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Analysis

The carbon implications of declining household scale economies

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ABSTRACT

In the United States, average household size decreased significantly over the past half century. From 1950 to 2010, the number of households increased 72% faster than population size. In this paper we consider how this drift toward more and smaller households, occurring alongside rising affluence, undermines efforts to curb carbon dioxide (CO_2) emissions by eroding household scale economies of consumption and associated CO_2 emissions. To estimate the household scaling of CO_2 emissions, we link consumer expenditure data to an economic input–output life-cycle assessment model. We find that the CO_2 scaling benefits of cohabitation are compellingly large, with the carbon footprint of a representative person cohabiting with others being 23% less, on average, than if that same person lived alone. Additionally, we find that household scale economies: 1) decrease in income, reflecting the rise in the percentage of household expenditures devoted to more rival goods and services; and 2) increase intuitively in household size, reflecting the direct expenditure sharing benefits of cohabitation. The combined downward pressure on scale economies from declining household size and rising incomes, typifying the trajectory of developing societies toward more and smaller households and rising affluence, places significant upward pressure on CO_2 emissions globally.

1. Introduction

From 1950 to 2010 the count of households (43 to 117 million) in the United States increased 72% faster than population size (157 to 309 million), with mean household size decreasing 26.3%, from 3.38 to 2.49 members (US Census Bureau, 2013; Vespa et al., 2013). By 2020, the single-person household is projected to eclipse the married couple as the modal household type in the United States. Census data indicate that the percentage of one-person households nearly tripled (9.3 to 26.7%) from 1950 to 2010. Today, over 30 million adults in the United States live alone (Klinenberg, 2012), roughly equal to the total population of Canada.

These demographic trends are not distinctly American. Across the planet, growth in the count of households is outpacing population growth. Liu (2013) reports that 79% of 172 countries surveyed experienced faster household versus population growth from 1985 to 2000. By 2030, Jennings et al. (2000) project that the single-person household will be the modal household type globally. The world is careening toward more people but faster toward more households, and this global drift toward *more and smaller households*, as we intend to show, has profound and underappreciated implications for anthropogenic climate change.

The proximate mechanisms of global convergence toward more and smaller households are amply detailed in economic and demographic research, including (but not limited to) declining total fertility rates (Bongaarts, 2001; World Bank, 2013), marital delay (Rosenfeld, 2007), and rising incidence of divorce and household dissolution (Yu and Liu, 2007).[1] These demographic trends are coincidental with economic and social development, function to slow rates of population growth, and stage the world for eventual decline in population size (Goode, 1963; McDonald, 1992; Bongaarts, 2001). Extrapolating from research linking population size to environmental impacts (Jorgenson and Clark, 2010; Rosa and Dietz, 2012; Shi, 2003; Alcott, 2012; Cohen,

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[1] In the United States, these proximate forces toward more but smaller households are pronounced. In the United States, the total fertility rate has fallen from 3.7 in 1960 to 1.9 in 2012 (World Bank, 2013). Young adults are waiting longer to marry (if at all), evidenced by the median age of martial onset increasing from 22.8 to 28.2 for males, and 20.3 to 26.1 for females over the period 1950 to 2010 (US Census, 2011). While young-adults between the ages of 18 and 34 account for 5.5 million or 17% of single-person households, they are the fastest growing segment of the solo-dwelling population (Klinenberg, 2012). Finally, the proportion of divorced households (households with a divorced head) increased from 5% in 1970 to 15% in 2000. Yu and Liu (2007) estimate 4.7 million "extra" households in 2001 resulting from increased prevalence of divorce in the United States. With respect to the United States, others have suggested that the desire for privacy and the "cult of the individual" explain the dramatic reductions in household size (Klinenberg, 2012; Salcedo et al., 2012).

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2010; Jiang and Hardee, 2011; Ehrlich and Holdren, 1971; Dietz and Rosa, 1997), and absent an appreciation of the dynamics of household formation, one may be tempted to project a global retreat in environmental damages with expected depopulation (Carson, 2010; Grossman and Krueger, 1995).

However, a growing body of literature recognizes that the structure and organization of human population can be as important in determining the environmental impacts of development as rates of population growth (Cole and Neumayer, 2004; Lepczyk et al., 2008; Liddle, 2004; MacKellar et al., 1995; O'Neill and Chen, 2002; O'Neill et al., 2010; Peterson et al., 2007; Prskawetz et al., 2004). Households are the predominant form of social organization, and patterns of household formation are vital to understanding per capita energy use and consequent environmental damages (Bradbury et al., 2014; Dalton et al., 2008: Dietz et al., 2009; Peterson et al., 2013). Studies find that household size is a significant determinant of carbon dioxide emissions (Cole and Neumayer, 2004) and per capita road energy use (Liddle, 2004). The bulk of this literature focuses on direct uses of energy and generation of emissions by households (residential and transportation related energy use and emissions). However, direct and indirect energy use (from home energy use and personal transport and energy embodied in other expenditures) by households in the United States constitute over 80% of national energy use and carbon dioxide emissions (Bin and Dowlatabadi, 2005). As we intend to show, the proliferation of households in the United States, occurring alongside rising affluence, places upward pressure on per capita carbon dioxide emissions by undermining the scale economies of household consumption.

The forces of social and economic development (as reflected in rising levels of affluence) endogenously (and paradoxically) slow rates of population growth but yield more and smaller households. From a sustainability standpoint, social and economic development generate countervailing forces, producing the wealth necessary for: 1) advancements in energy efficiency that drive both per capita energy use and emissions downward; and 2) advancements in cost efficiency that decrease the opportunity cost of household formation, undermining household scale economies and driving per capita emissions upward.

