ABSTRACT

HEDLUND, JOHN. Agriculture, Pesticide Use, and Economic Development: A Global Examination (1990-2015) (Under the direction of Dr. Stefano Longo).

Modern industrial agricultural production typically requires large quantities of chemical pesticides, a potential source of both environmental and social harm. Modernizationist social-environmental theories suggest that environmental problems, such as those associated with pesticide use, may begin to decline at higher levels of economic development, while critical theorists argue that economic development consistently leads to greater environmental despoliation. Using fixed effects models and panel data, I examine the relationships between economic development and pesticide use within nations and over time. This study draws on data from the World Bank as well as the Food and Agriculture Organization of the United Nations (FAO) from 1990 to 2015. My findings are considered from the contrasting theoretical perspectives on social-environmental interactions. The results of this study generally support the claims made by critical perspectives in environmental sociology, such as treadmill of production and structural human ecology, as they show a positive relationship between economic development and pesticide consumption, with no decline in use at higher rates of economic growth. Further, because other possible explanatory variables like agricultural employment and agricultural production are held constant, it appears that developed countries are actually adopting more chemical-intensive agricultural practices. I consider the implications of these results in an era of increasing global environmental concerns.

Agriculture, Pesticide Use, and Economic Development: A Global Examination (1990-2015)

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DEDICATION

To my parents. Thank you for showing me what unconditional love looks like, and for always believing in me.

BIOGRAPHY

John Hedlund was born on August 23, 1986 in Chapel Hill, North Carolina. Raised in Durham, he attended high school at C.E. Jordan High. He earned his Bachelor of Arts degree in Sociology (*summa cum laude*) with a minor in History from City College of New York (CUNY) in July 2015. Since the fall of 2016, he has been a sociology graduate student at North Carolina State University, with a focus on Food and Environmental Sociology.

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Introduction

Modern agricultural production, in its conventional mode, relies upon large amounts of chemical inputs in the form of fertilizers and pesticides during production (Aktar, Sengupta, and Chowdhury 2009; Davis 2014; Schreinemachers and Tipraqsa 2012). While both pesticides and fertilizers have allowed for the rapid expansion of global food production and consumption for some, these agrochemicals have been associated with a number of human and environmental hazards. Pesticide use, for example, is linked to thousands of annual accidental fatal poisonings from either direct contact with the chemical, or indirectly from contact with contaminated objects (Aktar et al. 2009; Devine and Furlong 2007; Schreinemachers and Tipraqsa 2012). Further, pesticides are culpable in non-target species loss (Aktar et al. 2009; Davis 2014; Devine and Furlong 2007; Relyea 2005; Schreinemachers and Tipraqsa 2012), ground and surface water contamination (Aktar et al. 2009), and soil contamination (Aktar et al. 2009; Davis 2014), among many other concerns. Thus, pesticide consumption is an important phenomenon of sociological study, as it has significant social and ecological effects.

While agrarian societies have used various means of agricultural pest control for millennia, the rise of synthetic pesticide use in agriculture in the first half of the 20th century was intimately connected with the increased use of monoculture crop production (Davis 2014), as the lack of biological diversity leads to a greater risk of pest invasions. Since the introduction of DDT as an insecticide for agricultural use post-World War II (Davis 2014; Zadoks and Waibel 2000), the use of synthetic pesticides has spread throughout the globe and become an obligatory component of conventional agricultural production. Since Rachel Carson's seminal work *Silent Spring* in 1962, pesticides have been scrutinized for their harmful effects on ecosystems as well the human body. However, pesticide consumption and its socio-ecological impacts are an understudied phenomenon in the field of sociology, even environmental sociology.

Environmental sociological research has developed a robust body of literature on the socio-structural drivers of various environmental impacts – such as air pollution (York and Rosa 2012), environmental racism (Benz 2017: Brulle and Pellow 2006), toxic waste contamination (Brown 1992), and climate change (Clark and York 2005; Jorgenson 2012; McCright and Dunlap 2011), among others. This study will contribute to this research by examining the relationship between chemical pesticides and economic development. Pesticides, as an indicator of environmental impact, act as one type of measure of socially induced ecological harm. Previous sociological studies have considered the relationship between economic processes—including economic growth, trade, and foreign direct investment—and pesticide use using cross-national quantitative analytical approaches (Longo and York 2008; Jorgenson and Kuykendall 2008). Longo and York (2008), in testing contrasting predictions of the relationship between integration into the global economy and levels of economic harm, find that while the export of agricultural products generally correlates with greater pesticide consumption, at higher levels of GDP per capita this relationship appears to reverse slightly. Jorgenson and Kuykendall (2008) find that foreign investment dependence is positively correlated with pesticide use intensity in less developed countries (LDC) during the last decade of the 20th century. My study will further this research by analyzing the relationships between different types of chemical pesticides - insecticides, herbicides and fungicides, as well as the aggregation of all pesticide types - and economic development within nations, over time.

I will draw on theory in environmental sociology and make use of two overarching theoretical frames to analyze the relationship between pesticide consumption and economic development. One framework, which includes the treadmill of production theory and structural human ecology, critically examines the role of economic development in environmental outcomes and posits that there is generally a positive relationship between economic growth and environmental harm. I call this the critical social-environmental framework. The other framework, which includes ecological modernization theory (EMT) and the Environmental Kuznets Curve hypothesis (EKC), proposes that a decoupling of economic growth and environmental harm may occur at later stages of modernization, which can eventually lead to a reduction in environmental impact in relation to continued development. I call this latter framework the modernizationist social-environmental framework. Drawing on these analytical approaches, I will seek to gain further clarification on the association between economic growth and pesticide use within nations.

In the following sections, I introduce the relevant theoretical frameworks for this study, followed by a review of sociological literature concerning pesticide use and its effects, as well as a succinct survey of other research testing the general theoretical frameworks used in this study within environmental sociology. Next, I test the competing claims of the modernizationist and critical social-environmental frameworks concerning the relationship between economic development and environmental harm by examining the relationship between pesticide use intensity and GDP per capita within nations, over time. My outcome variables include insecticide, herbicide, fungicide, and total pesticide consumption. My findings show that GDP per capita is positively correlated with all of the measures of pesticide consumption, and thus lend support to the critical social-environmental framework. I conclude by considering some shortcomings of this study and discuss avenues for possible future research.

Theoretical Frameworks

Theories in environmental sociology offer contrasting explanations regarding the dynamic between modern economic processes and environmental concerns. Ecological modernization, the treadmill of production, structural human ecology and the Environmental Kuznets Curve hypothesis – each of which will each be discussed in detail below—provide different hypotheses on the specific relationship between economic development and pesticide use.

Critical Social-Environmental Frameworks

Structural Human Ecology

Structural human ecology (SHE) is a foundational approach in environmental sociology. Research developed in this tradition locates human societies within a general ecological framework, noting that the key factors which shape all ecosystems – such as demographic, environmental and climatic characteristics, as well as resource use and distribution – are important factors that influence human ecosystems as well (Dietz and Rosa 1994; Jorgenson and Clark 2011; York, Rosa and Dietz 2003a; York and Rosa 2012). SHE is rooted in the human ecology tradition, outlined by thinkers such as Otis Dudley Duncan (1964) who argued against cordoning off sociological concerns from environmental factors, and for the contextualization of social problems in a larger ecological framework, or "ecological complex." His POET concept–Population, Organization, Environment and Technology—was put forward as a heuristic method with which to analyze social concerns without denying the effect of non-social factors, and in fact placing such factors front and center (Duncan 1964).

