



Developing an Instrument to Measure Autonomous Adaptive Capacity to Climate Change among Urban Households

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The capacity of households in urban environments to adapt and react to climate change can affect the resilience of the whole community, and instruments for systematically measuring that capacity are needed. We used Raleigh, NC as a case study to explore the dimensions of autonomous adaptive capacity of urban households and to create a scale and associated survey instrument to measure them. Our approach was guided by four capitals that support human livelihoods: social, human, physical, and financial. We surveyed 200 households in Raleigh, NC, and used a principal components analysis to test the scale and survey instrument. Results suggest the scale is a useful and concise tool. Three major dimensions were present among the scale items: financial capital, political awareness, and access to resources. Together, these three dimensions can be used to measure adaptive capacity among different households. These findings are supported by similar work illustrating the value of income inequality and political awareness as indicators of adaptive capacity. Our results also demonstrate that complex relationships among the livelihood capitals may confound our ability to measure financial, physical, and human capitals separately. This framework for assessing adaptive capacity of households, with further refinement and testing, may be used in urban areas to evaluate programs designed to impact resilience to climate change.

Keywords: adaptive capacity, climate change, scale development, vulnerability, urbanization, resilience, capitals, livelihoods

INTRODUCTION

Adaptive actions, once popularly considered the “lazy” alternative to climate change mitigation, are now a primary focus of the Intergovernmental Panel on Climate Change’s (IPCC) strategy (Pielke et al., 2007; Prins and Rayner, 2007). Mitigation to limit carbon emissions or enhance carbon sequestration and storage will not produce noticeable results for decades (Pielke et al., 2007). Therefore, adaptive actions are vital components of any climate change policy, regardless of mitigation efforts. Although both coordinated “bottom up” and “top down” strategies will be crucial in climate change adaptation (Hill and Engle, 2013; Bierbaum et al., 2014), adaptive efforts

are often more successful at smaller scales (Brooks and Adger, 2005; Estrada et al., 2017), with cities now widely recognized as important actors in responding to climate change (Rosenzweig, 2010). Cities, which are often hubs of innovation and economic activity, allow for a more comprehensive and context-specific response to climate change (Carter et al., 2015). However, climate change in cities is expected to affect municipal energy systems, water demand and supply, wastewater treatment, transportation, and public health (Rosenzweig et al., 2007; Rosenzweig, 2010). Poor urban households are particularly susceptible to these impacts as they are often in the locations most vulnerable to climate change effects (Rygel et al., 2006; Rosenzweig, 2010).

Controlling the cost of adaptive actions through the use of strategic and targeted initiatives is a priority for cities managing limited resources. Because the manner in which people adapt to stress can affect the costs and benefits of public policy (Kane and Shogren, 2000; Head et al., 2013), the adaptive capacity of individual households should be understood before municipal resources are allocated (Bierbaum et al., 2014; Araya-Muñoz et al., 2016). Large-scale governmental efforts to combat climate change that do not consider household-level actions and resources can undermine the inherent adaptive capacity of households (Dietz et al., 2009) or de-incentivize further protective measures taken by households (Barrett, 2006; Toole et al., 2016). Because the decisions of individuals can have cumulative effects on communities and policy outcomes (Kane and Shogren, 2000; Head et al., 2013; Elrick-Barr et al., 2016), households are increasingly viewed as foundational social units for observing adaptation and resilience (Toole et al., 2016). However, the factors that determine the adaptability of urban households are poorly understood (Nhuan et al., 2016; Toole et al., 2016) and most studies that attempt to quantify adaptive capacity are performed at spatial scales larger than households (Adger and Vincent, 2005; Brooks et al., 2005; Araya-Muñoz et al., 2016) and in rural locations (Wall and Marzall, 2006; Below et al., 2012; Lockwood et al., 2015).

