFamy model are nonlinear, and even non-monotonic in some years.

Next, we analyzed how future technical change in labor productivity, and in the energy sector, interacts in the PET model with demographic change to influence future economic growth and emissions. Results with demographic and technical change are presented in two ways: the first requires only the representative household version of the model, without demographic heterogeneity, to match the rates of change in both GDP and carbon intensity from the B2 scenario. Productivity growth rates from this version are then used in configurations of the model that represent demographic heterogeneity, thus producing different outcomes. The specific growth rates that are used in these different configurations for China and India are given in the first column of numbers in Tab. 1 and Tab. 2, respectively. With the first way of including technical change, the effect of demographic heterogeneity on emissions, in percentage terms, is approximately the same as in the set without technical change, described above. This result is not surprising, given the smooth manner in which technical change is introduced in the model. However, because emissions grow faster in the scenarios with technical change, the effect of demographic heterogeneity in absolute terms is substantially larger: CO_2 emissions in China reach 3.6 billion tons in 2100 with urbanization in Fig. 13, compared to about 2.4 billion tons without. While the specific values from Tab. 1 and Tab. 2 that are used in the representative

household versions of the model imply that relative differences in growth rates for labor and energy productivity are larger for India than for China, the absolute effects of demography appear to be about the same in Fig. 13 and Fig. 14.

The second way of analyzing the combined effects of demographic and technical change is to tune each version of the model with demographic heterogeneity separately to the same GDP growth assumptions in the B2 scenario. Productivity growth rates for each version are reported in Tab. 1 and Tab. 2 for China and India, respectively. These results are intended to provide a test of the importance of demography net of first order GDP effects. According to the tables, effects of demographic heterogeneity on energy productivity are negligible, but the scale effect associated with urbanization implies about half a percentage point less growth in labor productivity per year in China (sustained over 100 years), a slightly smaller effect in India's medium urbanization scenario, and about two-tenths of a percentage point less growth in labor productivity under the low urbanization scenario. Labor productivity, overall, is assumed to grow at a slower rate with urbanization to offset (i.e., balance) the positive effects on economic growth implied by the changing rural-urban composition of the population. Likewise, the negative effects on economic growth that are implied by population aging are offset by higher growth rates of labor productivity. While the direction of these changes may at first seem counterintuitive, these are necessary to maintain the same average rate of economic growth in each version of the model.

Finally, results are presented on production of energy in physical units, petajoules (PJ), by source. As described above, the conversion of results to energy units is possible because our production data are balanced using the national energy accounts of China and India. The results in Fig. 17 and Fig. 18 come from growth rates in the representative household column of Tab. 1 and Tab. 2. In the figures, production of Oil and Gas, and Coal, grow at roughly equal average rates in China over the next century, about 1% per year. In particular, Coal remains the predominant primary energy source in China. In comparison, the relatively large difference in energy and labor productivity growth rates from Tab. 2 implies that production of Oil and Gas in India grows at an average rate of about 3% per year, while Coal production grows about 2% per year. Consequently, Oil and Gas production surpasses Coal production in India, around 2085. Production of Electricity, and Refined Petroleum, grow more quickly than the primary fossil fuels, on average (respectively) around 3-4% per year in China and 4-5% per year in India. The explanation is that these secondary energy sources have lower carbon intensities than the primary fossil fuels. For example, Electricity includes non-fossil fuel based energy sources such as biomass. In fact, tuning the PET model to match carbon intensities in the B2 scenario is achieved specifically by adjusting productivity growth rates for these secondary energy sources. With productivity growth from for example an increase in energy efficiency, the secondary sources become relatively less expensive in the model, and therefore, producers substitute away from primary fossil fuels to less carbon intensive sources.

General Equilibrium Effects

Most of the results described above employed a single dynasty approach to incorporating demographic heterogeneity in the PET model. As noted earlier, this approach does not allow for the possibility of general equilibrium effects on consumption and savings decisions from separate dynasties. We briefly discuss such effects in more detail and report the results of simulations using a true multiple dynasty approach.