Structural human ecology is informed by the Malthusian notion that population growth and natural resource availability are intricately linked (Dietz and Rosa 1994). It thus represents "the convergence of the social and biological sciences to a common problem": the tendency of modern human populations to reproduce at rates incompatible with their environments. (Dietz and Rosa 1994:278). However, unlike much conventional Malthusian thinking, research in structural human ecology takes on more sociological nuance. For example, the SHE tradition does not treat population as the lone, or unmediated, factor in human impacts on the environment, recognizing that the correlation between population and impact is modulated by levels of that population's resource consumption, operationalized as affluence per capita (Dietz and Rosa 1994).

The three main areas that structural human ecologists focus on when examining anthropogenic environmental impacts are: demographic characteristics, levels of technological development, and economic conditions relating to resource production and consumption. This framework is clearly influenced by the human ecological POET model (Duncan 1964). In order to test empirically the postulations of structural human ecology theory, Dietz and Rosa (1994) reformulated the IPAT model—well-known in the ecological science literature—which posits that environmental impact (I) is the product of a society's population (P), degree of affluence (A), and level of technological development (T) (i.e. I = P*A*T).

While the IPAT formula generally concurs with the premises of structural human ecology, it has a number of shortcomings (Dietz and Rosa 1994). Particularly, it requires reformulation "in stochastic terms to permit hypothesis testing and the inclusion of social structural factors" (York and Rosa 2012:286). The STochastic Impacts by Regression on Population, Affluence and Technology, or STIRPAT, is the reformulated model, which both allows for hypothesis testing and the incorporation of other socio-structural variables. The STIRPAT model thus uses social science regression methods to calculate environmental impact, where each factor is transformed to its natural logarithm to account for non-linear variability, and the technology factor is incorporated into the equation's error term, due to a lack of consensus regarding its appropriate measurement (Dietz and Rosa 1994; York et al. 2003a).

The Treadmill of Production

The treadmill of production theory, first introduced by environmental sociologist Allan Schnaiberg (1980), posits that the contemporary industrial-capitalist system (as well as some other modern industrial economic systems) is fundamentally at odds with basic ecological principles (Schnaiberg and Gould 1994). While human existence has always resulted in environmental strain and some degree of ecological impact, industrial capitalism, especially in the post-World War II era, has led to systematic, widespread ecological impacts on a scale qualitatively greater than during any pre-industrial social system (Schnaiberg 1980; Schnaiberg and Gould 1994). The level of natural resource withdrawals (such as fossil fuel extraction, timber and fresh water) and harmful additions (including carbon emissions, industrial waste, agrochemicals, and water contamination) overloads the planet's natural restorative, absorptive, and regenerative capacities, leading to devastating social and ecological consequences (Gould, Pellow and Schnaiberg 2004; Gould, Pellow and Schnaiberg 2008; Schnaiberg and Gould 1994).

The "treadmill" metaphor represents the ever-accelerating enduring demand for natural resources required to increase production, which is necessary in order for a competitive enterprise to maintain profitability. Pressures associated with capital growth, which spurs increased commodity production, constitute the motor of the treadmill. Meanwhile, investment in new, laborsaving production technologies, a byproduct of competition and expansionary forces, also leads to a requisite increase in production, in part to offset costs and increase profitability (Gould et al. 2004; Gould et al. 2008; Schnaiberg 1980; Schnaiberg and Gould 1994). While some of these technological advancements may lead to more ecologically sustainable production practices, creating a reduction in environmental impact per unit of production, the overall increase in production volume generally cancels out these ameliorative effects (Gould et al. 2004; Schnaiberg 1980).

While the initial formulation of the treadmill of production theory was the result of analyzing advanced industrial economies, particularly the United States (Schnaiberg 1980), the global nature of the treadmill has been explored especially in its more recent iterations (Buttel 2004; Gould et al. 2004; Gould et al. 2008). The logic of the treadmill is inherently transnational in scope, as its pursuit of never-ending profit accumulation is “absolutely boundless” (Schnaiberg and Gould 1994:52), and thus uninhibited by national boundaries. As more and more regions of the planet are incorporated into the treadmill, transnational corporations become increasingly powerful actors, politically and economically. Further, a globalized division of labor develops, as production for countries of the global North (such as the United States and Western Europe) largely shifts to the global South (Gould et al. 2008). This change in the locus of industrial production and raw materials extraction to less-wealthy countries may appear on the surface to reduce the environmental impact of industrialized nations; it instead merely outsources this impact, along with production and extraction, to the global South. This analysis rejects the notion that a “hypermaterialism,” or super-industrialism, is occurring in the global North, in which the ecologically harmful production practices of industrialization are being transcended in favor of ecologically sustainable ones (Gould et al. 2008).

The line of analysis followed by the treadmill of production leads to the need for structural transformation, rather than ameliorative environmental reforms or technological fixes, to halt the processes of ecological destruction. Therefore, treadmill scholars are critical of both “sacred cow” solutions of the mainstream environmental movement that often center on individual consumption patterns rather than production, as well as of technological solutions that aim to develop “cleaner” instruments of production and resource extraction without challenging the underlying logic of the treadmill (Gould et al. 2004; Gould et al. 2008; Schnaiberg 1980).

Modernizationist Social-Environmental Frameworks

Ecological Modernization Theory

Another important sociological framework for analyzing social-ecological interactions is ecological modernization theory (EMT). This framework explicitly challenges environmental sociological approaches that view capitalism and ecological sustainability as inherently conflictual (Spaargaren & Mol 1992). Instead, while EMT theorists identify the era of “modernity” as undoubtedly concurrent with “the decisive alterations in the relations between environment and society” (Spaargaren & Mol 1992:327), they simultaneously locate the remedy for these “decisive alterations” in the institutions of modernity itself. The process of modernity, initially defined by industry-induced ecological devastation, has the potential to undergo a reflexive metamorphosis as it begins to take into account – and potentially ameliorate – its environmental impact.

According to EMT, modern industrial societies can be divided into three epochs: one, the beginnings of industrialization; two, the period of industrial development; and three, “the ecological switchover” in which a process of “superindustrialization” can occur (Spaargaren & Mol 1992: 335). Three primary processes characterize this “ecological switchover,” i.e. the transformation from industrial to ecological modernization: technological innovation and change, the reinsertion of nature into the economic, and, more generally, social calculus, and political change. The first process, technological transformation, involves the development and growth of new “smart” technologies that move away from the environmentally costly technologies of industrialism, such as the shift to "microelectronics." The second process involves a transition in economic thinking, in which the effects of production on the environment are reincorporated into economic calculations and planning (Spaargaren & Mol 1992: 335). The third process involves political reforms and socio-political awareness of environmental problems, associated with social movements (including consumer movements) and the development of policies to address environmental concerns.

EMT exists as both a theoretical framework explaining relations between economic structures and the natural world, and as a political program that offers prescriptions for solving environmental problems (Spaargaren & Mol 1992). True to its form, EMT's political program is fundamentally at odds with approaches such as the treadmill of production—that call for political transformations and a radical restructuring of society to remedy environmental ills (Gould et al. 2008). The political program of EMT "challenge[s] the environmental movement's traditional idea that a fundamental reorganisation of the core institutions of modern society . . . [i]s essential" to create a sustainable social-economic system (Mol & Spaargaren 2000:19). Instead, modern capitalism is capable of reform, and in some regions of the world is already in the process of shedding its environmentally deleterious flaws. The modern economic system is dynamic and flexible, according to EMT theorists, and can self-correct its hitherto ecologically harmful practices (Spaargaren & Mol 1992; Mol & Spaargaren 2000). In Mol and Spaargaren's (2000) iteration of EMT, capitalist development is viewed as neither inherently positive nor problematic in terms of ecological redress. Rather, from this view, capitalism has no workable alternatives, and is not a significant obstacle to environmental reforms. The theorists posit that as the environment and the economy begin to decouple, production and consumption under capitalism will adjust toward more environmentally sustainable methods. Over time, economic development will no longer positively correlate with indicators of environmental destruction (Mol & Spaargaren 2000).

