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Research and Theory in Human Ecology

Introduction: Progress in Structural Human Ecology

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Abstract

Structural human ecology is a vibrant area of theoretically grounded research that examines the interplay between structure and agency in human–environment interactions. This special issue consists of papers that highlight recent advances in the tradition. Here, the guest co-editors provide a short background discussion of structural human ecology, and offer brief summaries of the papers included in the collection.

Keywords: structural human ecology, carbon intensity of well-being, sustainability, coupled human and natural systems

Structural human ecology

Structural human ecology (SHE) is a term that covers the research of a network of scholars who examine the interplay between structure and agency in human–environment interactions.[2] The perspective of SHE is very much grounded in Darwinian thinking (Dietz & Burns, 1992; McLaughlin, 2001, 2012). The structures of the physical, biological and social worlds constrain human action by shaping the responses that will result from a human decision. But human actions also reshape the physical, biological and social worlds. To paraphrase G. Evelyn Hutchinson, SHE examines the cultural evolutionary play enacted in the human ecological theater (Hutchinson, 1965).

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2 *Structural Human Ecology: New Essays in Risk, Energy, and Sustainability* (2013) Dietz, T., & Jorgenson, A. K. (Eds.) was reviewed by Eric Bond in *Human Ecology Review Vol 21(2)*. It can be accessed online from ANU Press at press.anu.edu.au/titles/human-ecology-review/volume-21-number-2/.

Of course, concern with agency and structure has long been evident in human ecology (Richerson, 1977; Richerson & Boyd, 1997/1998). SHE emerged from two streams of environmental social science research that both embody these concerns. One was the emergence of quantitative macro-comparative work on the anthropogenic drivers of environmental change (Dietz & Rosa, 1994). An early motivation for this work was to offer strategies for, as Gene Rosa often put it, "disciplining theory with data" around long-standing arguments, such as the relative importance of population, affluence and technology as drivers of environmental change (Dietz & Rosa, 1997). This has led to a robust literature examining many forms of anthropogenic environmental stress and many factors that drive it (Jorgenson & Clark, 2012; Rosa & Dietz, 2012). Recently, this line of research has turned to a question central to sustainability, initially raised by Mazur and Rosa (Dietz, Rosa, & York, 2009; Jorgenson, 2014; Jorgenson & Dietz, 2015; Mazur & Rosa, 1974): what is the relationship between human well-being and environmental stress, and in particular is it necessary to produce high levels of environmental stress to achieve high levels of well-being?

Examination of risk and uncertainty is a second stream of scholarship in structural human ecology. The literature on risk and uncertainty is somewhat distinct from the macro-comparative literature but both are pursued by an overlapping group of scholars (Dietz, 2013; Rosa, Renn, & McCright, 2013; York, 2013).[3] While much more work is needed to effectively link these two themes, they do converge around growing efforts to examine the risks associated with global social and environmental change that are the focus of much of the macro-comparative literature (Rosa, Dietz, Moss, Atran, & Moser, 2012), and with efforts by macro-comparative scholars to address policy issues in their work, discussions that inevitably lead to considerations of risk and uncertainty (e.g., Jorgenson, 2012; York, 2012).

This special issue consists of papers that highlight some of the ways in which recent progress has been made in the structural human ecology tradition. The work illustrates the breadth in SHE scholarship, and the diversity in the career stages of the authors underscores the vibrancy of the tradition. It was a pleasure to organize the issue, and we thank the authors and anonymous reviewers for their hard work and excellent contributions.

3 In *Structural Human Ecology*, an edited volume assessing the contributions of Eugene Rosa to the field, five of eight papers deal with risk (Dietz & Jorgenson, 2013).

Theoretical perspectives

The papers by Burns and Rudel and by Dietz and York both advance theoretical understanding in structural human ecology. Burns and Rudel offer an innovative integration of a theme from the ecological literature, the adaptive cycle, with a theme from the macro-comparative social science literature, world-systems theory. Adaptive cycle theory in ecology emerged from consideration of ecosystems but has been applied to coupled human and natural systems as well, although mostly at the scale of particular landscapes and the natural resources in them. World-systems theory is framed at the global level, and has long engaged with the idea of Kondratiev cycles (as well as other large-scale cycles and long-term trends, see Chase-Dunn, 1998), waves of change induced in part by new technologies and structures of inequality that unfold over many decades. By juxtaposing these two theories, Burns and Rudel challenge us to think about how ecological changes may interplay with large-scale social changes, offering the dynamics of the Irish Potato Famine as an example. Conceptualizing these changes as cycles emphasizes that responses to large changes often transform the systems responding, eventually leading to yet another round of change.

Dietz and York pursue the growing attention to non-human animals in human ecology. They suggest that animals do not easily fit into traditional categories of manufactured, natural, human and social resources. In particular, animals used in the production of goods and services can act with agency that disrupts the management of the production processes. That in turn has led to ongoing historical efforts to rationalize and control the way animals act in production to increase the economic efficiency of the process. Examining the role of animals in parallel with the role of human workers offers insights into the political dynamics and ethics of production.

These two papers, while addressing different bodies of theory and focusing on different phenomena, do reflect a common theme in structural human ecology: a strong emphasis on developing theory that integrates across fields of inquiry. To date most structural human ecologists are grounded in sociology. But they are sociologists who make a point of embracing other disciplines. They focus on work that is informed by, while concurrently informing, the full body of scholarship on human–environment interactions.

Driving the human ecological footprint

Perhaps the most robust area in structural human ecology is the large body of research that articulates the ways in which various human drivers produce stress on the biophysical environment. Clearly the size of human populations

and their level of affluence are major drivers of environmental stress—they constitute the scale of human activity. But the effects of scale can be moderated by both the content of what is consumed and the technique, or technology, that is used in production, including disposal of waste. In turn, the composition of consumption and the techniques of production are influenced by a variety of structural factors, including culture and institutional arrangements that allow manifestation of power by some and suppress the exercise of power by others. Thus the set of factors that influence anthropogenic environmental stress is very diverse and is the subject of a rapidly growing literature. Papers by Longo and York, by Marquart-Pyatt, and by Jorgenson, Schor, Huang and Fitzgerald offer important new insights into the drivers of anthropogenic environmental stress.

Longo and York note that there have long been hopes that new information technologies will "dematerialize" economies, leading to reduced environmental stress. They examine the empirical evidence that the growth in traditional landline phones, cell phones and internet use changes energy consumption and production, electricity consumption and production, and the number of cars. Unfortunately, the hope that electronic communication will displace energy use is not warranted. Cell phone use has no observable effect on the prevalence of cars, the production or consumption of energy in general, and electricity in particular. In contrast, an increase in landline phones is associated with an increase in both overall energy production and consumption, and with increased electricity consumption and production. And increased internet use is associated with an increase in car ownership. Overall, the growing use of electronic communications does not reduce stress on the environment and may be part of a process by which it is exacerbated.

Marquart-Pyatt provides an analysis that combines a central theme in structural human ecology—the analysis of the ecological footprint of nations—with an emerging methodological approach—the analysis of a regional subset of nations. The ecological footprint is a widely accepted integrative measure of stress on the environment, and was the subject of some of the earliest work in structural human ecology (Jorgenson, 2003; York, Rosa, & Dietz, 2003). The overall footprint and its components (land area devoted to crops, to grazing, to the built environment and CO_2 emissions) continue to be a major theme in structural human ecology. But while initial studies typically considered the full set of nations for which data were available, more recent analysis, being attentive to structural variations across nations, have examined drivers within regional subsets. Here Marquart-Pyatt offers an examination of the drivers of the ecological footprint and its components in a critical region: West Africa. Looking at longitudinal data for five nations (Burkina Faso, Ghana, Mali, Niger, and Nigeria), she gives us a better understanding of the factors driving environmental stress within a critical context over a 45-year time span. A particularly important finding of her

analyses is that, with the exception of CO_2 emissions, affluence (gross domestic product per capita) does not drive environmental stress among the regions within West Africa, while population size and various aspects of population distribution do.

Jorgenson et al. examine the effects of income inequality on residential CO_2 emissions. While concern with inequality with regard to who suffers from environmental risks is long-standing (Burch, 1976; Hare, 1970), relatively little work has been done on how income inequality may influence stress placed on the environment. Jorgenson et al.'s paper is also part of a new methodological move in structural human ecology to complement analyses that compare nation-states with those working at the sub-national level, in this case U.S. states. They choose a measure of inequality that is sensitive to the concentration of income among the most affluent and find that income inequality does exacerbate CO_2 emissions, another problematic impact added to the growing set of concerns being raised about income inequality (e.g., Pickett & Wilkinson, 2015). Their study also encourages us to remember that structural analyses must consider how resources and power are distributed within a society, as well as between societies, the latter of which is commonly addressed in SHE scholarship at more macro levels.

Human well-being

While the majority of studies in structural human ecology examine the drivers of stress on the environment, one of its pioneering contributions—made by Mazur and Rosa—examined the relationship between environmental stress and human well-being (Mazur & Rosa, 1974). This theme is being revitalized in a number of recent studies examining the question of whether or not increases in well-being can be achieved without attendant increases in environmental stress. Papers by Givens and by Sommer, Shandra, Restivo and Coburn contribute to this line of analysis on human well-being and the environment.

Givens provides a detailed examination of how urbanization and efforts to provide improved water services in urban areas are related to the carbon intensity of well-being (CIWB; CO_2 emissions per capita divided by average life expectancy at birth). She finds that both urbanization per se and provision of improved water services (potable water and sanitation) increase CIWB, and that these effects are stronger in developing nations than in developed nations. As with the findings of Longo and York, Givens' results counter a long-standing hope that urban areas might be able to provide well-being efficiently with

modest environmental impact. Not only does urbanization increase CIWB, but provision of critical water services further exacerbates emissions per unit of human well-being.

Sommer et al. conduct an analysis, which, like that of Marquart-Pyatt, focuses on Africa. They examine two related key indicators of human well-being: maternal and neo-natal mortality for a sample of nations located throughout the continent. Their work is motivated in part by a sociological literature investigating how institutional arrangements have affected human well-being. They consider the requirements for "structural adjustments" imposed by the International Monetary Fund on a number of developing nations. These "adjustments" required moves towards neoliberal economic policy in exchange for restructuring crippling debt on international loans. Sommer et al. find that access to improved water and sanitation decreases mortality. But structural adjustment policies still have an adverse effect on human well-being, even when improved water and sanitation are accounted for in the analysis.

Emerging directions in structural human ecology

Each of the papers in this special issue makes specific contributions to theory and our empirical understanding of human ecology. In the aggregate, they also point to several emerging directions of inquiry in structural human ecology. First, efforts are underway to connect SHE with a number of other lines of theory. These include links to theories of ecosystem and world-systems dynamics, to the growing body of work in animal studies, to growing concerns with the effects of inequality, and to work on the human well-being impacts of economic growth and development policies, such as broad neo-liberal structural adjustments and ongoing efforts to improve access to potable water and sanitation.

Second, a number of papers in this issue counter commonly held conceptions about factors that enhance sustainability. Both increased use of telecommunications and increased urbanization seem to make things worse, despite hopes that the opposite might be true. However, we also have evidence that, at least in some West African nations, economic growth over the last 45 years has not tended to increase stress on the environment—at least in the context of the ecological footprints of nations—although population growth has. These findings demonstrate a particular value of structural human ecology: disciplining theory with data and thus identifying what social changes may enhance sustainability and which, at least to the present, have not.

Third, several papers are especially attentive to context by examining a subset of all nations to elucidate processes that may be at work in some places but not others. In addition, Jorgenson et al. is one of the first papers in SHE to use subnational units of analysis. Structural human ecology embraces units of analysis from the individual to the globe, noting that each level of analysis has its strengths and limits and thus all are needed to provide a robust understanding of how structure affects ecological and evolutionary processes. Examinations of subsets of nations and subnational units are important contributions to better understanding the relevance of context.

Reading across these papers it is clear that structural human ecology is flourishing. New theoretical arguments are emerging. Empirical analyses are becoming more sophisticated and nuanced. Researchers are examining both broad theoretical questions and issues of immediate policy relevance. Thus SHE seems to reflect the core themes of human ecology: to span disciplines while doing work that contributes to fundamental understanding and that also addresses important practical problems.

Coda

The papers in this special issue are intended as a gesture of respect for the work of the late Eugene A. Rosa. Gene was a long-time and enthusiastic member of the Society for Human Ecology. He was at the hub of the network of what has come to be called structural human ecology, making foundational contributions to both macro-comparative analyses (Dietz & Rosa, 1994; Mazur & Rosa, 1974; York et al., 2003) and to structural perspectives on risk (Rosa et al., 2013). His influence was felt not only through his written work but also through his extensive collaborations; nearly half the authors of the papers in this issue co-authored with Gene. Gene would have enjoyed the session from which these papers emerged, and would have insightful and supportive comments on them. We thank him for his immense intellectual and personal contributions to the field.

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Metatheorizing Structural Human Ecology at the Dawn of the Third Millennium

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Abstract

While its processes have been unfolding for centuries, some aspects of human interaction with the natural environment are unprecedented. In recent centuries, the world has experienced unparalleled technological change, wealth accumulation and population growth and concentration; these have led to extraordinary levels of other problems, particularly environmental degradation. Focusing on mismatches between the adaptive cycle and the organization of the world economy, we examine material and cultural changes that lead to social and ecological devastation. We apply our theoretical framework to one of the largest ecological and social catastrophes since the Industrial Revolution—the Irish Potato Famine of the 1840s. There are a number of lessons, particularly in terms of the relations of production and humankind's connection with the natural environment. It is now as important as ever to learn from past mistakes and modify current modes of theory and analysis as history moves into the Third Millennium.

Keywords: Potato Famine, adaptive cycle, coupled natural and human systems

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Introduction

The advent of coupled natural and human (CNH) systems research (in our opinion, human ecology by another name) has in recent years fostered welcome increases in empirical research, but comparable kinds of theoretical syntheses have been slow to appear. Metatheoretical advances in human ecology could be achieved in several different ways, both of which we explore in this paper. One path to metatheory would merge models with different parent disciplines, in particular, the adaptive cycle from ecology and the world system from sociology. A second path would focus on the theoretical architecture of this combined approach, the appropriate set of variables, its scalar properties, and the measures that would capture the dynamics of change. These paths are not mutually exclusive. Here we take some initial steps down each one of them. Pursued in tandem, these analytic directions could provide us with a theory that could serve as a focal point for the new wave of work in human ecology prompted by the environmental crisis.

Merging the adaptive cycle and the world economy

We begin with brief sketches of the adaptive cycle and the world economy. Before we outline the differences between the two models, it might be useful to underline one of their shared attributes. Both of them represent "populationist approaches" to CNH theories in that they outline mechanisms of change that characterize how communities cope with the larger contingencies that they face (McLaughlin, 2012).[2] The dynamics of these mechanisms differ dramatically, but a glance at the most common graphical depictions of the two systems suggests how the two theories might be combined. The metaphor that captures the adaptive cycle most clearly is a temporal one, with communities progressing through stages. The metaphor that summarizes the world system most clearly is a spatial one: a map, in which systems have cores, semi-peripheries, and peripheries (e.g., Wallerstein, 2004; Chase-Dunn & Hall, 1997).

2 We acknowledge here the long-standing debates and discussions about the respective merits and pitfalls of individual- and population-level analyses. We do not engage those debates here, and point the interested reader to Richerson (1977), Fain, Burns, and Sartor (1994), Dietz and Burns (1992), Vayda (1988), Becker (1976), and Richerson and Boyd (1998) for elaboration and discussion. While we recognize the utility of micro-level approaches, we nonetheless utilize for this paper, a macro-level framework that we believe is more in concert with a structural view of human ecology.

Systems ecologists, perhaps most notably C. S. (Buzz) Hollings (Hollings, 1973; Gunderson & Hollings, 2002), developed a model of a recurrent sequence of changes, dubbed "the adaptive cycle," that they describe as characterizing most communities of living things. They chose to subtitle the book that presents a summary of the adaptive cycle, "Understanding transformations in human and natural systems." In truth, almost all of the published applications of the adaptive cycle model (e.g., Walker & Salt, 2006) focus on ecological communities. They do not represent a test of the model's applicability to human communities, and have little to say about *changes in* those human communities.[3]

Still the model has impressive analytic reach and could be used as an important component in understanding human ecology. The structure of the system changes dramatically as it moves through the adaptive cycle. Four stages characterize these processes of change: a system that expands, then collapses, then reorganizes itself, and then proceeds to begin expanding again. In a further and helpful simplification of the model, Ruth DeFries (2014) describes three essential stages in the adaptive cycle: a ratcheting up (when it expands) of the system, a hatcheting (when things fall apart) of the system, and finally, a pivoting, often accompanied by new technologies, when the systems begins to reassemble and grow in size again. Structural changes in communities accompany these changes in process. For example, as systems expand, they become more tightly coupled, more culturally complex, and less resilient in the aftermath of external shocks. The most recent work on adaptive cycles has expanded the scope of these adaptive dynamics to the entire globe. The concept of telecoupling describes how processes of change in distant, seemingly disconnected places represent, in fact, different manifestations of a single, larger global dynamic of climate change (Liu et al., 2014).

Considering how to apply the adaptive cycle model to coupled natural and human communities exposes some lacunae in the model. In particular, it contains few ways of meaningfully representing the political power that structures so much of human affairs. Politico-economic conflict does occur in the model, largely as contests between communities at different scales. For example, fast-moving, local entities (including local governments) may revolt against conservative strictures imposed by slow-moving institutions, such as central governments, embedded economic systems, and/or foreign hegemonic powers, invested in the maintenance of growth in the overall system. Similarly, when disaster strikes a local community, the hegemonic power structure typically works to restore the local unit to its former state (Gunderson & Holling, 2002). Groups exercise power

3 The journal *Ecology and Society* is edited by scholars who endorse the adaptive cycle and employ a resilience framework in which adaptive cycle models would fit, but few of the articles in the journal test the adaptive cycle model in a meaningful sense.

over one another in these extraordinary circumstances. More routine exertions of power that, for an example, try to maintain elite privileges or a trajectory of growth in a community seem difficult to incorporate into adaptive cycle models.

The world systems models would seem to be strong where adaptive cycle models are weak. The people inhabiting the different spaces in the world system have different amounts of power, with people in the core able to exert power over people in the periphery. Power ebbs and flows as the core of the world system shifts from country to country across historical periods, but the system retains its core-periphery organization (Chase-Dunn & Hall, 1997). The world system has a cyclical dimension, referred to as Kondratiev cycles (Barnett, 1998), in which the whole system undergoes perturbations every several generations, oftentimes associated with the introduction of new technologies. While these cycles are not necessarily as marked or as central to the operation of the world system model as are the stages in the adaptive cycle model, they nonetheless represent another way in which economic and ecological systems are related, even if not tightly coupled.

Ecologists in the Marxist tradition have worked to develop a conceptual apparatus for integrating ecological variables into broader global systems. James O'Connor, for example, has argued that the second contradiction of capitalism implies that capitalism will eventually destroy the ecological bases for the wealth that it produces for the capitalist class (O'Connor, 1998; also see Spence, 2000). The idea of unequal exchange between core communities and peripheral populations shows how, over time, trade between wealthy and poor nations fails to incorporate into the prices of goods the costs of the ecological degradation entailed in the production of these goods in the periphery (Jorgenson, 2006; Burns, Kick, & Davis, 2006). The Netherlands fallacy explains how these patterns of vertical trade relieve human pressures on natural resources in the core countries at the cost of increasing these pressures in peripheral countries (Meyfroit, Rudel, & Lambin, 2010).

The difficulty with these analyses is that they do not go far enough in their exploration of ecological variables. For example, one could make the case that unequal exchange routinely results in the creation of ecosystems on the Global South that are dominated by invasive species such as the bracken fern in the Southern Yucatan (Schneider & Fernando, 2010). Once established, these places are difficult to transform into productive landscapes, either ecologically or economically. As Meyfroit, Rudel, & Lambin (2010) point out, the exploitation and exhaustion of increasingly fine-grained swathes and more accessible rain forests in smaller countries often aggregate to devastating macro-level effects. These practices tend to drive timber and agricultural enterprises to focus their

land-clearing efforts on the few countries with large blocks of still unexploited forests, such that there truly are now precious few places left where there are truly virgin forests.

World systems and structural human ecological analyses could help to inform the other. What one would want to see is a set of analyses in which the adaptive cycle and the world system interpenetrate, and, in so doing, produce robust explanations for change in socioecological systems. How do we do this? Perhaps, an example here will help.

A brief example of the merged approach: The Irish Potato Famine

> By a lonely prison wall, I heard a young girl calling: Michael, they have taken you away; for you stole Trevelyan's corn, so the young might see the morn. Now the prison ship lies waiting in the bay … Against the famine and the Crown, [he] stood up, they brought [him] down … Now she'll live and hope and pray, for her love in Botany Bay, but it's lonely here, in the fields of Athenry … (From the Irish folk song, *The Fields of Athenry*, by Pete St. John).

The Irish Potato Famine of the late 1840s represents a singular event in the 19th-century demographic history of Europe. More than a million Irish probably perished of hunger-related causes during the 1840s and an additional million emigrated from Ireland to other parts of the world—primarily, but by no means solely, to the Americas—in successive waves beginning in the 1840s.

Elements of the adaptive cycle explain both the demise and eventual recovery of Irish agro-ecology during the mid-19th century. Described as "the most lethal natural disaster in 19th century Europe" (O'Grada, 1999), the famine, like other disasters (McLaughlin & Dietz, 2008), had historical roots. It stemmed from the introduction and spread of potatoes in Europe after 1600. In Ireland, the abundance of the potato harvests stimulated a considerable increase in rural populations during the first few decades of the 19th century. A corresponding increase in the amount of land being cultivated for potatoes also occurred. The genetic uniformity of the harvested potatoes also grew during this period as smallholders, as well as absentee landowners, adopted the highest-yielding variety of potato. This last development made Irish smallholders and tenant farmers more vulnerable to crop failures. In the 1840s a fungus began to decimate the crops, leading to widespread starvation, particularly among the smallholders. When the crops failed, landlords evicted tenants who could no longer pay their rents because they no longer had potatoes to sell. Tenants evicted lodgers (farm workers) because they no longer needed the additional labor to harvest the decimated crops. Evicted tenants and lodgers appealed to

British-run workhouses in the cities, but the colonial government provided little in the way of relief (O'Grada, 1999). Impoverished and weakened from malnutrition, the Irish died either from starvation or from opportunistic diseases (Mokyr & O'Grada, 2002).

Gradually, in the 1850s new fungus-resistant strains of the potato, bred in the Americas, were introduced, and large numbers of the younger Irish emigrated, so the smallholders' vulnerability declined (DeFries, 2014). The sequence here resembles the adaptive cycle. The system ratchets up in the early 19th century, disintegrates (the hatchet) during the 1840s, and pivots after the 1850s with the introduction of the new varieties of potato and the emergence of more agro-biodiverse set of cultivars.

This account of the Irish Potato Famine provides only a partial explanation for all of the deaths by famine. Famines in a world with extensive, long-distance trade only occur because elites make political choices to deprive marginal groups of food supplies (Sen, 1983). In the case of Ireland, at the same time that Irish smallholders and tenant farmers were increasing their reliance on the potato and their vulnerability to crop failures, vertical trade with overseas English consumers increased. English landlords with extensive landholdings in Ireland increased their cultivation of wheat and corn for export to consumers in English cities. When the potato crops began to fail, the English landlords refused to divert the supplies of Irish wheat and corn to feed the Irish people unless they could pay for the foodstuffs, which, with no crops to sell, they could not. The landlords exported the wheat and livestock to England and starvation ensued among the Irish.

Differential amounts of political power, explicable in terms of the world system, shed light on this dynamic. Given their dominant political position, the English owned prime agricultural lands in Ireland. The English landowners' allegiance to the country's core consumers and their political representatives most likely stemmed from the advantaged politico-economic position of these people. These factors would explain the landlords' unwillingness to reserve their harvests to feed the tenants on their lands.

This material advantage then filters its way into an ideological apparatus that serves to legitimate this unequal exchange. What is seen as "truth" becomes, in this sense, a function of the social definition expressed through the rhetoric of those in power (Burns & LeMoyne, 2003b). With power comes agency, and the powerful can assert that agency on multiple levels—not only on the structural, but on the cultural level as well, particularly by the shaping of discourse (Dietz & Burns, 1992; Burns, 1999). In our example of the Irish Potato Famine, the major British colonial administrator at the time was Charles Edward Trevelyan. Even as shiploads of the substitute crops of corn and wheat were

expropriated through the 1840s from Ireland so that absentee landlords could continue to profit, Trevelyan publicly proclaimed the famine as "God's way of removing surplus population." He refused help to those in need (whose need he had had no small hand in extending, if not causing!), with the rationale that any aid would encourage laziness and shiftlessness among the Irish.

In sum, the crop failures leading to the famine appear largely explicable in terms of an adaptive cycle, but the absence of any effort to come to the assistance of the starving Irish tenant farmers become most explicable in terms of a world system in which British hegemonic interests reigned supreme. The most complete account of the famine could therefore draw upon both adaptive cycle and world system theory; and a metatheory with adaptive cycle and world system components would seem, at least in this instance, to have considerable heuristic value.

A brief excursus on metatheory

One of the seminal figures in developing the ideas underpinning metatheory in the social sciences, George Ritzer, has identified three major uses of metatheory: to better understand the work itself (Mu); the identification of overarching themes in the literature (Mo); using theory as a prelude to further theorizing and empirical work (Mp) (Ritzer, 1975, 1991, 1992). We see our work as contributing on all three fronts, but particularly in terms of the third usage.

Particularly, given the daunting social and environmental problems faced by researchers moving into the Third Millennium, it is important to have a sense of how a given piece of research helps inform the whole. Major theoretical ideas that run throughout the research and inform it will serve a tremendous heuristic value. In the words of psychologist Kurt Lewin, "There is nothing more practical than a good theory."

There is a growing body of literature in structural human ecology, and we believe the field will benefit greatly from efforts to identify major trends and overarching themes of the work in the area. Recent work in a collection of essays by Dietz and Jorgenson (2013) takes steps in that direction (in particular, see Dietz & Jorgenson, 2013; York, 2013; Dietz, 2013; Jorgenson, 2013). We see our work in that spirit.

What we offer in this paper is what we envision as a useful metatheoretical framework for structural human ecology and related fields. We do believe that it can inform research now and in the short-run future, and we hope and trust that, in the long run, something more robust and universal will supplant it. In the meantime, we offer it as a heuristic device.

Structural mismatches as metatheoretical throughlines

We can see several metatheoretical lessons in the tragic history of socio-structural precursors and consequences of the Irish Potato Famine. First, there are serious mismatches between the way natural ecologies actually operate, and the way the institutions of modernity operate. We could unpack any number of these institutions, but for the purposes of this article-length work, we will focus on one of the most stark sets of mismatches—that between the human ecological adaptive cycle on the one hand, and the way the global economy is organized on the other.

The entropy of ideas in general, and of neo-classical economic ideas in particular

A number of interrelated assumptions underlie the logic of global trade networks. These are at cross purposes with, and often antithetical to, ways in which ecological cycles actually operate. We look in particular at the ideas that underpin the world economy. Many of them go back to Adam Smith (1776), and remain, in one form or another, even today.

Yet as ideas develop and are refined through intellectual effort and research, their popular understanding may degrade. Entropy is an important metaphor for what happens in the diffusion of ideas (Burns & LeMoyne, 2003a). Here, we re-examine how ideas from a crude, dumbed-down version of 18th-century economics has come to dominate much of the economic and social practices since then. A number of the ideas have been remarkably immune to significant change, and are as prevalent now, in mainstream thinking here in the 21st century (see Lux, 1990; Stiglitz, 2003), as they were in the 19th-century Potato Famine.[4]

A number of ideas from economics make sense on some level yet, when taken to extremes, become toxic (Weaver, 1984; McCloskey, 1998). Some of these most notably include the emphasis on economies of scale; hyperspecialization; the law of comparative advantage; the reification of the "invisible hand" of the market; the tendency to externalize latent aspects of the production process; and the assumption of a world populated with rational actors with access to large amounts of undistorted information that they understand and act upon deliberately. Also of particular importance in terms of the natural ecology is "discounting the future." Let us examine these one by one.

