Abstract

Demographic and economic growth will account for most of the anticipated growth in greenhouse gas (GHG) emissions in the next century. Education is associated with development, and the world population in the near future is likely to be significantly better educated than today. Previous studies of household energy demand and associated emissions have not directly considered the consequences of a more educated population. In this study, I estimate the energy intensity of consumption dollars and the total impact of households according to their demographic characteristics, with particular attention to differences in spending habits by education and the environmental consequences. I find that education results in fewer emissions per household, holding other household characteristics constant. Each year of education is associated with an average effect in CO_2-equivalent emission of -466kg/yr. After controlling for household characteristics, the effect of a year of education is -163.1kg per year. Educated households spend less on home energy and transportation by car, two of the most important sources of household-level atmospheric GHG production. They spend relatively more on investment goods, public transport, and other activities which have a low environmental footprint.

Keywords

Human capital, environmental impact, household emissions.

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The carbon cost of an educated future: a consumer lifestyle approach

Ethan Sharygin

1 Introduction

Climate change anticipated over the next century as a result of global warming is widely accepted to be of primarily anthropogenic origin, related to our use of fossil fuels (IPCC 2008). Fossil fuels are the most significant source of anthropogenic greenhouse gas (GHG) emissions, and also the engine of economic growth during the last two centuries. Economic growth is an central goal of most nations, and among the consequences of development are greater per capita income and energy demand. Population growth is anticipated as well, with significant implications for energy demand. Demographic and economic growth will account for growth in GHG emissions of 25–90 percent in the next century, depending on changes in fertility, household size, and growth in real income (Bongaarts 1992; MacKellar et al. 1995; Dyson 2005).

Prosperity is a compelling goal, and there are excellent reasons to desire continued economic growth. Under the current technological regime, continued growth appears ecologically unsustainable; however, growth may also be essential for global prosperity. Of utmost importance, then, is identifying ways in which energy demand can be reduced while still allowing growth to be an over-arching goal. Education may be one such pathway; educated societies may produce more technological innovation, lower population growth, and "smarter" consumption that reflects knowledge and concern for environmental impact. Like economic growth, a more educated population is a goal of all nations, developed and developing. If education has an independent effect on behaviors that affect climate change, then it is potentially an important omission from our understanding.

Here, I am concerned specifically with how household energy demand and associated emissions will be affected by a more educated population. Education is associated with development, and the world population in the near future is likely to be significantly better educated (KC et al. 2010; EPDC 2005). I estimate the energy intensity of consumption dollars and the total impact of households according to their demographic characteristics, with particular attention to differences in spending habits by education and the environmental consequences. This includes differences in spending on housing, transportation, durable and non-durable goods, and the associated energy and emissions from production, use, and disposal. This method of accounting has been referred to in various ways; here, I adopt the nomenclature of "consumer lifestyle approach" (CLA) used by Bin and Dowlatabadi (2005).

I find that education results in fewer emissions per household, holding other household characteristics constant. Each year of education is associated with an average effect in CO_2-equivalent emission of -466kg/yr. The most educated households are smaller and are headed by younger adults. After controlling for demographic characteristics, the effect of a year of education is -163.1kg per year. Educated households spend less on home energy and transportation by car, two of the most important sources of household-level atmospheric GHG production. They spend relatively more on investment goods, public transport, and other activities which have a low environmental footprint.

Section 2 reviews relevant prior research on population, environment, education, and the demographics of household energy use. Section 3 describes the empirical strategy and the sources of data used in the analysis. Section 4 presents the results, and Section 5 concludes with broader implications of the findings and directions for future research.

2 Background and related literature

2.1 Population and environment

Population has long been recognized as a driver of energy use. An influential thread within the environmentalist movement began to express renewed interest in the Malthusian hypothesis—that the growth of population must out-pace the growth of resources, with tragic consequences. In 1948 two important books on this topic appeared, *Our Plundered Planet* and *The Road to Survival* (Osborn 1948; Vogt 1948). Both authors critiqued environmental exploitation and overpopulation, were immensely influential in their time, and came to inform the arguments of ecologists and environmentalists of the next generation, including P. R. Ehrlich and others (Robertson 2012; Desrochers and Hoffbauer 2009).

Population has been explicitly used as a scale variable to calculate environmental impact since the early 1970s at latest, with the advent of the I=PAT identity, which defines environmental impact as a function of population, income, and production technology (Ehrlich and Holdren 1971; Commoner 1972).[1] The first treatments of population assumed that emissions increase linearly with population growth, but subsequent research has shown that approximation to be insufficient in long-run projections, as additional characteristics such as age structure and household size can have a significant effect.

In the wake of the discussions during the 1970s and 1980s, much more has been learned about the role of population characteristics on energy demand and emissions. MacKellar et al. (1995) found that smaller household size is associated with greater per capita energy demand—an important result, considering that later marriage, lower fertility, and changing social norms regarding the family have tended to reduce average household size in developed countries. O'Neill and Chen (2002) expanded on this analysis by considering age as well as household size, and found that there is a distinct age pattern of

[1] A discussion of the I=PAT formulation is beyond the scope of this paper, but interested readers may refer to O'Neill and Chen (2002).

energy consumption that may translate into more energy use in the U.S. as the mean age of the population rises in the future. Zagheni (2011) conducted a thorough and refined analysis of direct and indirect energy demand which confirms that aging is likely to cause small but significant increases in GHG emissions of U.S. households. The robustness of these results has led to major efforts to incorporate demographic change into mainstream global emissions models (Dalton et al. 2008; O'Neill et al. 2010).