The Environmental Kuznets Curve Hypothesis

The Environmental Kuznets Curve hypothesis (EKC) shares some overlap with the ecological modernization theory as it predicts an inverted U-shaped relationship between economic growth and environmental impact (Dinda 2004; Stern 2004; Uchiyama 2016). EKC postulates that there is a nonlinear correlation between economic growth and negative environmental effects. In the early stages of economic development, often indicated by GDP or income per capita, environmental impacts are likely to rise steadily. However, once a certain critical ‘turning point’ in development is reached, it is predicted that environmental impact will begin to level out, and then decrease as GDP per capita continues to grow (Dinda 2004; Stern 2004; Uchiyama 2016). Named after economist Simon Kuznets (1955), who argued that economic growth and income inequality correlated in an inverted U-shaped pattern, EKC was first articulated in the early 1990s by economists Gene Grossman and Alan Krueger, in their research into the potential ecological impacts of the North American Free Trade Agreement (NAFTA) (Stern 2004). In response to environmentalist critics, who argued that increasing economic development would inevitably lead to greater ecological devastation, EKC proponents contended that while the initial stages of industrialization are undoubtedly environmentally intensive, with further economic growth comes a rise in both environmental concern among the public and the resources required to invest in greener practices (Stern 2004). The intersection between EKC and EMT are clear. With wealth comes the luxury of environmental concern and the ability to adopt cleaner technologies that less-developed, poorer nations do not have (Dinda 2004; Stern 2004).

Alternative interpretations of the potential existence of an EKC have been offered, including Lynch's (2016) "Marxian Environmental Kuznets Curve (M-EKC)", which posits that nonlinear growth is characteristic of capitalist development, with booms and busts rather than constant monotonic growth being its defining trajectory. Thus, according to Lynch (2016), from a macroeconomic perspective, no inverted U-shaped curve exists, but instead a cyclical curve, which corresponds to the vicissitudes of the various production and accumulation cycles under capitalism. Nonetheless, EKC enjoys a prominent place within contemporary environmental economic thought. In addition, while it has been tested via a number of indicators of environmental harm at a national level, greenhouse gas emissions have overwhelmingly been the primary mode of operationalizing environmental impact (Stern 2004). With respect to pesticide consumption as an environmental harm indicator, EKC would predict a nonlinear, inverted U-shaped relationship between a country's level of pesticide use and its GDP per capita.

Literature Review: Environmental Impacts and Pesticides

There is a wealth of literature within environmental sociology based upon empirically testing the competing theoretical frameworks of what I am calling Critical and Modernizationist Social-Environmental Frameworks.[1] I will discuss a few prominent studies in this area of work and follow this with an examination of some of the sociological research on pesticide use.

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[1] Longo and York (2008) cite a number of different perspectives that fit within these two theoretical umbrellas beyond the scope of this study - such as Foster's (1999) Marxian theory of metabolic rift, world systems theory (Wallerstein 1974) and other Neo-Marxian frameworks such as O'Connor's (1991) "second contradiction of capitalism" - for their International Political Economy (IPE) framework, and environmental economics for their neoliberal theories of modernization framework, which is closely related to EKC. This is true for some of the other articles cited in this section as well (Jorgenson and Clark 2011). However, the characteristics of these two theoretical frameworks - where the former views economic growth and capitalist development as inherently environmentally problematic while the latter sees economic development as a means of ameliorating environmental conditions - constitute the general parameters of the two schools of thought that are being tested in this paper.

Jorgenson and Clark (2012) test whether a "decoupling" or "intensification" of economic development and negative environmental outcomes is occurring on a global scale. They specifically consider the contrasting arguments of treadmill of production and EMT, using carbon dioxide emissions as an indicator of negative environmental impact. The authors operationalize this variable in three different ways—as total emissions, per capita emissions and emissions per unit of production—treating each indicator as an outcome variable for three separate cross-national panel regression models. The authors find some evidence of a relative, limited decoupling between total carbon dioxide outputs and economic development in developed countries (DCs), but not in less-developed countries (LDCs). For per capita emissions, an overall increase in a positive correlation between emissions and development was consistent over time for LDCs. For DCs, the results suggest a cyclical pattern of slight decoupling and intensification (Jorgenson and Clark 2012:26). For emissions per unit of production, development is negatively correlated to emissions for LDCs and DCs.

While the results indicate some support for limited decoupling between the economy and the environment in DCs, this should be interpreted cautiously. The authors note that these findings could be the result of a global shift in environmentally intensive production practices from DCs to LDCs (Jorgenson and Clark 2012). Further, even this "relative decoupling" still constitutes an overall (or "absolute") increase in carbon dioxide emissions into the atmosphere (Jorgenson and Clark 2012:33). Perhaps most significantly, this relative decoupling is likely insufficient "from sustainability, international inequality, and climate change perspectives" (p. 30), and thus does not indicate evidence of an emissions-reducing trajectory at the level required to prevent accelerated global climate change.

Another study by Jorgenson and Clark (2011) uses ecological footprint, a measure of the amount of productive land required to sustain the level of resources consumed and absorb the amount of carbon dioxide emissions a society produces, as indicator of environmental impact. Testing for a potential nonlinear EKC, they find a positive correlation between GDP per capita and its quadratic and ecological footprint per capita, which is evidence of support for the treadmill of production (Jorgenson and Clark 2011). They find no evidential support for an economic-environmental decoupling over time, as EMT proposes, for either DCs or LDCs. Instead, they find evidence of an intensification in this relationship.

Mol and Spaargaren (2005), in a non-empirical overview of the treadmill of production and EMT frameworks, argue that the debate may not be resolvable through empirical testing. This is partly because, while there are overlaps in both subject matter and overall epistemological orientation between the two theories, their geographical applicability and specific focuses may be distinct. Further, their interpretive schemas differ, in that treadmill of production theorists purportedly view ecological problems only (or mainly) in economic terms, while ecological modernization theorists view environmental issues through political and cultural spheres as well (Mol and Spaargaren 2005). The authors instead suggest that both camps should “mov[e] beyond the debate” (p. 96) and adopt a different analytical framework, a “sociology of flows” approach which assists in transcending some of the inadequacies of both the treadmill of production and ecological modernization (Mol and Spaargaren 2005).

York (2004), in his conceptual critique of EMT, frames the debate between ecological modernization and the treadmill differently. He argues that EMT’s focus on select areas within the global economy that are improving their ecological footprint misses the point—what matters from an environmental standpoint is both the average trends and overall impact. Thus, according to York (2004), ecological modernization theorists may be mistaking "diversification" of production—including some environmental improvement among certain firms, industries and nations—with a general improvement in environmental outcomes in relation to modern development. In other words, without being able to demonstrate that a decoupling of economic growth and environmental impact is taking place to a degree and scale that can reduce net impact, the use of case study evidence demonstrating small pockets of ecological modernization is insufficient to validate the theory's primary claims.

There is a qualitatively broad, albeit quantitatively limited body of sociological research on pesticides and their application. Longo and York (2008) examine the relationship between agricultural exports and both fertilizer and pesticide use intensity, proposing that the two are positively associated, with an increase in a nation's agricultural exports (as a percentage of GDP) correlating to an increase in domestic fertilizer and pesticide consumption. The authors use two competing theoretical frameworks, broadly categorized as theories of international political economy (IPE) and neoliberal modernization theories (NLM). IPE theorists posit that the pressures inherent in a capitalist export-based model of agricultural production lead to an increase in environmental inputs and outputs, and thus greater agricultural exports will likely lead to an increase in the use of harmful pesticides, as well as fertilizers (Longo and York 2008). In contrast, NME theorists view global trade, and the liberalization policies that spur it, as a producer of positive environmental outcomes. Thus, according the NME, an increase in connectivity to the world market should potentially lead to a subsequent decrease in pesticide and fertilizer use intensity (Longo and York 2008).