4 Many of the structural inequalities and power dynamics that we examine here in the case of Irish Potato Famine have been found in the relations of production of other globally traded commodities, including cotton (Beckert, 2014), sugar (Mintz, 1985), and coffee (Jacob, 2015).

Mismatches of scale

The principle of economies of scale holds that with increasingly large scales of production, the efficiency of the overall operation goes up, thereby yielding more output for a given amount of effort. Yet it is the case in social systems, of which the economy is a part, that increases in size eventually lead to qualitative changes as well.

Social sciences in general, and particularly economics, tend to be oblivious to tipping points, beyond which adding another increment leads to some reorganization of the system itself. In *any* system, there typically are interactions, thresholds, indirect effects, and other non-linearities (Prigogine & Stengers, 1984; Burns & LeMoyne, 2003a).

The transformation of the potato crop to fewer varieties on larger tracts of land (in DeFries's terms, the "ratchet"), led to a truncation of the biodiversity, which had before served as a natural break to a fungus being able to wipe out entire crops. What had been confined to smaller, isolated places, was now in a position to become more widespread.

Yet the retrospective lessons of the Potato Famine go largely unheeded, even now. Especially in cases where businesses ratchet up into large-scale production without planning or preparing for the inevitable hatchet of collapse to follow.

In many business systems, there is a bias toward large scales of production, typically at the expense of smaller and more ecologically sustainable ones. This manifests in ways too many to enumerate (for further discussion, see Schumacher, 1975/1989). Some salient examples in terms of the natural environment include unsustainable agricultural practices such as monocropping, and large concentrated animal feeding operations (CAFOs) at the expense of small and ecologically integrated farming.

A more pragmatic approach from the standpoint of ameliorating the mismatches between the sciences of economics and human ecology would be to frame a series of research question in terms of what is done optimally, and *at what scale*? For whom and for what is it optimal? As Max Weber (1921/1978) pointed out in *Economy and Society*, in large-scale formally rational systems, efficiency of the system itself (many aspects of which may indeed be measurable in terms of money) tends to trump the needs of the people subject to it. To that, we would add that it also trumps environmental concerns through monetarizing non-monetary values (e.g., fresh air, clean water) or by ignoring ("externalizing") them completely. In such a dynamic, money had become an end in itself (Simmel 1907/1978).

Hyperspecialization and comparative advantage

When individual workers are highly specialized in just a small and focused part of a larger project, and those tasks are coordinated, the overall productivity will, in the short run, outstrip a simple aggregate of each individual making the overall product. Again, taken at face value and within circumscribed ranges, this gives the appearance of an obvious truth—a scientific truth from the standpoint of economics and a reified one from that of business.

By extension, people specializing at what they could do efficiently and leaving the other tasks to others who could do *their* respective tasks more efficiently would redound to efficiency for the overall system. David Ricardo (1817) moved the focus of Adam Smith's absolute advantage theory to what became more popularly accepted in mainstream economics—the principle of comparative advantage. It soon became known as the *law* of comparative advantage.

As England industrialized, its trading partners were encouraged, or coerced, into taking other roles. Ireland was gradually drawn into an unequal exchange relationship with England, in which English capital (and the political power with which it was intertwined) controlled Irish resources and labor.

Ricardo's law was repopularized in the 20th century by Paul Samuelson (1947/2011) who, when challenged to name a single principle of economics that was both non-trivial and true, argued that the law of comparative advantage fit both criteria.[5] But *is* it true and, if so, under what conditions? More importantly, even if it is "true," is it true in such a way that it could or should trump other considerations, most notably human well-being and ecological sustainability?

Taken at face value, these interrelated economic principles—economies of scale, hyperspecialization, and the law of comparative advantage—sound quite reasonable. With *The Wealth of Nations* appearing in 1776 in the early stages of the Industrial Revolution, these became guiding principles that organized the workhouses of urban England, and the farming economy of Ireland.

The excesses of what this wrought in the early Industrial Revolution served as much of the fodder for novels by Charles Dickens and were critiqued by social theorists such as Marx and Engels (Stearns & Burns, 2011). These sorts of practices, taken to an extreme, also led to the Irish Potato Famine of the 19th century.

5 Samuelson (1947/2011) himself, for example, attempted to synthesize a number of important ideas from within (particularly the ideas in the tradition of J. M. Keynes) and without (most importantly, thermodynamics) economics with the dominant neo-classical model. Yet, if we were to engage this through a framework of human ecology, we would need to consider the trajectory of such ideas in the common consciousness.

Yet these lessons were not internalized by global markets—far from it. By the early 20th century, these principles had gained enough momentum, particularly in the eyes of those with access to capital and the concomitant political power to bolster it, to base entire systems of production on them. The relationship of Ireland and England was to be replicated, in innumerable variations, around the globe.

Invisible hands, unanticipated consequences

If Adam Smith's idea that the "invisible hand" of the market will result in the common good for humankind and, by extension, for the environment, was ever was true (and we are not suggesting that it was), it most certainly needs extensive qualification. Without that, the invisible hand becomes a truism, an article of faith no more or less *bona fide*, for example, than the old belief in "phlogiston" in alchemy (for an example of a contemporary economist promulgating thought in this mode, see Simon, 1983/1984).

Bracketing questions about how much of the invisible hand is reified to begin with, questions about time and scale of the invisible hand need to be examined closely. *How long*, for example, does the invisible hand take to operate? When does it and when does it not operate? *How tight or loose is the feedback loop?* If it works in the smaller scale, does it also work in truly global *dimensions* that far outstrip even the scale of what the forward-thinking Smith could have imagined?

Even if it did work with total "efficiency," precisely as it should in the textbooks, so what? At best, it privileges the variable of market price over other aspects of life and the human condition, most notably health and the natural environment.

It may be, for example, that the price of potatoes does indeed go up with a general famine. But more important questions speak to the human and ecological costs and outcomes. To be sure, higher prices do not get the potatoes back. In fact, that could set off a perversity in the market to actually increase the overall ecological rift (Foster, York, & Clark, 2011), because as arbitrageurs see rising prices, their incentives go up to engage in even more ecologically marginal activity in attempts to pursue potentially greater profits.

If the invisible hand works efficiently within certain ranges, it tends not to work nearly as well outside of those ranges. Schnaiberg and Gould (2000), for example, discuss the perverse effects of luxury goods markets, particularly when there are huge concentrations of capital in a few hands. What is "rational" for the rich may in fact be irrational for someone with more limited resources, and vice versa. What logic does the market then follow? With the crash in

potatoes, the land becomes reduced to a fungible resource for the absentee landlords who then see it as "rational" to shift to an exportable cash crop of wheat or corn.

In human ecological terms, the invisible hand can be seen as a type of evolutionary process. While its effects are seen most readily on the macro-structural level, the assumption of enlightened self-interest operates primarily on the micro level. There is a long-standing debate among human ecologists, as well as sociologists about the efficacy of a more micro or macro approach (for discussion of the relative merits of micro and macro analysis in ecology, see Richerson, 1977).

From a metatheoretical perspective, it is important to consider the scope or range of a theory. A theory may work well within certain ranges, and poorly in others (Walker & Cohen, 1985). When considering the invisible hand proposition, it is important to ask who is making a decision, and for whom is it "rational"? History shows that power dynamics play themselves out in such cases (e.g., Beckert, 2014; Mintz, 1985; Jacob, 2015).

Time frames and feedback loops

While the idea of the invisible hand guiding the market, particularly to encourage ingenuity when it is needed to solve problems of shortages, has been around since the time of Adam Smith, it has most recently been championed by influential economists (e.g., Simon, 1983/1984), and has become particularly so with neo-conservative think tanks and talk show hosts. It is so ubiquitous that it has become part of the common way of thinking.

Yet here, the common way of thinking leads us astray. Certainly if one resource is depleted, the invisible hand of the market will see to it that another resource is substituted. But even if that is true, it is myopic at best. When the potato crop failed, Irish tenants could not simply substitute wheat for potatoes because the yield in tons and calories from wheat were so much lower than they were for potatoes.

Ingenuity operates differently for people, depending upon their access to, and relationship with, natural resources. Many of the Irish adapted, as best they could, by leaving, or perhaps by stealing or by rebelling.

In a related vein, it bears asking: In what *time frame* does the invisible hand work? It may well be that shortages do indeed encourage ingenuity because, after all, as the folk wisdom dictates, "necessity is the mother of invention." But particularly in the increasing pace of modern times, when technology and population pressures are creating problems and shortages rapidly, can the

responses of ingenuity keep up? Further, new inventions have their unintended and unforeseen consequences as well, which in turn will require a need for a focus of attention and resources.

Shortages, of course, are of central concern with the natural environment. In fact, economics tends to reduce shortages to an economic problem—one of supply. As Hardin (1991) points out, every shortage of supply can be seen as a "longage" of demand. The demand in the case of the Potato Famine was increased greatly by the exporting of food.

More profoundly, shortages may come to compromise the well-being of the planet and its ecosystems, threatening the health or even lives of those dependent upon it. Economic theory tends to ignore problems of temporality with the invisible hand. The longer it takes for the invisible hand to restore equilibrium, the more devastating the consequences. In terms of the adaptive cycle, the longer and more profound the ratchet phase, the harder the hatchet falls when the inevitable move to establish equilibrium occurs.

Hard and soft limits to growth

To be sure, there is a place to consider the law of supply and demand—but with what limit? Even if it is true that the market is subject to the laws of supply and demand, the ethical question arises as to whether it makes sense to let things go until the harsh reality of undersupply with inelastic demand brings misery to humanity.

Here it is worthwhile to consider the differences between soft, voluntary limits and hard limits. Using a resource until the bitter end represents a hard limit. The depletion of a scarce resource makes it, by definition, scarcer with use. This tends to price low-end users out of the market. In a truly free market, there typically are only *hard* limits.

A cross-cutting entity (e.g., government regulators) can do nothing and wait for the hard limit to kick in, or can help ameliorate the effect. The Irish Potato Famine case was so tragic because, in no small part, the people who were so devastated had no representation. Those in power were able to promulgate their own hegemonic version of the reality, as the story of Trevelyan's reign attests.

In virtually any case, and the Irish case is but one example—albeit an extreme one—resources are distributed unequally. That inequality gets more severe and more complex with greater shortage. The entire social system works differently under conditions of shortage than under plenitude.

One way a society can handle shortages is to wait until the last minute and deal with undersupply and hyper-demand. Economists like Ester Boserup (1965) and Vern Ruttan (Binswanger & Ruttan, 1978) would argue that these conditions "induce innovations," which they do, but the transitions from crop to crop are often more halting than the theoretical constructs would have us believe. Certainly, the "helping hand" of government assistance was not available to distressed Irish tenant farmers during the 1840s.

The time and trajectory of change are crucial social variables that tend to be ignored in the glib fatalism of belief in the invisible hand. A gradual change allows people to adapt, perhaps even gracefully. A quick change is typically catastrophic (for an extended discussion, see Stiglitz, 2003). In terms of the adaptive cycle, a crucial way to hedge against the seriousness of the "hatchet" is to go easy on the "ratchet" that comes before it by, for example, avoiding monocropping.

Notes on sustainability and equity

Every time a resource is used, it impacts others. Particularly with globalization, there is the increased ability for resource transfer between places. This process is characterized in the literature in terms of unequal ecological exchange, the ecological footprint, and metabolic rift (for reviews, see Jorgenson, 2003, 2004; Jorgenson & Burns, 2007). As we have seen, the Irish Potato Famine, and events surrounding it, was rife with unequal exchange.

Processes of resource transfer are guided by norms. While those norms may not be explicitly stated, people ignore them at their peril. The norm of the "free" marketplace is no small part of the default, although a truly free market may be neither common nor desirable. Ideally, a normative system is most rich, nuanced and robust when tempered by humanistic concerns. Yet the norms and ideologies that often carry the day are promulgated by those who also have sufficient power to benefit from the unequal exchange.

Perverse consequences of science and technology in an age of globalization

These considerations, particularly those involving mismatches of scale, come into play again when the "pivot" is applied. Much of technology tends to be organized around routinized large scales of production and consumption, and so small systemic eccentricities, or imbalances, tend to be magnified. This combination of entropy in parts of the system, multiplied by large-scale production, leads to potentially catastrophic consequences. This then is the crux of why "technology" is such a potential problem in the contemporary era of global scales of production and consumption (for further discussion,

see Burns & Jorgenson, 2007). Moving into the Third Millennium, an important focus of human ecological research could be on the pivot of technology, with an eye to ensuring the solutions introduced do not in turn cause larger problems than they solve.

The organization of the global economy comes with a number of tradeoffs, which, if not balanced, lead to serious social and environmental problems. Particularly with the intertwining of technology with the economy, there is the increased risk of the upset of the natural balance of the world's ecosystems.

As Allen Schnaiberg (1980) has pointed out (for further discussion in a structural human ecological framework, see Dietz, 2013), there is a mismatch between the leading edge of technology that is intertwined with the treadmill of production of the modern economy, and the following technology that could potentially clean up and address environmental problems. In the words of Garrett Hardin (1968, 1998), technology creates problems it cannot solve.

The scientific method, as it facilitates technology and business interests, carries with it many of the economic perversities we have been considering, particularly the problem of externalities. The science of narrowly business-driven technology tends to focus on circumscribed aspects of reality and in so doing largely ignores other factors.

In its focus on some circumscribed aspect of an overall system, science and the technology stemming from it is able to bring a greater level of control over what is under its microscope. Yet imposing order on some aspect of a system often imposes entropy on other parts of the system (Prigogine & Stengers, 1984). This can be seen under a number of lenses, including that of post-normal risk. Typically, the most profoundly affected parts are those most closely connected ecologically with the part under study and manipulation, and yet defined out of the system for purposes of scientific investigation and technological development.

The problem with the culture of business and its relationship with technology, particularly in late modern times, is not so much a hostility to the natural environment (although there is plenty of that to go around), nearly so much as the tendency to treat the environment as an externality. There is a general tendency to view the natural environment as if it is limitless, when in fact it is not.

A number of theorists have noted how institutional practices, over time, become part of the culture (Burns, 1999; Burns & LeMoyne, 2003b). At the dawn of the Third Millennium, a case can be made more strongly than ever that there is an emergent global culture of late modernity (Burns, 2009). This is characterized by practices and beliefs that reflect many of the ideas we have examined herein—

economies of scale, mass externalization, discounting the future, and a growth model that is commonly characterized in human ecology as the treadmill of production.

With the enframing (Heidegger, 1967) of destructive technologies that make sense from a business standpoint, but not from that of the adaptive cycle, we can see a collision course of the global economy with its value of continual growth, and the necessary limits of the natural ecology. The separate paths of the world economy and the adaptive cycle cannot diverge much longer. To the extent they do, the risks are truly daunting.

Conclusion

The structure of the world economy is based on a number of ideas that are limited. Particularly problematic are the mismatches between the ways in which the world economy operates, and the constraints of the adaptive cycle experienced in natural systems.

Bringing these two worlds into alignment will be no easy task, and yet the consequences of not doing that will, over time, prove to be catastrophic. As a guiding metatheoretical principle, it is important to understand and to address the mismatches between these two systems.

As an extended example, we looked at the Potato Famine of the 1840s in Ireland. We then looked at how many of the ways of thinking and acting institutionally are at least as embedded now as they were then.

In sum, in this article, we have looked more closely at the structure of some of these mismatches and their related perversities, including questions of scale, externalization, comparative advantage, the invisible hand, and discounting the future. Each in their own right serve as rich theoretical guideposts. In combination, they serve as an overarching way of making sense of, and addressing in a praxeological way, the daunting ecological problems of the Third Millennium.

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Animals, Capital and Sustainability

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Abstract

Taking serious consideration of the engagement of non-animals in human-society often transforms our understanding of human society. Here we offer insights that come from considering the role of non-human animals in the production of human well-being. Drawing on Braverman's critique of the deskilling of labor, we examine the effects of the drive for efficiency in capitalist production on both humans and non-human animals. Non-human animals provide well-being through their role in ecosystem services, as companions, as objects used as both raw materials and as processors of raw materials, and as labor. The drive for efficiency impacts all four of these roles, especially by reducing the agency of non-human animals. Our analysis suggests several lines for future research, and re-enforces the idea that taking non-human animals seriously can substantially hone thinking in human ecology.

Keywords: deskilling of labor, animal labor, efficiency, agency

Introduction

Recent scholarship in the area of Animals and Society has "brought animals in" to social science discourse by making it clear that non-human animal species are active, engaged and integral parts of human society, and of coupled human and natural systems. This work has shown that our understandings of agriculture (Gunderson, 2013), identity (Jerolmak, 2013), technology (York & Mancus, 2013) and violence (Fitzgerald, Kalof, & Dietz, 2009), among many other topics, shift when we take non-human animals seriously (for additional examples,

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see York, 2014). This literature challenges us to more fully integrate non-human animals into human ecology and recognize that animals are more than symbols or social constructions (York & Longo, forthcoming).

In this essay, we offer some thoughts about one approach to bringing non-human animals into discussions of human ecology and sustainability theory. We do not suggest the approach we outline here is the single or the best way to incorporate animals into human ecology, but that it is one useful way to engage existing theories about economic and social development and sustainability. We will not take up the complex ethical issues involved in considering human–animal relationships, but we consider these highly important and necessary for developing any program for social change. Rather, we will develop arguments around the production of human well-being and the several ways in which non-human animals contribute to human well-being. In particular, we will argue that taking animals seriously encourages us to think in new ways about the production function for well-being.[2]

The basic framework of the production function is based on the recognition that humans deploy resources to produce goods and services that enhance their well-being. While the idea of the production function was initially developed to understand how industrial firms operated, the concept was quickly expanded to explain the economic output of nations and, ultimately, the livelihood activities of households (Dietz, 2015). While this might seem an esoteric topic, the logic of the production function is fundamental to much thinking about sustainability. The most common definition of sustainability is usually traced to the Brundtland Report, where sustainable development is defined as a process of development that "meets the needs of current generations without compromising the ability of future generation to meet their own needs" (World Commission on Environment and Development, 1987, p. 23). Meeting the needs of current and future generations requires the production of goods and services. So sustainability theory is essentially asking questions about how current actions will affect the ability of future generations to produce well-being. That question can be made precise by thinking about what is necessary to produce well-being: the production function.

In the classical formulation of the production function, societies or firms deploy three kinds of resources: manufactured resources (tools, equipment, physical infrastructure, etc.), land and labor. In modern terminology, we refer to natural resources rather than land. Sometimes the term human resources is used instead of labor but if we look across the scope of human history, animals have also been an important source of labor. One of the most important debates in sustainability theory—strong versus weak sustainability—is about the degree to which one

2 Of course, humans are animals. But to simplify writing, from this point on in the essay we will typically use the term "animals" to refer to non-human animals.

kind of resource can be substituted for another (Neumayer, 2010). Advocates of weak sustainability argue that it is often feasible to substitute one type of resource for another in the production of well-being. Thus, it might be prudent to deplete natural resources to build up the stock of manufactured resources and human resources for future generations. Advocates of strong sustainability argue that substitution across types of resources is limited and so our obligation to future generations is to provide adequate supplies of all three resource types.

The production function logic also appears in major assessments and policy analyses as well as in the research literature. The central theme of the Millennium Ecosystem Assessment (MEA) is the contribution of ecosystem services to the production of human well-being (Reid et al., 2005; Yang, Dietz, Kramer, Chen, & Liu, 2013; Yang, Dietz, Kramer, Ouyang, & Liu, 2015; Yang, Dietz, Liu, Luo, & Liu, 2013). The relative efficiency of nations, other geopolitical units, communities and even households in producing well-being underlies the literature on Environmental Intensity of Well-Being (EIWB) (Dietz, Rosa, & York, 2009; Jorgenson, 2014; Jorgenson & Dietz, 2015; Lamb et al., 2014; Mazur & Rosa, 1974; Mulder, Costanza, & Erickson, 2005; Steinberger, Roberts, Peters, & Baiocchi, 2012; Vemuri & Costanza, 2006). We believe that by examining how non-human animals participate in the production of human well-being, we can clarify how that process actually takes place and highlight the political struggles around it.

Our work has strong parallels to Gunderson's arguments about the negation of animal needs under the logic of capitalist production, especially his insight, drawn from Adorno (1966), that the domination of nature required for capitalist production is violent (Gunderson, 2013).[3] Our arguments are similar to those of Hribal on animals and agency and the resistance of animals to the labor process (Hribal, 2003, 2007). York and Mancus's examination of the role of non-human animals in the historical trajectory of human societies is a foundational underpinning of our thinking (York & Mancus, 2013). But while these efforts inform our work, our goal is somewhat different. We want to explore the implications of thinking seriously about animals for the kinds of production processes that are at the heart of sustainability theory.

We will begin with an examination of the production of human well-being and the drive for efficiency per unit labor in capitalist production. We then suggest four ways in which non-human animals contribute to the production

3 Use of violence as a means to control the production of raw materials and goods, and access to markets and trade has been a key feature of capitalism (Beckert, 2014; Lough, 1999). So, in a sense, the logic of violence against animals fits with the historical development of capitalism. This is not to argue that other ways of organizing production have not involved violence. Evidence about the amount of violence in food foraging societies is debated (Boehm, 2012; Bowles, 2012; Fry, 2012; Lawler, 2012a; Lawler, 2012b). But at least since the rise of horticulture and certainly with the rise of states dominated by elites, violence has been a tragically common part of the production process, including both organized warfare to appropriate control of resources and violence in the control of human and animal labor.

of well-being and how the drive for efficiency effects each. We conclude with some suggestions regarding the implications of bringing animals into the logic of production of well-being and suggest some questions for further research.

Efficiency in production

The production of human well-being

In its early use the production function was conceptualized around the output of goods from factories, but this was quickly generalized to the overall output of goods and services in a society. In parallel, the output of goods and services came to be equated with utility—the satisfaction produced from goods and services—which is a form of subjective well-being. Thus, the output of the production function was assumed to be equivalent to human well-being.[4]

The basic idea of the production function is that households, firms, communities or nations make use of the resources to which they have access to produce well-being. In many analyses, national well-being is equated with economic output of the sort measured in standard national accounts, such as gross domestic product per capita. For households or firms the desired outcome is measured in income or profits. Efficiency can then be defined as how much output is produced per unit of input.

This formulation—that human well-being is served by deploying manufactured, natural and human resources in production—has long been the basis of policy (Dietz, 2015). The equation of well-being with economic output implies that growth in output, that is growth in profits for firms, gross domestic product per capita for nations and income for households, is socially beneficial. This logic

4 The founders of utilitarianism often argued for considering the well-being of non-humans, and utilitarianism continues to provide an important basis for arguments about animal rights and the treatment of animals (Frey, 2011). But the versions of utilitarianism that have influenced contemporary economics do not take into account the well-being of non-humans except as it effects human well-being.

underpins the politics of the treadmill of production or growth machine that has dominated economic policy in the developed nations at least since World War II (Logan & Molotch, 1987; Schnaiberg, 1980).[5]

While the logic of the production function can be applied to all societies, a key feature of capitalist economies is production for profit. This is what differentiates the idea of capital from the idea of a resource. A resource may be deployed to produce well-being. But under capitalism, the principal goal in using resources is to produce profit. Resources are used as capital to produce outputs that have greater market value than the inputs. As Bourdieu puts it, capital has "potential capacity to produce profits and to reproduce itself in identical or expanded form" (Bourdieu, 2008, p. 280). To use classical Marxist terminology, in capitalist economies, the goal is to produce exchange value rather than use value and to have the scale of exchange value continually expanding.[6]

This leads to the question that underpins our analysis: how do those seeking profit from their use of resources manage the production process to produce profit, and what are the implications of these strategies for animals? Braverman's insightful analysis of the labor process makes clear the conflict between those who are managing the labor process—capitalists and their agents—and the human resources they deploy in the process—workers (Braverman, 1974). We believe his argument also provides insights into the situation of animals in contemporary capitalist production. We begin by sketching his arguments and then turn to its application to animals.

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5 The critique of growth for growth's sake is a central tenant of many analyses of environmental and sustainability issues. We endorse this critique, but we also note that there are many people at present who suffer from material deprivation and would benefit from increased consumption. However, providing more to the poorest people does not require an increase in aggregate consumption—indeed it could be accomplished with a substantial decrease in aggregate consumption—since consumption is very unequally distributed, so that a decline in consumption by the most affluent people in the world would allow for more consumption by the poorest without overall growth. During the historical period when the production function and theoretical interest in growth developed, even the most affluent nations had modest economic output by today's standards. For example, the GDP per capita of England grew from around US$1,540 (in 2005 dollars) in 1700 to approximately US$2,200 in 1800 (Bolt & van Zanden, 2013). In comparison, Egypt's 2013 GDP per capita was US$1,566 and Morocco's was around US$2,500 (both in 2005 dollars). But, of course, even at low levels of affluence growth improves overall well-being if and only if the benefits of growth reach those who are most disadvantaged, which too often is not the case.

6 Of course, much of welfare economics would argue that increased production of exchange values in a market economy will enhance the ability of the population to consume desired goods and services, potentially including leisure and the appreciation of nature and culture, and thus enhance well-being. The relationship between this hypothetical situation in theoretical welfare economics and the processes unfolding in the contemporary world is a critically important topic that is beyond our scope here.

The drive for efficiency

In standard economic analysis, the cost of labor is assumed to be determined by the market for labor. Thus capitalists should structure the labor process so that as much output is produced per unit labor cost as possible. In theory, capitalists and managers cannot directly influence the price of a unit of labor, only how many units of labor they need to produce a given amount of output.[7] They will attempt to increase the efficiency with which labor inputs lead to output. Indeed, output per unit labor is so central to production and the pursuit of profit and growth that in many economic discussions, the term efficiency, used without modifier, means output per unit labor ("labor productivity") rather than output per unit manufactured or natural resource.

Braverman's core argument is that efforts to increase the efficiency of the production process—to rationalize it—involve the deskilling of labor by embedding the skill of workers in routines and in machinery (manufactured resources). This has two advantages for those organizing the production process. First, deskilling and rationalization can increase the output per unit of labor input. For humans, this came first with Taylorism, in which studies of what workers did in the production process was used to simplify tasks and make workers more interchangeable. This rationalization may lead to more effective ways of carrying out the actions of production via best practices. But it also increases control over labor, which can make workers more efficient at producing output in part because they are more easily subject to monitoring and control and are less able to take any actions at work other than those that serve production. Of course, rationalization also can lead to less time-consuming ways of doing things—the way we usually think about increased efficiency.

Second, deskilling what is needed from labor in production greatly weakens the bargaining power of human workers. If workers possess special skills that are hard to acquire, their bargaining position for a share of profits is bolstered by their ability to disrupt the production process by slow-downs, walk-offs, strikes and simply by finding employment elsewhere. But if they are easily replaceable because a new worker can acquire the needed skills very quickly, human workers lose bargaining power and the owners of capital can appropriate a larger share of profits.

From the start, part of the deskilling of labor was to embed more and more complex activities in manufactured resources. This process began during the Industrial Revolution when the skills of craftspeople, such as weavers, were

7 In practice, one major strategy, ironic in a system whose logic is often justified by the effects of competition, is to eliminate or minimize competition by creating oligopolies, oligopsonies, monopolies and monopsonies that allow strong influence on the prices of inputs and outputs rather than accepting market prices.

roughly replicated by machines, notably mechanical looms (Beckert, 2014). It continued in the 20th century with automation and the first industrial robots, and continues to expand as increased capabilities of robots and artificial intelligence displace more and more human skills. Historically, manufactured resources possess no agency. Thus using manufactured resources enhances efficiency via the first strategy—machines do what they are programmed to do. While there may be errors in design that lead a machine or a production system to behave in ways that are not anticipated, it is difficult to argue that manufactured resources follow their own agenda (Latour's efforts to expand the concept of agency aside (Latour, 2014a, 2014b)). This may change as we use increasingly complex and powerful artificial intelligences and robots that might be viewed as possessing some degree of agency (Barrat, 2013).[8] But for the moment, manufactured resources are free of agency that could reduce the ability of their owner to control the production process. So moving skill from human resources to manufactured resources increases control over the production process. There is an equally long history of using machines to displace animals in order to increase efficiency and control. We will discuss this in the next section of the paper.