In our simulations, labor income is taken to be exogenous, while capital income is endogenous, depending on asset accumulation within each dynasty, and the price of capital in each time period, which signals its relative abundance or scarcity in the economy as a whole. The price of capital, its depreciation rate, and the price of new investment goods determine the model's market interest rate, and it, along with household income, is a primary driver of households' savings decisions. In general, the price of capital, and therefore interest rates, will depend on every economic element in the model, which together may be broadly characterized in terms of preferences, technology, and endowments of labor and capital. Therefore, a host of interesting economic interactions that affect prices are possible when separate age- or size-structured dynasties are represented in the PET model. The aggregate influence on prices, across industries and sectors, from variations in the labor supply across households are general equilibrium effects. In other words, our simulations can be seen as analyzing the relationship between the general equilibrium that simultaneously takes place in all markets represented in the PET model, and the distribution of labor among households, as distinguished by age and size.

We performed 9 sets of simulations to evaluate the importance of general equilibrium effects associated with variations in the distribution of labor supply: 2 sets for China, 1 for India, and this triple replicated across the 3 types of models; without technical change, with technical change gross of demographic scale effects, and with technical change net of demographic scale effects. The pair for China includes one model with 3 dynasties to handle population age structure, albeit in a limited way. A second has 6 dynasties to represent age structure, and two sizes of households, large and small. Simulations for India involve only the 3 dynasties needed to represent population age structure. General equilibrium effects associated with interactions among separate dynasties, and within dynasties across time, are estimated from our simulations to be around 5% for China, and negligible for India. For comparison, we found these effects were about 15% of the total demographic effect caused by aging over the next century in a low population scenario for the U.S., and note this value is sensitive to the numerical values used for household substitution elasticities in the model.

Comments on the Methodology and Plans for Future Work

The analysis presented in this paper addresses the question of whether demographic change in China and India is likely to be influential in terms of affecting future economic growth, energy demand, and CO_2 emissions. Our analysis is based on a comprehensive set of household and production data, recent household and population projections, and simulations using the Population-Environment-Technology (PET) model. Our methodology, which can be extended to other countries, is capable of evaluating the effects of aging, changes in household size, and urban migration. Given its scope, a number of important caveats regarding this methodology should be expected. For example, the need for an Indian household projection using the ProFamy model was identified in the results above, to replace the one used in this paper based on constant headship rates, which may limit shifts in population composition by household type expected in the coming decades. In addition, our approach for China and India would benefit from a more carefully specified set of urbanization scenarios.

For the household surveys and production data, we are utilizing all relevant sources available from the national accounts and statistical databases of China and India. However, we anticipate some methodological improvements in how final demand is treated in the production data. We have a potentially serious problem to contend with regarding period and cohort effects in the

household surveys. Specifically for China, recent economic and policy changes have lead to a boom in spending among young and highly educated households, particularly on housing, which is seen in our results from the household surveys. It is not clear now whether this pattern will persist, or whether it is an anomaly of the current period, or youngest cohort.

We plan to expand the number of consumer goods beyond the four used in this paper. We have a special interest in disaggregating the energy and food commodities in our data, using nested functional forms, and investigating the conditions under which changes in consumption patterns might matter. For example, the model specification used for the analysis described in this paper is based on homothetic demand functions that are invariant in a certain sense to changes in income. However in reality, expenditure patterns depend on income. For example, it would be natural to assume, and it is often observed, that expenditure shares on food will decrease with rising income. The PET model's demand system is based on a functional form that allows non-homothetic demand to occur, but we need an empirical foundation for this parameterization. Similarly, based on previous work, sensitivity testing is recommended for the household substitution elasticities used in our analysis.