Developing instruments to measure adaptive capacity among households is a critical first step toward allowing cities to evaluate how local policy affects community resilience. To address this, we used Raleigh, NC, as a case study to develop a scale of autonomous adaptive capacity of urban households. Autonomous adaptation is defined here as the reactive adoption of certain perceptions and actions that allow households to better cope with emergencies, including those events resulting from climate change (Fenton et al., 2017). Because there is no well-established method for measuring autonomous adaptation, we utilized the extensively researched rural livelihoods framework and the determinants of adaptive capacity described by the IPCC to develop our survey instrument. The IPCC summarized the main determinants of adaptive capacity as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al., 2001; Engle, 2011). These attributes of adaptive capacity are included in the five capitals that comprise the rural livelihoods framework used by researchers to capture the combination of resources utilized to reduce vulnerability (Farrington et al., 1999; Hammill et al., 2005; Park et al., 2012). Economic resources are considered financial capital;

technology and infrastructure are products of economic activity and are considered physical capital; institutions and equity are considered social capital; and information and skills that contribute to well-being and productivity are attributes of human capital (Ellis, 2000; Brown et al., 2010; Tinch et al., 2015). This instrument for assessing autonomous adaptation of households, with further refinement and testing, may be used in urban areas to evaluate programs designed to impact resilience to climate change. Results of this study may also aid in the development of indicators of autonomous adaptation for households in other similar urban environments.

MATERIALS AND METHODS

Study Site

Raleigh, NC provides a good context to explore the drivers of autonomous adaptation of urban households. Raleigh had the twenty-first largest numeric increase in population among the nation's cities between 2010 and 2015 (Tippett, 2016), making it an ideal location for capturing a rapidly urbanizing population. The results of this study will become increasingly applicable as the world's population continues to urbanize. According to the American Community Survey from 2011 to 2015, Raleigh's estimated population is 432,520 people, where about 60% of the population is Caucasian, around 31% of people more than 25 years of age have a bachelor's degree, and the median household income is \$55,398 (U. S. Census Bureau, 2015). In comparison, North Carolina is 69.5% Caucasian with 18.4% of persons over 25 years old having a bachelor's degree, and a median household income of \$46,868 (U. S. Census Bureau, 2015). In addition, the Triangle Region of North Carolina is a technology hub of highly educated people (U. S. Census Bureau, 2015) that provides job growth, real estate expansion, and overall prosperity (Jones Lang LaSalle, 2014). These qualities are indicative of developed nations, which have been under-researched in the adaptive capacity literature (Toole et al., 2016). Climate change in the study region is expected to result in more extreme heat, more intense hurricanes, and altered precipitation patterns causing both flooding and droughts (Woodruff, 2013). These trends are projected to negatively affect the forestry and agriculture industries in the state, as well as municipal water resources and public health (Karetinkov et al., 2014).

Survey Instrument

Our survey instrument contained 19 capital-specific questions, each on a five-point scale. Physical, financial, social, and human capitals were assessed with several questions each. Designing non-overlapping questions for each capital is challenging, because physical, financial, and human capitals can often intersect (Ellis, 2000; Lockwood et al., 2015). We relied on previous studies (Table 1) and analytical techniques (see Data Analysis section) to evaluate whether four separate capitals were measured in the instrument. Natural capital is a traditional component of the rural livelihoods framework, because local natural resources often provide crucial support for rural households especially in times of stress (Twine

TABLE 1 | Definitions of the four capitals utilized in this study, adapted from Brown et al. (2010), Ellis (2000), and Tinch et al. (2015).

Physical capital	Material goods and items produced by economic activity from other types of capital. It can include infrastructure, equipment, and improvements.
Financial capital	The level, variability and diversity of income sources, and access to other financial resources (credit and savings), that together contribute to wealth—its value is purely the ability to secure services of natural, human, social, or manufactured capital.
Social capital	The structures, institutions, networks, and relationships that enable individuals and societies to function effectively and facilitate cooperative action and the social bridging.
Human capital	The skills, health, education, knowledge, civic engagement, political participation, and motivation of individuals that contributes to productivity and well-being.

et al., 2003). Because traditional indicators of local natural capital do not adequately address the livelihoods of urban households, we omitted them from the survey. The design of the survey instrument was largely guided by Dillman's (2011) tailored design method, and the survey was pretested before use. The instrument was reviewed and approved by the NC State University Institutional Review Board for the Use of Human Subjects in Research (Protocol Number 4087).