Bringing animals back in

Having laid out an analysis of the production process, we now turn to how animals contribute to human well-being. For our purposes, it will suffice to distinguish four types of animal contribution: as key components of all of the ecosystems upon which humans depend for survival; as companions; as objects that can sometimes be treated simply as natural resources and at other times rather like manufactured resources; and as labor. As we will see, the boundary between these categories is fluid. The contributions of some species to human well-being might fall primarily into one category. But in general it is an interaction between the evolved (and especially co-evolved) characteristics of a non-human species and a particular form of human engagement with that species that defines how a particular non-human animal contributes to human well-being at a particular time and place.

Animals as part of ecosystems

As the MEA documented, humans depend on ecosystems for survival and the production of well-being in myriad ways. These include direct use through activities such as agriculture and forestry. They also include less direct benefits

8 Ethical obligations towards artificial intelligences and robots is a serious topic of discussion in the community doing research on these systems, addressing questions that go back at least to Isaac Asimov's contemplations on robots in human society; see especially his discussion of whether or not the term "killed" can apply to a robot in *The Robots of Dawn* (Asimov, 1956, 1983)

from ecosystems, including the simple aesthetic appreciation of them, as well as ecosystem processes that regulate climate, water supply, production of soil and much else critical to human well-being (Reid et al., 2005). Animals influence all other components of ecosystems, such as plants and fungi, and thus directly and indirectly influence ecosystem structure and function and biogeochemical processes. For example, worms and nematodes are central to building the fertility of the soil on which humans depend for food and fiber production, and the manure from large mammals is an important source of nutrients for soil. But the importance of animals as part of ecosystems goes well beyond simple and direct contributions such as these, since they are intimately tied in the web of interactions among living and non-living components that make ecosystems function. Without ecosystem services human societies could not survive, and without animals the ecosystems of the world and the biosphere itself would not be remotely like it is. As animal populations change, often as a result of human intervention, the ecosystems and the services humans can derive from them also change with attendant impacts on human well-being.

The effects of production processes on ecosystems are of course a central theme of ecology, human ecology and environmental science. Using ecosystems as a source of raw materials and as a sink for waste changes their structure and function. The MEA estimates that 60% of the types of ecosystem services examined are being degraded or used unsustainably (Reid et al., 2005). More recent assessments reach similar conclusions—human activity is substantially altering the structure and function of ecosystems around the planet with problematic implications for the well-being of both humans and other species (Hughes, Carpenter, Rockström, Scheffer, & Walker, 2013).

Animals as companions

Engagement with species that have co-evolved to interact socially with humans is a major source of well-being for many people. In the case of dogs, *Homo sapiens* and *Canis familiaris* have been domesticating one another for at least 12,000 and perhaps more than 32,000 years (Grimm, 2015; Shipman, 2015). The result is a close and satisfying emotional bond (MacLean & Hare, 2015; Nagasawa et al., 2015). The period of co-domestication has been shorter for other species, but there are many domestic and even liminal species that interact with people in mutually satisfying ways (Clutton-Brock, 2012; O'Connor, 2013).

Of course, the evolution of mutualistic interactions between humans and other animals has often been related to production. Dogs aid in hunting and in guarding their human group and other domesticated animals. Cats prey on mice and other species that consume human food supplies. Birds have been trained for hunting. Horses have been a major source of labor for transportation and agriculture. Indeed, the distinction between horticulture and agriculture in

many areas of the world is defined in part by the use of equids for labor (York & Mancus, 2013). But while animals still fulfill these roles in production in many parts of the developing world, in the developed world most of the benefit from these species is simply from social interaction with them.

In some cases, humans derive substantial satisfaction from observing or even simply contemplating other species without direct interaction. The obvious example is the many species that are classified as wildlife, especially birds and large mammals. Overall, the value to human well-being from interaction with animals and the benefits to humans derived from their existence have been recognized by the MEA as "cultural services" (Reid et al., 2005). The MEA acknowledges that very substantial and important cultural services flow from both human-dominated and relatively pristine ecosystems.

While we are not aware of research on this issue, it may be that contributions to human well-being of animals as companions and objects of contemplation requires that we view those animals as having agency. Although we may become frustrated with some actions of domesticated species, we certainly expect our companion animals to act with some degree of autonomy and even emotional engagement. It may also be that the contemplation of wildlife is in part derived from thinking of those animals—ungulates, large predators, marine mammals, birds and many others—as independent organisms who act as authors of their own lives.[9] If that is the case, then we would expect less success at rationalizing the production of this form of well-being. However, we note that commercial enterprises, whether the production of nature documentaries or marine theme parks, do seem to move towards increased efficiency in the production of engagement with other species. And certainly the pet breeding industry has developed conditions, such as puppy mills, for producing dogs, cats and other species of companion animals at low economic cost although often with great cruelty.

Animals as objects

Animals are also treated as natural resources, and enter into the production of human well-being as a material input, much as a mineral or plant might. In addition, animals, with the ability to produce meat, milk, eggs, fur, wool and other valued materials often play much the same role as some kinds of machines—they transform inputs into more useful outputs. We aggregate both these roles in production into the general category of animals as objects. As both Gunderson and Hribal have shown, an industrial capitalist political economy

9 This creates a special ethical dilemma. There is a long tradition of displaying the animals we consider most interesting in zoos. But if our conjecture is correct and we are most interested in and most enjoy seeing animals that are capable of an autonomous life with agency, then we are confining those species that will suffer most to the limited space and possibility for activity of zoos.

favors organization of production so that all inputs, including animals, can be treated as acting in predictable ways and controlled so as to increase efficiency. We will discuss three forms of the use of animals as objects: as individuals pursued by hunters; as natural resources to be harvested; and as living "processors" that transform input materials into desired output materials. Each of these is somewhat distinct but for ease of explication we have included all three in the general category of "objects."

Many accounts of hunting describe an extensive interaction between hunters and the animals they hunt. Certainly, in cultures where hunting provides a substantial portion of food it seems to be common to treat the hunted animals as individuals with agency who deserve respect and even gratitude.[10] But in large-scale commercial hunting, such as 19th-century buffalo hunting in western North America, the use of "punt guns" for massive killing of game birds, industrialized whaling and much of contemporary commercial fishing, animals are clearly natural resources to be harvested—they are objects. If animals are inputs to a production process, then there will be pressure to reduce the agency of the animal so as to be able to treat it as an interchangeable and predictable object, whether the animal is raised in agriculture or hunted in the wild.[11] This is very evident in the evolution of commercial fishing (Longo, Clausen, & Clark, 2015).

Hunting remains culturally important in some socities, and in some places and for some people is economically important. Harvesting of non-domesticated animals, especially of fish, is also highly significant in some communities and for some countries. But the major contemporary human use of animals as objects is in agriculture. It is still useful to make a distinction between animals we hunt and animals that are domesticated, but we acknowledge that distinction has always been and continues to be blurred. The logic of making the distinction is that hunted animals are under only modest human control and so most efforts to increase efficiency come in the form of the technology, including social organization, of harvesting.

By contrast, in agriculture the full process of production is managed to increase efficiency, and animals are treated rather like machines for transforming inputs into valued outputs. Production processes that use animals in this way include, inter alia, fish farming, feedlots for production of beef, battery cage operations

10 This is not to deny that mass harvesting of animals seems to have been a part of many human cultures. While the role of human hunting in the extinction of Pleistocene megafauna continues to be debated, it is clear that many human societies have at least sometimes deployed hunting methods that in some ways resemble the mass harvesting that occurs under capitalist production.

11 Even trophy hunting, where the claims of hunters nearly always involve engagement with an animal that exhibits considerable agency, seems to move towards rationalization, with "canned" hunts in which the guides and firms being paid to structure the hunt go to great lengths to make sure that the right kinds of animals will be readily accessible to the hunters paying for the experience (Ireland, 2002).

for the production of eggs and confinement of sows. The search for efficiency leads to carefully researched regimens of food, supplements and medications to maximize production per unit input. And here too, the agency of the animal to do anything except produce the intended product is sharply restricted, typically with highly crowded conditions and limitations on the ability of the animal to pursue its own intentions, to interact with conspecifics and even to move. These conditions are well documented; we are simply noting that this is one more example in which the drive for economic efficiency in the production of outputs desired by humans leads to restrictions on animal agency and often to violence and cruelty.

Animals as workers

The fourth role in which animals contribute to human well-being is as workers. Throughout most of human history, animals have had a special role in the production of goods and services, acting as a form of labor that complements the labor of humans. We want to interrogate that role and its contribution to production, and to consider how the role of animals focuses attention on some general processes in the evolution of production in a capitalist political economy.

Thinking about agency and skills in production has usually considered only human resources. But non-human animals possess agency and in some cases skills that can contribute to the production process. In pre-industrial capitalist production systems, this agency could be deployed to good effect at least some of the time. Many domesticated animals act in ways that facilitate their use to produce human well-being precisely because humans and these animals have co-evolved in ways that might be considered mutually beneficial. Horses can follow routine paths with minimal direction, sheep and cows can be readily herded, cows want to be milked, cats are autonomous hunters of mice, and dogs in particular interact with humans more as partners than as automatons. Of course, anyone who has worked with any domestic animal will know that animal agency is not always at the service of the production of human well-being. Animals act in idiosyncratic ways that occasionally can be dangerous, vexing and somewhat inefficient when they are viewed as a resource used for production. Thus the history of human interactions with domestic animals involved the invention and refinement of methods to exert control over the agency of domestics—sometimes gently, sometimes cruelly (Clutton-Brock, 2012). Hribal (2003, 2007, 2010) elucidates the many forms of resistance that animals have offered as well as the many forms of control humans have exerted over them.

Unlike human workers, animals who are part of the production process cannot organize to represent their own interests. They cannot bargain for a larger share of profits, so they are not a threat to efficiency per unit labor cost in the way organized human workers can be. But, animals can behave idiosyncratically and

in that way reduce control over, and thus the efficiency of, production. Thus, a key dynamic of animal agriculture since World War II is increasing reduction in the ability of animals to act with agency and behave idiosyncratically. Just as the dynamic of ever-increasing efficiency leads to making the tasks of the human worker more routinized, predictable and controlled by management, so the tasks of non-human animals engaged in the production process become more uniform and more tightly controlled. Animals are treated more like machines or raw materials with predictable characteristics for the production of biological products than as independent organisms with distinct characteristics (Boyd, 2001; Gunderson, 2013; Hart & Mayda, 1998; King, 2000; MacDonald & McBride, 2009). That is, animals have moved from being more or less like human labor in the production function to being more like manufactured or natural resources; the same process Braverman has documented for human workers. The tendency has been to convert animals used as labor into animals used as objects that transform raw materials into desired products.

Implications of animals in the production function

Our basic argument is that resources become capital when they are organized to produce profit and growth. We then note that some types of resources—humans and many non-human animals—actively resist control by those organizing the production process. Thus to increase the efficiency of the production process, those seeking to use resources as capital have to find a way to either reduce their need for resources with agency or to reduce the resources' agency. We believe that this has a number of implications for human ecology and for sustainability theory.

Resources become capital through the exercise of power. Which resources can be treated as capital and controlled by managers and owners, and which remain as labor acting with agency, is not an inherent feature of the resource; rather, it depends on the social and technological organization of the production process. The use of a resource as capital often emerges from an interaction between the features of the resources and the social rules in play—norms and institutions—in a particular time and place. For too much of human history, humans were treated purely as capital in a production process via the institution of slavery. But of course the history of slavery is also a history of resistance, revolt and efforts to bring about abolition. Concerns with the treatment of non-human animals were often linked to efforts to end slavery (Hribal, 2003, 2007). There were also independent moves to protect animals, with the first laws against cruelty toward animals enacted in Ireland in 1635 (Kalof, 2007).

But there is of course a major difference between human and non-human animal resources. While some humans struggle on behalf of both humans and non-humans who are ill-treated, and both humans and non-humans have some capacity to directly resist efforts to control them, non-humans do not organize slow-downs, walk-outs, strikes or political movements, nor can they quit to seek "employment" elsewhere. Animals may resist control but they do not organize collective actions with demands for change. They are dependent on social movements and changes in moral norms in human societies to advance their interests. But the larger point remains: the production function is shaped not just by technology and scientific principles but also by laws, norms and institutional arrangements, especially those affecting the ability to shape the behavior of those in production who can exercise agency. Schnaiberg (1980) and neo-classical environmental economists have shown that profits can be increased by ignoring the environmental costs of production. So too profits can often be increased by reducing the agency of humans and non-human animals in production and ignoring the loss of well-being for some humans and animals that results.

Non-human animals complicate the logic of the production function. The agentic nature of at least some animal participation in production suggests a supplemental dimension exists beyond the simple tripartite distinction of manufactured, human and natural resources. We can ask the degree to which a resource can exert agency of either the first (organizing) or second (disruption of routine) type. The answer to this question is not entirely determined by the nature of the resources; it also depends on the political organization of the production process. Some humans—highly skilled workers organized into powerful unions—can exert substantial agency. Sometimes that agency is a drag on efficiency in the traditional sense of output per unit labor, although those inefficiencies may result from changes in the production process that enhance human well-being beyond what more efficient output would yield. While the labor costs of some goods or services may increase, making the goods more expensive, this might be the result of changes in working conditions and incomes that overall enhance well-being more than the increase in prices degrades it. In other cases—such as with low-skill workers with no political power drawn from a large labor pool—the ability to organize is minimal. But even when workers lack political power, they still have varying degrees of ability to act idiosyncratically—much depends on the technology to monitor their actions.

Most natural resources—e.g., minerals—have no agency. But animals are an exception. Indeed, where animals fit in the tripartite division of manufactured, natural and human resources is problematic. As we have argued, most contemporary processes that pursue "wild" animals as game attempt to treat

them as natural resources in the traditional sense—inputs with no agency. The same is true of domesticated animals where the general trend in animal agriculture has been to reduce any agency on the part of animals.

Before agriculture was mechanized, animals used as labor have been a key part of the production process and such labor is still important in the developing world. But since the Industrial Revolution most animals used to provide power in the form of plowing, pulling loads, turning winches and so on have been replaced by machinery, and in the last 150 years that machinery is driven largely by fossil fuels. Of course there are substantial engineering advantages to using a machine rather than an animal as a source of mechanical power. But there is also an increase in efficiency based on the removal of animal agency from the production process.

Since the middle of the 20th century, great effort has been made to increase the efficiency with which animals used as objects produce meat, eggs and dairy products. This has been the result of selective breeding for genomes better suited to human needs, use of feed supplements and antibiotics, and the design of technologies such as the feedlot, the battery cage and the gestation crate, that maximize the output per animal by decreasing any freedom or agency the animal has to engage in activities that would reduce production of the desired product. In parallel to Braverman's analysis of the rationalization of human labor, the production of meat, eggs and milk has been designed to ensure that the animals engage only in those activities that maximize output and thus profit. Now, experiments are underway for the in vitro production of foodstuffs including "animal" protein. As Gunderson notes, in the long run, this may change the conditions of animals in agriculture, reducing the need to treat animals as machines or raw materials (Gunderson, 2013).

Coda

Our major point is that ignoring the role of animals in production processes likely misrepresents those processes. In contrast, thinking about non-human animals as well as humans as resources for the production of goods and services raises at least two important issues that, while not invisible from other perspectives, at least are less sharp. The first of these is that agency can be a source of resistance to the rationalization of production in two ways. On the one hand, humans may actively organize to represent their interest and demand both changes in the production process and an increased share of profits. On the other, both humans and many non-human animals also exert agency by behaving in ways that are not fully predictable and thus interfere with strategies to get them to

behave more like machinery. While the same strategies are sometimes effective at minimizing both forms of agency, and while the two forms are not wholly distinct, we feel it is nonetheless useful to consider both.

Second, we have noted that monitoring, controlling and standardizing the actions of humans and other animals is important in improving efficiency and profits. While such efforts may increase output per unit of human and animal resource used in production, this should not be conflated with an increase in the well-being of humans and other animals for at least two reasons. First, this process reduces the ability of human workers to bargain for a share of profits and thus may exacerbate inequality. Second, both human workers and animals often suffer in small and large ways, from boredom and alienation to experiencing injury, pain and even death as a result of the drive for efficiency. Gunderson makes this point about the cruelty involved in the rationalization of animal agriculture (Gunderson, 2013). So while an increased availability of goods and services may contribute to enhanced human well-being, at least in some circumstances, the increased suffering that may accompany increased productivity reduces well-being. This suggests new questions for the Environmental Intensity of Well-Being research program: Does decreased use of animals as a form of labor increase human well-being? Does increased use of animals as a "raw material" (natural resource) lacking agency increase human well-being? Is there a way to take account of the well-being of non-human species in the EIWB program?

These remarks are only an initial foray into these issues. Our arguments may be flawed in detail and we have certainly not done justice to the existing literature. But we hope that they make clear that structural human ecology and sustainability theory, as they evolve, should take "the animal question" seriously. It is important in its own right on both scientific and ethical grounds. And it has the potential for highlighting conceptual issues that might otherwise be hard to see.

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How Does Information Communication Technology Affect Energy Use?

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Abstract

In recent decades there has been considerable optimism that information communication technologies may lead to structural transformations of production, consumption, and transportation systems, helping to reduce energy consumption. Here we analyze the effects of information communication technologies on energy production and consumption as well as on the number of cars used in nations, analyzing data for 1990–2012. We find that the prevalence of landline phones is positively associated with higher levels of energy and electricity production and consumption, that the extent of Internet use is positively associated with the number of cars on the road, and the ubiquity of cell phones is not associated with the number of cars or with electricity or total energy production and consumption. These findings suggest that information communication technologies have not typically contributed to environmental reform and, in fact, may have exacerbated some environmental problems.

Introduction

Technological innovation has long been regarded as a mechanism with the potential to increase the efficiency of production systems. With the rapid expansion of information communication technologies (often referred to by the acronym ICTs) in recent decades, such as Internet access and cell phones, there has been considerable enthusiasm that these technologies will offer important contributions toward addressing many environmental problems and concerns faced by modern societies. In this paper, we assess the relationship between information communication technologies and the energy use of nations. We develop national-level panel models to assess whether these technologies have produced positive environmental outcomes.

Research on environmental problems has become an area of growing interest in the natural and social sciences. Commonly, the development, application, and diffusion of technologies are regarded as central components for advancing social and ecological sustainability. That is, technological change is considered to be a central tool for postponing, alleviating, or solving ecological problems. Within science and policy circles, this postulation is sometimes referred to as "technological optimism" (Foster, Clark, & York, 2010). Although the social sciences have developed theoretical approaches that are more nuanced, the role of technology is often at the forefront for understanding environmental problems and proposed social reforms for addressing them (Fisher & Freudenburg, 2001; York & Clark, 2010).

In the social sciences, some economists have advanced theories that suggest technological innovations together with open markets will lead to continually advancing systems of production and consumption that can overcome any natural limits (Simon, 1981). In the area of environmental concerns, these economic theories submit that market forces will provide the most efficient outcomes when technologies are developed and applied in order to meet market demands, which include the demand for a cleaner and safer environment. Free markets are purported to prompt behaviors in social agents (individuals and firms) that improve the efficiency of production and consumption. Technologies are applied in this context with an eye toward advancing self-interest and profits. In doing so, new technologies are expected to advance the substitution of lower cost inputs and production processes for those that are more costly and less efficient, which are expected to benefit both producers and consumers. New technologies can increase environmental benefits by proportionately reducing material and energy throughputs due to more cost-effective production that reduces the natural resources necessary per unit of output. Also, by shifting from usage of resources that are overexploited and scarce (and thus more expensive), to more abundant or human-produced alternatives, environmentally beneficial improvements are anticipated.

Sociologists have also developed theoretical approaches that consider the effects of technological change on environmental outcomes. Here we consider the applicability of one of the leading theoretical perspectives in environmental sociology: ecological modernization theory (Mol & Spaargaren, 2000). The foundations of this approach lie in theorizing on the process of modernity and its relationship to the biophysical environment. The approach contextualizes the environmental conditions in the modern era. According to ecological modernization theorists, modernity has been associated with not only harmful, but also beneficial developments for humans and the environment. Thus, supporters of the theory have often been critical of research that

ignores the potential for the institutional processes of modernity to respond to environmental concerns and ameliorate human impacts on the environment (Mol, 2002).

Ecological modernization theory has advanced an approach that considers the various institutional forces that are at work in modern society and their relationships to environmental change. Among other important contributions, researchers have defined a variety of social processes that can direct societies toward environmental reforms. These processes include the increasing importance of market dynamics and economic agents (both producers and consumers); the changing role of the nation-state; modifications in the position, role, and ideology of social movements; and changing discursive practices and emerging new ideologies. In the context of these modernizing institutional processes, technological change has increasing potential to address existing and emerging environmental problems (Fisher & Freudenburg, 2001). Ecological modernization theory develops a multi-level explanation of environmental outcomes in which economic practices in the realms of production and consumption, political change, and cultural processes interact to further the capacity for an ecologically sustainable modernity.

The potential for technological change, such as those in the information communication sector, to advance social and ecological sustainability in the context of a growing capitalist economy is a principal tenet of economic market-based theories and ecological modernization theory. Technological change obviously plays an important role in producing what ecological modernization theorists have called "ecological rationalities" (Mol & Spaargaren, 2000), whereby there is the potential for dematerialization of production and consumption, or a decoupling of the economy and the environment, and natural resources and waste emissions are reduced even as the economy continues to grow (Mol, 2002; Jorgenson & Clark, 2012). With information communication technologies, dematerialization can come about, for example, as new communication technologies optimize production processes, eliminate redundancies and waste, and reduce travel and commuting. Further, information production and consumption are often considered "distinct from material and energy," and can act as substitutes for physical resources (Berkhout & Hertin, 2004, p. 905).

However, other theories in environmental sociology are skeptical of the claims made by ecological modernization theorists. Critical environmental sociological approaches offer competing theoretical explanations for the relationship between technological development and environmental problems in the modern era. These theoretical traditions, including human ecology, treadmill of production, and metabolic rift, are less optimistic about how technological change can lead to meaningful environmental benefits in capitalist economies (Foster, Clark, & York, 2010; Schnaiberg, 1980; York, Rosa, & Dietz, 2003a, 2010).

Making use of the logic of the I=PAT (Impacts = Population x Affluence x Technology) model and its stochastic transformation, STIRPAT model, the human ecology tradition theorizes technology's effect on the environment in a multiplicative relationship with other variables, and thus it is a sort of wildcard variable, one that can either decrease or increase environmental impacts (York, Rosa, & Dietz, 2003a, 2003b). Treadmill of production theory emphasizes the growth dynamic in modern economies. This theory suggests that a coalition of social interests, including private corporations, labor, and the state, combine to continually advance economic growth, which drives increasing environmental inputs (e.g., pollution) and withdrawals (e.g., clear cut forests). Further, these theorists suggest that research and development in technology are biased toward those that increase productivity (and consequently displace workers), which accelerates the treadmill of production, since growth in production is needed to avoid an unemployment crisis (Schnaiberg & Gould, 1994). Other critical environmental sociological perspectives, including metabolic rift, suggest that technological development under capitalist social relations primarily serves capital accumulation (Foster, 1994; Foster, Clark, & York, 2010). Therefore, ecological benefits are often sacrificed for profits. Further, capitalist development is generally inclined toward a paradox of increasing technological efficiency of production (due to the motivation to decrease costs), but also increasing aggregate resource use driven by the growth imperative of capital (Foster, Clark, & York, 2010; Longo, Clausen & Clark, 2015; York, 2006).[1]

In this paper, we examine the competing claims of ecological modernization theory and critical environmental sociology in relation to structural changes in economic processes associated with information communication technologies and ecological outcomes. In particular, we look at the relationship between Internet usage, phone lines, and cell phone use and levels of energy production and consumption, including an analysis of electricity and of car ownership. Drawing on these theoretical approaches, we test the hypothesis that information communication technology, particularly cell phones and Internet use, serve to reduce the production and consumption of energy in nations.

1 Scholars have referred to this as the "Jevons Paradox," named after the 19th-century economist William Stanley Jevons, who observed that increasing efficiency of coal production led to increases in coal consumption, not decreases, due to the growth in coal-fueled technologies outpacing efficiency. Modern economists and others sometimes refer to this dynamic as the "rebound effect," which we mention later in the paper (see Clark and Foster, 2001; Plepys, 2002).

Information communication technology and the environment

Over the last several decades, environmental researchers have been increasingly interested in examining the potential for new technologies to alleviate environmental concerns related to energy production and consumption. Modern energy systems rely primarily on burning fossil fuels. These technologies have made a central contribution to industrial development. Fossil fuel energy production systems have been fundamental in furthering economic development throughout the world. However, it is widely recognized that fossil fuel combustion is also at the center of numerous environmental problems, including global climate change.

As a result of the severe social and ecological consequences of modern energy production systems, there are growing efforts in the scientific research community and policy circles to find solutions through technological change. As such, increasing the efficiency of energy use has been a leading policy approach in these matters. Methods of reducing the intensity of energy consumption in relation to economic output are a way to continue socioeconomic development, while reducing the associated environmental costs (Ghosh, 2002; Mathiesen, Lund, & Karlsson, 2009). In the social science research on economic development, economic growth is a central factor for maintaining and expanding the well-being of populations both in the wealthy nations of the global North, and the less wealthy nations of the global South. Therefore, understanding the potential for technologies to reduce the energy intensity of production and consumption within a nation is viewed as a key area for tackling modern environmental concerns such as climate change (Goldemberg, 1998).

The growth and application of information communication technologies over the last several decades has been significant, and are often seen as important developments in relation to addressing climate change. New information communication technologies such as the Internet and cell phones are considered essential to enhancing the efficiency of existing systems of energy production, as well as to developing new energy technologies that can decrease energy use (Walker, 1986). The advances in information communication technologies are expected to produce economic expansion that is decreasingly tied to expansion of energy consumption (Romm, 2002). For example, production and consumption of information can increase, but require less energy use than might be applied to material production and consumption. Researchers argue that powerful new information technologies in advanced capitalist nations will be associated with new production practices, "raising the efficiency with which energy is used in many parts of the economy" (Walker, 1985, p. 458).

In an analysis developed for the Center for Energy and Climate Studies, Romm et al. (1999) presented an enthusiastic analysis of the increasing benefits offered by the information technology sector. This report and a follow-up article based on it (Romm, 2002) contend that growth in the information technology sector will lead to energy efficiency and will have important implications for developing solutions to climate change for two reasons. First, the information technology sector is an area of the economy that is less energy-intensive than other areas of the productive economy, such as manufacturing. Second, new information technologies will make other areas of the economy more efficient by producing new innovations that will increase energy saving (and greenhouse gas curbing) practices in production. These latter changes are particularly important as they point to the structural changes in the economy that will alter the energy characteristics of production. The spread of Internet access, new hardware, and software systems will promote economy-wide structural change, resulting in the dematerialization of production. As the economy shifts toward a greater share of production in more energy efficient information technology sectors, it will (at the same time) make other economic sectors more efficient. Thus, technological transformations will make "e-materialization" possible (Romm, 1999). That is, dematerialization will occur through developments in information communication technologies.

Researchers submit that information communication technologies can structurally affect the energy intensity of a society by altering production and consumption systems (Romm, 1999; Laitner & Ehrhardt-Martinez, 2008). This suggests that the growth in information communication technologies fundamentally modify the methods and organization of production and consumption. For example, the expansion of Internet and cell phone technologies can reduce automobile usage and dependence as it promotes online shopping, decreases trips for errands and entertainment (for example, banks, libraries, or movie theaters), and promotes telecommuting for workers and online courses for students. As automobile use is a major contributor to greenhouse gas accumulation in the atmosphere, these deviations from previous practices can reform the structure of the economy in a more environmentally sustainable manner.