Urbanization is another important contributor to variation in the relationship between population and impact. The effect of urbanization depends in turn on the level of economic development (Pariakh and Shukla 1995; Martinez-Zarzoso 2008; Cole and Neumayer 2005). Less developed countries are likely to experience growth in emissions as populations move to the city, due to the relatively low energy intensity of the rural economy. Wealthier countries, on the other hand, see a modest reduction in emissions with further urbanization. In the U.S., the average difference in direct and indirect energy demand between suburban or rural households and urban households is approximately 20 percent (Shammin et al. 2010).

2.2 Households and energy demand

Households, and the consumers within them, are responsible for the lion's share of the total energy production and use in the U.S., through direct sources (such as combustion of fuel for heating and transportation) and indirect energy associated with demand for products and services. Somewhere between 70 percent (Shammin et al. 2010) and 85 percent (Bin and Dowlatabadi 2005) of total domestic energy demand and emissions can be explained by demands for goods and services embedded in lifestyle choices.

The analysis of emissions according to the households whose demand created them has been referred to as the "consumer lifestyle approach" (CLA) or "consumption based approach" (Bin and Dowlatabadi 2005; Wiedmann 2009). CLA and similar approaches have been used to estimate the environmental footprint of households in Australia (Lenzen

1998), India (Pachauri and Spreng 2002), China (Wei et al. 2007; Golley et al. 2008), and across Europe (Weber and Perrels 2000; Reinders et al. 2003; Hertwich and Peters 2009). Together, these findings have strengthened the case that the the final demand of households is a compelling perspective for measuring an economy's environmental impact.

3 Data and methods

In the subsequent sections, I estimate energy and GHG impacts of households by multiplying expenses in dollars by the carbon intensity (kg CO_2/\$) or energy intensity (TJ/\$) of goods and services. All expenditures less taxes and cash transfers are included, and all sources of income (after taxes) are included.[2] Total household emissions E is calculated by $E = \sum_{i=1}^{n} \rho_i Y_i$, where ρ refers to the intensity coefficient, Y is the total expenditure in the expenditure category i. I relate total emissions to expenditures by the following nonlinear model, following Herendeen et al. (1981); Pachauri (2004) and Lenzen et al. (2006):

$$E = K \times Y^{\alpha}, \tag{1}$$

Where K is a constant and α represents a coefficient on log income. Rewritten as a log-linear model with multiple predictors X and error term ε, Eq. 1 becomes:

$$\ln E = \ln K + \alpha \ln Y + \beta_1 X_1 + \ldots \beta_n X_n + \varepsilon \tag{2}$$

The model is executed as a generalized linear model with log link function, avoiding the introduction of transformation bias during the estimation.

[2]Cash transfers between households are excluded. Although tax-funded public services have an environmental footprint, taxes are excluded from expenditures because they are not very indicative of consumer lifestyle choices.

3.1 Carbon intensity of demand

The energy and carbon intensity of goods and services is calculated from input-output matrices of the U.S. economy produced by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce and extensively adapted by the Green Development Initiative (GDI) team at Carnegie Mellon University. The BEA matrices describe the economic activity generated in other industries for a given level of demand in dollars to a single industry, and these are modified and added to by GDI to provide estimated energy use and environmental externalities associated with a given amount of economic demand for a good or service over its entire lifecycle, including the production, wholesale, retail, transportation, use, and disposal phases.[3]

Environmental impact can be classified into two categories: indirect and direct. Direct impacts include demand for primary energy, in the form of electricity, natural gas, gasoline, and other fuels. Indirect impacts include non-energy goods and services, such as haircuts, apparel, and telephone service. Intensities are calculated on the basis of final purchaser price for a set of 65 categories of goods and services: 5 direct and the rest indirect. To generate the set of intensities in the form of the desired units of impact per dollar of final demand, I calculate the Leontief inverse of the relevant input-output matrices produced by GDI.

For direct impacts, I estimate the energy expenditure and GHG emissions from data published by the Energy Information Administration (EIA) of the US Department of Energy. For products such as gasoline, GDI matrices include energy and emissions associated with production, transportation, and sale of gasoline, but not the carbon released by combustion. The EIA provides historical information on the price of energy goods,

[3] There are two exceptions to this rule. First, GDI does not include impacts from the use phase of direct energy goods besides electricity. Second, the GDI electricity model does not account for regional variation in the carbon intensity of electricity production; The efficiency and carbon intensity of electricity production varies greatly by region. I opt to modify the GDI-calculated intensity coefficients by a factor equal to the ratio of the state-specific direct use coefficient to the national average coefficient. Additionally, I directly estimate the impact during the use phase of gasoline, natural gas, and fuel oil and add these to the GDI results when they are missing.

as well as their energy content and carbon density. Where applicable, I incorporate these data as annual averages at the state level. GHG emissions associated with electricity production, for example, varies across states and over time, and these variations are included in the calculations used in this paper. Associating emissions from direct consumption of energy contributes to the completeness and accuracy of CLA estimates, but this paper is the first to estimate direct impacts from a consumption survey directly. An advantage of this approach is that direct energy use can be studied across a fuller set of household characteristics than, for example, exist in alternative datasets such as the Residential Energy Consumption Survey (RECS).