Physical Capital

Physical capital questions were focused on personal assets and resources rather than infrastructure, because the surveys were conducted in an urban setting where people typically have access to running water and electricity (Table 2, Questions 1–4). We included transportation, housing, and emergency supplies as physical capital (Baum, 2008; Notenbaert et al., 2012). Access to transportation was considered physical capital, rather than financial, because Raleigh, NC, has a public transportation system that includes no-cost options. Housing can be considered financial capital, because room or house rentals can provide monetary gains (Moser, 1998). However, good quality housing is also a valuable physical asset in the urban context (Nhuan et al., 2016). Emergency supplies are wholly tangible items that a household can possess to better cope with stress (Ellis, 2000).

Financial Capital

Financial capital questions focused on sustainable employment, because labor is an urban dweller's most important asset in highly commoditized urban settings (Table 2, Questions 5–8; Moser, 1998). Questions also focused on market confidence (Ellis, 2000; Gasper et al., 2011) and monetary savings and assets (IPCC, 2001; Tinch et al., 2015). Lastly, financial capital questions focused on the respondent's assessment of their ability to secure, maintain, and utilize different financial assets (Ellis, 2000; Brown et al., 2010). We recommend that future research assess types of housing and utilities as a percent of income in order to more fully capture the financial assets of individual households.

Human Capital

Awareness and knowledge (Fankhauser and Tol, 1997; Smit and Pilifosova, 2003) and health and well-being (Ellis, 2000; Lwasa, 2010; Gasper et al., 2011) fall within the definition of human capital. We included questions regarding awareness of natural disasters, political awareness, and access to affordable health care (Table 2, Questions 9–12). Although political awareness and engagement can be polarizing, particularly regarding climate change (McCright and Dunlap, 2011), this trend is likely less pronounced at the scale of local governance (Estrada et al., 2017). We therefore included survey items on political awareness of state and local politics, because political awareness may increase adaptive capacity by increasing concern and possibly participation (Smith and Leiserowitz, 2014; Carlson and McCormick, 2015; Shi et al., 2016).

Social Capital

Social capital questions were written to measure contacts and associations, also known as bonding social capital (Table 2, Questions 13–14; Pelling and High, 2005). Bonding social capital can be described as the interpersonal relationships that are shared between individuals with a similar background—ethnic, religious, or otherwise. We also measured social and civic engagement (Adger, 2003; Sander and Lee, 2014) using questions about social bonds, safety nets, and community and political activities.

Sampling

Two hundred surveys were administered door-to-door in Raleigh, NC, during the summer of 2015. To ensure a representative sample of neighborhoods, the sample locations were evenly stratified across five social vulnerability classes, ranging from high to low vulnerability, found in Cutter et al.'s (2003) social vulnerability index (SoVI) data set. The 2006–10 SoVI data set is a national index of social vulnerability, comprising 27 sociological characteristics that are aggregated into quintiles. Within the boundary of Raleigh's city limits, forty households were randomly selected from each of the five SoVI levels using Hawth's tools in ArcMap 10.x GIS software (Beyer, 2004). We started sampling from those houses selected with the GIS analysis and, if no one answered, we visited every other house within the SoVI boundaries until a participant agreed to be surveyed.

Data Analysis

To limit the number of scale items, variables were removed that had correlations of ≤ 0.4 between the combined scale (all values added) and each of the scale's component variables (Dunlap et al., 2000). A principal components analysis enabled us to identify the important dimensions and assess the 14 variables' suitability for scale creation. We utilized the Kaiser criterion (Guttman, 1954) and extracted the factors with eigenvalues of 1.0 or greater and identified items that loaded at or above 0.3 within those factors (Spector, 1992). Cronbach's alpha scores were used to assess the internal consistency of the 14-item scale, as well as the important factors identified with the principal components analysis. We created an additive scale with the 14 items after removing the

TABLE 2 | Principal components analysis of adaptive capacity scale items after removing scale items with low item-total correlations.