While the relationship between agricultural exports and both pesticide and fertilizer consumption were positive and significant, a secondary result—regressing pesticide consumption on GDP-squared to test for a potential EKC—produced a negative and significant coefficient, indicating the possible existence of a pesticide EKC (Longo and York 2008). Longo and York (2008) offer a number of potential explanations for this finding, including, as also suggested by Jorgenson and Clark (2012), the possibility of wealthier nations outsourcing environmentally destructive production practices to less-developed countries. In addition, as the authors note, the harmful effects of pesticides have been the focus of much media and popular attention in wealthier countries, prompting outcry and mobilization against their use. As Devine and Furlong (2007) note, this has particularly been true for insecticide use. However, there has not been a comparable backlash against fertilizer use (there was no evidence of an EKC for fertilizer consumption). Thus is it possible that pesticide use has decelerated in wealthy countries because of this public response, while fertilizer use has remained steady. Yet, Longo and York (2008) note that these results should be interpreted carefully, as the data for international pesticide use were limited, the gaps in the data are unlikely to be random, and the downward slope of the EKC is relatively slight.

The evidence of a potential pesticide EKC found in Longo and York's (2008) paper forms the main basis for this study. While it may appear that economic development leads to a reduction in environmental impact, as indicated by pesticide consumption, there are a number of other possible alternative explanations to consider which require additional empirical testing. As noted above, one potential factor in an apparent pesticide EKC may be a global shift in use rates of different pesticide classes and types. Devine and Furlong (2007) suggest that pesticide use rates in DCs have not decreased but instead insecticides used in DCs have declined in average weight, as the active ingredients have become more concentrated.

Jorgenson and Kuykendall (2008) examine the relationship between foreign investment dependence and pesticide and fertilizer use intensity among lower-income nations over time, between 1990 and 2000. This paper expands upon Jorgenson's (2007) earlier study, which tested the hypothesis that foreign capital penetration is positively correlated with pesticide use intensity. Jorgenson and Kuykendall (2008) predict that both fertilizer and pesticide use intensity are positively correlated with foreign investment dependence in the agricultural sector. As LDCs are incorporated into the global marketplace, and their domestic agricultural economies become penetrated by transnational corporations based in developed countries (DCs), LDCs' agricultural practices often shift dramatically toward the direction of chemical pesticide and fertilizer consumption, which produce negative environmental and human health effects (Jorgenson and Kuykendall 2008). These practices generally replace the more environmentally sustainable pest-control and fertilization techniques such as "crop rotation and recycling of organic matter" in these LDCs (Jorgenson and Kuykendall 2008:532). Thus, the degree to which the impact of multinational corporate control of agricultural productions in LDCs affects rates of fertilizer and pesticide use is a question of great social and environmental import.

The authors apply an "ecostructural" theoretical approach, which analyzes the environmental impact of macro-level global economic processes and structures, to the specific question of foreign investment dependence and agro-chemical use (Jorgenson and Kuykendall 2008). Employing generalized least squares (GLS) random-effects models, Jorgenson and Kuykendall (2008) conclude that foreign investment dependence in the agricultural sector indeed has a positive effect on pesticide use intensity, and that this effect actually increased over the decade. For this final result, the interactive effect of time on the primary statistical relationship, Jorgenson and Kuykendall (2008) suggest a couple of possible explanations - including the impact of the “pesticide treadmill”, the phenomenon that occurs when pesticides produce pesticide-resistant organisms, leading to a cycle of increased pesticide use (Foster and Magdoff 2000).

Shorette (2012) examines whether incorporation into the “world society” reduces a nation’s pesticide and fertilizer use, and how those effects may be moderated by the country’s location in the world system. Regarding social-environmental relations, world-systems theory (Wallerstein 1974), argues that the global capitalist economic structure thwarts efforts to improve the environment, and that nations on the periphery of the global economy suffer an inordinate amount of the effects of environmental harm. World society theory, in contrast, postulates that the more integrated a nation is into the world culture, the greater their efforts will be at ameliorating their negative environmental impact. By synthesizing the claims of both the world systems and world society theories, Shorette (2012) formulates an “integrated theory of global environmental change”, which hypothesizes that the “decoupling” of environmentalism and environmental practices is strongest for nations in the periphery and weakest for core nations (p. 308); hypotheses that are borne out by her results (pp. 313-15).

Jensen and Blok (2008) apply Beck’s (1992a.) concept of “risk society” to laypersons’ perceptions of pesticides. Noting that Beck’s risk society framework exists primarily at the level of a “grand-theory,” with limited empirical application, Jensen and Block interview sixteen individuals and conduct two focus group interviews with fourteen lay-people and eight scientific experts (2008:762). Their aim is to “stage a dialogue between Beck’s account, on the one hand, and the accounts of actors living, experiencing and ‘enacting’ risk society, on the other.” (Pp.758-59).

In order to review Jensen and Blok's (2008) research, a brief explanation of the risk society framework is necessary. Beck's (1992b.) "Risk society" theory posits that, as society increasingly industrializes, it generates chemical, nuclear, genetic and ecological "mega-hazards" that can no longer be ascertained according to conventional processes of risk measurement and mitigation (pp.102-03). The rapid scientific, techno-chemical development that occurs under industrialization has given rise to corresponding chemical (and other types of) "risks" that modern science is no longer able to contain or even completely explain (Beck 1992a; Beck 1992b; Jensen and Blok 2008). A corresponding 'risk consciousness' arises among the public, as citizens become reflexively aware of the risks associated with the social proliferation of dangerous chemical (and nuclear) products (Jensen and Blok 2008). This manifestation of "risk consciousness," as it relates to pesticide risks, is what Jensen and Blok attempt to analyze.

Although not mentioned by Beck specifically, these risks of late modernity include the threats imposed by pesticide contamination, and Jensen & Blok (2008) argue that the risks associated with pesticide use constitute a "paradigmatic position" in Beck's risk society context (p. 761). Jensen and Blok (2008) conclude that, while the experiences of their interviewees (particularly the laypersons) generally correspond to the postulates of Beck's risk society, there is greater variability and range of experiences among 'risk society members'. In other words, not everyone experiences and interprets the effects of pesticide risk the same. In fact, some respondents - a minority of laypersons and a majority of the experts interviewed - expressed views on pesticide risk more akin to the framework of EMT than of risk society; viewing the role of environmental lobbyers and state regulators as being successful mitigations of the negative effects of pesticide use. Finally, Jensen and Blok (2008) discover that the laypersons of their study are far more active in the knowledge-making processes of risk society than Beck assumes.

Relatedly, the relationship between lay-knowledge and scientific expert-knowledge is much more “interw[oven]” than predicted by Beck (Jensen and Blok 2008:773).

Frey (1995) in his study of “The International Traffic in Pesticides” highlights the unequal distribution of pesticide-related human, environmental and economic hazards between less developed countries (LDCs) and developed countries (DCs). Pesticides, historically and contemporarily, have been used at greater rates in DCs, although use rates in LDCs have increased significantly. However, the citizens of LDCs bear an inordinate portion of the burden of the negative human and environmental effects of pesticide use (Frey 1995). There are a number of reasons for this disparity. One, transnational corporations located in DCs market and export highly toxic pesticides that are banned in the DCs to LDCs. Two, production of these banned toxic pesticides has increased in LDCs. Finally, growing consumer awareness in DCs of the health risks associated with “environmentally persistent organochlorine insecticides” has shifted pesticide consumption for export produce in LDCs to “nonpersistent, highly toxic organophosphate and carbamate insecticides.” (Frey 1995:158). These nonpersistents increase the pesticide-related health risks of the farm workers in LDCs while reducing the risk posed to consumers in DCs.