Indirect impacts from consumption are calculated using intensity coefficients described above. This process involves several steps: dividing expenditures in categories such as clothing or car leasing into BLS-standard commodity codes ("UCC"); converting these to BEA-standard commodity codes ("PCE"); converting these into BEA industry codes that match those in the GDI data, and finally calculating the Leontief inverse for the activity in the set of industries activated by final demand for the goods or service. These steps are illustrated in Table 1 for purchases of alcohol, with the final step simplified by summing the impact within each industry for all the industries activated by the purchase. Purchases of alcohol include of purchases of beer, wine, and other alcoholic beverages; these correspond to three PCE items: beer, wine, and spirits, which represented 45, 43, and 12 percent, respectively, of total spending on alcohol in the consumption survey. The BEA provides a bridge between commodity and industry codes, usually with several industry codes for each commodity. In this case, wine and beer are 100 percent represented by the activities of wineries and breweries, but only 95 percent of purchases of spirits accrue to distilleries, with 5 percent of the final demand for spirits going to food manufacturing.

[Table 1 here]

Over a decade of economic change, GDI produces evidence of significant efficiency gains that have reduced the carbon intensity of alcohol production: the amount of GHG per dollar of activity in this sector has fallen from 1.6lbs of CO_2e in 1992 (Bin and Dowlatabadi 2005) to just 1.1lbs in 2002.

3.2 Consumer Expenditures Survey

Expenses are calculated from the Consumer Expenditures Survey (CES) for the years 1997 and 2002, coinciding with the years that the GDI has calculated environmental impact matrices from the BEA data. The CES is a nationally representative survey of expenses collected quarterly from households that enroll for four quarters. Microdata from the interview portion of the survey, which contains records of major purchases and expenses at a highly detailed level of categorization, were combined into single annual records by Sabelhaus and Harris. (2000) and are hosted on the web by the National Bureau of Economic Research. Expenses are harmonized into 109 consistent categories across years. Additional household characteristics are included from CES microdata that were not included in the original extracts by Sabelhaus and Harris..

Rent payments or imputed rent are included with other expenditures on housing operations, so that renters and homeowners are treated equally. The sample is restricted to non-student heads of household with no missing income or expenditures data, and who remained in the panel for a full year. Descriptive characteristics of the resulting analytic dataset are reported in Table 2.

[Table 2 here]

BLS average income as tabulated in the CES in 2002 was approximately $47,000 after taxes, with expenses totaling $42,500. The average household head's age was 48, and the average size of the consumer unit was 2.5 persons. Income and expenses in this study are calculated differently from official BLS tabulations: I define income and expenditures in such a way that they sum to approximately zero, so that the total flow of post-tax income from all sources through the household is accounted for (cash savings and transfers between households are not counted). Sample restrictions also explain some of the deviation between published and estimated values. The samples are demographically congruent.

3.3 Model assumptions and limitations

Analyses of this type are subject to several important limitations and sources of bias. A limitation of the method used in this paper is the assumption of linear effects of additional expenditures. Since the calculated intensities are constants, the millionth dollar spent in an industry has the same environmental impact as the first. In addition, goods are distinguished only by their type and cost. The model cannot distinguish between identically coded goods, such as a $500 watch and ten $50 watches, or between a suburban tract house or a city condominium each costing $250,000. Errors are also introduced in the process of recoding purchases into a limited number of categories. For example, Sabelhaus and Harris. (2000) code bicycles, cameras, and hunting equipment into the same category ("Recreation and sporting equipment"). For the purposes of presentation, these are further aggregated into 12 categories, but this second aggregation step is performed after calculating environmental impact and therefore is not a source of additional error.

Foreign and domestic production technology is assumed to be equivalent, so that no distinction is made between the environmental impact of domestically produced and imported goods. This limitation may result in substantially lower or higher estimated indirect emissions, to the extent that U.S. production technology is more or less efficient than countries where imported goods are produced (Weber and Matthews 2007).[4]

[4]Multi-region input-output models have been developed which include international trade and allow for differences in production technology; these are not used here due to problems with classifications of goods and services across countries, although signs indicate that these models will be ready for deployment very soon (Kanemoto et al. 2011; Peters 2011).

4 Analysis and discussion

Table 3 summarizes the emissions profile of the average U.S. household in 1997 and 2002. The average household was responsible for 41.7 megatonnes (Mt) of CO_2e emissions in 2002, down from 42.8Mt in 1997.[5] In 2002, the total CO_2 inventory of the U.S. was approximately 5.825 billion Mt (USDOC ESA 2010). Collectively, emissions generated by consumption of goods and services by 109.3 million U.S. households totaled 4.56 billion Mt, or 78.2 percent of the total U.S. emissions inventory.

[Table 3 here]

The most important source of household emissions is residential energy, which in 2002 accounted for under 4 percent of total household spending but 35 percent of total energy demand an equal share of total emissions. Residential energy includes power and heating from electricity, natural gas, and fuel oil. Personal transport—mainly gasoline purchases—accounted for a further 3 percent of expenses and 25 percent of emissions. To contrast, household operations (non-power utilities such as phone and water, plus rent, furnishings, and maintenance) is the largest expenditure category at 33 percent of expenses, but only 12 percent of the average household's environmental footprint. In total, direct emissions from the consumption of electricity and liquid fuels totaled 12.1Mt, with the balance of 29.6Mt attributable to consumption of other goods and services.

