Title

Energy and the Evolution of World-Systems: Fueling Power and Environmental Degradation, 1800-2008

Author

Lawrence, Kirk Steven

Publication Date

2011

UNIVERSITY OF CALIFORNIA
RIVERSIDE

Energy and the Evolution of World-Systems: Fueling Power and Environmental Degradation, 1800-2008

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Sociology

by

Kirk Steven Lawrence

December 2011

Dissertation Committee:
  Dr. Christopher Chase-Dunn, Chairperson
  Dr. Robert A. Hanneman
  Dr. Matthew C. Mahutga
  Dr. Steven K. Sanderson

The Dissertation of Kirk Steven Lawrence is approved:

____

____

____

____
Committee Chairperson

University of California, Riverside

Acknowledgements/Dedication

I am grateful for the support of many people, without whom this dissertation would not have been possible. From the very beginning, my family has provided me with support and encouragement that have created the possibility to succeed. Natalie endured my stress while trying to cross the finish line. All of the instructors who have impacted my development, including my dissertation committee consisting of Drs. Robert Hanneman, Matthew Mahutga, and Stephen Sanderson, and with special thanks to Christopher Chase-Dunn, the Chair of my committee and the intellectual inspiration for much of this work. This manuscript is dedicated to them.

ABSTRACT OF THE DISSERTATION

Energy and the Evolution of World-Systems:
Fueling Power and Environmental Degradation, 1800-2008

by

Kirk Steven Lawrence

Doctor of Philosophy, Graduate Program in Sociology
University of California, Riverside, December 2011
Dr. Christopher Chase-Dunn, Chairperson

The dissertation that follows, organized into three parts, addresses an important question in the evolution of world-systems of human societies: how does energy use shape the dynamics that occur, in particular intersocietal differences in geopolitical and economic power and also in environmental degradation? A general theory is developed that predicts the existence of a positive feedback loop between levels of energy use and intersocietal power that can be constrained by resource shortages and other negative environmental effects, the growth of environmental ideologies, and competition between societies. In addition, the theory predicts that more powerful societies have the ability to generate ecological rent by locating their degradation outside their borders. This can create a power-reducing effect as the energy-related degradation is experienced more by less powerful societies.

In the second section, empirical analyses on a dataset of countries with available data since the early nineteenth century and an additional dataset for those from 1973-2008 are revealed. Results indicate that there has been a decoupling of economic growth from energy consumption within more developed countries. Growth rates for energy consumption per capita and geopolitical and economic power are strong predictors of each other, and both predict environmental degradation per capita, but with different effect sizes and contributing variables that vary by the type of world-system ranking used, and the location in the world-system. Specifically, the semiperiphery and periphery are the locations of the strongest growth rates while the core has the highest levels.

I close by suggested the need for future research on the dynamism of the periphery, the effects and location of environmental degradation, and the possibility of historical and contemporary country-level studies to enhance the research here. While we face enormous challenges due to constraints on energy supplies and the impacts of energy production and consumption, the problems are human-made and can therefore be can be solved by us.

Table of Contents

List of Tables

Tables

List of Figures

Figures

Preface

My dissertation addresses an important question in the evolution of world-systems of human societies: how does energy control and transformation shape the dynamics that occur, in particular intersocietal differences in geopolitical and economic power and in environmental degradation? To begin to answer that question it is necessary to understand intersocietal variance in the acquisition and use of energy resources, such as human and animal labor, and more recently fossil fuels. I assert that the more energy that can be controlled the more power can be generated, while the more power a society has the more energy that can be controlled—the relationship between power and energy forms a positive feedback loop. Moreover, power can be harnessed to displace some of the detrimental effects of energy-related environmental degradation on to less powerful societies, such as deforestation and ecological harm from the extraction and use of coal and oil. The societal impact of energy use can therefore be positive or negative, conditioned on the level of power a society has relative to others in its world-system.

While energy, intersocietal power, and environmental degradation have all received attention from various perspectives, there is a relative paucity of research on their relationship, particularly given both their essence for understanding social evolution in the past and their importance for a sustainable future. Part of this neglect likely stems from the refusal to appreciate the similarity of some human and non-human phenomenon—what sociologists Riley Dunlap and William Catton, Jr. (1978) call the "Human Exemptionalist Paradigm." Indeed, the environmental historian Jason Moore (2011) argues for the use of the term "ecology" to encompass the oft-separated social, political, economic, and environmental interrelationship. It is this kind of holistic thinking that informs this dissertation. For while it is generally accepted that energy flow, and the laws of thermodynamics, are seen as essential and applicable to the evolutionary dynamics of non-human systems, their role within world-systems of human societies is less clear; either ignored, left implicit, or otherwise unaccounted for. This leaves a gap in our knowledge that my project is designed to help address.