Laitner (2002) notes that, in the United States, significant gains in energy efficiency have been made during the late 20th and early 21st centuries, and considers whether information and communication technologies have "significantly reduced the nation's energy intensity" (Laitner, 2002, p. 15). The analysis concluded that the "initial evidence with respect to information technologies appears to support a trend toward decreasing energy intensity" (Laitner, 2002, p. 20). Similarly, Laitner and Ehrhardt-Martinez (2008) assert that information and communication technologies have played an important role in significant energy savings throughout the U.S. economy. They argue that these

technologies have been critical to increasing energy efficiency and reducing waste. The authors point out that there has been growing attention paid to the energy-consuming aspects of information and communication technologies (for example, server farms), calling this "the ICT energy paradox." They suggest that the focus should be on the energy-saving capacity that will result from the widespread application of the new technologies in production processes (Laitner & Ehrhardt-Martinez, 2008, p. 48).

In fact, numerous researchers have considered aspects of this energy paradox and other paradoxes associated with information communication technology and the environment (Berkhout & Hertin, 2004; Fuchs, 2008; Hilty et al., 2006; Moyer & Hughes, 2012; Plepys, 2002). The indirect effects of information communication technological development can result in increased efficiency and dematerialization, such as improving the productivity of labor, capital, and natural resources, as well as structural changes to an economy, including consumer behaviors (Berkhout & Hertin, 2004; Hilty et al., 2006). Even while these processes are driven by the desire to reduce costs, it is suggested that they tend to have positive environmental benefits as they can be, for example, less polluting (Berkhout & Hertin, 2004). However, the information communication technology can also have direct effects, or first-order effects, from the manufacture and use of the technology, which may be environmentally damaging (Hilty et al., 2006). Producing technologies such as semi-conductors and liquid crystal displays, for example, can result in increased energy and resource use and toxic emissions (Berkhout & Hertin, 2004). Thus, the dematerializing effects and re-materializing influences must be assessed in tandem.

Moyer and Hughes (2012) maintain that advances in information communication technologies can concurrently improve economic productivity and reduce energy intensity. However, they argue that in order to substantially reduce carbon emissions and address concerns related to climate change, innovations in these technologies must be coupled with a global price on carbon. Accordingly, new information communication technologies must be accompanied by new environmental policies that will together provide potential environmental benefits.

Others have examined the ways in which information communication technologies can increase efficiency and economic growth, but paradoxically result in rebound effects in the energy sector (Plepys, 2002; Hilty et al., 2006). That is, the reduction of energy costs can spur increases in production and consumption that impede the potential improvements in environmental outcomes. Plepys (2002) suggests that there may be too much optimism about the positive role of information communication technologies regarding environmental impacts.

This research contends that direct and especially higher-order impacts on the economy and the environment should be better understood, illustrating the complexity of the relationship between technology and environmental impacts.

Fuchs (2008) considers the potential for new information communication technologies to foster environmental sustainability and contends that economic processes associated with advancements in technology have generally prioritized profit maximization. As a result, they have not always had the positive effects that many have hoped for, particularly in the global South. The benefits of information and communication technologies on the environment are shaped by economic imperatives, and thus environmental sustainability is not an inevitable outcome (Fuchs 2008).

Similar to our present study, Sandorsky (2012) models the effects of information communication technologies in 19 "emerging economies." The study employs three per capita measures of information communication technologies: the number of Internet connections; the number of mobile phone subscriptions; and the number of personal computers. The study finds that use of information communication technology has a positive and significant relationship with energy consumption (Sadorsky, 2012). Further, in an assessment of worldwide electricity consumption of information communication technologies from 2007 to 2012, researchers found that "combined electricity consumption of communication networks, personal computers and data centers is growing at a rate of nearly 7% per year (i.e., doubling every 10 years)" (Heddeghem et al., 2014, p. 75). Thus, while there have been continuing efforts toward increasing energy efficiency, total energy consumption in the sector increased over this period of time (Heddeghem et al., 2014).

The body of research we have reviewed suggests that information communication technologies may lead to reductions in energy use. However, this literature also points to the possibility that these technologies may be ineffective at bringing about environmental benefits due to structural characteristics of the global economy that prioritize profit maximization and potentially subvert the benefits that may come from technological developments. Here we contribute to this scholarly discussion by empirically assessing the degree to which information communication technologies have been associated with levels of overall energy production and consumption, electricity production and consumption, and the number of cars in nations around the world.

Data and methods

We use national-level panel models to assess the relationship between three different types of information communication technologies (phone lines, Internet usage, and cell phones) and five different dependent variables that measure different aspects of energy use or that are closely connected with energy use (energy use per capita, energy production per capita, electricity production per capita, electricity consumption per capita, and the prevalence of passenger cars).[2] To the extent data allowed, we analyzed data from 1990 to 2012, the most recent year for which data are available for most nations. We include all nations and time points in the specified time range for which there are data on all variables, or for which we could reasonably interpolate data, in the models.

The sample of nations varies somewhat across models based on data availability, ranging from 121 to 135, and not all nations have data for all years. In all models the sample of nations includes those that contain the vast majority of the world's population, economic activity, and energy production and consumption.

We estimate fixed effects panel models using the Prais-Winsten correction for first order autocorrelation, including dummy variables for each year to control for period effects. We also include a suite of independent variables commonly employed in research on energy use as controls. All of our data come from the World Bank's (2014) World Development Indicators.

Dependent variables

For each of the five models we estimated the effects of the independent variables on unique dependent variables. In the first two models we employ measures of energy production and consumption as dependent variables. The first model tests for the effect of the independent variables on energy use per capita. This variable represents forms of primary energy consumption—including fossil fuels, combustible renewables and waste, and primary electricity (e.g., nuclear and hydropower)—before conversion to end uses and is equal to indigenous production plus imports minus exports. The second model employs energy production per capita as the dependent variable. This variable reflects indigenous production of the same forms of energy accounted for in energy use. Both of the above variables are measured in kilograms of oil equivalent.

In the third and fourth models, we use measures of electricity consumption and production per capita. The electricity variables are measured in kilowatt-hours. We utilize a measure of automobile dependence in the final model: passenger

2 Unlike Sandorsky's (2012) study, which examined only 19 emerging economies, we do not include personal computers since the data are not available for most of the nations/times we examine here.

cars per 1,000 people. This measure includes road motor vehicles, excluding two-wheelers, designed for carrying nine or fewer passengers. Data on this final variable are only available for 2000 to 2011. The five dependent variables we examine are fairly closely connected (see Table 1 for a correlation matrix for the year 2000), but each measures a distinct aspect of the energy production and consumption system in nations.

Table 1. Pairwise correlation (Pearson's r) matrix of dependent variables for the year 2000

	1.	2.	3.	4.	5.
1. Energy use p.c.	1.000				
2. Energy production p.c.	0.743	1.000			
3. Elec. Consumption p.c.	0.835	0.508	1.000		
4. Elec. Production p.c.	0.776	0.538	0.943	1.000	
5. Cars per 1000 people	0.660	0.224	0.752	0.672	1.000

Independent variables

The independent variables included in all models consist of the three variables of interest along with a variety of control variables. The first variable used as a measure of information communication technology is phone lines per 100 people. Telephone lines report the number of connections to the telephone system. Next, we use a measure of cell phone usage per 100 people. Cell phones report the number of subscriptions to mobile phone services. The third variable of interest associated with information communication technology is Internet users per 100 people. Internet users are people who have used the Internet in the last 12 months. Where missing values were reported at the beginning of the time series, they were imputed to be 0. Missing values in the series after the first measured value were interpolated assuming a linear trend. The imputation of missing values increases the observations in each model by about 10%, except for the cars model, where it adds only 14 observations. Note that the substantive findings we report below are the same if the imputed values are excluded. Internet users per 100 people has a high correlation (Pearson's r = .86) with Internet subscribers per 100 people, so the two are similar measures. Internet users variable is used instead of subscribers because it has more than 50% better data coverage. These three key independent variables (phone lines, cell phones, and Internet users) are fairly highly correlated with one another, with pairwise correlations among them ranging from .82 to .86 for the year 2000, indicating

they are closely connected; although clearly based on face validity they each measure a different aspect of the information communication technology system of nations.[3]

The control variables included in the models have been established to be the primary forces influencing energy use variously measured. As a measure of national affluence, we include GDP per capita in 1,000s of constant year 2005 U.S. dollars and the quadratic of GDP per capita. The quadratic of GDP is used to allow for a non-linear relationship between GDP per capita and the dependent variables. This is a common method used to test for the presence of Environment Kuznets Curve (EKC). The EKC is an inverted "U" shaped distribution that has been used to assess potential non-linear effects of economic growth on various environmental outcomes (Dinda, 2004). We also include the percentage of GDP that comes from the industrial sector and the percentage of GDP that comes from the service sector to control for the structure of the economy.

We also include measures of global economic activities that can affect energy production and consumption in our models: the value of imports as a percentage of GDP, the value of exports as a percentage of GDP, and foreign direct investment inflows as a percentage of GDP. Demographic variables included in the models are the percentage of the population living in urban areas, and the age dependency ratio. Finally, we include a measure on military expenditures as a percentage of GDP.

Results

The results of our analyses are presented in Table 2. Since our focus is on information communication technologies, we will only very briefly comment on the effects of the other variables. GDP per capita is clearly significant in each model, as is its quadratic. While the negative quadratic term suggests that the effect of economic growth on the dependent variables attenuates as GDP per capita rises, in all models the projected turning point on an EKC is over $60,000, a value beyond the reach of most nations. In most models, most of the other control variables do not have significant effects. The exceptions are: energy use is affected by urbanization and the age dependency ratio; energy production is

3 These correlations are not sufficiently high to raise concerns about multicollinearity. It is difficult to assess the extent to which multicollinearity may affect results in fixed effects panel models since statistics like the VIF cannot be calculated in a straightforward way due to how variance is parsed across units and over time. However, indications are that multicollinearity is not a serious problem in our models. For example, if all of the observations (nation-years) are simply pooled and analyzed using a standard OLS regression model instead of using a panel approach, thereby allowing for the estimation of VIFs, no variable has a VIF in excess of 10, except for GDP per capita and its quadratic, which is to be expected.

affected by industrialization, imports, and exports; electricity consumption is affected by FDI inflows and the age dependency ratio; and electricity production is affected by the age dependency ratio.

Table 2. Fixed effects panel regression analyses of per capita energy use and production, per capita electricity consumption and production, and passenger car ownership per 1,000 people for most nations of the world, 1990–2012

Independent Variable (I.V.)	Energy use per capita Coef. (S.E.)	Energy prod. p.c. Coef. (S.E.)	Electricity cons p.c. Coef. (S.E.)	Electricity prod. p.c. Coef. (S.E.)	Cars per 1,000 Coef. (S.E.)
GDP pc (1,000$)	171.565*** 17.100)	748.530*** (50.093)	175.267*** (17.311)	271.987*** (27.788)	9.061*** (1.757)
(GDP pc)^2	-1.059*** (0.181)	-4.601*** (0.522)	-0.365* (0.186)	-1.905*** (0.311)	-0.069*** (0.020)
Urban pop. (%)	-21.704* (10.097)	63.437 (39.544)	-2.284 (10.005)	13.551 (12.407)	0.540 (0.660)
Indust. (% GDP)	2.318 (2.323)	15.951* (6.537)	1.750 (2.347)	3.094 (6.546)	0.037 (0.485)
Service (% GDP)	2.472 (2.183)	5.160 (6.167)	1.916 (2.212)	-7.811 (6.094)	0.369 (0.409)
Imports (% GDP)	-1.244 (0.951)	-15.726*** (2.688)	1.026 (0.967)	-2.782 (2.329)	-0.247 (0.168)
Exports (% GDP)	1.222 (1.115)	18.612*** (3.159)	-0.371 (1.135)	-0.260 (2.655)	-0.157 (0.210)
Military exp. (% GDP)	0.389 (4.203)	-1.467 (11.769)	-0.073 (4.249)	3.242 (10.697)	0.676 (1.697)
FDI inflows (% GDP)	0.512 (0.746)	-1.784 (2.094)	2.877*** (0.765)	1.383 (1.920)	-0.116 (0.092)
Age dep. ratio	-22.307*** (5.491)	29.580 (19.159)	-16.509** (5.415)	-15.719* (7.655)	0.266 (0.620)
Phone lines (per 100)	9.319** (2.982)	40.115*** (8.710)	13.374*** (2.968)	18.651*** (4.580)	0.462 (0.343)
Cell phones (per 100)	1.135 (0.662)	-3.410 (1.910)	1.177 (0.662)	0.819 (1.210)	0.159 (0.085)
Internet users	-2.327 (1.414)	-0.629 (4.153)	1.065 (1.393)	1.691 (2.242)	0.683*** (0.187)
R^2 (w/b/o)	0.154/0.194/ 0.040	0.191/0.120/ 0.074	0.286/0.433/ 0.114	0.194/0.006/ 0.004	0.205/0.096/ 0.002
N/countries	2148/135	2111/124	2077/124	2111/124	965/121

Notes:

- * p<.05, ** p<.01, *** p<.001
- Models correct for AR(1) disturbances using the Prais-Winsten method. The model for car ownership uses data for only 2000 to 2011.

Focusing on the information communication technologies, the prevalence of phone lines stands out as the most generally influential, having a positive significant effect on all dependent variables except cars. Cell phone access does not significantly affect any of the dependent variables. The number of Internet users does not have a significant effect on any dependent variables except for the number of cars, where its effect is significant and positive. Taken together, the results provide no support for the hypothesis that the rise of information communication technologies will help conserve energy resources, and even suggest that information communication technologies may spur greater resource use.

To assess the robustness of these findings with regard to model and error specification, we took two approaches. First, we estimated less saturated versions of the models presented here, where some of the control variables that were not significantly influential were removed from the models so as to improve statistical power. Second, we estimated models that instead of correcting for autocorrelation, corrected for errors clustering by nation. In general, these approaches produced models where the direction of effect was the same for the three key information communication technology variables as in the models presented here, but the significance level did differ in some cases. In some model/error specifications the effect of cell phones was statistically significant and positive. In contrast, in some model specifications the effect of Internet users was significant and negative. This latter finding does provide some support for the claim that information communication technologies can have some beneficial effects on resource conservation, but since it is coupled with the opposite finding that cell phones spur resource use, the overall picture remains the same as that suggested by the main models we present here: there is not substantial support for the claim that information communication technologies are generally helping to conserve energy resources.

Discussion and conclusion

Growing concerns about climate change and other environmental problems have promoted efforts to develop ways to reduce fossil fuel use. A central approach for addressing this issue has been the development and application of new technologies that will allow for more efficient production in terms of the amount of energy use in relation to economic output. As Laitner and Ehrhardt-Martinez (2008, p. 53) have noted, "Energy efficiency is not about doing without energy resources, but about extracting greater value from our energy resources whether we put them to work as kilowatt-hours of electricity or gallons of gasoline."

While there are multiple avenues for pursuing such goals, some economists and sociologists have suggested that a fundamental way to achieve this is through the dynamics of markets and technological change.

In regard to information communication technologies, their growth has generally been suggested to stimulate the expansion of energy efficiency, which can serve as a way to mitigate environmental concerns like climate change. These technologies have been considered important tools in developing more energy efficient production systems. Through both the application of new, less energy-intensive production processes that include or are supported by information communication technologies, and changing the structure of the productive system, they can aid in decreasing general energy needs through mechanisms such as telecommuting or information communication systems. As a result, there is greater potential for the dematerialization of production.

We analyzed the effects of information communication technologies on energy production and consumption as well as on the number of cars used in nations, analyzing data for 1990 to 2012. We found that the prevalence of landline phones is positively associated with higher levels of energy and electricity production and consumption, and that the extent of Internet use is positively associated with the number of cars on the road. Also, the ubiquity of cell phones is not associated with the number of cars or with electricity or total energy production and consumption. These findings suggest that information communication technologies have not typically contributed to environmental reform and, in fact, may have exacerbated environmental problems. Thus, technological development in this sector has not necessarily advanced ecological modernization in the manner that the theory might expect. However, our results should be taken as preliminary, since some exploratory analyses we have done using different model specifications suggest the prevalence of Internet users may help to suppress some resource use, although these alternative models also suggest cell phone usage may serve to increase some types of resource use. Future research using more nuanced models and methods may be able to refine our findings and detect more subtle effects. Nonetheless, the overall picture presented by our results is that information communication technologies have not proven to be clearly beneficial for resource conservation.

Critical environmental sociologists have been skeptical of the ecological benefits of technological development in the modern socioeconomic context. Those drawing on the treadmill of production have theorized that modern capitalist production systems are geared towards growth, which usually occurs at the expense of the environment (Schnaiberg & Gould, 1994). Other sociologists critical of the modernization perspective also propose that capital accumulation processes tend to advance profits, often at the expense of the environment (Foster, Clark, & York, 2010). Our results lend support to these critical environmental

sociological theories. That is, although information communication technologies have the potential to limit or reduce energy use, they are not likely to be applied in a manner that substantially reduces environmental impacts, but rather may be directed primarily at increasing profits.

Economists and some sociologists have argued that market mechanisms will bring about desired energy efficiency outcomes, as it is cost-effective to reduce energy use. Information communication technologies can transform production processes by lowering the energy requirements of production (producing more with less), or providing important information (e.g., on energy use), which can reduce waste. Structural changes to the economy associated with technological advances in this realm can affect general practices, such as reducing automobile commuting or providing information that can limit errors or unnecessary practices (e.g., limiting extra trips or redundant activities with easier and faster communication). Further, a more technology-intensive economy can be a more efficient economy, as information communication technologies require less energy and waste than traditional manufacturing systems.

Surely, in many specific instances these benefits may arise. However, our results do not suggest that this is generally occurring economy-wide in most nations. As environmental sociologists critical of traditional economic growth models have argued, in growth-oriented economies efficiencies may be outpaced by aggregate growth. Information communication technologies have the potential to increase energy efficiency and reduce environmental impacts. Nevertheless, this potential may not foster positive ecological benefits if the primary emphasis remains on capital growth rather than ecological efficiency.

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Environmental Sustainability: The Ecological Footprint in West Africa

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Abstract

Although achieving sustainability remains a key goal of development, efforts to attain it vary across places, making a regional focus important. This paper investigates the ecological footprint—one measure of environmental sustainability—over time with focus on West Africa. Expectations from environmental impact and structural human ecology approaches are incorporated into an investigation of key factors driving national-level environmental sustainability in five countries. Results reveal that demographic attributes are key factors that affect ecological footprints in these countries. Findings are discussed with attention to policy implications regarding the West African context and in relation to opportunities for exploration in further academic study.

Keywords: environmental sustainability, West Africa, ecological footprint

Introduction

Prominent international organizations including the United Nations (UN), United Nations Development Programme (UNDP), Food and Agriculture Organization of the UN (FAO), and the World Bank focus on the importance of the environment for continued development efforts (FAO, 2013; UNDP, 2014; World Bank, 2014, 2015). Ensuring environmental sustainability, for instance, was one of the Millennium Development Goals (MDG) from 2000 to 2015. Although these goals have been reformulated, beginning in 2015 with an eye to transforming development, the environment features prominently in many of these goals, including providing access to clean water and sanitation, maintaining healthy ecosystems, addressing climate change, and improving other aspects of well-being (UNDP, 2014). Questions regarding how to examine spatial and temporal variability in the environment–development link remain core objectives of academic research. This research contributes to this work by examining a measure of environmental sustainability over time with emphasis on five countries in West Africa as context.

Comparative sociological research examining the processes affecting environmental sustainability seeks to answer the salient question of how much pressure nations exert on their surrounding environment through various industrial processes and related consumptive activities. To date, research demonstrates ecological footprints—a widely used measure of environmental sustainability—to be driven by a variety of economic, political, ecological, and demographic factors at varying—national, regional, and global—scales. An understudied domain of scholarship is that of a specific region over time that also allows for regional heterogeneity (Dietz & Jorgenson, 2014). The main purpose of this paper is to examine the driving forces of environmental sustainability over time with emphasis on five West African countries as a region and attention to dynamics across different components of ecological footprints with significant within-region implications.

A dataset of five West African countries—Burkina Faso, Ghana, Mali, Niger, and Nigeria—for 46 years (over 224 case years) is used in empirical models integrating expectations from prior work with emphasis on structural human ecology. Countries in dryland West Africa have unique environmental challenges for their cropping systems, and thus for the coupled human and natural systems investigated in this research. Results demonstrate the importance of demographic factors over time in these five nations, although these driving factors do differ to some extent across four of the ecological footprint's subcomponents.

The paper proceeds as follows. The next section describes theoretical frameworks informing this research, with special attention to structural human ecology. The empirical models designed to test expectations from prior research are discussed next, followed by results and discussion of the analyses. The paper concludes with a discussion of avenues for future academic work on macro-comparative, cross-national scholarship on environmental sustainability.

Explaining the factors affecting environmental sustainability

Developing a better understanding of how human actions lead to environmental change is an essential task for academic research in an increasingly interconnected world. And, as briefly outlined at the outset, such an agenda features prominently in the work of international organizations like the UNDP, FAO, and World Bank. Describing these large-scale processes that span human and natural systems requires an approach that is able to articulate how social structure and institutions both shape and are shaped by the physical environment (Dietz & Jorgenson, 2013; Liu et al., 2007a, 2007b). As a discipline, sociology, and specifically the subfield of environmental sociology, has made

important contributions to this work, including our understanding of human activities and aggregate societal characteristics leading to the atmospheric emissions of greenhouse gases (GHG) (Rosa & Dietz, 2012). Environmental sociologists, therefore, are well equipped to investigate how human activities, social institutions, and relations between social units at numerous scales—community, national, regional, and international, for instance—contribute to environmental changes like those portrayed in a measure of environmental sustainability like the ecological footprint.

The essential conceptual background for such investigations derives from models like those of Duncan (1959), Ehrlich and Holdren (1971), and York, Rosa, and Dietz (2003a, 2003b). The shared pillars of these approaches are population, (social) organization, environment and technology, which form the core of Duncan's (1959) POET model. Each of the four domains is posited to play a role in social and environmental change and each has a unique role in the system of relations whereby human societies and the physical environment are involved in an interconnected web of often-reciprocal relations. Ehrlich and Holdren (1971) developed the IPAT model from a similar background, where the Impact is a function of population, affluence and technology. According to this approach, increasing populations interact with changing levels of affluence and technology to yield an environmental impact. The third model, the STIRPAT model (York et al., 2003a, 2003b), has strong ties with both ecological models and uses the same dimensions but in a stochastic form.

To determine how much pressure nations exert on their surrounding environment, sociological scholarship examines a number of aggregate factors as core influences on a measure of environmental sustainability like the ecological footprint. This research draws from a range of theoretical traditions, including ecological modernization, world systems approaches, ecologically unequal exchange frameworks, and world polity perspectives.[1] Briefly, this scholarship examines economic, political, ecological, and demographic factors as primary drivers of change in environmental conditions. Initial studies in this vein examined society–environment relations as embodied in sociological work on

1 Ecologically unequal exchange uses the system of international stratification essential to a world systems perspective (Snyder & Kick, 1979; Wallerstein, 1979) and investigates the movement of goods across national boundaries (Bunker, 1985; Jorgenson, 2004; Rice, 2007). Examining power imbalances related to environmental space, it focuses on material–ecological exchanges and vertical flows of exports that reinforce existing global inequalities. These flows are intimately tied to environmental degradation. More specifically, exports to wealthier or core nations from poor or peripheral nations increase environmental degradation in some places (Jorgenson, 2004; Rice, 2007). This is especially true in lesser developed countries. Core nations externalize environmental costs related to their consumptive-based lifestyles and industrial production processes onto lesser developed countries (Jorgenson & Rice, 2005; Rice 2007). In effect, lesser developed countries engaged in greater exports to core nations will differ in levels of resource-intensive consumption compared with other developing nations.

ecological footprints (York, Rosa, & Dietz, 2003a, 2003b; Jorgenson, 2003, 2005, 2009; Jorgenson & Burns, 2007a, 2007b; Jorgenson & Rice, 2005; Rice, 2007; Rice & Rice, 2009; York, Rosa, & Dietz, 2009).

More recent work casts a wider net in terms of the potential influences important for sociologists to investigate (Jorgenson & Clark, 2011; Knight, Rosa, & Schor, 2013). Economic factors feature prominently in this research. Economic drivers include, for example, the growth of the service sector base, integration into the world economy, degree of export dependence, and national affluence. State environmentalism, democracy, distance from the equator, the degree of urbanization, and population size have also been found to affect national resource consumption as political, ecological, and demographic factors, respectively. From this base of institutional structures, which continues to inform empirical studies, research has broadened to include both measures of militarization with regard to physical size of the military and military expenditures (Jorgenson & Clark, 2011) and employment (Knight, Rosa, & Schor, 2013).

Environmental impact theories that include, for instance, ecological modernization, emphasize anthropogenic forces like demographic and economic factors as drivers of environmental change. York et al. (2003a) articulated expectations regarding primary demographic influences on environmental change like population age structure, specifically the size of a country's adult population, and a country's urbanization. With regard to urbanization, some argue that the effects of urbanization may promote less environmentally threatening forms of consumption (Ehrhardt-Martinez, Crenshaw, & Jenkins, 2002; York et al., 2003a). Regarding economic activity, some argue from a modernization framework that shifting economic base from manufacturing toward service-based economies could reduce impacts on the environment through declines in natural resource extraction (Ehrhardt-Martinez et al., 2002; York et al., 2003a).

Although the focus has shifted slightly, institutional structures continue to inform this scholarship. For instance, along with economic development, international trade regimes, urban population growth, and ecological conditions, research demonstrates that militarization has an effect on national ecological footprints in developing countries (Jorgenson & Clark, 2011). In addition, research reveals that work hours have a positive effect on national ecological footprints in industrialized or developed nations alongside other economic measures (Knight, Rosa, & Schor, 2013). In this way, scholarly work considers ecological footprints as consumption-based, national environmental impacts that apply at multiple scales, including nations, regions, and the world; thus, they comprise a major indicator of changing natural environments.

The importance of structural human ecology

Structural human ecology (SHE) specifies anthropogenic forces as key drivers of environmental change. At its core, SHE endeavors to describe coupled human and natural systems through showing recursive relations between societies and natural environments—both how human systems affect and are affected by their surrounding environment (Dietz & Jorgenson, 2013; Liu et al., 2007a, 2007b; Rosa, York, & Dietz, 2004; York et al., 2003a, 2003b). The discipline of sociology contributes insights through identifying anthropogenic drivers of ecological footprints. That is, it describes the range of human activities and societal characteristics that may affect the human imprint on the environment. This relevance for a sociological lens is especially true when combined with SHE. Research on human activities, social institutions, and relations between social units at multiple scales and across places linked with contexts, contribute to our understanding about factors affecting ecological footprints. Two important guiding principles from SHE provide a baseline for this research. First, the importance of context cannot be understated (Dietz, 2013), and the manner in which context has a particular regional flavor should be an object of investigation (Jorgenson et al., 2012). Second, the type of demographic measure incorporated into a study's design should be carefully considered and feature prominently in the empirical investigation (Marquart-Pyatt, 2013; York & Rosa, 2012).

Incorporating these expectations refocuses the discussion about contexts to encompass societal attributes including social institutions and social structure, social organization, technology, and demographic factors in a way that extends prior work. Specifically, it adds a much-needed examination of a range of different demographic attributes to the economic and environmental dimensions that have long formed the core of this work. Essential to structural human ecology are theoretical and empirical assessments of relations among population, affluence, technology, and the environment, with environmental impacts comprising the outcome variable as in the STIRPAT model (Dietz & Rosa, 1994, 1997).[2]

2 The acronym STIRPAT encapsulates Stochastic Impacts by Regression on Population, Affluence, and Technology (York, Rosa, & Dietz, 2003a, 2003b). The baseline STIRPAT equation includes the outcome or dependent variable as the environmental impact along with an intercept term, estimated coefficients linked with population and affluence measures respectively, "technology" representing everything else in the equation, and an error term. The STIRPAT equation was designed for testing theoretically derived hypotheses from human ecology concerning the effects of population, affluence, and technology, which is now referred to as a core approach of structural human ecology (Dietz & Jorgenson, 2013).