The aggregate data hide significant variation across Census regions. State level variation in the price of gasoline means that, for example, one dollar in 2002 translated to approximately 6.2 kg of GHG in the West and 6.8 kg in the South. Likewise, variation in the carbon intensity and retail price of electricity production means that one dollar spent in 2002 on electric utilities resulted in 6.5 kg of GHG in the Northeast and 11.7 kg in the Midwest.

Using Eq. 1, I begin by analyze the univariate relationship between emissions and

[5] Bin and Dowlatabadi (2005) estimated 54.4Mt per household in 1997, using a 1992 emissions model, producer prices instead of end-user prices, and sources other than the CES for direct energy use. Jones et al. (2008) estimated 23Mt per household for indirect emissions only in 2007 using aggregate data, based on a 1997 emissions model with a significant number of adjustments detailed in their paper.

expenditures. I estimate the univariate model by GLM for three quantifications of emissions: total, direct, and indirect. I combine data from 1997 and 2002 using expenditures in real 2000 dollars, adjusting for inflation rates specific to each purchased commodity. The results are shown in Fig 1a.

[Fig 1 here]

The elasticity η of energy equals the percent change in emissions for a 1 percent change in expenditures at the means. Direct energy intensity starts at low levels of expenditures accounts for twice as many emissions as indirect consumption, but grows slowly with expenditures. The relationship between indirect energy and expenditure is almost perfectly linear. Indirect emissions by households equals direct emissions at an expenditure of about USD$60,000, at which point the average household emissions are above 50Mt. For expenditures above that level, indirect energy demand from consumption is a more important source of emissions than are direct energy purchases.

I introduce additional explanatory variables using Eq. 2. I begin with a bivariate analysis, in which I model total household emissions as a function of expenditures and education. As educated households are on average wealthier and have greater income, I control for expenditures to compare households that consumed at a level around the population mean of $41,000. There is a small but significant difference evident, with more educated households producing significantly fewer emissions at a given level of consumption. A marginal year of education for the household head is associated with approximately -351kg/yr of GHG emissions for the household (p¡.001). Figure 1b shows the modeled relationship of household emissions to expenditures for four discreet levels of education. Only 40 percent of household heads in 2002 had completed college; if the remaining 60 percent were to spend two more years in school, e.g. to earn an associate degree or complete a baccalaureate, then emissions could, *ceteris paribus*, drop by as much as 46 million Mt per year, approximately 0.8 percent of total U.S. GHG emissions. While perhaps a small impact compared to the mammoth scale of population-wide emissions, this is the first evidence that consumption patterns of educated households may have less environmental impact per dollar than other households.

From whence are the emissions savings accruing? In Fig 2, I present plots of predicted spending and total associated emissions on a variety of expenditure categories, sorted from greatest to least.

[Figure 2 here]

Household operations (including housing costs) is the largest category of expenditures for most households each year. Housing costs diminished somewhat between 1997 and 2002 as a percentage of spending for all households except the least educated, controlling for income. The other categories of spending and emissions vary by education. Controlling for income, educated households spend much larger share of their income on pensions and other financial instruments, and a much smaller share on vehicles and related services. Educated households spend more on books and tuition, both relatively low-impact activities. The important category of personal transport, which captures expenses on gasoline, is a smaller share of household expenses for more educated households.

The results translate directly into lower emissions for educated households, controlling for expenditures. While housing energy and personal transportation are the most important categories of emissions for all education groups, educated households' lower spending on these areas means their emissions are lower. They produce more emissions in several categories—food and beverages, for example, and their greater expenses on rented or owned housing means that they produce more emissions related to household operations and non-personal transportation method such as mass transit and flying. Educated households produce fewer emissions attributable to vehicle purchase and operation, which is a major source of emissions for households whose heads have no college experience.

4.1 Multivariate analysis

Education may be correlated with other variables that may independently explain some of the variation in carbon intensity of consumption dollars. For example, more educated households may have fewer children, or be located in urban areas where the average household environmental impact is lower. To the bivariate model above I introduce additional demographic covariates that may explain household energy demand. The multivariate model is of the same form as Eq. 2, with additional covariates X added to the model. The results are presented in Table 4.

[Table 4 here]

The first model is a univariate regression of emissions on expenditures, discussed already above. The second column presents the bivariate regression results including education and holding expenditure constant. Educated household heads produce less GHG per dollar of expenditure: the marginal effect of one year of education is -466kg of CO_2 per year emitted. This can add up quickly at the population level. Forty percent of U.S. household heads have not completed a college degree. If these households spent two additional years in school, total U.S. emissions would fall by 40.7 billion tonnes, without any reduction in household spending necessary.

Subsequent models introduce additional covariates in order to reduce the possibility that education is capturing the effects of unobserved variables. The introduction of income has little effect, net of actual spending. While in model 3 it is marginally significant, the effect disappears when adding demographic controls (model 4). The higher emissions of wealthy households is due to greater spending, not to spending in categories which produce greater emissions. In model 4, age and household size and composition (adults and children in the household) have important effects. Some of the effect of education, then, is related to differences in age and household size between households with relatively more and relatively less education. Household heads with some college or a completed 4-year degree are the youngest on average in the CES. As total household consumption has been demonstrated to grow during middle age, excluding the age term biases the effect of education. Likewise, more educated households tend to be smaller, and to have fewer children. Years of education remain highly significant, although the scale of the effect is greatly diminished. The marginal effect of education in this scenario is -168.1kg of CO_2 per year per household, or approximately -14.3 billion kg across all households in 2002. This effect would be equal in size to the annual GHG emissions of nearly 3 million personal vehicles.[6]

In general equilibrium, the results are more complicated; more education may translate to faster income growth, and correspondingly higher emissions. However, the wage returns to education may diminish as the average worker becomes more educated, and any treatment effect of education in terms of consumer habits may in fact become larger as those who have less propensity to self-select into education receive it. It is also possible that demographic characteristics of households are jointly determined with their education; this regression model cannot distinguish the direction of causality or determine which model should be preferred.