Frey (1995) notes that there have been an array of proposals and actions by international organizations, states, and non-governmental organizations (NGOs) to limit the hazards associated with pesticides (pp.161-62). Yet he concludes that these enacted and proposed measures are unlikely to effectively mitigate, much less eradicate, the harmful consequences of pesticides and the unequal distribution of these consequences internationally. Without targeting the larger socio-economic forces that facilitate and encourage the use of toxic pesticides, alternatives such as Integrated Pest Management –which relies on a combination of biological controls, regular monitoring of crops, preventative cultural practices and limited pesticide use—are unlikely to replace chemical pesticides as the dominant mode of agricultural pest management (Frey 1995).

Pesticides are an important and relevant topic of inquiry for environmental sociologists, as they are an essential element of modern food production and agriculture. However, pesticide use is an understudied phenomenon in the field. Further, thus far sociological research has not differentiated between different classes or types of pesticides. Instead, most of the literature pays little attention to such distinctions, opting instead to combine herbicides, insecticides, fungicides, and other methods of agrochemical pest eradication into a singular variable. Particularly when engaged in an international analysis, where rates of different classes of pesticides often correspond to differing economic characteristics between nations, such as levels of affluence and economic development, operationalizing such distinctions has the potential to expand our understanding of the dynamic, changing role of pesticide use in global agriculture, and its social and environmental effects (Aktar et al. 2009; Devine and Furlong 2007; Frey 1995; Schreinemachers and Tipraqsa 2012). Further, quantitative models in the sociological literature have been based on cross-sectional analysis (one-point in time). In this study, I advance this research by developing a time-series analysis, which seeks to better understand change of pesticide use over time.

Schreinemachers and Tipraqsa (2012), in their study of global rates of pesticide consumption, also conclude that overall pesticide use rates have not been reduced in developed countries. Rather, in certain high-income countries, the class of pesticide used has changed, with insecticide use decreasing while herbicide and fungicide use rates increased (Schreinemachers and Tipraqsa 2012). Thus, it may be the case that simply using an aggregated pesticide use variable, where all classes of pesticides are collapsed into a single indicator, is inappropriate for adequately measuring the relationship between economic development and pesticide consumption on a global scale. Disaggregating pesticide consumption into its three primary categories (insecticides, herbicides and fungicides) should give a clearer, more nuanced picture, and provide new insight into the nature of this relationship.

Both EKC and EMT make claims about how economic development and resource use change over time (Dinda 2004; Mol and Spaargaren 2000; Spaargaren and Mol 1992; Stern 2004). Further, these theories hypothesize about temporal changes that occur within nations. For example, the EMT argument that capitalist societies can be divided into three eras–early industrialization, industrialization, and “superindustrialization” (Spaargaren and Mol 1992)–is based on chronological transformation in socioeconomic structures. The EKC is a hypothesis about how the relationship between economic development and environmental impact evolves within nations over time. While such changes would no doubt be expected to take place at differing rates cross-nationally, measuring the effects of GDP per capita on national pesticide consumption over time, within individual nations, would provide an empirical examination of these claims from a different angle. Therefore, using panel data might prove to be a more appropriate method for testing these claims.

The Current Study

<u>Treadmill of Production Hypothesis:</u>

1) GDP per capita will be positively correlated with each of the “pesticide consumption” outcome variables.

Structural Human Ecology Hypotheses:

1) Population (Total) will be positively correlated with each of the “pesticide consumption” outcome variables.
2) GDP per capita will be positively correlated with each of the “pesticide consumption” outcome variables.

Ecological Modernization Theory Hypotheses:

1) GDP per capita will be negatively correlated with each of the “pesticide consumption” outcome variables.
2) Urban Population will be negatively correlated with each of the “pesticide consumption” outcome variables.

Environmental Kuznets Curve Hypothesis:

1) GDP per capita will have a curvilinear, inverted U-shaped relationship with each of the “pesticide consumption” outcome variables.

Longo and York’s (2008) study operationalized “pesticide value” as the aggregated, total amount of pesticides used, and developed cross-sectional OLS regression models to examine the effects of agricultural export on pesticide use levels for the year 2000. Thus, there are two primary differences between my project and their research, each of which have been selected to try to expand upon and improve the explanatory and analytical power of the results. First, I will disaggregate “pesticide value” into its three main respective categories: insecticides, herbicides and fungicides (which includes bactericides). Second, I will be running a fixed effects panel regression model to measure the effect of time on the relationship. In other words, a time-series method will allow us to see whether the relationship between pesticides, GDP and the other independent variables changes at different points in time within nations, over the course of the 1990-2015 period, as opposed to between nations at a single point in time.

Data and Methods

The data I use in this study come from two sources: The World Bank (World Bank 2017) and the United Nations Food and Agriculture Organization (FAOSTAT 2017). The dependent variables, insecticide, herbicide, fungicide and aggregated pesticide value per tonnes of active ingredients, are sourced from the FAOSTAT (2017) database. All of the independent variables used in the analysis I obtained from the World Bank's World Development Indicators database (World Bank 2017). The data are from 1990-2015, as this is the period available for dependent variables. I include in the study all nations for which data are available, which makes up the vast majority of the world population. Table 1 below lists the nations included in my analyses.

Table 1: Countries Included in the Analyses

Albania	Greece	Panama
Algeria	Guatemala	Paraguay
Angola	Honduras	Peru
Argentina	Hong Kong SAR, China	Poland
Armenia	Hungary	Portugal
Australia	Iceland	Romania
Austria	India	Russia Federation
Azerbaijan	Indonesia	Rwanda
The Bahamas	Iran, Islamic Rep.	Saudi Arabia
Bahrain	Ireland	Slovak Republic
Bangladesh	Italy	Slovenia
Barbados	Jamaica	South Africa
Belgium	Japan	Spain
Belize	Jordan	Sri Lanka
Bhutan	Kazakhstan	St. Lucia
Bolivia	Korea, Rep.	Suriname
Brazil	Kyrgyz Republic	Sweden
Brunei Darussalam	Latvia	Switzerland
Bulgaria	Lesotho**	Tajikistan
Burkina Faso	Lithuania	Thailand
Canada	Luxembourg+	Trinidad and Tobago

Table 1 (continued).

Chile	Macedonia, FYR	Tunisia
China*	Madagascar	Turkey
Colombia	Malaysia	Ukraine
Costa Rica	Malta	United Kingdom
Croatia	Maldives	United States
Cyprus	Mauritius	Uruguay
Czech Republic	Mexico	Venezuela, RB
Denmark	Moldova	West Bank and Gaza
Dominican Republic	Montenegro	Yemen, Rep.++
Ecuador	Morocco	Zimbabwe
Egypt, Arab Rep.	Nepal	
El Salvador	Netherlands	
Estonia	New Zealand	
Ethiopia	Nicaragua	
Finland	Norway	
France	Oman++	
Germany	Pakistan	

***** Only included in Model 4
** Only included in Models 1, 2 and 4
+ Only included in Model 2
++ Only included in Models 1, 3 and 4

In order to better understand and interpret the impact of economic development on pesticide consumption rates, I will be employing fixed-effects panel regression models, allowing me to test for temporal variation within nations, as opposed to variation across nations at a time-specific point. Each of the three disaggregated indicators of pesticide value discussed above–total national insecticide, herbicide and fungicide use–will constitute the outcome variable in a separate regression model. In addition, I will use total national pesticide use, the aggregated variable, as the outcome variable of a fourth model for purposes of comparison with the results of the disaggregated models.