Research utilizing the STIRPAT frame has examined numerous environmental variables approximating relations between the impacts of human societies on the environment (see Rosa & Dietz, 2012 for a recent overview). For instance, research has explored ecological footprints and total greenhouse gas emissions as well as carbon dioxide emissions, fossil fuels, and alternative energy (Dietz & Rosa, 1997; Dietz, Rosa, & York, 2007, 2009; Rosa, York, & Dietz, 2004; York, 2012; York, Rosa, & Dietz, 2003a, 2003b). Findings from this research tradition demonstrate that population and affluence (wealth, GDP) are primary factors affecting environmental degradation (Jorgenson, 2013; Mazur, 2013).

Demographic factors feature prominently in this research. York et al. (2003a, 2003b) articulated expectations regarding how population structure influences environmental change through two key factors: the population age structure, specifically the size of a country's adult population; and a country's level of urbanization. Subsequent studies further attest to the importance of model specification, particularly in relation to the manner in which population measures are incorporated in empirical analyses, as stressed throughout STIRPAT research. As an example, York and Rosa (2012) explore nuances of population in examining how social structures and air pollution are related. Findings reveal that in addition to population size and growth, the distribution of population across households is important for understanding relations between population and the environment (York & Rosa, 2012).

West Africa as context

The question of whether the factors driving sustainability are the same over time within West Africa, as derived from the regional emphasis in prior work (Jorgenson, 2013), has not yet been intensively examined and thus forms a core contribution of this work. I use a dataset of five developing nations in dryland West Africa over 46 years in empirical models integrating expectations from structural human ecology. The five countries examined in this research—Burkina Faso, Ghana, Mali, Niger, and Nigeria—are geographically in the Savanna/Sahel regions of West Africa where environmental challenges are of paramount concern. A major reason for a heightened level of concern is how cropping systems are responding to environmental challenges and development, where West Africans face important questions about how to increase crop productivity and simultaneously enhance the resilience of their cropping systems to climate change (CGIAR, 2013). As of 2013, all five countries are of medium (Ghana), high (Burkina Faso and Mali) to high-extreme (Niger and Nigeria) risk of food insecurity (Maplecroft, 2013). Understanding how demographic, economic, and ecological factors shape environmental sustainability provides timely

information for the challenges rural and urban populations in these countries face. The next section outlines the empirical models, describing the measures utilized and analytical approach employed.

Data and methods

I employ a pooled cross-section time-series analysis of a sample of five developing nations—Burkina Faso, Ghana, Mali, Niger, and Nigeria—over a 46-year time period from 1961 to 2006. The unit of analysis is the nation-year. I focus only on these five nations given the theoretical focus on environmental sustainability according to ecological footprints in Western African nations. I use a Prais-Winsten (PW) regression model with panel-corrected standard errors (Beck & Katz, 1995, 1996, 2004), which allows for heteroscedastic disturbances that are contemporaneously correlated across panels. Due to the presence of serial correlation, I specify first-order autocorrelation (AR 1) within panels. I transform all variables via logging. I use Stata 12 for the analyses. Below I discuss the operationalization of the outcome measures and the independent variables.

Outcome variables

The outcome (dependent) variable for the first set of models investigated is the ecological footprint. In the analyses, I use country level aggregate measures of the total ecological footprint. *Ecological footprints* (EF) represent the land area required to support levels of consumption for an individual living in a particular geographic place (i.e., country). The EF measure incorporates various land areas required for production and consumption, for waste absorption related to energy use, and for necessary infrastructure, adjusted for biological productivity (Chambers, Simmons, & Wackernagel, 2000; Wackernagel, Onisto, & Bello, 1999; Wackernagel & Rees, 1996). The data was obtained from the Global Footprint Network (Global Footprint Network, 2009). In general, core, wealthy nations like the United States tend to have large ecological footprints, while developing nations, including those in West Africa, tend to have lesser environmental imprints.

Four of the EF's six subcomponents comprise the second set of outcome measures—cropland, grazing land, carbon uptake land, and built-up land. I use country level aggregate values of these composite footprint measures in the analyses. I selected these measures given their importance in the region as drivers of environmental change. Visual inspection confirmed these four subcomponents comprise a major share of the footprint for each of the countries

individually over the time series.[3] Cropland footprints take into account arable land area required to grow all crop products for a country. Grazing land is the area necessary to support livestock, including grasslands and areas required for crop growing. Carbon uptake land is the amount of forested land required to absorb human-induced CO_2 emissions. The built-up land footprint takes into account the amount of land covered by societal infrastructure like transportation, housing, and industrial areas. Data for the four subcomponents are from the same time frame (1961 to 2006) (Ewing et al., 2008).

Independent variables

The models include a measure of economic development or affluence, which has been shown to be an important influence on environmental impacts (Jorgenson, 2005, 2009; Jorgenson & Burns, 2007a, 2007b; Jorgenson & Rice, 2005; York et al., 2003a, 2003b). Gross domestic product (GDP) per capita is included to measure economic development. GDP per capita estimates, measured in constant 2000 international dollars, are from the World Bank (2015).

Demographic factors have also been shown to influence ecological footprints, and given expectations from SHE are integral to this empirical investigation. Given predictions of structural human ecology frameworks, three aggregate demographic measures are included in the model in addition to the total population (World Bank, 2015). To gauge urbanization, a measure of urban population as a percent of the total population of a country living in urban areas is included. Rural population density is the number of people per square kilometer of land in rural areas. The population age structure or age dependency ratio is the ratio of individuals younger than 15 and older than 64 (i.e., dependents) to individuals aged 15 to 64 years (i.e., the working age population). Previous research shows more urbanized countries have larger environmental impacts (Jorgenson, 2003, 2005; Rice, 2007; York et al., 2003a, 2003b). Two measures are included to account for environmental conditions. Land area and arable land area in hectares are from the World Bank (2015). When we examine the measures that comprise the ecological footprint individually, a different picture emerges than when we investigate them as an aggregate measure (Marquart-Pyatt, 2010). Teasing out these relations at the within-region level over time is thus an important extension of prior work. The focus on West African nations is unique and salient as well, building on proposed future work as articulated in the discussion and conclusion that follow.

3 For example, the per capita footprint in Burkina Faso from 2006 is 1.61 hectares (ha). Within this aggregate measure, the cropland piece is 0.91 ha, grazing land is 0.19 ha, carbon is 0.04 ha and built-up land is 0.11 ha. Combined, this is 1.25 out of the 1.61 ha. In Mali in 2006, the total ecological footprint is 1.90 ha. The four subcomponents make up 1.69 ha of this value (e.g., the cropland piece is 0.73 ha, grazing land is 0.63 ha, carbon is 0.03 ha, and built-up land is 0.05 ha).

Analyses

Figure 1 presents the ecological footprint measures for 10 time points over the 46-year time span from 1961 to 2006 for all five countries, and includes the value for the World as a reference point. Figure 2 shows the cropland footprint for ten time points over the 46 year time span from 1961 to 2006 for all five countries, also including the World value for anchoring and to aid in interpretation. Exact years are 1961, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, and 2005. These data points reveal that per capita ecological footprints have changed slightly over the time period shown in Figure 1. Niger, for example, had the highest per capita ecological footprint over time of these five West African countries. It was the only one of these cases with a higher EF than the world average until the early 1980s. For these years, Ghana tended to have the lowest per capita ecological footprint of these cases, with Nigeria having similar values for these data points.

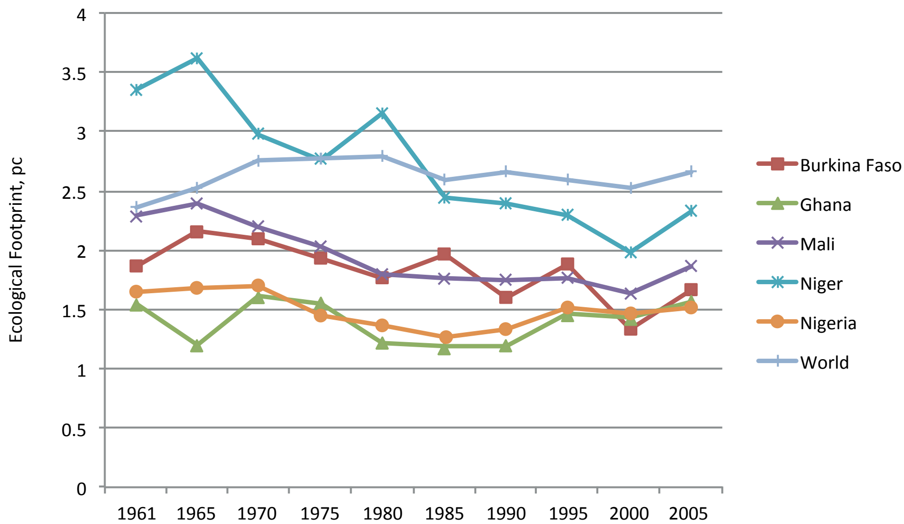

Figure 1. Per capita ecological footprint values for five countries in West Africa and the World from 1961 to 2005
Source: Global Footprint Network

Figure 2 provides a snapshot of how cropland footprints have changed over time in these five cases. Niger had the highest cropland footprint over time of these five West African countries, with a value consistently above the World average. Ghana had the lowest values for the cropland footprint of these cases for the

time frame shown. A steady decline in the cropland footprint is only shown in the World average; otherwise, values show some variability both over time and across place (i.e., individual countries).

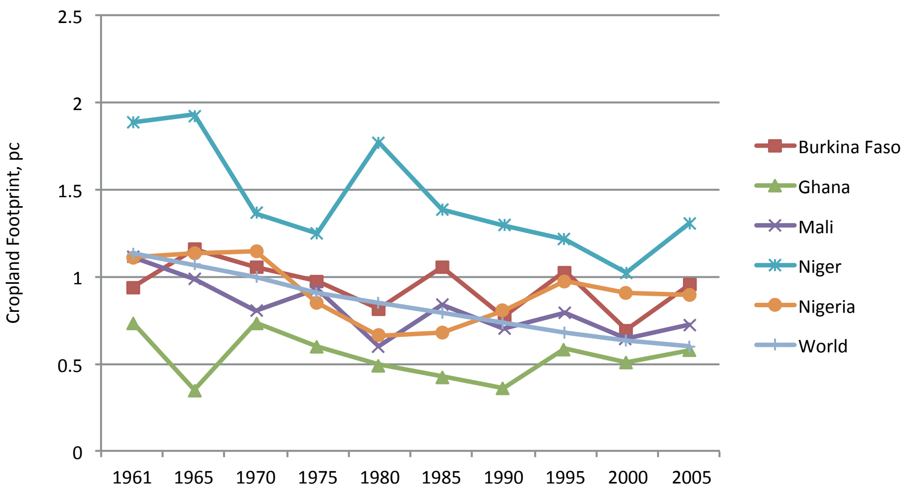

Figure 2. Per capita cropland footprint values for five countries in West Africa and the World from 1961 to 2005

Source: Global Footprint Network

Table 1 presents the descriptive statistics from the variables used in the analyses, and Tables 2 and 3 present the substantive investigation of the theoretical models. Although I include the variables according to economic, demographic, and environmental grouping of predictors, I focus on the full equation shown in model 2 of Table 2. Beginning with Table 2, although there is no significant effect for GDP, the arable land area has a positive effect on the logged ecological footprint. As shown in the third column of results, the log of urban population has a significant negative effect, where each logged percent increase in the percent of population residing in urban areas decreases the logged ecological footprint by 0.110 units. The rural population density also has a negative effect, causing a 0.270 decline in the logged ecological footprint. Combined, these results demonstrate that demographic factors, specifically the urban population and rural population density, matter for the ecological footprint in these five West African countries.

Table 1. Descriptive statistics

	Mean	Std Dev	Min	Max	N
Total ecological footprint	16.977	0.857	16.027	19.212	230
Cropland footprint	16.249	0.968	14.804	18.698	230
Grazing land footprint	14.964	0.836	13.157	16.362	230
Carbon-uptake footprint	13.013	1.996	5.758	17.071	230
Built land footprint	13.705	1.028	11.329	16.223	230
GDP (*10,000)	0.229	0.131	0.018	0.715	224
Total population	16.379	0.996	15.0479	18.781	230
Percent urban	2.999	0.549	1.758	3.902	230
Age dependency ratio	4.527	0.077	4.331	4.661	230
Rural population density	2.903	1.028	1.266	4.559	230
Land area	0.081	0.080	0.006	0.379	230
Arable land	2.365	0.791	0.851	3.701	230

Table 2. Prais-Winsten regression models for total ecological footprints in West Africa, 1961–2006

	Model 1	Model 2
Constant	36.7417***	3.049***
	(8.7348)	(0.911)
GDP	1136.566	593.305
	(1574.262)	(1363.917)
Total population	1.101***	0.961***
	(0.027)	(0.027)
Percent urban	-0.245***	-0.110***
	(0.045)	(0.031)
Age dependency ratio	0.165	-0.305
	(0.306)	(0.192)
Rural pop density	-0.200	-0.270***
	(0.025)	(0.046)
Arable land		0.265***
		(0.033)
Land area		0.511
		(0.414)
R-Square	0.992	0.992
Sample size	224	224
rho	0.708	0.471

Notes: *p<.05, **p<.01, ***p<.001 (two-tailed)

Table 3 shows the results from the empirical models for the cropland footprint, grazing land footprint, built land footprint, and carbon footprint, respectively. Beginning with the first column, although there is no significant effect for GDP, the arable land area has a positive effect on the logged cropland footprint. The log of urban population has a significant negative effect, where each logged percent increase in the percent of population residing in urban areas decreases the logged cropland footprint by 0.372 units. The rural population density also has a negative effect, causing a 0.323 decline in the logged cropland footprint. The second column shows findings for the grazing land footprint, revealing five significant effects. Two demographic measures cause significant declines in national ecological footprints. Urban population's effect is negative, where each logged percent increase in the percent of population residing in urban areas decreases the logged grazing land footprint by 0.424 units. The rural population density also has a negative effect, causing a 0.891 decline in the logged grazing footprint. And, the age dependency ratio has positive effects on the logged grazing footprint, while the arable land area's effect was negative.

The final two columns of results reveal the effects of economic, demographic and environmental predictors on the built land footprint and carbon footprint. Results for the built land footprint, shown in the third column of Table 3, yield slightly differing effects that make sense with regard to what this composite indicator measures. In line with previous results, the effect of urban population is negative, where each logged percent increase in the percent of population residing in urban areas decreases the logged built land footprint by 0.272 units. The rural population density has a positive effect, with a 0.501 increase in the logged built land footprint. Results in the final column are for the carbon footprint. We see a significant positive effect for GDP and negative effects for arable land area and land area on the logged carbon footprint. The log of urban population has a significant positive effect, where each logged percent increase in the percent of population residing in urban areas increases the logged carbon footprint by 1.186 units. The age dependency ratio has a significant positive effect as well, causing a 2.782 unit increase in the logged cropland footprint.

As was the case with the total EF, results suggest that demographic factors in particular matter for the cropland footprint in these five West African countries. These findings also reveal that the factors driving the different components of the ecological footprint—cropland, grazing land, built land, and carbon—differ in some regard within this set of countries. Generally, these results are in line with prior work on the ecological footprint as an aggregate measure and its constituent pieces (Marquart-Pyatt, 2010). The findings also support the work of structural human ecologists, which strives to account for complex empirical links between populations and the physical environment through extensive investigation of measures across scales, over time, and in varying contexts.

Table 3. Prais-Winsten regression models for cropland, grazing land, built land, and carbon footprints in West Africa, 1961–2006

	Model 1: Cropland	Model 2: Grazing Land	Model 3: Built Land	Model 4: Carbon
Constant	-2.952***	-9.156**	-3.215	-25.918***
	(1.610)	(3.253)	(2.816)	(3.697)
GDP	-640.275	1627.925	-204.365	13091.200***
	(2428.627)	(986.261)	(2965.38)	(2493.835)
Total population	1.122***	1.206***	1.181***	1.454***
	(0.046)	(0.116)	(0.063)	(0.102)
Percent urban	-0.372***	-0.424***	-0.272***	1.186***
	(0.053)	(0.133)	(0.088)	(0.127)
Age dependency ratio	0.450	1.926***	-0.147	2.782***
	(0.338)	(0.590)	(0.584)	(0.715)
Rural pop density	-0.323***	-0.891***	0.501***	-0.088
	(0.079)	(0.094)	(0.131)	(0.153)
Arable land	0.339***	-0.224***	-0.988***	-0.237 ***t***
	(0.057)	(0.103)	(0.098)	(0.139)
Land area	0.548	-0.045	-0.719	-6.893***
	(0.714)	(0.492)	(1.149)	(1.182)
R-Square	0.973	0.971	0.967	0.873
Sample size	224	224	224	224
rho	0.415	0.871	0.692	0.763

Notes: *t*<.10, *p<.05, **p<.01, ***p<.001 (two-tailed)

Discussion and conclusion

This research was motivated by prior work on development that placed ensuring environmental sustainability in sharp focus for both scholars and practitioners, given its strong links with prominent international organizations. While progress has been made according to some metrics, work remains regarding realizing the global goals of achieving progress related to development and improving the well-being of individuals worldwide. Of paramount importance to this work are questions of how to model spatial and temporal variability in the environment–development link. Further, such research must include salient issues linked with quality of life like having access to clean water and sanitation, addressing climate change, and maintaining healthy ecosystems. By focusing on a single region, this research sought to contribute to this global agenda through empirical investigation of key drivers of environmental sustainability over time

in five West African countries. Results demonstrate that, over time, national environmental imprints for this set of countries are shaped by demographic factors, supporting expectations from structural human ecology. These driving forces do differ to some extent, however, across four of the ecological footprint's subcomponents in these five nations over time.

There are at least four avenues for future work: 1) extend the analyses to examine all African countries; 2) compare this with another developing region like Southeast Asia or Latin America; 3) incorporate additional predictors like political institutions and integration in world society/polity into the model; and 4) consider how this work on EF relates with work on well-being and food security. The first two recommendations squarely focus on a core question of cross-national scholarship in sociology, namely how to construct a comparative study and what the relevant parameters are for investigation. That is, how focused or broad should the comparison be regarding the appropriate scale as well as the number of countries that comprise the relevant sample. From the five West African countries that were the focus here, future work might cast a wider net and examine all countries in Africa to determine whether these processes operate similarly across the vastly different terrestrial ecological systems on the continent. From a comparative standpoint, a second intriguing study would be one that builds a cross-regional component as a central dimension. The compelling question would then be whether the demographic factors shown to be influential in the West African context are similar to or different from how human societies and the physical environment are related in another geographically distinct region like Southeast Asia or Latin America, depending on the aspect of environmental change being investigated.

As noted above as a third recommendation, with an expanded set of cases, researchers should also consider including in the theoretical model additional predictors that derive from explanatory frameworks seeking to describe global processes of diffusion. Additional measures include a country's position in the overall world polity (like the INGO Network Country Score) (Hughes, Peterson, Harrison, & Paxton, 2009), state environmentalism or environmental treaty participation (Roberts, Parks, & Vasquez, 2004), and political institutions like democracy. These variables may aid in developing models that examine how being involved in different networks of relations may lead to occupying different positions in the overall world polity, where even if countries have identical numbers of INGO memberships, they may be involved in different networks that aid in explaining regional comparisons. A related measure of environmental treaty participation, which could account for engagement with international efforts for environmental protection, is also included. Additional possible measures to add to future work account for political institutions. A measure of political structure such as liberal democracy that includes both

democratic rule and civil liberties, incorporating a country's political rights, legislative effectiveness, process of legislative selection, suffrage, and whether groups are excluded from the political process may also aid in future academic work. Resource access is likely to be tied to stratification processes like the openness of a social system to all citizens or whether restrictions are placed on natural resources and land ownership is based on citizenship rights.

Regarding extending this work beyond environmental sustainability, it is important for future work to consider the larger processes over time and across places within which these processes are embedded. Consider, for example, two related indicators of agricultural transformations describing food availability and access which provide context for understanding these issues in West Africa (FAO, 2013). Semi-arid West African countries are considered to be at medium-to-high risk of food insecurity (Maplecroft, 2013). From 1990 to 2010, food production in the region increased, with the largest gains in Ghana (from 172 to 271 international dollars per capita) and a slight increase in Burkina Faso (from 109 to 122 international dollars per capita) (FAO, 2013). At the same time, the depth of the food deficit that shows how many calories are needed to change the status of undernourished individuals, reveals declines over time in four countries, with the notable exception of an increase in Burkina Faso to 178 from 142 calories per capita daily (FAO, 2013). While some gains have been made in achieving food security, the correspondence between availability and access is not guaranteed, which has relevance for emerging work on well-being. Given the complexity of these issues vital for understanding the society–environment–development links, further refining the correspondence between our theoretical expectations and empirical models to account for variability in many forms—including temporally and spatially—remains an integral priority, fruitful avenue, and challenge for future research.

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Income Inequality and Residential Carbon Emissions in the United States: A Preliminary Analysis[1]

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Abstract

The authors investigate the relationship between U.S. state-level residential carbon emissions and income inequality for the 1990–2012 period. Results of the analysis indicate a positive association between emissions and income inequality—measured as the Theil index—and these findings hold across a variety of model estimation techniques and net of the effects of other established human drivers of emissions. The authors conclude by underscoring the need for more research on the effects of income inequality on carbon emissions and other related environmental outcomes.

Keywords: climate change, income inequality, carbon emissions

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Introduction

Much research in the structural human ecology tradition focuses on the human drivers of greenhouse gas emissions. The majority of this research—to date—considers how population, affluence, and related factors explain growth in and variation between national-level emissions. Without doubt, population and affluence are primary drivers of national-level carbon emissions, methane emissions, and other greenhouse gases (e.g., Dietz, 2015; Dietz & Jorgenson, 2013; Jorgenson & Birkholz, 2010; Jorgenson & Clark, 2012; Knight & Schor, 2014; Rosa & Dietz, 2012; Rosa, York, & Dietz, 2004; Shandra et al., 2004; York, Rosa, & Dietz, 2003).

Research that further broadens structural human ecology has considered how various forms of international inequality also shape uneven levels of and growth in national-level emissions and related outcomes. This research consistently shows that types of international inequalities tied to asymmetrical global production and trade networks as well as coercive forms of international power (e.g., military power) contribute to many environmental problems, including anthropogenic carbon emissions (e.g., Burns, Davis, & Kick, 1997; Clark, Jorgenson, & Kentor, 2010; Grimes & Kentor, 2003; Jorgenson, 2012). Overall, these bodies of international research enhance our collective understanding of the human dimensions of global climate change and other environmental problems (Rosa et al., 2015).

With the growing availability of data, in recent years researchers have begun to investigate the human drivers of carbon emissions at smaller scales, such as at the U.S. state and county levels (e.g., Clement & Schultz, 2011; Dietz et al., 2015; Elliott & Clement, 2014). Many of the findings are consistent with the results of the comparative international research, especially the commonly observed impacts of population size, affluence, and urbanization. While it is recognized that comparative international research is important for a variety of substantive and practical reasons (Rosa et al., 2015), the assessment of society/nature relationships at smaller scales allows for further theoretical testing as well as the execution of research with perhaps more actionable policy implications (Rudel, 2005), especially considering the gridlock in international negotiations on climate change (Ciplet, 2015; Roberts & Parks, 2007).

A key issue that is absent from these streams of structural human ecology at all scales is research on greenhouse gas emissions and income inequality. Climate change and growth in income inequality are two of the most pressing problems of the current era. The former, if it continues unchecked, will not only undermine established ways of living, but also create catastrophic impacts on both natural and human systems (Intergovernmental Panel on Climate Change,

2014). The latter not only increases poverty and undermines well-being, but has become so pronounced in some nations that it threatens their basic economic functioning (Piketty, 2014). If income inequality was found to contribute to environmental problems such as carbon emissions, and thus climate change, policies to reduce income inequality could be promoted as both ecologically and socially beneficial (Jorgenson, 2015).

This preliminary study seeks to help remedy this absence by assessing the relationship between carbon emissions and income inequality at the U.S. state level.[2] In particular, we conduct a state-level longitudinal analysis of the effects of income inequality on residential carbon emissions for the 1990–2012 period. We employ the STIRPAT approach, a foundational tool in the structural human ecology tradition, in our analysis. The results suggest that income inequality, measured by the Theil index, increases residential carbon emissions in the United States, and these findings hold net of the effects of other well-established drivers of anthropogenic emissions.

Brief literature review

There are relatively few research findings on the relationship between carbon emissions and income inequality, and they mostly originate in the discipline of economics. We briefly summarize portions of this literature.

Ravallion et al. (2000) hypothesize that when the relationship between household income and emissions is concave, the wealthy emit less than the poor for each dollar of additional income, so that a redistribution of income from the wealthy to the poor will result in increased emissions. They posit that consumption demand is the key factor determining the increase of emissions induced by an increase in disposable income, i.e., the marginal propensity to emit. However, this is only one of the possible mechanisms at work. In a Keynesian model, lower-income households consume more than higher-income households for each dollar of additional income (i.e., the marginal propensity to consume declines with income). In that case, reductions in inequality that result in greater income for the poor yield a higher level of overall consumption demand and thus emissions.

In contrast, James Boyce's (1994, 2003, 2008) "power-weighted social decision rule" suggests that when the beneficiaries of environmental degradation are more powerful than those who bear the costs, the overall level of environmental degradation will be greater. Since the wealthy benefit more from environmental

2 While the focus for this preliminary study is on U.S. state-level emissions, in other research in progress we are investigating the relationship between carbon emissions and domestic inequality cross-nationally.

degradation as both consumers and producers, and the poor benefit less and are more vulnerable to harmful consequences, higher levels of income inequality are likely to lead to increased carbon emissions and other environmental harms because the interests of the wealthy are protected in the political sphere (see also Cushing et al., 2015). In a similar vein, Pattison et al. (2014) find that counties in the U.S. with the highest average household incomes have greater consumption-based carbon emissions but lower production-based emissions than less affluent counties. Pattison et al. (2014) conclude that wealthier communities are able to avoid some of the consequences of their carbon-intensive consumption by shifting carbon-intensive industrial activities into poorer areas.

Others have suggested that domestic inequality undermines environmental protection by reducing social cohesion and cooperation. By eroding social trust, income inequality may inhibit pro-environmental collective actions and socially responsible behaviors, thereby leading to growth in emissions (Cushing et al., 2015; Ostrom, 2008; Wilkinson & Pickett, 2010). Related to this, Knight and Rosa (2011) demonstrate that countries with higher levels of social trust achieve greater subjective human well-being with less environmental impact.

Another approach argues that rising income inequality can increase status-based consumption of goods and fossil fuels as individuals spend more and more to emulate the standards set by the "overconsuming" wealthier members of society in what we may call a Veblen effect (Schor, 1998; Veblen, 1934). Average working hours have also been shown to increase with rising income inequality (Bowles & Park, 2005), and recent cross-national research indicates that longer working hours are associated with greater environmental impacts, including growth in energy consumption and carbon emissions (Fitzgerald, Jorgenson, & Clark, 2015; Knight, Rosa, & Schor, 2013).

Vona and Patriarca (2011) find that in wealthy countries, growth in income inequality reduces the development and diffusion of environmentally beneficial consumer products because it creates a larger gap between what wealthy early adopters are willing to pay and what the less wealthy can afford. And research by Jorgenson, Rice, and Clark (2010) shows that in developing nations, growth in fossil fuel consumption is positively associated with overall urbanization (the percent of the population residing in urban areas), but negatively associated with growth in urban slum prevalence (the percent of the population residing in urban slum conditions). Jorgenson et al. (2010) conclude that these divergent relationships are partly attributed to the differences in average incomes between urban slum residents and non-slum urban residents as well as the broader structural inequalities that inhibit access for urban slum residents to energy and other resources for household consumption.