5 Conclusion

Fossil fuels are the backbone of the world economy, and have enabled most of the economic growth experienced since the 18th century. As long as fossil fuels continue to supply most of the world's energy, the carbon intensity of production and consumption are not likely to radically change (cf. Dyson 2005). Highly effective ways to reduce emissions include halting population growth or halting economic growth. Nations, however, are not desirous to reject growth and affluence for their populations, and thus interest in the role of demography in environmental impacts has grown alongside research and adoption of alternative energy. Household size, mean age, and urban/rural location have been repeatedly demonstrated to have a significant effect on the elasticity of population growth and total emissions in an economy. Education also appears to have a significant effect on household emissions. More educated individuals earn higher incomes, but they

[6] 14.26 billion kg of CO_2 is equivalent to the emissions indirectly and directly generated by the gasoline purchased by 1,435,095 households (average of 2.04 vehicles and 9.9 tonnes of CO_2e per household). This is rougly equivalent to the US EPA estimate of 5.1 tonnes/yr for the average passenger car, which also equates to nearly 3 million car-years.

also spend their income in ways that reduce the carbon intensity of every marginal dollar relative to other wealthy but less educated households. Household heads with college or greater education spend more on housing but less on energy utilities; more on airfare and mass transit, but less on gasoline.

Education is a way out of poverty, and has also played a major role in world development. Improving education in the developing world is a U.N. Millennium Development Goal, and developed nations also seek to expand access to higher education as a way to increase innovation. In the end, the greater environmental benefit of education, from the perspective of reducing carbon emissions and other adverse impacts, will likely be the enrichment of societies' capacity to innovate technologically and accelerate alternatives to fossil fuels for the energy needed to support economic growth. Inasmuch as we wish to reduce the environmental externalities of economic growth, we should hope to see that gains in education keep pace with economic growth.

References

American Public Transportation Association. 1999. "Public Transportation Fact Book."

———. 2004. "Public Transportation Fact Book."

Bin, S. and H. Dowlatabadi. 2005. "Consumer lifestyle approach to US energy use and the related CO2 emissions." *Energy Policy* 33(2):197–208.

Bongaarts, J. 1992. "Population Growth and Global Warming." *Population and Development Review* 18(2):299–319.

Carnegie Mellon University, Green Design Institute. 2008. "EIOLCA Economic Input-Output Life Cycle Assessment." Accessed 7-11-2013.

Cole, M. and E. Neumayer. 2005. "Examining the impact of demographic factors on air pollution." *Population and Development Review* 2(1):5–21.

Commoner, B. 1972. "A Bulletin Dialogue: on 'The Closing Circle'." *Bulletin of the Atomic Scientists* 28:17–56.

Dalton, M., B. O'Neill, A. Prskawetz, L. Jiang, and J. Pitkin. 2008. "Population aging and future carbon emissions in the United States." *Energy Economics* 30:642–675.

Desrochers, P. and C. Hoffbauer. 2009. "The Post War Intellectual Roots of the Population Bomb." *The Electronic Journal of Sustainable Development* 1(3):73–97.

Dyson, T. 2005. "On development, demography and climate change: the end of the world as we know it?" *Population and environment* 27(2):117–149.

Ehrlich, P. and J. Holdren. 1971. "Impact of population growth." *Science* 171:1212–1217.

EPDC. 2005. "Window on the Future: 2025." Technical report, Education Policy and Data Center,. Washington, DC.

Golley, J., D. Meagher, and M. Xin. 2008. "Chinese household consumption, energy requirements and carbon emissions." in *China's Dilemma: Economic Growth, the Environment and Climate Change*, edited by L. Song and W.T. Woo. Asia Pacific Press, Brookings Institution Press and Social Sciences Academic Press, 2008.

Herendeen, R., C. Ford, and B. Hannon. 1981. "Energy cost of living, 197273." *Energy* 6:1433–1450.

Hertwich, E.G. and G.P. Peters. 2009. "Carbon footprint of nations: a global, trade-linked analysis." *Environmental science & technology* 43(16):6414–6420.

IPCC. 2008. "Climate Change 2007: Synthesis Report." Technical report, IPCC, Geneva, Switzerland.

Jones, C., D. Kammen, and D. McGrath. 2008. "Consumer-oriented Life Cycle Assessment of Food, Goods and Services." *Energy and Climate Change* .

Kanemoto, K., M. Lenzen, and M. Geschke, A. 2011. "Building Eora: a Global Multi-region Input Output Model at High Country and Sector Resolution." Paper presented at the 19th International InputOutput Conference, Alexandria, VA, USA.

KC, S., B. Barakat, A. Goujon, V. Skirbekk, W. Sanderson, and W. Lutz. 2010. "Projection of populations by level of educational attainment, age, and sex for 120 countries for 2005-2050." *Demographic Research* 22(15):383–472.

Lenzen, M. 1998. "Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis." *Energy Policy* 26(6):495–506.

