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Local path dependence of U.S. socioeconomic exposure to climate extremes and the vulnerability commitment

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ABSTRACT

Despite improvements in disaster risk management in the United States, a trend toward increasing economic losses from extreme weather events has been observed. This trend has been attributed to growth in socioeconomic exposure to extremes, a process characterized by strong path dependence. To understand the influence of path dependence on past and future losses, an index of potential socioeconomic exposure was developed at the U.S. county level based upon population size and inflation-adjusted wealth proxies. Since 1960, exposure has increased preferentially in the U.S. Southeast (particularly coastal and urban counties) and Southwest relative to the Great Plains and Northeast. Projected changes in exposure from 2009 to 2054 based upon scenarios of future demographic and economic change suggest a long-term commitment to increasing, but spatially heterogeneous, exposure to extremes, independent of climate change. The implications of this path dependence are examined in the context of several natural hazards. Using methods previously reported in the literature, annualized county-level losses from 1960 to 2008 for five climate-related natural hazards were normalized to 2009 values and then scaled based upon projected changes in exposure and two different estimates of the exposure elasticity of losses. Results indicate that losses from extreme events will grow by a factor of 1.3–1.7 and 1.8–3.9 by 2025 and 2050, respectively, with the exposure elasticity representing a major source of uncertainty. The implications of increasing physical vulnerability to extreme weather events for investments in disaster risk management are ultimately contingent upon the normative values of societal actors.

1. Introduction

Climate variability and change are key driving forces influencing the vulnerability, and therefore sustainability, of socio-ecological systems (IPCC, 2012). Although a number of definitions are currently in use across a broad range of disciplines, the concept of vulnerability is generally recognized as being a function of both biophysical and socioeconomic determinants as well as being context-specific and placed-based (Cutter, 1996; Adger and Kelly, 1999; Cutter et al., 2000, 2003; Turner et al., 2003; Preston et al., 2011; IPCC, 2012). Despite the apparent importance of vulnerability to sustainability, questions have been raised in recent years with respect to the efficacy and utility of vulnerability metrics (Barnett et al., 2008; Hinkel, 2011; Preston et al., 2011; Soares et al., 2012). Much of this criticism focuses on the capacity of such metrics to generate robust metrics regarding vulnerability at relevant spatial and temporal scales (Barnett et al., 2008; Klein, 2009; Hinkel, 2011; Preston et al., 2011). This can be attributed, in part, to a reliance upon indicators of static capital assets without consideration for the socio-ecological processes that influence entitlements to that capital and how it changes over space and time.

One of the key processes influencing vulnerability to climate variability and change is path dependence – the dependence of future societal decision processes and/or socio-ecological outcomes on those that have occurred in the past (see Page, 2006 for further elaboration). One common approach for framing vulnerability is as the interaction between exposure, sensitivity, and adaptive capacity (e.g., Smit and Wandel, 2006; Vincent, 2007; Füssel, 2007; Preston et al., 2009; Dawson et al., 2011). Much of the discussion of path dependence and vulnerability within the global change literature focuses on adaptive and/or mitigative capacity (Woerdman, 2004; Pahl-Wostl et al., 2007; Chhetri et al., 2010; Garrelts and Lange, 2011; Libecap, 2011; Simmie, 2012; Thomsen et al., 2012). For example, multiple generations of global greenhouse gas emissions scenarios reflect path dependence in global energy technologies and economic development, resulting in increases in greehouse gas emissions over at least the first half of

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the 21st century (Nakicenovic et al., 2000; Moss et al., 2010). Meanwhile, Libecap (2011) suggests that historical capital investments in water infrastructure in the U.S. West constrain management choices regarding water allocation in the present. Similarly, Chhetri et al. (2010) suggest that path dependence in the U.S. agriculture industry constrains farmers' capacity to alter management practices and technology in response to a changing climate.

Other studies, however, have focused on the exposure element of vulnerability. The Intergovernmental Panel on Climate Change (IPCC, 2012) notes that societal exposure is a product of bottom up development processes on hazardous landscapes, specifically demographic change and urbanization. Such processes exhibit strong path dependence (Ausubel and Herman, 1988; Martin and Sunley, 2006; Frenken and Boschma, 2007), as economic investment in a given location creates positive economic externalities and feedbacks that incentivize additional investment (Page, 2006). Various studies have therefore included demographic change and, to a lesser extent, economic growth as elements influencing societal exposure to climate hazards (Parry et al., 2001; Pielke, 2007; Hinkel et al., 2010). Yet, exposure is also influenced from the top down by the geographic distribution of natural hazards (IPCC, 2012). Climate research has indicated a commitment to future global warming regardless of future emissions trajectories (Wetherald et al., 2001; Friedlingstein and Solomon, 2005; Wigley, 2005; Hare and Meinshausen, 2006; Armour and Roe, 2011). This committed warming reflects lock-in of the climate system and, as a consequence, changes in climate-related natural hazards (IPCC, 2012).