In this study, we explore a particular type of inequality—namely, high-income concentration at the top of the distribution. We hypothesize that where there is more income concentrated at the top, emissions will be higher for (at least) two reasons. First, there will be a stronger political economy effect in which the wealthy use their political power to avoid carbon-control measures. Second, high-income concentration leads to stronger Veblen effects in which high-income households compete for status via the "over-consumption" of goods and services which require high energy use (Schor, 1998; Ehrhardt-Martinez & Schor, 2015). Veblen identified houses and transportation, both of which are highly energy intensive, as two of the three major areas of status competition (Veblen, 1934). High-income households today compete via the purchase of large homes (Dwyer, 2007; Frank, 2010), which in turn yields low population density and high residential energy use. In transportation, wealthy households purchase powerful motorized vehicles (autos, boats, and airplanes) and engage in frequent long-distance travel. In addition, this portion of the distribution engages in high consumption overall. More generally, this approach is in some ways similar to that of Chakravarty et al. (2009) who emphasize the strong intra-national differences in carbon intensity, with emissions highly concentrated at the top of the income and wealth distribution.

Data and methods

The dataset

Our dataset contains annual observations from 1990 to 2012 for all 50 U.S. states, as well as the District of Columbia (i.e., 23 annual observations per case). This yields an overall sample of 1,173 observations, and a perfectly balanced panel dataset.

Model estimation techniques

We employ multiple model estimation techniques to assess the effect of income inequality on residential carbon emissions. Doing so allows for evaluating empirical relationships across a range of model specifications, each of which has its relative strengths and weaknesses (Allison, 2009). We first estimate random effects models, using the "xtreg" suite of commands in Stata version 13 software ("xtreg re").[3] One of the advantages of random effects models is the ability to include time invariant predictor variables (e.g., census region). We then estimate

3 We note that the Hausman test comparing the "xtreg" fixed effects model and random effects model is non-significant. Nonetheless, the estimated standard errors for the fixed effects model are generally larger than the random effects model, leading to more conservative hypothesis testing.

fixed effects models, first with the within estimator in Stata ("xtreg fe"), and then with Prais-Winsten regression with panel corrected standard errors (xi:xtpcse). The fixed effects models and random effects models also include unreported year-specific intercepts.

All continuous variables are in logarithmic form (base 10), a well-established approach in structural human ecology, and commonly referred to as STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology; see stirpat.msu.edu/; York, Rosa, & Dietz, 2003). Given that the variables are in logarithmic form, STIRPAT is by design an elasticity model. The coefficient for each continuous independent variable in such a model is the estimated percentage change in the dependent variable associated with a 1% increase in the independent variable, controlling for all other factors in the model.

Dependent variable

Our dependent variable is residential carbon dioxide emissions from fossil fuel combustion, measured in million metric tons CO_2 ($MMTCO_2$). We obtained these publicly available data from the United States Environmental Protection Agency (EPA), which provides state-level emissions data for various sectors, including residential, commercial, industrial, transportation, and electric power, as well as for all sectors combined (epa.gov/statelocalclimate/resources/state_energyco2inv.html, accessed July 1, 2015). The EPA bases the state-level emissions estimates on energy consumption data from the EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS), released Spring 2014 (www.eia.doe.gov/emeu/states/seds.html).

Independent variables

Our measure of income inequality is the Theil index for household income inequality (Theil, 1967), which we obtain from Mark Frank's U.S. State-Level Income Inequality Database (www.shsu.edu/~eco_mwf/inequality.html, accessed July 3, 2015). The steps used in the creation of these inequality measures are provided in great detail in the Appendix in Frank (2014). The Theil index measures the discrepancies between the distribution of income and the distribution of population between groups. It compares the income and population distribution structures by summing across groups the weighted logarithm of the ratio between each group's income and population shares. When this ratio is one for a particular group, then that group's contribution to income inequality is zero (Conceicao & Ferreira, 2000). An important property of the Theil index is its sensitivity to income transfers from the poor to the rich within a given population, which differentiates it from other common measures of income inequality, including the Gini coefficient. The Theil index tends to be

highly correlated with more simple measures that quantify the percentage of all income or wealth owned by those in the top 1%, top 5%, and top 10%, while the Gini coefficient tends to be only moderately correlated with such measures (Frank, 2014).

We include population size, measured in the number of persons, which we obtained from the United States Census Bureau database for state-level population estimates (www.census.gov/popest/data/intercensal/index.html, accessed July 1, 2015). We also include Gross Domestic Product (GDP) per capita by state, which we obtained from the United States Department of Commerce Bureau of Economic Analysis database (www.bea.gov/itable/, accessed July 1, 2015).

We note that there is a discontinuity in the time series of GDP by state at 1997, where annual estimates prior to that year are calculated using one classification system (and reported in chained 1997 dollars), while annual estimates from 1997 to the present (and reported in chained 2007 dollars) are calculated using a different classification system (for more information, see www.bea.gov/regional/docs/product/). Thus, caution must be used when merging data from these two different panels into one overall dataset. We suggest that these differences are partially accounted for by the inclusion of year-specific fixed effects in all reported models, and we prefer to include these measures as a merged dataset to allow for greater temporal depth in our analysis of the residential emissions and income inequality relationship. In a sensitivity analysis available upon request, we restricted the overall dataset to 1997–2012, and the results of interest are substantively consistent with the findings reported below in Table 2.

In the random effects models we also include dummy variables for Census Region, which consist of South Census Region (Alabama, Arkansas, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia), Midwest Census Region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin), Northeast Census Region (Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont), and West Census Region (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Washington, Wyoming).

Table 1 provides the descriptive statistics and bivariate correlations for the dependent variable and the independent variables. As a reminder, all continuous variables are in logarithmic form (base 10).

Table 1. Descriptive statistics and correlations

	Mean	Std. Dev.		1.	2.	3.	4.	5.	6.	7.
Residential CO_2 Emissions	0.736	0.361	*1.*							
Theil Index	0.246	0.043	*2.*	0.222						
Population Size	6.526	0.448	*3.*	0.804	0.252					
GDP Per Capita	4.549	0.135	*4.*	0.023	0.587	-0.074				
South Census Region	0.313	0.464	*5.*	-0.133	-0.046	0.210	-0.088			
Midwest Census Region	0.235	0.424	*6.*	0.258	-0.193	0.061	-0.063	-0.375		
Northeast Census Region	0.196	0.397	*7.*	0.198	0.203	-0.082	0.141	-0.333	-0.273	
West Census Region	0.254	0.436	*8.*	-0.291	0.052	-0.207	0.026	-0.395	-0.324	-0.288

Notes:

- 1,173 total observations;
- all continuous variables are in base 10 logarithmic form;
- West Census Region is reference category in analysis reported in Table 2

Results

The findings for the analysis are provided in Table 2. RE Model 1 includes the Theil index, population size, GDP per capita, and the unreported period-specific intercepts. RE Model 2 also includes the measures for census region. The fixed effects models include the same predictors as the first random effects model. FE Model 1 is based on the "xtreg" within estimator, and FE Model 2 is based on Prais-Winsten regression with panel-corrected standard errors and unreported dummy variable case-specific fixed effects.

Across all four reported models, the effect of the Theil index on residential carbon emissions is positive and statistically significant. The elasticity coefficient for the Theil index is slightly larger in the fixed effects models (.143) than in the random effects models (.137 and .133), and in FE Model 2 the p-value for its coefficient is slightly above the standard benchmark of .05 with a value of .057 (two-tailed test). These results indicate that a 1% increase in the Theil index leads to between a .133% and .143% increase in residential carbon emissions, net of the effects of population size, level of economic development, and both the time-specific and state-specific fixed effects.

Table 2. Longitudinal models of the effects of income inequality on residential CO_2 emissions in all 50 U.S. states and Washington, DC, 1990–2012

	RE Model 1	RE Model 2	FE Model 1	FE Model 2
Theil Index	0.137**	0.133**	0.143**	0.143*
	(0.058)	(0.059)	(0.059)	(0.075)
Population Size	0.792***	0.780***	0.835***	0.835***
	(0.032)	(0.030)	(0.037)	(0.066)
GDP Per Capita	0.177***	0.177***	0.170***	0.170***
	(0.043)	(0.043)	(0.044)	(0.059)
South Census Region		-0.119**		
		(0.058)		
Midwest Census Region		0.191***		
		(0.062)		
Northeast Census Region		0.251***		
		(0.065)		
R-square	0.666	0.826	0.665	0.995

Notes:

- RE denotes random effects; FE denotes fixed effects;
- 1,173 total observations; *p<.075, **p<.05, ***p<.01 (two-tailed tests); standard errors in parentheses;
- p-value for Theil Index coefficient is .057 in FE Model 2;
- all continuous variables are in base 10 logarithmic form; all models include unreported period-specific intercepts;
- West Census Region is reference category in RE Model 2;
- FE Model 1 is estimated with the "xtreg" within estimator in Stata;
- FE Model 2 is estimated with Prais-Winsten regression with panel-corrected standard errors;
- FE Model 2 includes unreported dummy variable fixed effects for each case;
- Hausman test for FE Model 1 and RE Model 1 is nonsignificant.

As expected, the estimated effects of population size and GDP per capita are positive and statistically significant across the four models. In the second random effects model, all census region dummy variables exhibit statistically significant effects on emissions as well. We note that the close to perfect R-square statistic for FE Model 2 is largely due to the use of dummy variables for the case-specific fixed effects.

Conclusion

This study makes a modest contribution to structural human ecology research on the causes of anthropogenic greenhouse gas emissions, with a broader goal of bringing greater attention to and facilitating additional research on the environmental impacts of income inequality at multiple scales, a surprisingly

understudied and overlooked topic. The results of our preliminary analysis suggest a positive relationship between state-level residential carbon emissions and income inequality, measured as the Theil index, in the United States, net of the effects of other well-established human drivers of emissions. For us, the next logical steps in this research involve evaluating the effects of other income inequality measures on state-level and national-level carbon emissions, such as the widely used Gini coefficient, which captures different properties of income distributions than the Theil index.

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Urbanization, Slums, and the Carbon Intensity of Well-being: Implications for Sustainable Development

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Abstract

Previous research in macro comparative environmental sociology analyzes both environmental and human well-being outcomes of urbanization. The carbon intensity of well-being (CIWB) concept simultaneously measures environmental and human well-being. Here I ask how various types of urbanization, an underexplored concept in the CIWB research, contributes differently to the CIWB of nations. Using longitudinal two-way fixed effects Prais-Winsten regression models for the years 1990–2011 for 78 countries, I find that level of development and urbanization are associated with higher CIWB, as are the percentage of urban populations with access to improved water and sanitation; conversely, urban slum prevalence is associated with lower CIWB. Comparing more versus less developed countries, I find the results are especially robust for lower-income countries. I also find that overall population access to water and sanitation is associated with lower CIWB. The findings suggest directions for sustainable development that take into account different forms of urbanization and both rural and urban population well-being.

Keywords: urbanization, slum, well-being, carbon, development, environment

Introduction

Urbanization is a global trend; however, in different contexts urbanization takes contrasting forms. Urban slums are a particular type of urbanization that is of concern to scholars interested in development, human well-being, and the environment (UN-HABITAT, 2012). Davis (2007) draws attention to the massive growth of urban slums and the development and sustainability challenges they present, and scholarly research analyzes both the human and environmental outcomes of slum growth (Jorgenson & Rice, 2010; Jorgenson, Rice, & Clark, 2010, 2012; Rice, 2008). Liu et al. (2007, p. 644) write, "although development-

as-usual has initial economic benefit, traditional development strategies need to be altered, and transforming them into sustainable practices is urgent … In the transition to sustainability, those not yet enjoying the fruits of development need help." Scholars have long recognized that if the less developed nations follow the development trajectories of the more developed nations it will be unsustainable on a planetary scale, and yet not meeting the well-being needs of the poor or calling nations with low CO_2 emission but with low population well-being "sustainable" is inaccurate and unjust.

The carbon intensity of well-being (CIWB) is a concept that enables a cross-national assessment of sustainable development by combining an environmental and human well-being measure into one indicator (Dietz, Rosa, & York, 2009, 2012; Jorgenson, 2014, 2015; Jorgenson & Dietz, 2015; Jorgenson & Givens, 2015). Countries with low emissions but low well-being and countries with high well-being but high emissions *both* have high CIWB, which is undesirable. Countries with low emissions but high well-being have low CIWB. An effective sustainability strategy includes reducing the CIWB (Jorgenson, 2014).

Focusing on equitable and green urban development is a key area for improvement in lowering the CIWB. Thus, in this paper I examine the varied effects of urbanization and urban slum growth on the CIWB. This work builds on the tradition of research that examines the effects of population dynamics in conjunction with affluence as a driver of environmental impacts and with the general body of macro-comparative quantitative work that examines human–environment relationships (Dietz & Jorgenson, 2013).

In what follows, I first review current information on urbanization trends and slums. I then discuss previous sociological research on the relationships between urbanization, slums, development, human well-being, and the environment. Next I describe the CIWB concept and literature. After a discussion of data, methods, and results, I conclude with some implications of the findings for sustainable development and suggestions for future research.

Urbanization and slums

As of 2008, half of the world's population was urban and the world continues to urbanize, with six out of 10 people expected to reside in urban areas by 2030 (UN-HABITAT, 2015b). Globally, however, urbanization occurs differently and takes different forms. Continued urbanization is occurring slowly in the more developed countries (MDCs), adding about six million people per year (UN-HABITAT, 2012), while more than 90% of the growth in urban areas will take place in Africa, Asia, Latin America, and the Caribbean (UN-HABITAT, 2015b).

This contributes to the fact that the population of less developed countries (LDCs), as opposed to MDCs, accounts for 82% of world population. Half of the world's urban population lives in Asia. Latin America and the Caribbean are the most urban regions of the world at 80% urban, compared to Europe which is 73% urban; Africa is the least urban, but African countries have some of the largest urban growth rates (UN-HABITAT, 2012).

In some cities the proportion of residents who live in slums is as high as 80% (UN-HABITAT, 2015a). Although the percent of the urban population living in slums has declined since 1990 for most regions, raw numbers of slum dwellers are increasing (UN-HABITAT, 2012). Since 2000, the global slum population has risen by 55 million (UN-HABITAT, 2015a). Although the pace of urban population growth in LDCs has slowed from about 3% to 2.4% as of 2010, this is still 3.5 times higher than the annual average population growth rate in MDCs. In developing countries, slum prevalence is highest in Sub-Saharan Africa, with 62% of the urban population living in slums, and lowest in North Africa (13%), and it is 25% in Western Asia, 35% in South Asia, and 24% in Latin America and the Caribbean (UN-HABITAT, 2012). In terms of raw numbers, Sub-Saharan Africa has a slum population of 199.5 million, South Asia 190.7 million, East Asia 189.6 million, Latin America and the Caribbean 110.7 million, Southeast Asia 88.9 million, West Asia 35 million and North Africa 11.8 million (UN-HABITAT, 2015a).

Slums present a variety of social and environmental problems. The United Nations Human Settlements Programme (UN-HABITAT) defines a slum household as a group of individuals living under the same roof in an urban area who lack one or more of the following five conditions: (1) durable housing of a permanent nature that protects against extreme climate conditions; (2) sufficient living space which means no more than three people sharing the same room; (3) easy access to safe water in sufficient amounts at an affordable price; (4) access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people; and (5) security of tenure that prevents forced evictions. In addition, 30–40% of non-permanent houses in the cities of less developed countries are located in areas prone to floods, landslides, hurricanes, and earthquakes. All slums are not the same, nor do all slum residents suffer the same degree of deprivation, as some may meet only one of the conditions while others may have all five. Slum residents are the most deprived in Sub-Saharan Africa (UN-HABITAT, 2006). As poverty is urbanized and patterns of settlement are established that are difficult to alter, these circumstances structure ongoing problems, and high rates of poverty and prevalence of slums impede the prosperity of cities (UN-HABITAT, 2012, p. 99). Slum dwellers are also often stigmatized and face discrimination. UN-HABITAT warns that "highly unequal cities are a ticking time bomb waiting to explode (UN-HABITAT, 2012, p. 95)

and that some cities are expanding in an unplanned and low density way that is not sustainable (UN-HABITAT, 2012, p. 28). UN-HABITAT (2012, p. 117) also states, "During the last two decades, the pitfalls of the conventional urban development model have become more glaring."

Addressing human and environmental issues related to urbanization and slums is an important sustainable development issue, and various groups work to improve the situations in slums. UN-HABITAT assists national programs by providing capital and technical assistance in the areas of productivity, infrastructure, quality of life, equity, and environmental sustainability, and the interdependencies and interactions among these. While the Millennium Development Goals focused on human well-being and sustainability, the post–2015 Sustainable Development Goals also add a specific goal focused on the sustainability of cities (Sachs, 2015). Amnesty International sponsors a radio project in Ghana and Kenya that aims to challenge negative perceptions of slum inhabitants by providing a way for them to tell their stories to the wider population (Amnesty International, 2012). Slum Dwellers International is a ground-up organization/global social movement that aims for solidarity among the global poor and provides structures for networking and programs such as community investment saving groups for women. High-density living may be more sustainable than other forms of urbanization if population needs can be met.

Research on urbanization, slums, development, and the environment

Scholars have observed and examined the increasing urbanization of the planet for decades, and comparative international sociologists study both the drivers and the consequences of this phenomenon. Early works focused both on internal dynamics within countries, such as rural push and urban pull factors (Firebaugh, 1979), and on external characteristics of the world system, such as dependency on foreign direct investment in structuring urban change, especially in less developed countries (Kentor, 1981; Timberlake & Kentor, 1983). While the former research focusing on dynamics within the nation-state is based on traditional modernization or ecological theory, the latter research drawing attention to forces external to the nation-state, such as the penetration of global capitalism, comes from political economy (Kasarda & Crenshaw, 1991; London, 1987). London (1987) highlights that the political economy perspective perceives push-pull internal dynamics, such as the commercialization of agrarian production, in addition to urbanization itself, as shaped by international forces, and he concludes that forces both internal and external to the nation-state must be considered to conduct a complete analysis of urban change. Furthermore,

urban growth is a product of both domestic and international migration, natural population growth of urban populations is affected by the fact that migration age often coincides with fertility, and boundary changes occur, thus necessitating going beyond simply looking at internal rural/urban push-pull factors (Kasarda & Crenshaw, 1991; London, 1987; Smith & London, 1990).

Urbanization occurred first in what are now the more developed countries and some therefore assume that what is currently occurring in less developed countries is a similar pathway to development; this view is in line with assumptions of modernization theory regarding development (Smith, 1996). However, the scale at which urbanization is occurring in less developed countries today is much larger (Kasarda & Crenshaw, 1991; Preston, 1979). Two explanations for this difference are that (1) natural population increase was lower when today's more developed countries were experiencing their urbanization, and (2) that the global context differed, for example in terms of the landscape of competition and in terms of colonial migration as an alternative to urban migration (Kasarda & Crenshaw, 1991; Massey, 1988; Williamson, 1988). Today there are vast inequalities in development and cities in LDCs (Evans & Timberlake, 1980; Kentor, 1981; Molotch, 1976). While urbanization may lead to economic development, the benefits often accrue unevenly, going disproportionately to international interests and domestic elites (Chase-Dunn, 1975; Rice & Rice, 2012). Current research examines debt dependence and how it increases the portion of the total population living in urban slums (Davis, 2007; Rice, 2008; Rice & Rice, 2012). The growth and scale of urban slums is therefore more accurately considered a development challenge rather than a natural occurrence in the course of development.

Current macro comparative research looks at the impacts of different forms of urbanization, including slums, on both human and environmental well-being. Rice (2008) proposes that the presence of urban slums affects population level measures of well-being including infant and under-five mortality, maternal mortality, and life expectancy. Also, Rice (2008) attributes the urbanization of poverty trend to a continuation of dependency relations in the world economy. This work calls into question the assumption that urban residents in general have better access to health resources, suggesting instead that urban residents of slums may suffer an urban penalty that is detectable at the national level. Slum proliferation indicates that attention should be paid to the development and path dependency of the construction of the built environment, how context matters for well-being outcomes, and the social causes of disease (Rice & Rice, 2009). Several empirical studies test and find support for the assertion that urban slum prevalence has negative impacts on population level measures of well-being while noting that more macro comparative work should attend to nuanced and uneven manifestations of urbanization (Jorgenson & Rice, 2010),

as there is evidence of temporal and regional variation (Jorgenson, Rice, & Clark, 2012). In terms of the relationship between slums and the environment, while urbanization is found to increase energy consumption, urban slum prevalence is associated with a decrease in energy consumption (Jorgenson, Rice, & Clark, 2010). Urbanization in general has a positive effect on CO_2 emissions, although this varies by level of development and region, and it changes in magnitude over time (Jorgenson, Auerbach, & Clark, 2014). In related literature, scholars assess whether rural environmental degradation and other related quality of life issues act as push factors contributing to high rates of urbanization in LDCs (Moriniere, 2012; Sanderson, 2009; Shandra, London, & Williamson, 2003) and examine the loss of arable land to urban and slum expansion (Fazal, 2000; Liu, Wang, & Long, 2009).

The carbon intensity of well-being (CIWB)

In their study on urbanization, slums, and energy consumption, Jorgenson, Rice, and Clark (2010, p. 193) note that energy consumption "underlies an improved quality of life." The CIWB gets directly at the relationship between emissions and quality of life. The CIWB and related concepts offer a way to assess sustainability by combining human and environmental components into one measure and capturing the relationship between human well-being and the stress humans, often in the pursuit of well-being, can put on the environment (Dietz, Rosa, & York, 2009, 2012). In an article seen as foundational to this area of research, Mazur and Rosa (1974) ask if massive energy consumption is necessary to maintain current living standards in the U.S., since other countries use less energy but maintain comparable living standards. While they find a high correlation between energy consumption and lifestyle when examining a global sample of countries, when they limit the sample to developed countries many of the correlations are no longer significant. Continuing this line of inquiry, Mazur (2011) finds a lack of association between energy consumption and improvements in quality of life over the past 30 years in developed nations. Dietz, Rosa, and York (2009, 2012, p. 26) are the first to create and use a measure that represents how efficiently a nation is producing well-being for its citizens, calling it a "foray into this reformulation of development" and analyzing the relationship between environmentally efficient well-being and economic growth. Others analyze the relationship between economic growth and the energy efficiency of well-being (Jorgenson, Alekseyko, & Giedraitis, 2014); ecological intensity of well-being (Jorgenson & Dietz, 2015); the environmental intensity of well-being using a subjective measure of well-being (Knight & Rosa, 2011); and the carbon intensity of well-being (Jorgenson, 2014; Jorgenson & Givens, 2015). The CIWB is a ratio of CO_2 emissions to a measure of well-being that is comparable cross

nationally (usually life expectancy). Thus, nations with relatively higher CIWBs have either high life expectancy but high emissions, or low life expectancy and low emissions. Nations with low CIWBs have relatively higher life expectancies with relatively lower levels of emissions.

A related body of work also examines the relationship between human needs and environmental impact and directly informs this research. Steinberger and Roberts (2010) find evidence in some contexts that energy use and carbon emissions are decoupling from human needs at higher levels of consumption and income, and that past a certain point increasing energy consumption or carbon emissions does not have major advantages in terms of progress on well-being. This is in line with earlier findings from Mazur and Rosa (1974; see also Mazur, 2011). This research draws upon Goldemberg et al. (1985) and the concept of a threshold of necessary energy consumption and develops the concept of "Goldemberg-Corner countries," which have relatively high life expectancies but with relatively low CO_2 emissions compared to countries with similar life expectancies. The presence of these Goldemberg countries shows that the high levels of emissions of some of the MDCs are not necessary to reach high levels of human well-being, and suggest alternative pathways to and conceptions of sustainable development. This research also examines the impact of affluence on increasing CO_2 emissions beyond sustainable levels (Steinberger et al., 2012) and other cross-national drivers in an effort to gain a better understanding of a new class of "sustainability states" (Lamb et al., 2014, p. 7).

The analyses

This study builds upon research, reviewed above, that finds generally that urbanization is associated with increases in both CO_2 emissions and life expectancy, while urban slums tend to decrease CO_2 emissions and life expectancy. This study aims to assess the effects of different forms of urbanization on the CIWB of nations. I test the following two hypotheses:

Hypothesis 1: Urbanization will be associated with an increase in the CIWB of nations.

Hypothesis 2: Urban slum prevalence will be associated with a decrease in the CIWB of nations.

The data are for a sample of 78 countries with yearly data from 1990 to 2011.[1] Countries included in the analyses that have the highest CIWBs include Bahrain, Rwanda, Zambia, South Africa, the United States, and Nigeria. Those with the lowest CIWBs, the Goldemberg countries, include Costa Rica, Vietnam, Panama, Uruguay, Sri Lanka, and Ecuador (see Lamb et al., 2014 for a visual depiction of CIWB country distribution). I estimate models for the entire sample of 78 countries and also for a split sample of 26 more developed countries (MDCs) and 52 less developed countries (LDCs). I also estimate a model with more control variables for a sample of 46 LDCs; the sample is reduced because there are missing data for some of the additional variables.

Dependent variable

The dependent variable, the CIWB, is a ratio between carbon emissions and life expectancy. This is the same ratio used in previous studies (e.g., Jorgenson, 2014). The data for the CO_2 emissions are from the CAIT 2.0 climate data explorer (World Resources Institute, accessed August 2, 2014). The CO_2 emissions data are provided in millions of metric tons, therefore I used population data from the World Bank (World Bank World Development Indicators, accessed July 24, 2014) to convert total emissions data into per capita measures in metric tons. The well-being measure, life expectancy, comes from the same World Bank source and is also per capita. Life expectancy is total life expectancy at birth, or the total number of years an infant would be expected to live if patterns of mortality at the time of its birth remained the same throughout its life.

The CIWB is a ratio. In order for the numerator or the denominator to not have a disproportionate influence, I take the same approach as previous research (Dietz, Rosa, & York, 2012; Jorgenson, 2014; Jorgenson & Givens, 2015) and constrain the coefficients of variation, the standard deviation over the mean, to be equal by adding a constant to the CO_2 measure, shifting the mean without changing the variance. I multiply by 100 to scale the ratio.

$$CIWB = [(CO_2pc + 28) / LE] * 100$$

1 Countries included in the analyses: MDCs: Australia, Austria, Bahrain, Canada, Chile, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Japan, S. Korea, Netherlands, Norway, Oman, Portugal, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States, Uruguay; LDCs: Bangladesh, Benin, Bolivia, Brazil*, Bulgaria*, Cameroon, China*, Colombia, Costa Rica, Cote d'Ivoire, Ecuador, Egypt, El Salvador, Ethiopia, Ghana, Guatemala, Guinea, Honduras, Hungary*, India, Indonesia, Kenya, Lao PDR, Madagascar, Malawi, Malaysia, Mauritius, Mexico, Morocco, Mozambique, Nepal, Nicaragua, Nigeria, Pakistan, Panama, Peru, Philippines, Romania*, Rwanda, Senegal, South Africa, Sri Lanka, Tanzania, Thailand, Togo, Tunisia, Turkey*, Uganda, Venezuela, Vietnam, Zambia, Zimbabwe (*indicates missing from model 4).

Independent variables

The independent variables all come from the World Bank (World Bank World Development Indicators, accessed July 24, 2014). I control for level of economic development as GDP per capita in constant 2005 U.S. dollars.[2] Level of development is the variable that most research in this area has examined (e.g., Jorgenson, 2014). I also control for exports as a percent of GDP, which represents the value of all goods and other market services provided outside the nation-state and is commonly included as a measure of connection to the global economy (Rosa & Dietz, 2012).

The first independent variable of interest is the measure of urbanization, urban population as a percent of total population.[3] The second variable of interest is the percent of the urban population with access to an improved water source and the third is the percent of the urban population with access to improved sanitation facilities. The fourth variable of interest is the percent of the total population with access to an improved water source and the fifth is the percent of the total population with access to improved sanitation facilities. In additional analyses, I also control for two other variables that are expected to have a detectable effect on overall population health and CO_2 emissions: the total fertility rate and the prevalence of HIV, measured as the prevalence of HIV in the population ages 15–49 (Jorgenson & Rice, forthcoming).