Lenzen, M., M. Wier, C. Cohen, H. Hayami, S. Pachauri, and R. Schaeffer. 2006. "A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan." *Energy* 31:181–207.

MacKellar, F., W. Lutz, C. Prinz, and A. Goujon. 1995. "Population, households, and CO2 emissions." *Population and Development Review* 21(4):849–865.

Martinez-Zarzoso, I. 2008. "The Impact of Urbanization on CO2 Emissions: Evidence from Developing Countries." Working Papers 2008.50, Fondazione Enrico Mattei.

O'Neill, B.C. and B.S. Chen. 2002. "Demographic Determinants of Household Energy Use in the United States." *Population and Development Review* 28:53–88.

O'Neill, B.C., M. Dalton, R. Fuchs, L. Jiang, S. Pachauri, and K. Zigovad. 2010. "Global demographic trends and future carbon emissions." *Proceedings of the National Academy of Sciences of the United States of America* 107(41):17,52117,526.

Osborn, F. 1948. *Our Plundered Planet*. London: Faber and Faber.

Pachauri, S. 2004. "An analysis of cross-sectional variations in total household energy requirements in India using micro survey data." *Energy Policy* 32(15):1723–1735.

Pachauri, S. and D. Spreng. 2002. "Direct and indirect requirements of households in India." *Energy Policy* 30:511–523.

Pariakh, J. and V. Shukla. 1995. "Urbanization, energy use and greenhouse effects in economic development." *Global Environmental Change* 5(2):87–103.

Peters, G. 2011. "Constructing an environmentally-extended Multi-Region Input-Output table using the GTAP database." *Economic Systems Research* 23:in press.

Reinders, A., K. Vringer, and K. Blok. 2003. "The direct and indirect energy requirement of households in the European Union." *Energy Policy* 31:139–153.

Robertson, T. 2012. *The Malthusian Moment: Global Population Growth and the Birth of American Environmentalism*. Rutgers University Press.

Sabelhaus, E. and Harris. 2000. "Consumer expenditure survey, family-level extracts."

Shammin, M., R. Herendeen, M. Hanson, and E. Wilson. 2010. "A multivariate analysis of the energy intensity of sprawl versus compact living in the U.S. for 2003." *Ecological Economics* 69:2363–2373.

U.S. Department of Commerce, Economics and Statistics Administration. 2010. "U.S. carbon dioxide emissions and intensities over time: a detailed accounting of industries, government and households."

U.S. Department of Energy, Energy Information Administration. 2013a. "Form EIA-1605: Voluntary Reporting of Greenhouse Gases (historical series)."

———. 2013b. "Form EIA-826: Monthly Electric Utility Sales and Revenue Report with State Distributions (historical series)."

———. 2013c. "State Energy Data System (historical series)."

U.S. Department of Energy, Energy Information Administration and Thomson Reuters. 2004. "Unit Conversions, Emissions Factors, and Other Reference Data."

———. 2013. "Annual average energy spot prices (historical series)."

U.S. Department of Transportation, Research and Innovative Technology Administration. 2013. "Form 41: Air Carrier Financial Reports (historical series)."

Vogt, W. 1948. *The Road to Survival*. New York: Slodne Associates.

Weber, C. and H.S. Matthews. 2007. "Quantifying the global and distributional aspects of American household carbon footprint." *Ecological Economics* 66:379–391.

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

Wei, Y.M., L.C. Liu, Y. Fan, and G. Wu. 2007. "The impact of lifestyle on energy use and CO2 emission: an empirical analysis of China's residents." *Energy Policy* 35:247–257.

Wiedmann, T. 2009. "A review of recent multi-region input-output models used for consumption-based emission and resource accounting." *Ecological Economics* 69(2):211–222.

Zagheni, E. 2011. "The Leverage of Demographic Dynamics on Carbon Dioxide Emissions: Does Age Structure Matter?" *Demography* 48(1):371–399.