Scale items	Capitals	Factor 1	Factor 2	Factor 3
		Financial capital	Political awareness	Access to resources
1. How confident are you that you have access to transportation whenever you need it? ^a	Physical	0.220	-0.123	0.325
2. How confident are you that you have the means (e.g., transportation, lodging, money) to temporarily leave the city? ^a	Physical	0.340	-0.151	-0.016
3. How confident are you that you have all the emergency supplies you would need for 72 hours after an emergency? ^a	Physical	0.201	0.238	-0.387
4. How confident are you that you would have access to all your basic goods and services if your primary means of transportation were not available? ^a	Physical	0.269	0.035	-0.497
5. How confident are you that you have the ability to receive a formal loan? (e.g., bank) ^a	Financial	0.309	-0.151	0.339
6. How confident are you that you can always find a source of income when you need it? ^a	Financial	0.313	-0.043	-0.100
7. How confident are you that you could support your household on savings for at least 3 months without income? ^a	Financial	0.287	0.019	-0.107
8. How confident are you in your financial ability to move if you needed to? ^a	Financial	0.356	-0.083	-0.136
9. How politically aware do you feel of your STATE government? ^b	Human	0.169	0.602	0.172
10. How politically aware do you feel of your LOCAL government? ^b	Human	0.150	0.620	0.201
11. How confident are you that you will be aware of any evacuation orders? ^a	Human	0.212	0.188	-0.138
12. How confident are you that you have access to affordable healthcare? ^a	Human	0.228	-0.022	0.468
13. How confident are you that if your dwelling were damaged, you would be able to stay with either family or friends? ^a	Social	0.295	-0.223	-0.103
14. How confident are you that you have the ability to receive an informal loan? (e.g. family, friend) ^a	Social	0.294	-0.199	0.153
Eigenvalue		4.6	1.9	1.3
Percentage of variance		33	13	10
Cronbach's alpha		0.76	0.92	0.60

Scale items are the survey questions that relate to the capitals indicated. The three factors were identified because they had eigenvalues ≥ 1.0 in the principal components analyses. The numbers in each cell are the loading factors in the principal components analysis. Loadings with an absolute value ≥ 0.3 are highlighted in bold.

High loading variables in each factor are indicated in bold. ^aCoding as follows: 5, completely confident; 3, confident; 1, not at all confident.

^bCoding as follows: 5, extremely aware; 3, somewhat aware; 1, not at all aware.

missing observations, and assessed criterion validity for the 14-item scale. The measure of criterion validity, or how much the scale is related to outcomes it is supposed to measure (Zeller and Carmines, 1980), was determined by the scale's significant correlations with well-defined and frequently utilized indicators of adaptive capacity: income, education, and renters' insurance (Molua, 2009; Harvatt et al., 2011; Safi et al., 2012). Statistical analyses were performed using SAS 9.4 software Copyright © (2013).

RESULTS

The 14 survey questions included in the scale exhibited internal consistency ($\alpha = 0.83$). The scale's consistency was also reinforced by its criterion validity, whereby it was positively and significantly correlated with income ($r = 0.37$), education ($r = 0.38$), and having renters' insurance ($r = 0.42$). These results suggest face validity, and that with further refinement the 14 survey questions utilized for this scale may be used to measure autonomous adaptive capacity of urban households.

Results of the principal components analysis indicate three major factors underlying the scale—financial capital, political awareness, and access to resources (Table 2). These three factors met the Kaiser criterion and together explained around 56%

of total variance. The first factor had the largest eigenvalue (4.6), explained the most variance (33%), and related to financial capital. The items with the most influence on the scale (loadings ≥ 0.3) were those regarding financial resources and assets. Together, these items had a Cronbach's alpha of 0.76, indicating their validity as a financial capital subscale. The second factor had an eigenvalue of 1.9, explained 13% of the variance, and highlighted items related to political awareness. Cronbach's alpha for the second factor also met the internal consistency criteria with a rather large alpha ($\alpha = 0.92$). The third factor, with an eigenvalue of 1.3, explained 10% of the variance, and highlighted resource access. The resource access items did not have as high internal consistency, with a borderline Cronbach's alpha of 0.60.

DISCUSSION

The increasing role of the private sector in modern society and economies around the world may help explain why financial capital was the strongest dimension within our adaptive capacity measure. Nhuan et al. (2016) had similar results when they quantified household-level adaptive capacity in Vietnam. Taken together, these results suggest unequal wealth may play a role in adaptive capacity across a range of social, economic, and cultural contexts globally (McKenzie, 2005). The high internal

consistency of our financial capital subscale ($\alpha = 0.76$) could be partially explained by the more uniform and directly observable nature of financial resources, as compared to the more qualitative concepts found within human, physical, and social capitals (Tinch et al., 2015).