While previous research has used the UN-HABITAT provided measure of a slum (e.g., Jorgenson et al., 2010; Jorgenson et al., 2012; Rice & Rice, 2009, 2012), I instead use two separate measures that focus on access to water and access to sanitation facilities. These World Bank data have better coverage of a greater number of countries, are comparable across both urban and overall population settings, and are the two that are arguably most directly linked to health and well-being. Also, lack of access to an improved water source and sanitation facility are the most common indicators of urban slum residence in the developing countries (Rice, 2008; UN-HABITAT, 2003). Furthermore, access to water and sanitation have historically been key parts of development; in addition to being basic needs, providing access requires not only the work of individuals and households but also collective systems, whether public, private, or a combination, to establish and maintain infrastructure. The two slum indicators used here are correlated at .66. See Table 1 for descriptive statistics and correlations.

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2 According to the data source dollar figures for GDP are converted from domestic currencies using 2005 official exchange rates.

3 According to the data source these data are based on national definitions of what constitutes rural versus urban, and while this means that cross-national comparisons may need to be made with caution, allowing for this variation arguably allows for a more accurate assessment of what constitutes rural versus urban in a particular country.

Table 1. Descriptive statistics and bivariate correlations

	Variable	Obs	Mean	Std. Dev.	Min	Max				
1	CIWB (ln)	1,782	3.865	0.141	3.611	4.653				
2	GDP per capita (ln)	1,782	8.122	1.740	4.717	11.124				
3	Exports as a % of GDP (ln)	1,782	3.381	0.579	1.163	5.439				
4	Urban population (% of total)	1,782	56.022	23.452	5.4	100				
5	Improved water source, urban (% of urban population with access)	1,774	94.355	6.782	70.3	100				
6	Improved sanitation facilities, urban (% of urban population with access)	1,727	75.623	27.144	8.6	100				
7	Improved water source (% of population with access)	1,748	84.092	17.735	13.2	100				
8	Improved sanitation facilities (% of population with access)	1,718	67.599	32.036	2.4	100				
9	Fertility rate, total (births per woman)	1,781	3.158	1.660	1.1	7.3				
10	Prevalence of HIV, total (% of population ages 15-49)	1,056	2.680	4.627	0.1	27.6				
		1	2	3	4	5	6	7	8	9
1	CIWB (ln)									
2	GDP per capita (ln)	-0.543								
3	Exports as a % of GDP (ln)	-0.292	0.470							
4	Urban population (% of total)	-0.443	0.853	0.322						
5	Improved water source, urban (% of urban population with access)	-0.435	0.636	0.354	0.451					
6	Improved sanitation facilities, urban (% of urban population with access)	-0.597	0.811	0.342	0.606	0.657				
7	Improved water source (% of population with access)	-0.600	0.790	0.398	0.621	0.815	0.783			
8	Improved sanitation facilities (% of population with access)	-0.608	0.862	0.404	0.646	0.670	0.950	0.803		
9	Fertility rate, total (births per woman)	0.740	-0.754	-0.411	-0.558	-0.656	-0.784	-0.805	-0.802	
10	Prevalence of HIV, total (% of population ages 15-49)	0.687	-0.290	-0.032	-0.292	-0.070	-0.332	-0.296	-0.311	0.390

Model estimation technique

I estimate Prais-Winsten models with panel-corrected standard errors (PCSE). This is an appropriate method for dealing with comparative international time series cross-sectional data where data often have the structure of 10 to 100 units observed over 20 to 50 years, and where errors may be serially (i.e., temporally) correlated, spatially (i.e., contemporaneously) correlated, and characterized by heteroscedasticity (all the error processes may not have the same variance) (Beck & Katz, 1995). The method suggested by Beck and Katz (1995) and employed here retains OLS parameter estimates but uses panel corrected standard errors, which deal with spatial correlation and heteroscedasticity, while the Prais-Winsten transformation corrects for AR1/serial correlation.

I include country-specific and year-specific intercepts, making the model equivalent to a two-way fixed effects model. As with a fixed effects model, this technique estimates effects within countries (rather than between countries) over time and controls for variation between countries. This model construction is especially well-suited to hypothesis testing as it controls for all period-specific and country-specific variation. For this reason most models are parsimonious and only control for level of development, level of economic integration, and the key population measures related to urbanization or well-being.

Results

Table 2 presents the findings for the analyses. Model 1 contains all 78 countries included in the analyses and controls for the following: GDP per capita, logged to address positive skew; exports as a percent of GDP, also logged; urban population as a percent of the total population; the percent of the urban population with access to an improved water source; the percent of the urban population with access to improved sanitation facilities; the percent of the total population with access to an improved water source; and the percent of the total population with access to improved sanitation facilities. Model 2 presents the results for these same variables on a subset of 26 more developed countries (MDCs) and model 3 presents these analyses on the remaining 52 less developed countries (LDCs). Model 4 includes two additional control variables expected to have population well-being and environmental effects: the total fertility rate and the prevalence of HIV in the population of 15–49 year olds. For each model I report regression coefficients, significance level, panel corrected standard errors, R-squared statistic, the number of countries included, the number of observations, and the minimum observations per country. The high R-squared statistics are common for this methodological approach to analyzing longitudinal data that includes unreported unit and year specific intercepts (Jorgenson, 2011; Jorgenson & Givens, 2015). While the data

set is unbalanced, meaning there are missing values, the data are mostly complete with the minimum observations per country not falling lower than 18 out of a possible 22 for the years 1990–2011. Although models with variables added incrementally are not reported, results are substantively similar. Results of these sensitivity analyses are available upon request.

Table 2. Predictors of the carbon intensity of well-being (CIWB) for high (HIC) and non-high (non-HIC) income countries: Results from two-way fixed effects Prais-Winsten regression models, 1990–2011

	Model 1 All	Model 2 MDC	Model 3 LDC	Model 4 LDC
GDP per capita (ln)	0.049***	0.163***	0.036*	0.017
	(0.014)	(0.019)	(0.017)	(0.017)
Exports as a % of GDP (ln)	-0.009**	0.010	-0.007*	-0.009*
	(0.003)	(0.008)	(0.004)	(0.004)
Urban population (% of total)	0.001*	0.002**	0.000	-0.002*
	(0.000)	(0.001)	(0.001)	(0.001)
Improved water source, urban (% of urban population with access)	0.008***	0.021***	0.007***	0.008***
	(0.001)	(0.004)	(0.001)	(0.001)
Improved sanitation facilities, urban (% of urban population with access)	0.008***	-0.009**	0.009***	0.008***
	(0.001)	(0.003)	(0.001)	(0.001)
Improved water source (% of population with access)	-0.005***	-0.009**	-0.005***	-0.005***
	(0.001)	(0.003)	(0.001)	(0.001)
Improved sanitation facilities (% of population with access)	-0.005***	0.012***	-0.006***	-0.005***
	(0.001)	(0.003)	(0.001)	(0.001)
Fertility rate, total (births per woman)				0.013*
				(0.005)
Prevalence of HIV, total (% of population ages 15–49)				0.012***
				(0.002)
R-squared	0.9981	0.9987	0.9981	0.9983
Number of countries	78	26	52	46
Number of observations	1704	571	1133	1004
Minimum observations per country	18	21	18	18

Notes: * p<.05, ** p<.01, *** p<.001; panel-corrected standard errors in parentheses

In models 1, 2, and 3, GDP per capita, the indicator for level of development, is positive and significant in the total sample of countries and in the subsets of more and less developed countries. Positive and significant GDP per capita is associated with increasing CIWB, which is undesirable for sustainability. GDP per capita is not significant in model 4 on the reduced sample of 46 LDCs, which also controls for fertility rate and HIV prevalence. Exports as a percent of GDP, the indicator for

connection to the world economy, is significant for the total sample of countries and in both analyses of LDCs. Urban population is positive and significant for the total sample and for the MDCs, non-significant for the LDCs, and weakly negative in model 4 on the reduced sample of LDCs. These findings are in line with the assertion that urbanization varies in different contexts.

In terms of the findings of specific interest, urban population access to an improved water source has consistently positive and significant effects across all four models, and urban population access to improved sanitation is also positive and significant in models 1, 3, and 4. These variables were retained in the form of urban population access to mirror the variables that indicate total population access; however, creating a slum measure by subtracting the urban percent with access yields results with the same coefficients but a sign change, meaning urban slum presence has a negative effect on the CIWB.

Conversely, total population access to an improved water source is consistently negative and significant across all four models, and total population access to improved sanitation is negative and significant in models 1, 3, and 4. In model 2, the analysis on 26 MDCs, there is a finding counter to the rest of the analyses that urban access to improved sanitation has a negative effect on the CIWB and total population access to improved sanitation has a positive effect on the CIWB, however, making too much of these findings should be avoided for two reasons: the small sample and, more importantly, the low amount of variation for these variables within the sample of 26 MDCs over the time period analyzed. While urban access to water and sanitation varies from 70.3% to 100% and 8.6% to 100%, respectively, in the total sample, the variation is only from 83.4% to 100% and 91.3% to 100%, respectively, for MDCs. Likewise, the total population access to water and sanitation varies from 13.2% to 100% and 2.4% to 100%, respectively, in the overall sample, whereas it only varies from 78.8% to 100% and 81.8% to 100%, respectively, in MDCs.[4] Finally, in model 4, both the fertility rate and the prevalence of HIV are associated with an increase of the CIWB in LDCs, as they are both associated with lower life expectancies.

4 In the reported models only GDP per capita and exports as a percent of GDP are logged, as it is standard practice to log some variables that have high skew while having other variables in the model that are unlogged. As a sensitivity analysis, however, I also run elasticity models in which every variable in the model is logged. The models are substantively similar with the only substantive difference being that in the elasticity models for all three groups of countries, exports as a percent of GDP is no longer significant. These sensitivity analyses are available upon request.

I also address potential multicollinearity in the reported models in another set of sensitivity analyses. An examination of variance inflation factors indicated potential multicollinearity when the percent of the population with access to improved sanitation was included in the models. I dropped this variable and re-ran the models and found the results were substantively similar. The only difference was that for the subset of MDCs the percent of the population with access to water and the percent of the urban population with access to improved sanitation were no longer significant. After making this change the mean VIF for the year 2011 was an acceptable 4.43. These sensitivity analyses are available upon request.

Discussion and conclusion

The results presented here align with previous research results suggesting the impacts of urbanization are not monolithic (Jorgenson, Auerbach, & Clark, 2014). I find that urbanization has a positive (i.e., undesirable) effect on the CIWB overall, but when separated out by level of development, it has a non-significant or negative effect in LDCs. However, the results also reveal the general pattern that urban *development is* associated with an increase in the CIWB, as indicated by the percent of the urban population with access to improved water and sanitation being associated with a higher CIWB. This finding substantiates concerns that if urban areas continue to follow traditional development models, it may result in some population well-being gains (such as increases in life expectancy), which can reduce the CIWB, but it will likely ultimately be detrimental to the health of the planet and consequently the planet's inhabitants (Jorgenson, 2014). In other words, even if this form of urbanization *is* a path to development, if it follows the same process as urbanization in MDCs, it will not be sustainable.

Conversely, the presence of urban slums, while highly problematic, does have the desirable consequence of being associated with a reduction in the CIWB. Both justice concerns and logic suggest that we as a global community need to find ways to meet the development needs of all urban dwellers, including those living in slums (Sen, 1999). The current situation of underconsumption, where people are not able to meet basic needs with dignity while elsewhere others are able to overconsume, has negative impacts on social welfare and is unacceptable (Jorgenson, Rice, & Clark, 2010; Rice, 2008). Yet policies to address underconsumption must also be sustainable, meaning they must decrease the CIWB, and they must not increase carbon emissions beyond certain thresholds (Steinberger & Roberts, 2010). Furthermore, more developed countries must find ways to reduce their CIWBs. Sustainable development requires change in both less and more developed countries (Steinberger et al., 2013). In considering ways to build upon the results from this paper, I conclude by reviewing some of the literature on meeting the sustainable development needs of urban slum dwellers; such a review might also provide insights into alternative paths of development in multiple contexts (Lamb et al., 2014).

The non-significant and even negative findings for urbanization in general for LDCs suggest that if population needs can be met for slum dwellers using means that retain low emissions, this could be a way forward for sustainable development. While being especially cautious not to fall into the trap of absurd optimism that has led to such travesties as relabeling slums "Strategic Low-Income Urban Management Systems," which Davis (2007, p. 179) ridicules, we may consider policies and programs that might result in the socially and

environmentally desirable outcome of having percent of urban residents with access to improved water and sanitation have a negative effect on the CIWB. In other words, what can we learn from slums, which are associated with a reduction in the CIWB, to improve well-being without proportional environmental degradation?

Although not all slums are the same and some are characterized by somewhat more sprawling, lower-density development compared to other slums, slums tend to be low income and high density, two qualities that have been found to be more sustainable than other alternatives (Stein, 2009). Steinberger et al. (2012) find that low carbon emissions are not compatible with high incomes at the country level and Jorgenson (2015) finds that reducing population inequality has a negative effect on the CIWB. Attention to density may also be addressed in more or less sustainable ways. For example, some research finds that increasing numbers of households may result in less sustainable outcomes than population increase alone (Cramer, 1997, 1998; Liu et al., 2003).

The results here also show overall population access to improved water and sanitation is associated with a reduction in the CIWB, indicating that meeting human needs is not inherently unsustainable. This draws attention to rural population dynamics and rural–urban linkages as part of sustainable development (Rees, 1992; Tacoli, 2003). This also relates to the findings of Jorgenson (2015) on reducing inequality.

In addressing human well-being issues and sustainability in urban settings a way forward may be to focus on current strengths rather than promoting traditional or imported models of economic development that are associated with increasing CO_2 emissions. Sachs (2015), in his suggestions for sustainable development, highlights the creation of the new Sustainable Development Goals and the need for international aid and assistance. While such attention by the global community is vital, Davis (2007) is critical of reliance on general economic development and market-based attempts to address urban poverty, such as methods advocated by De Soto (2000) that promote microcredit, land titling, and the free market. One interesting and specific problematic result of market-based development policies is described in a study of urban food vendors in Mozambique; the study finds that as men enter markets traditionally dominated by women, the women are driven from certain professions, are economically marginalized, and experience competition that undermines their ability to work collectively (Companion, 2010). This example elucidates two points. First, urban sustainable development strategies cannot be gender-blind (Davis, 2007; Rice, 2008). Second, traditional development strategies that foster competition can undermine some of the strengths that lower-income communities are sometimes found to have.

Globally, lower-income communities have been found to use social capital as a strategy for resilience (Portes, 1998). Research finds that lower-income neighborhoods in Brazil, including favelas, have higher social cohesion (Villareal & Silva, 2006), social capital among slum dwellers in Dhaka help them deal with natural hazards, although social capital alone does not enable long-term development (Aßheuer et al. 2013), and development strategies can increase social capital, such as those that foster group participation in urban agriculture (Gallaher et al., 2013). While remaining cognizant that social capital can have negative effects (Portes, 1998), fostering social capital may be one part of a strategy for a resilient relationship between urban society and the environment (Folke, 2006).

People in communities also tend to have a better understanding of the actual needs of their community. Satterthwaite (2001) notes that much international aid is only as effective as the local governments and organizations that are funded to actually implement programs, and therefore developing strong community organizations that have the capacity to achieve effective results is a vital part of addressing urban poverty in LDCs. Groups such as Slum Dwellers International focus on female community savings groups as a means to empower women to learn to manage money, and on projects related to investments in community infrastructure (Patel et al., 2001). Burra et al. (2003) detail successes that local urban groups in India have had with community toilets. Community groups have an understanding of local needs and can focus on building community strengths, partnering with local or international non-governmental organizations, garnering and managing aid, implementing projects, and empowering local residents, which also reduces stigma and builds resilience.

Meeting the needs of urban slum dwellers is a global sustainable development challenge. Without forgetting or neglecting the deprivation that is present in many situations of urban poverty in LDCs, sustainable development strategies might also concentrate on what can be learned from situations that already are associated with reductions in the CIWB, such as urban slums. Insights from this study and related research indicate that strategies to reduce the CIWB include reducing inequality, promoting low-income and high-density living, increasing social capital, and fostering community resilience. Such strategies might also be considered in different contexts to lower CIWB in MDCs. Future research should explore such different pathways to sustainable development and lower CIWBs, attend to the role of gender in urbanization and the CIWB, and continue to examine the links between different forms of urban development and the CIWB and how this might vary regionally and over time.

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Water, Sanitation, and Health in Sub-Saharan Africa: A Cross-national Analysis of Maternal and Neo-natal Mortality

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Abstract

We examine the impact of access to an improved water source and sanitation facility on maternal and neo-natal mortality. We analyze data from a sample of 32 Sub-Saharan African nations from 1990 to 2005 using a two-way fixed effects regression model. We find that access to both improved water and sanitation facilities are associated with decreased maternal and neo-natal mortality. We also consider other structural barriers or facilitators of good reproductive health and find that International Monetary Fund structural adjustment, gross domestic product per capita, female educational attainment, and conflict intensity are related to maternal and neo-natal mortality. We conclude by talking about the theoretical implications, methodological implications, policy suggestions, and directions for future research.

Keywords: water, sanitation, Sub-Sahara, mortality

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Introduction

The World Health Organization estimates that 289,000 women die from pregnancy complications and 3,000,000 infants die during the first 28 days after birth annually (World Bank, 2015). Nevertheless, maternal and neo-natal infant mortality are not distributed equally. Sub-Saharan Africa has the highest levels of maternal and neo-natal mortality in the world (World Bank, 2015). In 2005, approximately 614 women died during pregnancy or one month afterwards per 100,000 live births and 38 infants died before reaching 28 days per 1,000 live births (World Bank, 2015).

Recently, cross-national research has been published that focuses on structural political-economic explanations for why maternal mortality is so high in the region. For instance, Pandolfelli, Shandra, and Tyagi (2014) find that International Monetary Fund structural adjustment is associated with increased maternal mortality in Sub-Saharan Africa. The authors find that this may well be the case because the International Monetary Fund requires recipient nations to cut government spending for health, implement user fees for services, and privatize hospitals. Further, Buor and Bream (2004) find that gross domestic product per capita and public health expenditures are related to lower levels of maternal mortality in Sub-Saharan Africa. Alvarez, Gil, and Hernandez (2009) find that female educational attainment corresponds with lower maternal mortality in the Sub-Saharan Africa.

This research serves as the starting point for our study. However, we seek to address an important gap in the literature. There is little cross-national literature that examines the relationship among maternal and neo-natal mortality and access to an improved water source and improved sanitation facility in Sub-Saharan Africa. This is somewhat surprising because the region has the lowest percentage of population with access to an improved water source (66%) and improved sanitation facility (32%) (World Bank, 2015). Further, a lack of clean water and basic sanitation facilities can impact pregnant women in several ways. First, they may contract illnesses that either kill them directly or weaken their immune systems, leading to complications during pregnancy (Benova, Cumming, & Campbell, 2014). Second, pregnant women who habitually travel long distances to collect water often experience weight loss and issues during birth (Dankelman & Davidson, 2008). Third, a lack of clean water and sanitation prevents essential hygiene practices—including hand washing by birth attendants, delivering the infant on a clean surface, sterilizing equipment for cord cutting, and providing clean blankets—which can lead to sepsis, tetanus and, ultimately, death (Blencowe, Cousens, & Mullany, 2011). Fourth, clean

water and adequate sanitation are necessary to treat mothers and infants for complications following delivery (Mamaye, 2015). We elaborate upon these factors in detail below.

Thus, we seek to expand upon existing cross-national research here by testing the hypothesis that having access to an improved water source and an improved sanitation facility should lower maternal mortality and neo-natal mortality in Sub-Saharan Africa. We do so by analyzing cross-national data using two-way fixed effects models for a sample of 32 Sub-Saharan African nations from 1990 to 2005. We now turn to a detailed discussion of how access to clean water and basic sanitation may impact maternal and neo-natal mortality. We go on to describe the variables used in the analysis, our methodology, and the findings. We conclude by summarizing the findings, discussing the theoretical and methodological implications, offering some policy suggestions, and suggesting possible directions for future research.

Water, sanitation, and health in Sub-Saharan Africa

The lack of access to clean water and basic sanitation may contribute to increased maternal and neo-natal mortality at three different points. First, it may affect the health of the woman and the fetus during the pregnancy. When a pregnant woman drinks polluted water, she is exposed to a host of bacterial, viral, and parasitic infections (Benova, Cumming, & Campbell, 2014). In many instances, women contract various diarrheal diseases including dysentery, cholera, or typhoid. These diseases may directly kill a woman or weaken her immune system, which leads to complications during birth (Save the Children, 2014). Certain diseases, like Hepatitis E, are more commonly transmitted when a community lacks access to basic sanitation facilities. Such waterborne diseases tend to have more severe consequences for pregnant women than for the broader population (Mamaye, 2015). Pregnant women are both more susceptible to and more severely affected by diseases due changes in the immune system while adapting to the new fetus (Jamieson, Theison, & Rasmussen, 2006). Additionally, inadequate sanitation leads to the transmission of intestinal nematode infections. In Sub-Saharan Africa, hookworm infects nearly 44 million pregnant women annually, which increases their risk of anemia and, as a result, severe bleeding during birth (World Health Organization, 1996). There are also instances of chemicals from industry, agriculture, and mining contaminating water sources (Mamaye, 2015). For example, arsenic used in mining is also known to increase the risk of anemia (Vahter, 2009). Further, certain agricultural practices increase

levels of salt in drinking water, leading to increased risk of hypertension and pre-eclampsia in pregnant women, factors associated with maternal mortality (Mameye, 2015). These factors also contribute to neo-natal mortality. The diseases are passed from the mother to the fetus in utero, leading to weakened immune systems, early births, complicated births, and possibly death.

Further, maternal and neo-natal mortality may be exacerbated by poor access to water. In many Sub-Saharan African nations, women are tasked with collecting water for household tasks like cooking, cleaning, and bathing (Shandra, Shandra, & London, 2008). When women must travel longer distances or spend more hours collecting water, they tend to collect less water (Dankelman & Davidson, 1988). This has implications for household and personal hygiene with disproportionate consequences for pregnant women, who are more vulnerable to water- and sanitation-related diseases (Howard & Batram, 2003). It also increases the possibility that such diseases will be passed along during the pregnancy. At the same time, walking long distances over extended periods of time to fetch water adversely affects a woman's weight gain during pregnancy, thereby leading to complications during birth for both the mother and child (Mamaye, 2015).

Second, a lack of clean water and basic sanitation also leads to women and infants dying during or immediately after delivery. A recent study drawing on a sample of 56 low-income nations estimates that only 38% of hospitals have access to an improved water source and only 19% have access to adequate sanitation (World Health Organization, 2015). Approximately 35% do not provide soap and water for staff and patients to wash their hands (World Health Organization, 2015).

These statistics have real implications for pregnant women and newly born infants because it means that hygiene practices essential for safe deliveries are not being carried out in many Sub-Saharan African nations (Yardley, 2010). Thus, women are at a higher risk of getting infections and dying from diseases like sepsis if clean water and adequate sanitation are lacking (World Health Organization, 2015). Further, there are implications for newborns because they are even more vulnerable to life-threatening infections like sepsis and tetanus shortly after birth. It is estimated that between 30% and 40%of the infections resulting in sepsis-related deaths are transmitted from mother to child at the time of birth (Blencowe, Cousens, and Mullany, 2011). After delivery, women need running water and working toilets for personal hygiene and to bathe infants, which further limits the spread of infections and diseases (Mamaye, 2015). Running water is also essential to treat pregnancy-related complications like obstetric fistula and perineum rupture among women, and diarrheal diseases among newly born infants (Cotingham & Royston, 1991). These issues are even

more pronounced for women who give birth at home, because less than 2% have access to clean water and basic sanitation in their homes (World Health Organization, 2015).

Third, lack of clean water and basic sanitation has the potential to affect women and newly born infants in the months following delivery and beyond. Access to adequate water and sanitation is key to good menstrual hygiene, which prevents subsequent infections in both mothers and their children (Shordt, Smet, & Herschderfer, 2012). For instance, repeated diarrheal or intestinal nematode infections contribute to women and children becoming malnourished. This may contribute directly to neo-natal mortality. For women, it translates into being underweight, which has the potential to complicate future pregnancies (Shordt, Smet, & Herschderfer, 2012). Malnutrition also means women and infants are more vulnerable to other infectious diseases (e.g., malaria, tuberculosis, polio) that can lead to death (Rice, 2008). Finally, clean water is crucial for mothers who do not breastfeed, to ensure that formula is safe for consumption (Save the Children, 2014).

The preceding discussion suggests that lacking access to clean drinking water and basic sanitation adversely affects pregnant women and newly born infants in Sub-Saharan African nations. Thus, we expect that access to an improved water source and an improved sanitation facility should correspond with decreased maternal and neo-natal mortality. However, we need to consider a number of other important predictors when testing this hypothesis. This is because there may be structural barriers that hinder the provision of water and sanitation facilities, inhibit accessibility, or limit opportunities for their use in hygienic practices. These variables include structural adjustment, debt service, foreign investment, gross domestic product, domestic investment, female educational attainment, democracy, public health expenditures, conflict, and human immunodeficiency virus prevalence.

Dependent variable

Maternal mortality ratio

The dependent variable in our study is the maternal mortality ratio for a Sub-Saharan African nation. This variable measures the annual number of deaths from pregnancy-related causes per 100,000 live births. A maternal death is defined as the death of a woman while pregnant or within 42 days of the termination of a pregnancy from any cause related to or aggravated by pregnancy (World Health Organization, 2010). We take the square root of the ratio to correct for its skewed distribution. The data are available for 1990,

1995, 2000, and 2005. We obtained the data online from the United Nation's Millennium Development Goals portal. All other data may be obtained online from the World Bank's World Development Indicators unless otherwise noted. The descriptive statistics and bivariate correlations for the variables used in this analysis are contained in Table 1.

Table 1(a). Univariate descriptive statistics and bivariate correlations for variables in the analysis

Variable	n	Mean	S.D.	Min.	Max.
Maternal mortality (per 100,000 live births)*	72	25.50	6.19	5.29	36.06
Neo-natal mortality (per 1,000 live births)†	72	3.64	0.30	2.29	4.08
IMF structural adjustment (1 = yes)	72	0.67	0.47	0	1
Access to improved sanitation†	72	3.17	0.74	1.39	4.54
Access to improved water source†	72	4.04	0.30	3.00	4.61
Female secondary school enrollments	72	20.83	17.10	4.00	87.00
Multilateral debt service†	72	2.50	0.81	0.45	3.77
Multinational corporate investment†	72	2.29	1.12	-1.05	4.81
Domestic investment†	72	2.94	0.30	1.90	3.68
Gross Domestic Product per capita†	72	5.86	0.80	4.65	8.39
Democracy	72	4.64	1.46	1	7
Public health expenditures†	72	0.62	0.45	-0.78	1.41
Human immunodeficiency virus prevalence	72	4.36	5.54	0.10	26.40
Year = 1990	72	0.22	0.42	0	1
Year = 1995	72	0.31	0.46	0	1
Year = 2000	72	0.29	0.46	0	1
Year = 2005	72	0.18	0.39	0	1
No conflict	72	0.81	0.40	0	1
Minor conflict intensity	72	0.03	0.17	0	1
Intermediate conflict intensity	72	0.06	0.23	0	1
High conflict intensity (war)	72	0.11	0.32	0	1

Notes: * indicates data transformed using square root and † indicates data transformed using the natural logarithm

See text for data sources.