Tables and figures

Figure 1: Univariate regression of GHG emissions on expenditures, US 1997–2002

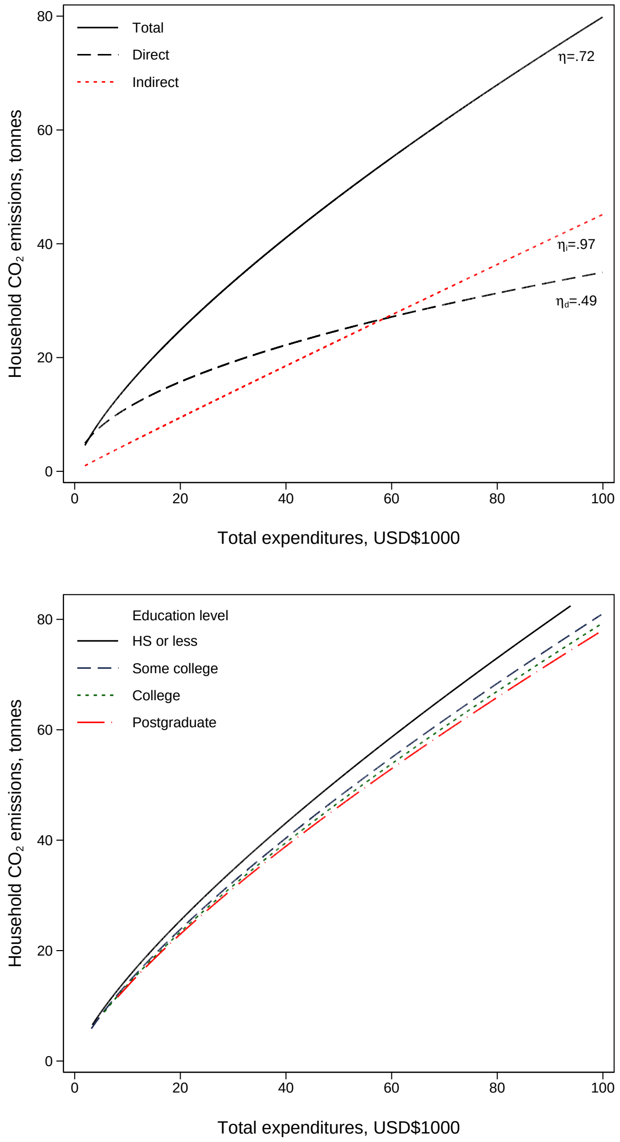

Table 1: Example crosswalk between CES survey and IO model codes, US 1997–2002

Expenditure category (UCC)	**BEA Expense Item (PCE)**			**BEA IO tablea**			*Net*	**GDI IO tablesc**	
Name and example UCC codes	*Example PCE code*		*Weight*	*Example IO Code*		*Weight*	*weightb*	*1997*	*2002*
"Alcohol at home" (M790310,M790320)	DLIQRC	Beer	12.31%	311990	Other food mfg.	4.40%	0.54%	5.9	4.5
	DMLTRC	Wine	44.52%	312140	Distilleries	95.60%	11.76%	49.5	37.2
	DWINRC	Beer	43.17%	312120	Breweries	100.00%	44.52%	253.0	253.0
				312130	Wineries	100.00%	43.17%	235.0	194.0
equiv lb/$: 1.63 in 1992 (Bin & Dowlatabadi 2009)									
1.20 in 1997				Total weighted carbon intensity (Mt/$1m):				543.4	488.7
1.07 in 2002									

Notes: a "Alcohol at home" has identical IO codes in 1997 and 2002. b Net weight represents share of value in UCC category to assign to activity in each industry. c Leontief inverse of total CO2-equivalent output (Mt/$1m) estimated from GDI IO tables, weighted by column 'net weight'.

Table 2: Demographic and economic characteristics of CES sample, US 1997–2002

	1997	2002
Age category (%)		
15-24	6.4	6.9
25-49	51.7	49.3
50-64	20.7	24.1
>65	21.2	19.8
Education Category (%)		
<HS	16.3	14.0
HS	29.8	29.2
AA/SC	27.8	29.5
COL+	26.2	27.3
Marital Status (%)		
Currently married	57.0	54.6
Ever married	83.6	81.8
Household size	2.7	2.6
Number of children	0.8	0.8
Nominal income	43,605	53,052
Income after tax	35,548	44,282
Expenditures	37,012	43,650
N	4,950	7,351

Table 3: Mean household emissions (CO_2e), US 1997–2002

	1997	2002
Direct influences (kg)		
Residential energy	14,284	14,601
Transportation use		
Personal (incl. gasoline)	9,777	10,523
Mass transit	283	275
Air transport	805	824
Indirect influences (kg)		
Housing	6,290	5,096
Vehicles	1,841	1,920
Food and beverages	5,230	4,555
Entertainment	1,398	1,321
Apparel and services	946	662
Health care	381	406
Other	1,608	1,513
Total emissions (Mt)		
Total direct	25.15	26.22
Total indirect	17.69	15.47
Total per household	42.84	41.70

Source: CES; EIA; GDI; author's calculations.
Notes: Calculations include production, use, and disposal phases. Other includes pensions, finance costs, and education expenses. See Table 6(appendix) for full list of expenditure categories.

Figure 2: Emissions and expenses by category and education of household head, US 2002