In this paper we consider how the drift toward more and smaller households and rising affluence undermines efforts to curb CO_2 emissions by eroding household scale economies of consumption/emissions. Most directly, a household's carbon dioxide emissions are determined by the energy embodied in the mix of goods and services consumed. A less obvious mechanism is the inherent rivalry of goods and services consumed by households. While direct energy expenditures are more carbon intensive than indirect energy expenditures, direct uses of energy are decidedly more sharable — they are less rival. In the demographic drift toward more and smaller households, per capita emissions increase in the lost opportunities to share (less rival) carbon-intensive direct energy uses. Additionally, per capita emissions rise in income through the erosion of household scale economies because household expenditures on less sharable indirect goods and services increase in household income. Due to differences in both carbon intensity and rivalry across direct and indirect energy expenditures, understanding how shrinking household size and rising affluence operate through declining scale economies requires analysis of indirect energy expenditures. Therefore, the contribution of this paper to the literature is twofold: (1) providing micro level foundations, through consumption rivalry, to explain the observed negative relationship between household size and carbon dioxide emissions; and (2) showing how rising affluence exacerbates this effect through the confluent shift in expenditures toward less sharable indirect energy expenditures. In the next section, we describe data sources and statistical procedures used to quantify the carbon intensity of household expenditures. After that, we discuss notions of consumption rivalry and present descriptive statistics on the allocation of household expenditures across direct and indirect uses of energy, providing an empirical basis for the investigation of household scale economies of consumption/emissions. We follow with regression analyses showing sizeable emissions scaling benefits from cohabitation, and how the twin forces of declining household size and rising household incomes undermine household scale economies/emissions. The paper ends with thoughts on potential policy implications of our results for the United States and developing economies similarly undergoing economic and demographic transitions toward more and smaller households and rising affluence.

2. Data and Measurement

To determine household level emissions we first establish pollution intensities of sectors in the economy that produce items consumed by households. The economic input–output life cycle assessment (EIO-LCA) model used was developed by the Green Design Institute (GDI) at Carnegie Mellon University (Hendrickson et al., 2006). The GDI model uses industry-to-industry transactions to assess impacts from production processes. Industries are defined by the North American Industry Classification System (NAICS), and industry transactions tracked using benchmark input–output accounts from the Bureau of Economic Analysis (BEA). The accounts used in the present analysis are for the years 1997 and 2002, splitting the economy into 483 and 428 disaggregated sectors, respectively.

Differences across model years in terms of sector definitions were reconciled, leaving us with a set of 419 sectors common across model years. Pollution intensities are expressed in metric tons of carbon dioxide equivalent emissions (tCO_2e)[2] for \$1 million of final demand from a given sector. Log-linear extrapolation and interpolation was used to determine pollution intensities in off years.[3] Estimated carbon intensities by sector and year were then matched to household microdata obtained from the Bureau of Labor Statistics' (BLS) Consumer Expenditure Survey (CES) for the years 1996 to 2009.

CES Interview Survey data on household expenditures cover 14 broad categories: food, alcoholic beverages, housing, apparel, transportation, healthcare, entertainment, personal care, reading, education, tobacco products, cash contributions, personal insurance, and miscellaneous. These 14 categories disaggregate into 50 detailed expenditure categories that we match to the 419 production sectors to estimate carbon intensities from consumption. Expenditure categories are classified by final demand and production sectors by output from industry.[4] The resulting intensities by expenditure category, measured in kilograms of CO_2 equivalent emissions per 2002 U.S. dollar, are largely consistent

[2] GHGs differ in their warming influence on the climate due to differences in their radiative properties and lifetime in the atmosphere. Differences can be expressed in CO_2 equivalent emissions, which is defined as "the amount of CO_2 emissions that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amounted of a long-lived GHG or a mixture of GHGs" (IPCC, 2013, p. 710–720). Equivalent CO_2 emissions are obtained by multiplying the emissions of multiple GHGs in the EIO-LCA model – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) – by their global warming potential (GWP) for a given time horizon (in this case: 100 years) and summing results.

[3] Let α_j be the raw carbon intensity of sector j in 1997 and β_j the raw carbon intensity of sector j in 2002. Additionally, let t be a time parameter taking on values from −1 to 12, representing the years 1996 through 2009. Therefore, $\theta_j = \frac{\ln\alpha_j - \ln\beta_j}{t_{2002} - t_{1997}} = \left(\frac{1}{5}\right) \ln\left(\frac{\alpha}{\beta}\right)$. Estimated carbon intensity for sector j in time t can be represented as: $\hat{C}_{jt} = e^{\left(\ln\alpha_j + t\theta_j\right)}$, with the exponential function necessary to convert logged values back to levels. This method was implemented for all 419 sectors in every year from 1996–2009, with 1997 and 2002 returned to their initial values. The CPI was used to convert values back to current year dollars, as expenditures in CES data are measured in that manner.

[4] The expenditures are matched to sectors using, in some cases, only one production sector, but in other cases an average of carbon intensities from multiple production sectors. For example, electricity expenditures are matched to the NAICS sector (22111) "Power Generation and Supply", a very direct match. While apparel and related services expenditures are matched to multiple NAICS sectors (31511) "Hosiery and Sock Mills", (31521) "Cut and Sew Apparel Contractors", and (31599) "Apparel Accessories and Other Apparel Manufacturing" and the average carbon intensity among these sectors is used in the final calculations.