In addition to data issues, we see a need for further analysis of the modeling approach in this paper, and perhaps, refinements. Multiple dynasties, in our view, are an improvement over the typical approach in energy-economic growth models, which is based on a fictitious social planner that in special circumstances is equivalent to a single dynasty, or large number of identical households. However, by treating groups of separate households as a perfectly cohesive unit, the current methodology is prone towards overgeneralization. For example, the construction of expenditure shares for each dynasty essentially smoothes any differences that may exist among age groups in the household data. In terms of model dynamics, the current approach implicitly assumes that concern for welfare extends symmetrically across generations, and that household transfers are free and perfect. We are interested in the implications of these assumptions.

A major challenge that is immediately in front of us is to conduct an analysis with international trade. The PET model can handle trade in goods (but not factors), and now that detailed demographic and production data are available for 3 countries, the returns from doing so are potentially very high. Recently, we began working with production data from the Global Trade Analysis Project (GTAP), which manages a global source of benchmark IO data, social accounting matrices, and bilateral trade flows that are based on the national accounts, and other sources. In the near future, we will have an IO matrix for the rest of the world, which will enable us to complete a global analysis that includes China, India, the U.S., and the rest of the world.

Results in this paper lead us to conclude that urbanization and aging will have opposing effects on emissions and economic growth in China and India, with the positive effect of urbanization outweighing the negative effect of aging by roughly two-to-one, but these magnitudes probably differ in other countries or regions. Effects of demographic heterogeneity with international trade are unknown, but based on the moderating effects that markets have on results in this paper, such as those for large and small households in China, we anticipate that international trade will, in fact, offset some effects from the demographic processes that we have imposed on closed economies. However, aging and urbanization are ongoing, global processes that will almost surely persist for decades, and it is not clear *a priori* how large the long run aggregate effects of each may be. We find these questions to be compelling, and motivate further research.

REFERENCES

Alcamo, J., Leemans, R., and Kreileman, E. (eds), 1998. Global Change Scenarios of the 21st
Century: Results from the IMAGE 2.1 Model. Elsevier Science Ltd, Oxford, UK. 296 pp.

CEA (Central Electricity Authority). 2000. Public electricity supply: all India statistics. Ministry
of Power, Government of India, New Delhi

CMIE (Centre for Monitoring the Indian Economy). 2005. India's energy sector. Mumbai, India

CSO (Central Statistical Organisation). 2005. Input-Output Transaction Table for 1998-99.
Department of Statistics and Programme Implementation, Government of India, New Delhi

CSO (Central Statistical Organisation). 2005. National Accounts Statistics. Department of
Statistics and Programme Implementation, Government of India, New Delhi

CSO (Central Statistical Organisation). 2000. Energy Statistics. Department of Statistics and
Programme Implementation, Government of India, New Delhi

Dalton, M., B.C. O'Neill, A. Prskawetz, L. Jiang, and J. Pitkin. 2006. Population aging and
future carbon emissions in the United States, forthcoming *Energy Economics* (available
online at www.sciencedirect.com or www.iiasa.ac.at/Research/PCC/research-proj/dem-
emiss.html).

FAO (Food and Agriculture Organisation). 1997. Regional Wood Energy Development
Programme in Asia (RWEDP) Wood Energy Database. Rome, Italy.

Goulder, L. 1995. Effects of carbon taxes in an economy with prior tax distortions: an
intertemporal general equilibrium analysis, *J. Environmental Economics and Management*,
29, 271-297.

GoI. 2000. Indian Petroleum and Natural Gas Statistics. Ministry of Petroleum and Natural Gas,
Government of India, New Delhi.

GoI. 2000. Coal Directory of India. Department of Coal, Government of India, New Delhi.

GoI. 2001. Census of India 2001: B Series : General Economic Tables. Registrar General and
Census Commissioner of India, Ministry of Home Affairs, New Delhi.

Grübler, A., O'Neill, B. C., Riahi, K., Chirkov, V., Goujon, A., Kolp, P., Prommer, I., Scherbov,
S., and E. Slentoe. Regional, national, and spatially explicit scenarios of demographic and
economic change based on SRES. *Technological Forecasting and Social Change* (in press).