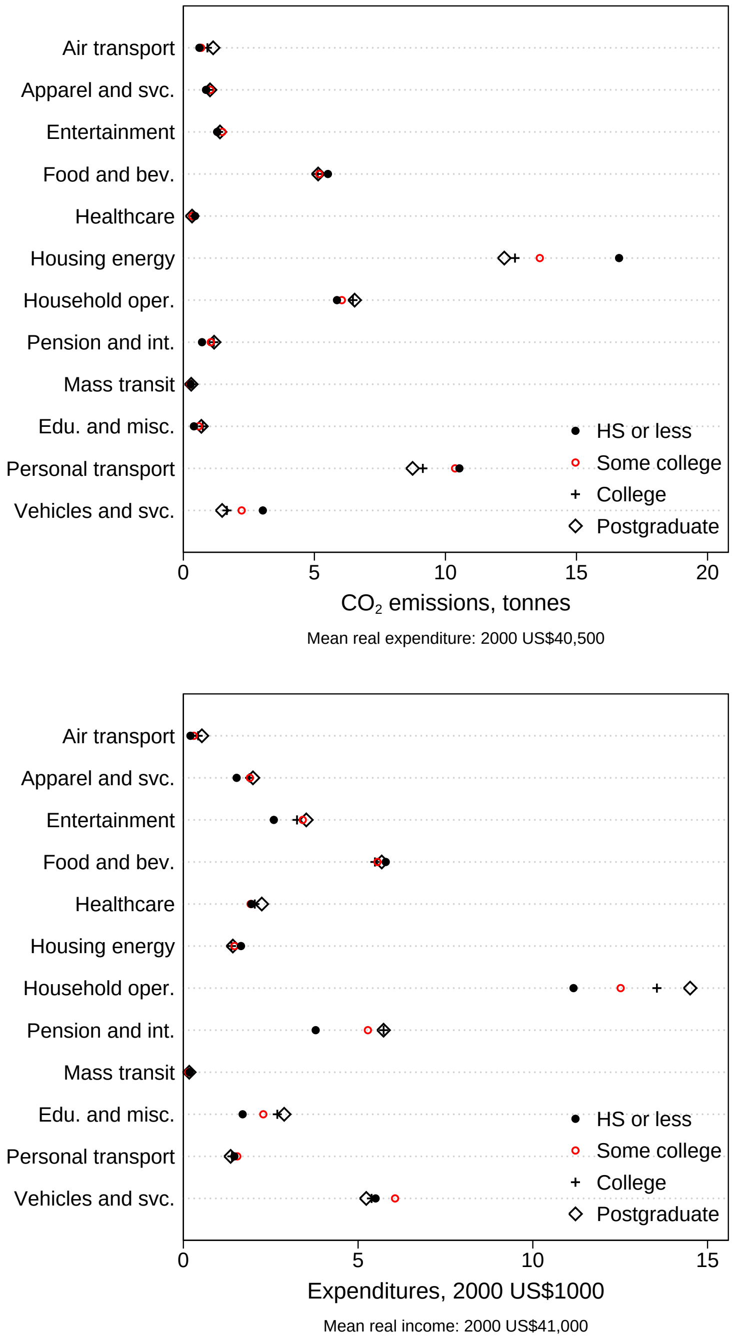

Table 4: Multivariate regression of household characteristics on CO_2 emissions, US 1997–2002

CO_2 (kg, log)=	(1)	(2)	(3)	(4)
Expenditure ($, log)	0.717***	0.740***	0.731***	0.682***
	[0.00743]	[0.00796]	[0.00976]	[0.00850]
Education (years)		−0.0116***	−0.0119***	−0.00406***
		[0.00106]	[0.00107]	[0.000988]
Income ($, log)			0.00894*	0.00566
			[0.00439]	[0.00424]
# Children in hhd				0.0274***
				[0.00265]
# Adults in hhd				0.0675***
				[0.00357]
Age of head				0.00100***
				[0.000186]
Location (1=Rural)				0.0650***
				[0.00769]
Constant	3.108***	3.022***	3.028***	3.254***
	[0.0796]	[0.0806]	[0.0814]	[0.0708]
N	12301	12153	12153	12153
AIC	262315.8	259016.2	259006.1	257520.5

Robust standard errors in brackets. Includes controls for survey/emissions year (not shown).
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: (Appendix) Carbon intensity of direct energy goods, US 1997–2002

	Carbon content	1997		2002	
		Price	GHG (kg/$)	Price	GHG (kg/$)
Electricity	*(see notes)*	8.43	8.15	8.44	8.01
Natural Gas	116.39	11.30	4.67	12.40	4.26
Gasoline	154.91	9.81	7.16	10.69	6.57
Oil/other home fuel	159.66	7.45	9.72	8.60	8.42
Jet fuel/kerosene	154.69	4.51	15.45	5.34	13.14

Notes: Prices for electricity in US cents/kWh; other prices in US dollars/mBtu. GHG content for electricity in mt/mWh; other GHG content in lb/mBtu. GHG content of electricity in 1997=0.687 and 2002=0.676. National averages shown.

Source: Electricity prices by state from US Dept of Energy, Energy Information Administration (USDOE EIA), Form EIA-826; other prices except jet fuel by state from USDOE EIA, State Energy Data System (SEDS); prices for jet fuel/kerosene from USDOE EIA, energy spot prices; electricity CO2 content by state from USDOE EIA, Form EIA-1605, Appendix F; other CO2 content from USDOE EIA, Unit Conversions Emissions Factors and Other Reference Data (2004).

Table 6: (Appendix) Detailed expenditure categories, US 1997–2002

Summary category	Detailed categories
Home energy	electricity (direct+indirect), natural gas (direct+indirect), other home fuels (direct+indirect).
Personal transport	gasoline (direct+indirect), tolls
Mass transit	mass transit (direct+indirect), other transit (direct+indirect)
Air transportation	airfares (direct+indirect)
Housing operation	home rent (or imputed rent), vacation rentals, furniture, housing supplies, water, telephone service, domestic workers
Food and beverages	food at home, food provided by employer, food outside the home, alcohol for home consumption
Apparel and allied	clothing, tailors, jewelry, toiletry products, health and beauty services
Entertainment	tobacco, alcohol consumed outside home, books, periodicals, sports and recreation, gambling, other recreation
Health care	medicines, medical devices, health insurance, hospital visits, nursing home, doctor visits
Vehicles	autos (new or used, purchase or lease), auto parts and accessories, auto services, car insurance
Interest and pensions	car loan interest, other interest, pension contributions
Other	professional services (lawyers, accountants), life insurance, education expenses, charitable contributions.

Note: Mass transit and airfare include a portion of direct energy goods, calculated as the product of (passenger revenue/total revenue)*(fuel expenses/total expenses)*(carbon intensity of fuel mix).

Source: Share of mass transit and air transportation spending attributable to fuel from American Public Transit Association (APTA) yearbooks and USDOT BTS, Table 41: Schedule 11–12, respectively. For lower-level spending codes in the CES, see Sabelhaus and Harris. (2000)