Table 2 presents some basic statistics for each of the dependent variables in unlogged form, including the number of observations (N), mean, median and range (minimum and maximum observations). Note that the N varies slightly between variables. This is because there are some gaps in the data; not every country has data for each year of the period. Thus, there is a problem of missing data, which is the result of paucity and sparsity of available data on national rates of pesticide consumption. The sample sizes are large enough to conduct acceptable analyses (Longo and York 2008), although this is a limitation of the study. Of the three disaggregated dependent variables, insecticide value has the largest number of observations (2,229), ahead of fungicides (2,136) and herbicides (2,121). Interestingly, herbicides compose the greatest portion of the sample in terms of weight, as it has the largest mean (7,683.48 metric tons) median (1,038 metric tons) and maximum value (239,657 metric tons) of the three pesticide classes, with fungicides comprising the second-greatest representation. This is surprising, as insecticides are generally considered the most widely used form of pesticide globally (Aktar et al. 2009). It is possible that gaps in data collection are responsible for this discrepancy.

Table 2: Descriptive Statistics for all Dependent Variables

Dependent Variables	Number of Observations (N)	Mean	Median	Min.	Max.
Pesticide Consumption (Total)	2,274	30,352.75	2,400.97	0	1,807,000
Insecticide Consumption	2,229	3,375.6	339.4	0	111,583.6
Herbicide Consumption	2,121	7,683.48	1,038	0	239,657
Fungicide Consumption	2,136	4,013.42	699.12	0	66,856

Note that the data for rodenticide value and disinfectants, two other major classes of pesticides that are not included in the above table, are much sparser, with significantly less observations and a lower median and mean than the other variables. Rodenticide value only has an N of 1,134, about a thousand fewer than the other pesticide variables. Further, its median value is only 3 metric tons, and has a mean of 220.76, both much lower than the other indicators included. Therefore, I do not include rodenticides as a separate, disaggregated dependent variable. Disinfectants only have 59 total observations and are thus not used as a separate indicator either. However, these data are included in the aggregated total pesticide variable.

Table 3 below provides a brief description of each variable used in this study. The primary independent variable used as an indicator of economic development is gross domestic product (GDP) per capita, measured in constant 2010 US dollars in order to adjust for inflation. For further testing the claims made by the competing theoretical frameworks, I include a number of additional independent variables, such as total national population, urban population as a percentage of total population, agriculture value added as a percentage of GDP, and employment in the agricultural sector as a percentage of total national employment.

Table 3: Summary of the Dependent and Independent Variables

Dependent Variables	Description	Transformation	Data Source
Pesticide Consumption (Total)	Total annual national pesticide consumption within a nation – metric tons.	Logged	UNFAO – FAOSTAT data (2017)
Insecticide Consumption	Total annual insecticide consumption within a nation – metric tons.	Logged	FAOSTAT data (2017)
Herbicide Consumption	Total annual herbicide consumption within a nation – metric tons.	Logged	FAOSTAT data (2017)
Fungicide Consumption	Total annual fungicide and bactericide consumption within a nation – metric tons.	Logged	FAOSTAT data (2017)

Table 3 (continued).

Independent Variables			
GDP (per capita)	Gross domestic product per capita – Constant 2010 U.S. dollars.	Logged	World Bank (2017)
Population (Total)	Total annual population	Logged	World Bank (2017)
Urban Population	The percentage of the total population that resides in urban areas.	Logged	World Bank (2017)
Agriculture, Value Added (Control Variable)	The amount of value added to the GDP from the agricultural sector as a percentage of the GDP.	Logged	World Bank (2017)
Agricultural Employment (Control Variable)	The percentage of the total number of employed persons that work in the agricultural sector.	Logged	World Bank (2017)

I include the total population variable in accordance with the expectations of structural human ecology and the STIRPAT model, which stresses the importance of population on societal environmental impacts (Dietz and Rosa 1994; York and Rosa 2012). Thus, when regressing pesticide consumption on total population, a positive and significant coefficient would provide support for the claims of structural human ecologists. The urban population (as a percentage of the total population) is included in accordance with the postulates of ecological modernization theorists, who argue that the process of modernization will eventually lead to reduced environmental impact (Mol 1996; Mol and Spaargaren 2000; Spaargaren and Mol 1992). Thus, following previous research in this tradition, I use urbanization—a key component of modernization–as an index of modernity, along with growth in economic development.

The GDP per capita variable is included to test the competing claims of EMT and both the treadmill of production theory as well as structural human ecology about the relationship between economic growth and environmental impact. Treadmill of production theorists argue that economic growth is predicated on an increase in environmental withdrawals and inputs that have negative ecological impacts (Schnaiberg 1980; Schnaiberg and Gould 1994; Gould et al. 2004; Gould et al. 2008). Structural human ecologists argue that a society's level of affluence, which is often operationalized as GDP per capita in the STIRPAT model, is a key driver in its levels of environmental impact (Dietz and Rosa 1994; York et al. 2003a; York and Rosa 2012). EMT theorists, on the other hand, contest that economic development, production and environmental impact are not necessarily coupled (Mol 1996; Mol and Spaargaren 2000; Spaargaren and Mol 1992). In fact, according to the postulates of EMT, we should see a reduction in negative environmental impacts over time in nations that experience economic growth. Therefore, a positive, significant GDP per capita coefficient would support the arguments of the treadmill of production theory and structural human ecology. Reduced usage at higher levels of economic development would support the arguments of EMT.

The variable "agriculture, value added (as a percentage of GDP)" indicates the level of national agricultural production in its degree of sectoral contribution to the GDP. Measuring growth at both the national and sectoral level allows for a more nuanced understanding of economic activity as it relates to agriculture and the use of agrochemicals. While a nation's GDP per capita provides an index of overall levels of economic activity and social affluence, ascertaining the degree of productivity within the agricultural sector allows for an empirical examination of the relationship between production and environmental impact within a specific industry, or sector of the economy. This variable is included to test the argument made by treadmill of production theorists that increased production leads to increases in negative environmental impacts, as it will require an addition of resource inputs and will result in an increase in outputs (Schnaiberg 1980).

As mentioned above, EMT theorists argue against a necessary coupling of economic activity and environmental harm, and on the contrary argue that continued economic activity may lead to a reduction in impact. Thus, as with the GDP per capita coefficient, a positive, significant relationship between pesticide consumption and "agriculture, value added" amounts to empirical support for the treadmill of production theory. A negative, significant relationship between the variables would provide support for EMT. Similarly, the variable "agricultural employment (as a percentage of total employment)" is also included as an indicator of the level of production in the agricultural sector. Therefore, the coefficients of this variable can be interpreted similarly to the coefficients of the "agriculture, value added" variable. Further, both of these variables act as "controls," generally holding constant the level of productive activity in the agricultural sector and allowing for an assessment of the effect of economic development on pesticide use.

All variables are transformed into natural logarithmic form to address issues of non-normal distribution and non-linear growth, making these models log-log models. This makes the results interpretable as those produced by elasticity models–the variable coefficients express the percentage change in the dependent variable in accordance with a one-percent change in the value of the independent variable (York, Rosa and Dietz 2003b). The measurement of proportional change in an indicator of environmental impact–such as pesticide consumption–as it corresponds to changes in driving factors is known as ecological elasticity, with each coefficient representing the ecological elasticity of the given independent variable (York et al. 2003b). I include year dummy variables, or period dummies, to control for multicollinearity between years, and for factors that are temporally variant but cross-nationally invariant (Jorgenson and Clark 2011; Longo, Clark, and York 2013; York and Rosa 2012).