Exploring the relationship between path dependence and vulnerability requires specificity with respect to the definition of what is vulnerable (Preston et al., 2011). To this end, a number of studies have identified causal relationships between physical exposure (i.e., exposure of physical capital) to extreme weather events and economic losses (van der Vink et al., 1998; Changnon and Changnon, 1999; Changnon et al., 2000; Changnon and Hewings, 2001; Changnon, 2003a; Pielke, 2007; Pielke et al., 2008; Bouwer, 2011; Gall et al., 2011). Due to the inertia of socioeconomic systems, demographic change and economic development are anticipated to be key driving forces contributing to future physical vulnerability to extreme weather events (Pielke et al., 2007; Hinkel et al., 2010; IPCC, 2012), even while such development reduces vulnerability to other types of social impacts (Folke et al., 2002; Yohe and Tol, 2002; World Bank, 2010; IPCC, 2012). This phenomenon is evidenced by recent assessments that suggest disaster losses are on the rise globally (Munich Re, 2011), particularly in rapidly developing, middle-income countries (IPCC, 2012). Such trends have also been observed in the United States (Cutter and Emrich, 2005; Gall et al., 2011). Therefore, economic losses from extreme events appear to be a metric of physical vulnerability that is sensitive to socioeconomic exposure, and, subsequently, a useful indicator for exploring the consequences of path dependence.

There is little information available regarding how future U.S. socioeconomic development trajectories will influence economic losses from extreme weather events at spatial scales relevant for planning (Preston et al., 2011). Although some estimates appear in the literature, they are often based upon regional or national scenarios of socioeconomic change (e.g., Pielke, 2007) and/or address losses from tropical cyclones while neglecting other types of natural hazards (e.g., Pielke, 2007; ECAWG, 2009; Mendelsohn et al., 2012). However, the determinants of societal exposure as well as policies and measures to mitigate exposure are largely local (Næss et al., 2005; Dolan and Walker, 2006; Smit and Wandel, 2006; Rayner, 2010). Hence, increasing quantitative understanding of how local development trajectories will contribute to future societal exposure and vulnerability requires the development of socioeconomic scenarios that are both spatially and temporally dynamic. At the same time, the natural hazards to which society is exposed are also spatially heterogeneous, making the co-occurrence of extreme events and socioeconomic change an important determinant of losses (Diffenbaugh et al., 2009).

The objective of this study was to assess historical and future changes in U.S. socioeconomic exposure to extreme weather events at the county level. Historical data for county demography and wealth were reconstructed for the time period 1960–2009 and integrated into a metric of socioeconomic exposure. Future exposure was subsequently projected for the time period 2009–2054 based upon county-level scenarios of demographic and economic development that are constrained by historical trends. These generic estimates of socioeconomic exposure are then examined in the specific context of county-level direct economic losses associated with a range of climate-related natural hazards. The results illustrate the spatially heterogeneous implications of the continuation of historical patterns of socioeconomic development for U.S. exposure to extreme events; the importance of socioeconomic uncertainty in understanding future physical vulnerability to climate variability and change; and the need for transformational change if the current trajectory of vulnerability is to be altered.

2. Estimating changes in U.S. socioeconomic exposure

2.1. Methods

2.1.1. Demographic data and scenarios

Historical changes in population at the county level were obtained from the U.S. Census Bureau. Annual changes in population for 1970–2009 were based upon intercensal population estimates (U.S. Census Bureau, 2009a). Prior to 1970, decadal censuses for 1960 and 1970 were used to calculate a linear interpolation of intervening years. Annual changes relative to 1960 were subsequently calculated for each county by dividing the observed population in each year by the 1960 population.

Scenarios of future county-level population changes were based upon a stochastic component cohort model. Population size, age structure, and racial/ethnic composition were modeled for each county in five-year time steps, with population counts adjusted at each time step according to changes in demographic components using the following equation:

$$P_{t1} = P_{t0} + B + M_d + M_i - D \quad (1)$$

where P_{t1} = population size at time $t = 1$; P_{t0} = population size at time $t = 0$; B = number of live births; D = number of deaths; M_d = net domestic migration; and M_i = net international migration. The U.S. Census Bureau 2009 population estimates were used as the baseline year for the model (U.S. Census Bureau, 2009a), and the model maintained the same stratification of gender, age cohorts, and race/ethnicity as the population estimates. Births for each time step were calculated by applying race-specific female fecundity rates to county female population in reproductive years (ages 15–45). Estimates of race-specific fecundity were based upon two sources, one from the American Community Survey and one from the National Center for Health Statistics (U.S. Census Bureau, 2004). The two estimates were used to generate a uniform probability distribution for race-specific fertility rates. Death rates were obtained through an examination of age and race-specific life expectancies and associated death probabilities from the U.S. Centers for Disease Control's United States' Life Tables 2006 (Arias, 2010). Life expectancies in each year of life (birth to 100+ years of age) were aggregated into the 18 age cohorts used in the