Political awareness, the second-strongest dimension identified, may illustrate the importance of public awareness of governance structures in the measurement of autonomous adaptation in urban households. Governance indicators have been identified as important determinants of adaptive capacity at nearly all other spatial scales and locations: nationally (Brooks et al., 2005), in rural agricultural communities (Lockwood et al., 2015), and in several countries around the globe (Engle and Lemos, 2010; Nhuan et al., 2016). Municipal governance is critical in the global response to climate change, as cities often do not face the same political barriers to mitigation and adaptation as national governments (Estrada et al., 2017). Without the divisiveness of national politics, political awareness at the local level may influence the adaptive capacity of individuals by increasing concern and possibly engagement with the political process (Smith and Leiserowitz, 2014; Shi et al., 2016). This is particularly meaningful to the urban poor who often live in places more at risk from climate change effects and are excluded from the policy making process (Adger, 2003). Therefore, policy makers and stakeholders should engage the public to contribute to a higher overall adaptive capacity.

Access to resources comprised items from human, physical, and financial capitals, which suggests that these three capitals may be interrelated. Similar relationships among these capitals have been found in rural studies conducted at refined spatial scales (Ellis, 2000; Lockwood et al., 2015). While the capitals are often treated as discretely measurable items at the national level (Tinch et al., 2015), these findings indicate that different combinations of capitals may be required to measure adaptation at the household level. Traditional livelihoods assessments at large spatial scales that cast household actions as voluntary and calculated do so without gathering information on how people gain and utilize the capitals, and may not reflect the interdependencies of people's needs and arrangements (Dijk, 2011).

Social capital was not influential to the measurement of autonomous household adaptation in this case study, the questions we developed may not have been sufficiently comprehensive. For instance, social capital has been shown to include many distinct dimensions that may be difficult to quantify (Van Beuningen and Schmeets, 2013). Alternatively, social capital can contribute less to adaptive capacity in populations that are more educated, as well as among those with a more individualistic culture (Guiso et al., 2004). Raleigh has both of these characteristics, with a high percentage of people with secondary degrees (U. S. Census Bureau, 2015) and, as part of the United States, traditionally considered a more individualistic society (Han and Shavitt, 1994).

Our sample overrepresented the economic diversity of Raleigh, NC and was also limited in scope to that region, these limitations likely impacted the dimensions of autonomous adaptation identified with the PCA. Thus, future analyses with

larger samples, representing larger geographic areas, are likely to improve both the instrument and understanding of dimensions underlying autonomous adaptation. Future research should also explore the role of natural capital in urban locations, as the current methodology and indicators are limited. Lastly, a more comprehensive measurement of social capital should be incorporated in future instruments.

With further refinement, our tool may help identify economic disparity, refine areas of interest for city planners, and direct municipal investments to the most vulnerable residents. Investments in the economic welfare (e.g., employment availability and sustainability) and resource access (e.g., healthcare and public transportation) of households could improve the overall adaptive capacity of cities. Although long-term city plans often incorporate these types of welfare and infrastructure projects, citywide socio-economic exclusion and income inequality could continue to increase without a targeted approach (Lee, 2011). Our instrument could help provide this targeted approach because it incorporates multiple measures of household welfare and economy that are rarely incorporated into publicly available data sets. While adaptation planning by cities is on the rise (Cruce, 2009), implementation is in its infancy because cities lack scientific guidance to justify expenses (Carlson and McCormick, 2015; Lehmann et al., 2015). Deeper and more context-specific understanding of household adaptation may help justify expenses as well as identify approaches that increase resiliency and climate adaptation without high-cost infrastructure, such as through initiatives to increase political awareness and engagement.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the NC State University Institutional Review Board for the Use of Human Subjects in Research, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the NC State University Institutional Review Board for the Use of Human Subjects in Research (Protocol Number 4087).

AUTHOR CONTRIBUTIONS

KS, GH, MP, SB, and MM all provided substantial contributions to the conception and design of the work, the interpretation of the data, the drafting of the manuscript, and the final approval of the manuscript. KS was responsible for the acquisition of the data.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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