Fixed effects models control for potential omitted variables, which are abundant in non-experimental social environments (Brüderl and Ludwig 2014). The practice of running fixed effects models with year dummy variables thus controls for two kinds of factors; the fixed effects method controls for those that do not change over time within nations, but are different cross-nationally, such as climatic and geological conditions; and the year dummies control for cross-national factors that are constant cross-nationally, but are temporally variant, such as international oil prices (Longo et al. 2013; York and Rosa 2012). Robust standard errors are included in the models to control for potential heteroscedasticity (Brüderl and Ludwig 2014), which also increases the difficulty of obtaining statistically significant coefficients, thus making it a more conservative estimator.

Results

The results of the four fixed effects panel regression models are presented below in Table 4. The population coefficient for the herbicides model (Model 2) is both positive and statistically significant at the 0.05 level, all else being equal. Note that all findings are reported with all other independent variables held constant. As the variables are logged, this coefficient can be explained as follows: a one percent increase in population results in a 1.651 percent increase in herbicide consumption. Because the coefficient is greater than one, there is an elastic relationship between the variables, as the consumption of herbicides increases at a rate that is greater than that of the population (York et al. 2013). The population coefficients for the remaining models—insecticides, fungicides, and total pesticides—are not statistically significant.

Table 4: Results from Fixed-Effects Multivariate Panel Regression Analysis (1990-2015), All Variables Log Transformed

Independent Variables	Model 1 - Insecticides	Model 2 - Herbicides	Model 3 - Fungicides	Model 4 - Pesticides (Total)
GDP (per capita)	1.407**	1.039*	1.209***	0.825**
	(0.455)	(0.401)	(0.301)	(0.289)
Population (Total)	0.298	1.651*	1.468	1.188
	(1.141)	(0.742)	(1.028)	(0.881)
Urban Population (% of total pop.)	-0.829	0.151	0.686	-0.0553
	(1.116)	(0.902)	(0.947)	(0.702)
Agriculture, Value Added (% of GDP)	0.703**	0.768***	0.423**	0.712***
	(0.223)	(0.207)	(0.152)	(0.177)
Agricultural Employment (% of total employment)	0.253*	0.317***	0.138	0.238**
	(0.102)	(0.052)	(0.084)	(0.074)
Constant	-9.963	-31.43*	-31.86*	-19.71
	(18.311)	(12.352)	(15.567)	(13.980)
N	1250	1243	1242	1279
R-squared within	0.106	0.269	0.139	0.221

All variables are in logarithmic form. The model included year dummies, which are not shown.
Robust standard errors in parentheses.
* $p<0.05$, ** $p<0.01$, *** $p<0.001$

The coefficients for GDP per capita are positive and significant for each model. In Model 1, where insecticide consumption is the outcome variable, the GDP per capita coefficient of 1.407 is significant at the 0.01 level. Thus, a one percent increase in GDP per capita is associated with a 1.407 percent increase in insecticide consumption. The coefficient for the herbicide model (Model 2) of 1.039 is significant at the 0.05 level. Accordingly, a one percent increase in GDP per capita is associated with a 1.039 increase in herbicide consumption. The coefficient for the fungicide model (Model 3) of 1.209 is significant at the 0.001 level, meaning that a one percent increase in GDP per capita is associated with a 1.209 percent increase in fungicide consumption. Finally, the GDP per capita coefficient for the total pesticide consumption model is 0.825, and is significant at the 0.01 level. A one percent increase in GDP per capita is associated with a 0.825 percent increase in total pesticide consumption. It is important to note that the "total pesticide consumption" variable includes all three of the other dependent variables as well as additional types of pesticides, such as disinfectants and rodenticides, which were not included as separate disaggregated variables because of their comparatively significantly lower rates of use. For the three disaggregated models, the GDP per capita coefficients are greater than one, and thus the relationship is elastic. For the aggregated pesticide model, the coefficient is slightly less than one (0.825) and therefore inelastic.

I also tested for a curvilinear relationship, including the quadratic of GDP per capita. However, with the inclusion of the squared term, neither GDP per capita nor the quadratic term reached the level of significance, indicating that the relationship is likely linear, rather than curvilinear. The results of the models where otherwise very similar. Thus, the inclusion of the squared term did not provide additional explanatory power, and I did not include it in the final models. The results of the models including the squared GDP variable are presented in Appendix A. As a reminder, period (yearly) dummy variables were also included in the models, but as standard procedure, these are not included in the results table.

The agriculture, value added (as a percent of GDP) coefficients are positive and significant across all models. The coefficients for the insecticides and fungicides models are significant at the 0.01 level, and the coefficients for the herbicides and total pesticides models are significant at the 0.001 level. Each of the coefficients are below one, meaning the percentage of the proportion contributed to the GDP by the agricultural sector increases at a rate that is higher than that of pesticide consumption, thus resulting in an inelastic relationship. In other words, while an increase in agricultural production does correlate with increases in pesticide consumption, the growth in pesticide consumption does not keep pace with the growth in agricultural sector – it grows too, but at a slower rate.

None of the coefficients for the urban population (percent of the total population) is statistically significant. The coefficients for agricultural employment—operationalized as the percentage of total employment accounted for by the agricultural sector—are all positive and significant, except for the fungicide model. The coefficient for the insecticides model is significant at the 0.05 level, while the herbicides and total pesticides models are significant at the 0.01 and 0.001 levels, respectively. Each coefficient is well below one, indicating that there is an inelastic relationship.

Discussion and Conclusion

Regarding my primary variable of interest, GDP per capita, the results indicate that economic development correlates with an increase in the use of pesticides over time within nations, during the period of 1990-2015. This relationship exists for each type of pesticide use measured, and is present in aggregated pesticide consumption. Further, for each of the disaggregated pesticide variables, the relationship between GDP per capita and pesticide use is elastic, meaning the rate of change for the dependent variable (pesticide use) is greater than the rate of change for the variable acting upon it (GDP per capita). As both the level of employment of and the value added to the GDP by the agricultural sector are being held constant, these results should not be attributed to increases in agricultural production. This suggests that, far from pesticide consumption declining along with economic growth, nations that are experiencing high levels of economic development may actually be adopting more chemical-intensive agricultural practices.

The relationship between the aggregated pesticide variable and GDP per capita, however, is inelastic, as the coefficient is slightly below one. This discrepancy could be the result of the inclusion of additional pesticide types within the aggregated pesticide count, which perhaps have a qualitatively different relationship with economic growth than do the three main pesticide types. Nonetheless, these results provide empirical evidence to support arguments made by the treadmill of production theory, in that the relationship between economic growth and environmental impacts, operationalized as use of chemical pesticides, is significant and positive. The proposed relationship between environmental impact and affluence made by structural human ecology is also evidenced by these results, as countries generally are using greater amounts of agrochemical inputs at higher levels of per capita affluence. There is no evidence to suggest a decoupling of economic development and environmental destruction, or an "ecological switchover," in which continued economic growth results in more ecologically sustainable production practices, as proposed by EMT and the EKC hypothesis.

The relationship between population and pesticide consumption was positive for each of the models, although only statistically significant for herbicides. Thus, there is minimal evidence to validate the claim of structural human ecologists regarding the positive relationship between population and environmental impact. While these results are surprising, it may be the case that population's environmental impact is moderated by other factors included in the models, such as levels of affluence and levels of agriculture production. York and Rosa (2012), for example, found that population operationalized as number of households—average number of people per household—had a greater effect on pollution emissions than total population. In other words, increases in the amount of resources used by the average member of the population, or its level of affluence, indexed by the number of households, has a greater effect than simply population growth. Therefore, it could be the case that other indicators would more appropriately measure the effects of population on pesticide consumption. Further, the role of global trade may be important here, as wealthy nations often outsource the production of environmentally intensive goods, including agricultural productions, outside of their national borders, where cost may be cheaper and both environmental and labor regulations laxer. Perhaps population, when coupled with economic growth, does not necessarily lead to an increase in environmentally taxing practices *within national borders*. This may indicate the need for alternative measures of national environmental impact – ones that take into account practices that relocate environmentally intensive production for domestic consumption overseas, such as the ecological footprint (York et al. 2003a).