Heston, A, R. Summers, B. Aten. 2006. Penn World Table Version 6.2, Center for International
Comparisons of Production, Income and Prices at the University of Pennsylvania.

Imai, H. 2002. The effect of urbanization in developing countries on carbon dioxide emissions:
Evaluation by modifying the Edmonds-Reilly model. Environmental Science 15(5), 331-340.

Intergovernmental Panel on Climate Change (IPCC). 2000. Special report on emissions scenarios
(Cambridge University Press, Cambridge UK). http://www.grida.no/climate/ipcc/emission/.

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

Lareau, T.J. and Darmstadter, J. 1983. Energy and Household Expenditure Patterns. Resources
for the Future, Washington, DC.

Morita, T., et al., 2001: Greenhouse gas emission mitigation scenarios and implications. Climate
change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report
of the Intergovernmental Panel on Climate Change, B. Metz, O. Davidson, R. Swart, and J.
Pan, Eds., Cambridge University Press, 115-166.

Nakicenovic, N. et al. 2000. IPCC Special Report on Emissions Scenarios. Cambridge
University Press, Cambridge, UK.

NBS (National Bureau of Statistics). 2004. China Energy Statistical Yearbook 2000-2002, Department of Industry and Transportation Statistics, China Statistics Press, Beijing (in Chinese).

NBS (National Bureau of Statistics). 2006. 2002 Input-Output table of China, Department of National Economic Accounting, China Statistics Press, Beijing (in Chinese).

NSSO. 2002. Unit level data from Sch 1.0 Household consumer expenditure Round 55 (July 1999-June 2000). National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.

O'Neill, B.C. and Chen, B. 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.

Parikh, J. and Shukla, V. (1995) Urbanization, energy use and greenhouse effects in economic development: Results from a cross-national study of developing countries. Global Environmental Change 5(2), 87-103.

PC (Planning Commission). 1999. Ninth Five Year Plan. Planning Commission, Government of India, New Delhi. Available at <http://planningcommission.nic.in/plans/planrel/fiveyr/welcome.html>.

Pradhan BK, Saluja MR, Singh SK (2006) Social Accounting Matrix for India: Concepts, construction and Applications. Sage Publications India Private Limited, New Delhi.

Pradhan B., M. Saluja, P. Roy, S. Shetty. 2003. Household Savings and Investment Behaviour in India. EPW Research Foundation, Mumbai.

Ravindranath, N. and D. Hall. 1995. Biomass, energy, and environment: a developing country perspective from India. Oxford University Press, New York.

Riahi, K., Gruebler, A. and Nakicenovic, N. Scenarios of Long-term Socio-economic and Environmental Development under Climate Stabilization.Technological Forecasting and Social Change, in press.

Sands, R. and A. Fawcett. 2005. The Second Generation Model: Data, Parameters, and Implementation. Pacific Northwest National Laboratory, PNNL-15431.

Schipper, L. 1996. Lifestyles and the environment: The case of energy. Daedalus 125, 113-138.

TERI (The Energy and Resources Institute) (2003) TERI Energy Directory and Yearbook 2003-03 (TEDDY). TERI, New Delhi.

van Vuuren, D. P., J. Weyant, and F. de la Chesnaye, 2006: Multi-gas scenarios to stabilize radiative forcing. Energy Economics, 28**,** 102-120.

van Vuuren, D., P. Lucas, and H. Hilderink, Downscaling drivers of global environmental change: Enabling use of global SRES scenarios at the national and grid Levels, Glob. Environ. Change (in press).

Weber, C. and Perrels, A. 2000. Modelling lifestyle effects on energy demand and related emissions. Energy Policy 28, 549-566.

Weyant, J.P. and Hill, J. 1999. Introduction and overview, costs of the Kyoto Protocol: a multimodel evaluation, Energy Journal, Kyoto Special Issue, vii-xiv.

Zeng Y., Wang Z., Jiang L., and Gu D. 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, Genus, (in press).