Table 1(b). Bivariate correlation matrix

Variable		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Maternal mortality (per 100,000 live births)*	(1)	1.000																
Neo-natal mortality (per 1,000 live births)†	(2)	0.854	1.000															
IMF structural adjustment (1 = yes)	(3)	0.326	0.369	1.000														
Access to improved sanitation†	(4)	-0.319	-0.311	-0.160	1.000													
Access to improved water source†	(5)	-0.501	-0.506	-0.241	0.447	1.000												
Female secondary school enrollments	(6)	-0.815	-0.824	-0.364	0.436	0.475	1.000											
Multilateral debt service†	(7)	0.333	0.231	0.464	0.041	-0.158	-0.231	1.000										
Multinational corporate investment†	(8)	-0.255	-0.084	-0.021	0.149	0.103	0.273	-0.267	1.000									
Domestic investment†	(9)	-0.374	-0.325	-0.200	0.099	0.068	0.255	-0.322	0.202	1.000								
Gross Domestic Product per capita†	(10)	-0.714	-0.669	-0.295	0.514	0.553	0.738	-0.225	0.200	0.136	1.000							
Democracy	(11)	0.342	0.308	-0.247	-0.103	-0.158	-0.288	0.018	-0.108	-0.182	-0.148	1.000						
Public health expenditures†	(12)	-0.273	-0.146	-0.100	0.105	0.128	0.168	-0.224	0.229	0.274	0.031	-0.172	1.000					
Human immunodeficiency virus prevalence	(13)	-0.148	0.018	-0.142	0.360	-0.042	0.163	-0.214	0.280	-0.071	0.149	0.104	0.361	1.000				
No conflict	(14)	-0.144	-0.101	-0.124	0.043	0.257	0.284	-0.094	0.054	-0.058	0.371	-0.050	-0.108	-0.069	1.000			
Minor conflict intensity	(15)	0.100	0.050	-0.060	0.100	0.017	-0.148	0.186	-0.160	-0.113	-0.146	0.100	-0.148	0.074	-0.344	1.000		
Intermediate conflict intensity	(16)	-0.042	-0.022	0.172	0.064	0.097	-0.105	0.010	-0.023	0.030	-0.068	0.060	0.074	0.025	-0.494	-0.041	1.000	
High conflict intensity (war)	(17)	0.160	0.117	0.063	-0.153	-0.403	-0.205	0.014	0.033	0.109	-0.341	-0.034	0.160	0.030	-0.720	-0.060	-0.086	1.000

Notes: * indicates data transformed using square root and † indicates data transformed using the natural logarithm
See text for data sources.

Neo-natal mortality ratio

We also analyze the neo-natal mortality ratio because the health of a mother is closely linked to the health of her newly born infant in the first month (World Health Organization, 2015). This variable measures the number of infant deaths before 28 days of age for every 1,000 live births in the specified year (World Bank, 2015). We log this measure to correct for its skewed distribution.

Main independent variables

Access to an improved water source

This variable measures the percentage of the country's population who has access to an improved water source. According to the United Nations (2010), an improved water source includes any of the following types of water sources: household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collection. An unimproved water source may include an unprotected well, surface water, vendor provided water, tanker provided water, and bottled water. We log this variable to correct for its skewed distribution. We hypothesize that higher levels of access to an improved drinking water source should be related to decreased maternal and neo-natal mortality within Sub-Saharan African nations.

Access to an improved sanitation facility

We also include the percentage of a population who has access to an improved sanitation facility in the models. The United Nations (2010) considers an improved sanitation facility to be a connection to a public sewer, connection to a septic tank, pour flush latrine, simple pit latrine, ventilated pit latrine, pit latrine with slab, and composting toilet. An unimproved sanitation facility includes an open pit latrine, public latrines, buckets, latrines, hanging latrines, flush to elsewhere (e.g., street, yard, river, ditch, etc.), and no facility (United Nations, 2010). This variable is logged to correct for its skewed distribution. We expect that higher levels of access to an improved sanitation facility should correspond to lower maternal and neo-natal mortality within a Sub-Saharan African nation.

Other relevant independent variables

International Monetary Fund structural adjustment loan recipient

This is a dummy variable where we code Sub-Saharan African nations that are under an International Monetary Fund structural adjustment loan at least one year prior to 1990, 1995, 2000, and 2005 with a value of one. All other Sub-Saharan African nations serve as the reference category and are coded with a value of zero. These data may be obtained from International Monetary Fund's online lending database. We hypothesize that when a Sub-Saharan Africa nation is under an International Monetary Fund structural adjustment loan then it should have higher maternal and neo-natal mortality than when the country is not under such a loan. This is because the International Monetary Fund tends to require nations to cut government spending for health and sell off government assets like hospitals (Peet, 1999).

Debt service ratio

In addition to the pressure to adopt macro-economic policy reforms under structural adjustment, poor nations must continually service their foreign debts. Clearly, it is also important to control for debt service as well as structural adjustment (Bradshaw & Schafer, 2000). Thus, we include the repayment of long-term debt. The data are measured as a percentage of exports of goods and services and, as a result, provides a measure of debt repayment relative to its earnings. This variable is logged to correct its skewed distribution. We hypothesize that higher levels of debt service should be associated with more maternal and neo-natal mortality within Sub-Saharan African nations because it removes resources available for governmental investment in health, family planning, and reproductive services.

Multinational corporate investment

We include the stock measure of multinational corporate investment in the models because structural adjustment loans often require that indebted nations liberalize trade for foreign investors (Jorgenson, Dick, & Mahutga, 2008). These data may be obtained online from the United Nations Conference on Trade and Development statistical portal. We log this variable to correct for its skewed distribution. We expect that higher levels of multinational corporate investment should be associated with higher maternal and neo-natal mortality in a Sub-Saharan African nation. As noted above, there are several reasons why this may be the case, especially foreign corporations expatriating the majority of their profits (Frey & Field, 2000).

Gross domestic product

As is standard in such analyses, it is necessary to take into account a nation's level of development in order to make sure any effects are independent of a nation's level of wealth (London & Ross, 1995). In this regard, we employ a measure of gross domestic product per capita at purchasing power parity. We log this variable because of its highly skewed distribution. We expect that higher levels of gross domestic product per capita should correspond with less maternal and neo-natal mortality within Sub-Saharan African nations. This is because higher levels of wealth tend to bring higher standards of living, advanced medical technology, and demographic changes that improve health (Shen & Williamson, 1999).

Domestic investment

We also include a measure of domestic investment, known as gross capital formation, as a percentage of gross domestic product. It is standard to control for this variable when considering the impact of foreign investment. We log domestic investment to correct for its skewed distribution. We hypothesize that higher levels of domestic investment should be associated with lower maternal and neo-natal mortality in Sub-Saharan Africa. This is most likely the case because domestic investment increases capital available for government funding for health, education, family planning, and nutrition (Rice, 2008).

Female secondary school enrollment

We use gross female secondary school enrollments as an indicator of educational attainment. These data come from the World Bank's World Development Indicators (2005). We hypothesize that higher levels of female secondary school enrollment should be related to decreased maternal and neo-natal mortality in Sub-Saharan Africa. This may well be because secondary education for women is associated with wider use of health services, especially prenatal care. Secondary education may reduce maternal marriage, which is also associated with better reproductive health (Gupta, 2004; Malhortra, 2011). This is because when women are married very young, they tend have less control over health decisions (Gupta, 2004). Secondary education also tends to improve access to information about nutrition, birth spacing, reproductive health, and immunizations (Filmer & Pritchett, 1999). Further, educating girls also leads to higher economic growth, and ultimately, higher living standards (Rice, 2008).

Democracy

We use the average of Freedom House's political rights and civil liberties scales to measure the level of democracy within a nation. The data may be obtained online from Freedom House. According to Freedom House (2005), political rights refer to the degree to which a nation is governed by democratically elected representatives and has fair, open, and inclusive elections. The civil liberties scale measures the levels of freedom of press, freedom of assembly, general personal freedom, freedom of private organizations, and freedom of private property within a nation (Freedom House, 2005). The variables have the following coding: free (1–2), partially free (3–5), and not free (6–7). We hypothesize that higher levels of repression should correspond with increased maternal and neo-natal mortality in Sub-Saharan Africa. This is most likely the case because freely elected and open governments respond to popular demands for health services (especially for women) due to political activism and electoral accountability, while repressive governments do not (Wickrama & Mulford, 1996).

Public health expenditures

It is also important to control for the general provisioning of public health services in a cross-national study like this (Shen & Williamson, 1999). In this regard, we include a measure of the fiscal capacity of a nation by including public health expenditures as a percentage of gross national product in the models. This measure includes all current expenditures by all levels of government for the provision of medical services. These data may be obtained from the World Bank's (2005) World Development Indicators. We expect higher levels of public health expenditures to be related to lower maternal and neo-natal mortality within a Sub-Saharan African nation. This is because government investment in hospitals and primary care (e.g., immunizations, family planning, prenatal care, postnatal care, and nutrition counseling) should improve health (Moon & Dixon, 1985).

Conflict intensity

We also want to control for the impact of conflict intensity within a Sub-Saharan African nation in a given year. We create three dummy variables and include them in the analysis. The data and coding come from Wallensteen, Sollenburg, and Erickson (2005). The first dummy variable captures minor conflict intensity, which is defined as less than 25 battle deaths in a given year. The second dummy variable measures an intermediate level of conflict intensity of more than 25 battle deaths in a given year and a historical total of more than 1,000 battle deaths. The third dummy variable captures high-conflict intensity and involves more than 1,000 battle deaths in the specified year. The reference category indicates that a Sub-Saharan African nation is not experiencing any conflict and is coded with a value of zero. We expect that nations experiencing

conflicts should have higher maternal and neo-natal mortality because conflict often disrupts the delivery of health services within a nation (Scanlan, Jenkins, & Petersen, 2007).

Human immunodeficiency virus prevalence

We also include the prevalence of HIV for each Sub-Saharan African nation. This variable measures the percentage of a country's population ages 15–49 that is infected with HIV and alive at the end of the year specified, regardless of whether they have developed symptoms of acquired immune deficiency syndrome or not. We hypothesize that higher levels of HIV prevalence should be associated with greater maternal and neo-natal mortality. This is because women may experience opportunistic infections (e.g., tuberculosis, pneumonia, and malaria) due to weakened immune systems, which could lead to mortality of them or their infants (Foster & Williamson, 2000). There are also indirect effects. When mothers fall sick from the disease or die from associated illnesses, children assume the burden of earning money. In general, there are fewer resources (e.g., food, water, etc.) available for the family because children tend to earn less than adults (Scanlan, 2010). This also removes children, especially girls, from school, thereby eroding any potential gains in lowering maternal and neo-natal mortality via educational attainment (Scanlan, 2010).

Methodology

We estimate a two-way fixed effects regression model with robust standard errors clustered by country to examine the effect of access to an improved water source and sanitation facility within Sub-Saharan African nations. This is one of the most commonly used models by social scientists to deal with potential problems of heterogeneity bias (Halaby, 2004). The issue of heterogeneity bias refers to the impact of unmeasured time-invariant variables that are omitted from a regression model. To deal with heterogeneity bias, fixed effects models control for omitted variables that are time invariant but do not vary across cases. This is done by estimating unit-specific intercepts, which are the fixed effects for each case. This approach is appropriate for cross-national analysis because time-invariant unmeasured factors (e.g., climate, geography, etc.) can affect maternal and neo-natal mortality in Sub-Saharan Africa. Thus, a fixed effects approach should provide a stringent assessment of the relationship among the independent and dependent variables because the associations between the variables are the estimated net of unmeasured between-country effects (Brady, Kaya, & Beckfield, 2007). Generally, this modeling strategy is robust against missing control variables (Hsiao, 2003). Post-estimation regression diagnostics indicate no violation of this assumption.

The notation for the two-way fixed effects model is as follows:

$$y_{it} = a + B_1x_{it1} + B_2x_{it2} + \ldots + B_kx_{itk} + u_i + w_t + e_{it},$$

where

i = each country in the analysis,

t = each time period in the analysis,

y_{it} = dependent variable for each country at each time period,

a = the constant,

B_1 *to* B_k = coefficients for each independent variables,

x_{itk} = independent variables for each country at each time point,

u_i = country-specific disturbance terms that are constant over time,

w_t = period-specific disturbance terms that are constant across all countries,

and

e_{it} = disturbance terms specific to each country at each time point.

To determine if the two-way fixed effects model is more appropriate than the random effects estimator, we calculate Sargan-Hansen test statistics for each model. The coefficients for these χ2 tests reach a level of statistical significance for every model, indicating that the fixed effects estimator is more efficient than the random-effects estimator. This is because the country-specific error terms are correlated with the independent variables included in the models (Baum, 2006), whereas the random-effects estimator assumes that this correlation is zero.

Findings

In Table 2, we present the two-way fixed effects regression estimates of maternal and neo-natal mortality in Sub-Saharan Africa.[2] In every equation, we include structural adjustment, debt service, foreign investment, gross domestic product, domestic investment, female secondary school enrollments, democracy, level of conflict, public health expenditures, and human immunodeficiency virus prevalence. In equations 2.1 and 2.2, we examine the

2 The following 32 Sub-Saharan African nations are included in the analysis. They are: Burkina Faso (1990, 2000), Burundi (1990, 2005), Cameroon (1990, 1995), Comoros (1990, 1995), Congo (2000), Côte d'Ivoire (1990, 1995, 2000), Eritrea (2000), Ethiopia (1995, 2000, 2005), Gabon (1995), Gambia (1995, 2005), Ghana (1990, 1995, 2000, 2005), Guinea (1990, 1995, 2000), Kenya (1990, 1995, 2000, 2005), Madagascar (2005), Malawi (1995, 2000), Mali (1990, 1995, 2000), Mauritania (1995), Mauritius (1995, 2000, 2005), Mozambique (1995, 2000, 2005), Niger (1995, 2000), Nigeria (1990, 2000, 2005), Rwanda (1990, 2000, 2005), Senegal (1990, 1995, 2000), Sudan (1990, 1995, 2005), Swaziland (1995, 2000, 2005), Tanzania (1990, 1995), Togo (1990, 1995, 2000), Uganda (1995, 2000, 2005), Zambia (2000), Zimbabwe (1990).

determinants of maternal mortality. In equations 2.3 and 2.4, we examine the causes of neo-natal mortality. In odd-numbered equations, we include access to an improved water source. In even-numbered equations, we include access to an improved sanitation facility.

Table 2. Two-way fixed effects regression estimates of maternal mortality and neo-natal mortality in Sub-Saharan Africa, 1990–2005

	Eq. 2.1	Eq. 2.2	Eq. 2.3	Eq. 2.4
	Maternal	**Maternal**	**Neo-Natal**	**Neo-Natal**
Access to improved water	-4.182**		-0.104*	
	-0.200		-0.103	
	(1.279)		(0.054)	
Access to improved sanitation		-4.676***		-0.108**
		-0.561		-0.266
		(1.315)		(0.036)
IMF structural adjustment (1 = yes)	1.079**	1.172***	0.024*	0.022*
	0.083	0.090	0.038	0.035
	(0.329)	(0.338)	(0.012)	(0.012)
Debt service	0.379	0.437	0.027	0.028
	0.050	0.057	0.072	0.076
	(0.583)	(0.546)	(0.019)	(0.018)
Multinational corporate investment	0.738*	0.800**	0.017	0.018
	0.133	0.144	0.064	0.068
	(0.354)	(0.312)	(0.014)	(0.013)
Domestic investment	-1.570	-0.962	0.007	0.020
	-0.075	-0.046	0.007	0.020
	(1.116)	(0.981)	(0.025)	(0.027)
GDP per capita	-9.256**	-8.779***	-0.343***	-0.331***
	-1.195	-1.134	-0.913	-0.881
	(2.934)	(2.236)	(0.077)	(0.066)
Female secondary school enrollment	-0.299***	-0.278**	-0.009**	-0.008**
	-0.827	-0.767	-0.491	-0.459
	(0.082)	(0.083)	(0.003)	(0.003)
Democracy	-0.287	-0.299	-0.016*	-0.016*
	-0.068	-0.071	-0.077	-0.077
	(0.300)	(0.281)	(0.009)	(0.008)
Public health expenditures	0.355	0.372	0.043**	0.042**
	0.026	0.027	0.065	0.063
	(0.758)	(0.685)	(0.017)	(0.015)

	Eq. 2.1	Eq. 2.2	Eq. 2.3	Eq. 2.4
	Maternal	Maternal	Neo-Natal	Neo-Natal
Minor conflict intensity (1 = yes)	-0.591	-1.118*	0.049	0.039
	-0.016	-0.030	0.027	0.021
	(0.843)	(0.572)	(0.045)	(0.032)
Intermediate conflict intensity (1 = yes)	-1.829*	-2.251**	0.048	0.041
	-0.068	-0.084	0.037	0.031
	(0.843)	(0.853)	(0.038)	(0.036)
High conflict intensity (war) (1 = yes)	-8.392***	-8.653***	-0.187**	-0.190***
	-0.429	-0.442	-0.197	-0.200
	(1.527)	(1.655)	(0.055)	(0.052)
HIV prevalence	0.069	0.127	0.003	0.004
	0.061	0.114	0.055	0.081
	(0.084)	(0.082)	(0.003)	(0.003)
Year = 1995	-1.054*	-1.153**	-0.042**	-0.044**
	-0.079	-0.086	-0.064	-0.068
	(0.490)	(0.423)	(0.014)	(0.015)
Year = 2000	0.112	-0.219	-0.040	-0.049*
	0.008	-0.016	-0.061	-0.075
	(1.021)	(1.005)	(0.024)	(0.026)
Year = 2005	3.313*	2.841	-0.041	-0.054
	0.207	0.178	-0.053	-0.070
	(1.891)	(1.902)	(0.059)	(0.063)
Constant	105.733***	98.357***	6.197***	5.987***
	(19.003)	(17.477)	(0.531)	(0.400)
Sargan-Hansan test statistic	95.279***	336.087***	157.279***	94.845***
Observations (N)	72	72	72	72
Countries	31	31	31	31
Within R square	0.761	0.779	0.905	0.909
Overall R square	0.664	0.576	0.618	0.576

Notes:

- *p < .05, **p < .01, ***p < .001 for a one-tailed test.
- The first number is the unstandardized regression coefficient, the second number is the standardized regression coefficient, and the third number in parentheses is the robust standard error.
- The null hypothesis for the Sargan-Hansen test is that the random effects estimator is more efficient than the fixed effects estimator.
- The reference category for conflict intensity is no conflict in a country. The reference category for the IMF variable is no loan.

We begin with a discussion of the water and sanitation variables. In equation 2.1, we find that access to an improved water source is associated with less maternal mortality. The coefficient for this variable is negative and statistically significant. In equation 2.2, we find that access to an improved sanitation facility also reduces maternal mortality. The coefficient is also negative and statistically significant. We find a similar pattern for neo-natal mortality as well. In equations 2.3 and 2.4, the coefficients for access to an improved water source and sanitation facility are negative and significant. Taken together, the findings indicate the importance of water and sanitation in improving maternal and neo-natal health in Sub-Saharan Africa.

It is important to note other factors that explain maternal and neo-natal mortality in Sub-Saharan Africa. First, we find that when a Sub-Saharan African nation is under an International Monetary Fund structural adjustment loan, it tends to have higher maternal and neo-natal mortality. The coefficients for this variable are positive and significant in all four equations of Table 2. Second, we find that higher levels of gross domestic product per capita are associated with lower maternal and neo-natal mortality within Sub-Saharan African nations. The coefficients for this variable are negative and significant in every equation.[3] Third, we find that higher levels of female secondary school enrollments are associated with lower maternal and neo-natal mortality within Sub-Saharan African nations. The coefficients for this variable are negative and significant in all four equations. Fourth, we find that the intensity of a conflict is associated with decreased maternal and neo-natal mortality. The coefficients are negative and significant for the highest-intensity conflict dummy variable. This finding contradicts our hypothesis from above. However, it may be that high-intensity conflicts are only taking place in a portion of a Sub-Saharan African nation away from major population centers, thereby limiting disruptions to health services. We also note that the coding of this variable means that a negative coefficient indicates that when intensive conflict ends, maternal and neo-natal mortality are subsequently higher. This interpretation is consistent with the suggestion that conflict disrupts health services.

There are also some non-significant or non-consistent findings that merit comment. First, we do not find that debt repayment is associated with increased maternal or neo-natal mortality. Second, we find that domestic investment does not explain any significant variation in either dependent variable. Third, we do not find that HIV prevalence is related to maternal and neo-natal mortality in Sub-Saharan Africa. The coefficients for all of these variables fail to reach a level of statistical significance in Table 2. Fourth, the effects of democracy and public health expenditures are inconsistent and not in the expected direction.

3 We would like to control for the level of economic inequality within a nation. However, comparable data are not available for a large number of Sub-Saharan African nations across time from the World Bank (2015).

We find that democracy and public health expenditures are associated with increased neo-natal mortality but not maternal mortality. In equations 2.3 and 2.4, the coefficients are positive and significant. Fifth, we find that multinational corporate investment is related to increased maternal mortality but not neo-natal mortality. The coefficients for this variable are positive and significant in the maternal mortality models.

Discussion and conclusion

Sub-Saharan Africa has the highest maternal and neo-natal mortality rates in the world (World Bank, 2015). There have been several cross-national studies that have attempted to explain why this may be the case (Pandolfelli, Shandra, & Tyagi, 2014; Alvarez, Gil, & Hernandez, 2009; Buor & Bream, 2004). These authors find that several factors including structural adjustment, gross domestic product per capita, public health expenditures, and female education can affect maternal mortality. These findings serve as the starting point of our study.

We expand upon this work in a novel way. There has been no research to our knowledge that examines if access to an improved water source and sanitation facility influences maternal and neo-natal mortality rates in Sub-Saharan Africa. We begin to address this gap in the cross-national literature here and find that access to clean water and basic sanitation correspond with less maternal and neo-natal mortality in Sub-Saharan Africa. The coefficients for both variables are negative and significant across Table 2.

We also find that a number of other factors are related to maternal and neo-natal mortality. First, we find that International Monetary Fund structural adjustment is associated with increases in maternal and neo-natal mortality. Second, we find that gross domestic product per capita is associated with decreased maternal and neo-natal mortality. Third, the results indicate that higher levels of female secondary education correspond with lower maternal and neo-natal mortality.

There are some important theoretical insights that emerge from the findings. In general, there has been a lack of cross-national research addressing how the natural environment affects health and well-being (see Mazur & Rosa, 1974, who examined the decoupling between energy consumption and quality of life, as an early notable exception). However, this has begun to change in the past few years. For example, Dietz, Rosa, and York (2009) examine how life expectancy for nations is a function of their natural, physical, and human capital, and Jorgenson (2014) examines the impact of gross domestic product per capita on the ratio of life expectancy to carbon dioxide emissions or the carbon intensity of well-being.

Nevertheless, consideration of the impact of access to water and basic sanitation on health in cross-national research remains nascent at best. A review of the literature revealed eight cross-national studies appearing in peer-reviewed journals that considered water and sanitation (Burroway, 2010; Cairncross et al., 2010; Cheng et al., 2012; Chowdhury, Islam, & Hossain, 2010; Handa, Koch, & Ng, 2010; Prüss et al., 2002; Rutstein, 2000; Shandra, Shandra, & London, 2011). However, none examine the effects on neo-natal mortality in Sub-Saharan Africa. This is somewhat surprising because a lack of access to water and basic sanitation contributes to diarrheal diseases and other infections that kill women and infants directly or lead to complications at various points of pregnancy that put their lives at risk (World Health Organization, 2015). Thus, we argue that it is imperative to consider water and sanitation among other environmental factors in cross-national research because the welfare of women and infants is inextricably linked to the state of the natural environment. Pregnant women are more susceptible to disease due to weakened immune systems (Jamieson et al., 2006). Many such diseases are waterborne or water-transmitted and easily prevented by increasing access to clean water and sanitation. However, such factors only explain part of each phenomenon. There are "external" (i.e., structural adjustment) and "internal" (i.e., female educational attainment) factors that are essential to understanding how to curb maternal and neo-natal mortality rates in Sub-Saharan Africa. Our findings indicate that it is only when researchers consider such factors simultaneously that they will arrive at the most comprehensive understanding of reproductive health.

We can offer some methodological implications that correspond with the theoretical insights. It is typical for cross-national research to include dummy variables for the region of the world in which a country is located as independent variables in a model (Shandra, 2007). This helps control for findings that may arise out of geographical and historical circumstances, which cannot be accounted for by the other independent variables in the model. There are often statistically significant differences among the regions of the world in the dependent variable under examination. The authors often hypothesize why such differences exist or offer no reason for why such a relationship exists. For example, Scanlan (2010) finds that nations in Sub-Saharan Africa tend to have higher levels of child mortality than nations in other regions of the world. The author hypothesizes that this may be the case because Sub-Saharan African nations tend to have a higher prevalence of HIV (Scanlan, 2010). However, the author does not test this hypothesis. Scanlan (2010) analyzes a cross-national sample of less industrialized countries yet reiterates the need for multiple analyses, including regional analyses. We begin to address this gap by examining the factors that are associated with maternal and neo-natal mortality in *only* Sub-Saharan Africa. Our analysis allows us to examine within a specific region the factors associated with higher or lower maternal and neo-natal mortality,

rather than just speculate about why such relationships exist. We further refine previous research by controlling for all stable between-country variation and therefore avoid problems of comparing across such diverse countries in Sub-Saharan Africa.

There are some policy recommendations that follow from our findings. Given that International Monetary Fund structural adjustment adversely affects mothers and infants in Sub-Saharan Africa, we argue that non-governmental organizations, social movements, and concerned citizens should lobby officials at this institution to change or eliminate these policies. Some changes may include eliminating certain macroeconomic policy reforms, especially privatization of government assets, and user fees, which often limit not only access to health services but also to water and sanitation (Rich, 1994).

It is also important to support policy initiatives that increase women's education. Although female education tends to correspond with higher earnings for women, increased economic growth, and augmented standards of living, there are other notable benefits relevant to maternal and neo-natal well-being. In particular, educated women tend to be more knowledgeable about disease causation, more likely to utilize health services, more willing to travel outside of the community to access health care, more adept at interacting with health professionals, and better able to administer home treatment (Ware, 1984). Further, educated women are more likely to engage in efforts to protect and manage resources (Norgaard & York, 2005), which can improve maternal and neo-natal health by increasing access to clean water.

Lack of access to clean water and basic sanitation facilities also significantly impacts young girls attending school. This is in part because children suffering from diarrheal diseases miss school more frequently than children with access to clean water and basic sanitation. For girls, however, it is not just sickness that keeps them from attending school. Girls are disproportionately responsible for collecting water for the household, which tends to leave them with neither the time nor the energy for school (United Nations, 2010). Further, many girls in Sub-Saharan Africa also drop out of school because there are no separate latrines for girls and boys, which becomes particularly problematic when girls reach puberty (Buckingham-Hatfield, 2000). The resulting lack of education further marginalizes girls, reduces their chances of escaping poverty, and, ultimately, leads to a "vicious cycle," which reinforces other causes of maternal and neo-natal mortality (Buchman, 1996). In short, educated girls that become mothers may experience lower rates of maternal and neo-natal mortality. However, to increase education in girls, access to clean water and basic sanitation at school must be provided. Therefore, if girls are provided with access to clean water and

basic sanitation at school, their likelihood of attaining an education is drastically increased, which may result in them experiencing lower rates of maternal and neo-natal mortality in the future.

There are some directions for future research that follow from this study. First, we acknowledge that environmental factors affect women's (and early childhood) health; however, it may also be that water and sanitation have a unique and disproportionate impact on other aspects of a woman's life. For example, is the lack of access to an improved water source or sanitation facility more likely to adversely impact enrollment of girls in school at the primary and secondary levels than boys? Second, newly released data break down access to an improved water source and sanitation facility by rural and urban settings (World Health Organization & United Nations Children's Fund, 2015). It is important to consider if the effects of these measures are more or less pronounced by geographical context to refine further our understanding of how water and sanitation affect health. Overall, it is imperative that researchers continue to study maternal and neo-natal mortality in Sub-Saharan Africa. Our study demonstrates that access to clean water and basic sanitation may help significantly reduce mortality rates, thus improving quality of life for countless women and children. Future research on maternal and neo-natal mortality in Sub-Saharan Africa should address how water and sanitation affects primary and secondary school enrollments for boys and girls, as well as the impact of rural verses urban settings on improved access to water and sanitation. Further research is necessary to understand how maternal and neo-natal mortality can be reduced in Sub-Saharan Africa.

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