Because the coefficients for the variable "urban population (as a percentage of the total population)" are not statistically significant for each model, there is no evidence to support the claims of EMT regarding modernity and reduced environmental impact, as indicated by urbanization. According to the results of these models, urbanization has no clear impact on levels of pesticide consumption. This seems surprising, as it may be assumed that an increase in a nation's urban population, and corresponding decrease in its rural population, would lead to a reduction in agricultural production, and thus in pesticide consumption. However, it may be that a reduction in the rural population leads to less labor-intensive and more capital- and energy-intensive methods of agricultural production, including an increase in the use of agrochemical inputs (Satterthwaite, McGranahan and Tacoli 2010). It is also possible that there are other measures of modernization, besides urbanization, that would be worthwhile for inclusion in future studies.

The positive and statistically significant coefficients for both agriculture, value added and agricultural employment across all models, except for the agricultural employment coefficient for the fungicide model, provides evidence for the treadmill of production theory, in contrast to claims made by EMT theorists. Both increases in production and increases in employment within the agricultural sector result in increases in pesticide consumption. From these results, it appears that increases in net economic activity in agriculture are not generating new, ecologically sustainable production innovations, but are instead merely generating continued demand for agrochemical inputs.

The lack of statistically significant GDP per capita squared terms provides no evidence of an EKC in the relationship between economic growth and pesticide consumption. By looking at variation within nations over time, as opposed to variation between nations at a fixed point in time, we see no evidence of the existence of an EKC. Because many of the theoretical frameworks explored in this study, including EKC, make explicitly temporal arguments—that is, arguments about how socio-environmental conditions change over time—employing a fixed effects panel model to test these arguments is an appropriate methodological match. The lack of evidence of a pesticide EKC in these results therefore makes for a compelling counterargument, at least as applied to the phenomena being measured here. The fact that there was no evidence of an EKC for any of the four models indicates that even when taking a more nuanced look at pesticide consumption, in analyzing it by its constituent parts, there is still no evidence of a reduction in pesticide consumption, over time, at higher levels of GDP per capita.

There are some interrelated shortcomings to this study. The data panel is unbalanced; meaning the number of years for which data are available is not the same cross-nationally. In other words, for country a there might only be data for the years 1990-2002, whereas country b might have data for 1995-2015, etc. This is a common problem researchers face when working with panel data (Baltagi and Song 2006), particularly when using an international sample, as all countries may not start collecting certain data at the same time, or may have interruptions in the data collecting process.

The issue of an unbalanced panel is directly related to a second shortcoming: the issue of missing data. As Longo and York (2008) stated in their earlier study, pesticide consumption data are limited and contain gaps. Further, it is unlikely that these missing data are random. Therefore, while the data available are sufficient to use for analysis (Longo and York 2008; Schreinemachers and Tipraqsa 2012), these results should be interpreted with caution, taking into consideration that the data are incomplete.

The possibility of non-random missing data presents problems for the unbalanced panel too (Baltagi and Song 2006). One method of controlling for an unbalanced panel is to limit the analysis to the panels that are available for most or all of the countries. However, because of the variation in available panels per nation, I instead chose to utilize all of the available data in order to maximize the number of countries in the analysis, in conformance with the approaches of other scholars when working with unbalanced panel data (Jorgenson and Clark 2011).

Finally, there is the issue of how the variable pesticide consumption is operationalized. The FAO data measures pesticide consumption by weight of active ingredients (FAO data 2017). For the purposes of this study, it is therefore assumed that increases in the *weight* of pesticides consumed equals an increase for pesticides consumed, and a decrease in the weight is equal to a decrease in consumption. Yet this may not always be an accurate assumption, as newer, more advanced pesticides are sometimes more concentrated, and therefore a smaller amount may have the same degree of potency as heavier, less concentrated varieties. Because of this, some have suggested that operationalizing pesticide use as area of land treated more accurately captures rates of pesticide use, particularly in developed countries, than by weight measurement (Devine and Furlong 2007; Schreinemachers and Tipraqsa 2012). Future research on global rates of pesticide consumption could investigate this further, perhaps comparing weight vs. area, and seek out the requisite data.

Overall, the results of this study confirm many of the claims of the treadmill of production theory, as well as some of the arguments of structural human ecology, the two theories within the critical socio-ecological theoretical framework. The arguments of ecological modernization theory and the environmental Kuznets curve hypothesis (EKC) largely do not hold up to empirical investigation, within the bounds of this study. Further, these results are consistent when disaggregating the pesticide variable into its three largest categories, insecticides, herbicides and fungicides/bactericides. Economic growth and pesticide consumption appear to be coupled across each of these categories. Overall population's effect on pesticide use is limited to herbicides, while urbanization has no observable effect on rates of consumption. Agricultural production has a positive effect on pesticide use for each of the models, while the percentage of employment in the agricultural sector has a positive, albeit weaker, effect for each model except for fungicides. While some of the methodological shortcoming mentioned above counsel caution in interpreting these results, they nonetheless provide another important empirical challenge to some of the key claims of modernizationist theories regarding socio-ecological interactions (Clark and York 2005; Dietz, Rosa and York 2012; Longo et al. 2013; Longo and York 2008;

York et al. 2003a; York and Rosa 2012). Further research that empirically analyzes the claims of these two competing eco-sociological frameworks concerning other relevant phenomena is needed, as are theoretical reformulations rooted in the analytical results.

Within a world of widespread ecological disorder and environmental calamity, the connectivity of the social and natural worlds is becoming increasingly relevant and important to grasp. The impacts of climate change on society, at both local and global levels, are rendering the historic chasm between the social and the environmental obsolete. The long-held maxim of human ecology that environmental problems are human problems (Duncan 1964) informs both the context of this study and the concerns of environmental sociology as a discipline. The results of this study suggest that the use of environmentally deleterious agrochemicals has increased, and cast doubt on the claims that modernity and economic growth lead to a reduction in environmental impact. This study, therefore, highlight the gravity of our problems as well as challenge modernizationist solutions, such as technological fixes and more economic development, to these environmental problems. While further research examining these issues is needed, this study underscores the possibility that broader socio-structural transformations are required to substantively deal with our looming ecological crises.

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APPENDIX

Appendix A

Table 5: Results from Fixed-Effects Multivariate Panel Regression Analysis (1990-2015) (GDP per capita squared results included)

Independent Variables	Model 1 - Insecticides	Model 2 - Herbicides	Model 3 - Fungicides	Model 4 - Pesticides (Total)
Population (Total)	-0.0197 (1.222)	1.428 (0.735)	1.392 (1.094)	1.140 (0.8998)
GDP (per capita)	4.878 (2.719)	3.671 (3.962)	2.060 (1.8298)	1.416 (1.666)
GDP (per capita) squared	-0.207 (0.155)	-0.157 (0.219)	-0.051 (0.105)	-0.036 (0.099)
Agriculture, Value Added (% of GDP)	0.648** (0.2398)	0.727** (0.223)	0.410* (0.164)	0.703*** (0.179)
Urban Population (% of total pop.)	-1.115 (1.150)	-0.0496 (1.039)	0.624 (0.937)	-0.157 (0.768)
Agricultural Employment (% of total employment)	0.216* (0.098)	0.288*** (0.059)	0.129 (0.081)	0.231** (0.075)
Constant	-17.45 (19.740)	-37.48* (17.081)	-33.77* (15.083)	-20.78 (14.4595)
N	1250	1243	1242	1279
R-squared within	0.116	0.276	0.139	0.221