The dissertation contained in these pages is organized in the following way. Chapter One discusses the literature on energy and complexity, the thermodynamics of energy flow, and energy-related environmental degradation. Particular attention is given to their roles in the evolution of human societies and world-systems. Chapter Two builds a general theoretical model of the relationship between energy control and transformation, geopolitical and economic power, and environmental degradation. The concept of "ecological rent" as a key driver of the intersocietal dynamics of unequal exchange that emerge from the interrelationship. The theoretical framework guides the research that follows. Chapter Three presents descriptive statistics from data gathered on energy, power, and environmental degradation for countries from 1800-2008. The issue of the disarticulation of energy and economic growth is considered and compared to the available data. Chapter Four presents a quantitative analysis of energy and power for the more recent historical period 1973-2008. More specifically, the data, methods, and results of regression analyses on a panel of countries are discussed. The key variables are derived from my theoretical model: power (an index of economic and political-military strength), and energy consumption. A similar analysis is presented in Chapter Five, but environmental degradation and power are the main variables of concern. Chapter Six concludes the dissertation with a discussion of the theoretical and empirical implications, future research suggestions, and thoughts on sustainability.

The use of both long- and short-term time frames, as well as attempting to make both theoretical and empirical contributions stems from my desire to provide comprehensive coverage of the subject matter, given the limitations of time and data availability. Toward that end, this dissertation is also be cross-disciplinary in that I draw upon concepts from the natural and physical sciences, anthropology, and, of course sociology. Within the latter, the work in these pages will speak most directly to world-systems analysis and the environmental and evolutionary fields in the discipline.

By understanding the past we can make better projections into the future, and it is hoped that the results of this study can be useful in energy and environmental policy. Understanding the relationship between power and energy flows in the interstate system is an essential capability if we are to successfully manage the arrival of post-peak fossil fuels and increasing damage to the biosphere with a minimum of conflict. These are problems that all societies face, albeit unequally.

Chapter 1

Energy and Social Evolution

1.1 INTRODUCTION

The study of energy and social evolution has occurred primarily during the last century and half and across a number of academic disciplines and in various public and private organizations. In this chapter I move from the more general to the specific as I review extant knowledge on this topic. In section 1.2, I discuss our understanding of energy and evolution, with the terms broadly defined in order to encompass both "natural" and "social" evolution. This section includes an overview of work from a number of scholars that have considered the relationship between energy flows and the power of a society, both internally and/or in relation to other societies that are part of interaction networks of societies; i.e., world-systems. Section 1.3 considers the fundamental energy principles from complexity theory and thermodynamics that, I argue, govern evolution across all scales. In Section 1.4, I discuss the treatment of energy in economics and conclude with a preview of the issue of sustainability that is revisited throughout the manuscript.

1.2 ENERGY IN EVOLUTION

While energy is typically defined as the ability to perform work, such as the metabolic energy that can be harnessed by animals and humans to use their bodies for physical labor, on a broader level it can be defined as "the ability to transform a system" (Smil 2008a:12-13). Energy flows are at the core of planetary and star creation, destruction, and movement in extraterrestrial space, radiation from the sun is essential in the origins and flourishing of all life on Earth and heat energy from the burning of wood and fossil fuels allowed our species to produce food and materials that ushered in and continues to support “civilization.” Indeed, since the origin of the Universe, approximately fourteen billion years ago, energy dynamics have been essential to physical, biological, and socio-cultural evolution (Chaisson 2005; Christian 2004).

One of the earliest social theorists to consider energy flows was Hebert Spencer (1865). Spencer drew heavily from physics and biology in his explanation of the social world. He asserted that increases, and decreases, in the heterogeneity and complexity that formed the basis of his evolutionary laws were constrained by energy flows from the inorganic and organic realms into the social world. This was later incorporated into the Human Ecology theory of Amos Hawley (1986).

Marx also considered the role of energy in society, particularly with his idea of social metabolism and the energy “rift” between town and country. While not focused on complexity or hierarchy per se, Marx attempted to understand soil degradation stemming from urbanization and the resultant unequal energy flows, as well as their place of in historical materialism overall (Foster 1999b; Burkett and Foster 2006; Moore 2000, 2003, 2011).[1]

---

[1] The extent of Marx and Engels’ incorporation of energy dynamics in their historical materialism is debated. On one side are those that discount any ecological or thermodynamic appreciation by Marx and Engels. For example, a common story is that in 1880, Ukranian socialist Sergei Podolinsky wrote to Marx to stimulate his interest in applications of thermodynamics to political economy but Marx failed to comply. Engels later wrote that the “desire to re-import the thermodynamical category of work back into economics…is nothing but nonsense” (quoted in Adams 1988:xiv; see also Martinez-Alier 2007). On the other side are Burkett and Foster (2006), among others, who find the “Podolinsky Business” as they call it, to be misunderstood or seriously overstated. They find that Marx, possibly more so than Engels, did apply thermodynamic and energy principles to the study of political economy and to the human-environment relationship.

Alfred Lotka (1925, 1945) developed a principle that sees a surplus of available energy as essential in evolution: the general trend of organic systems is for natural selection to result in an increase in their total mass, which is both dependent upon more energy and generative of it. Lotka also noted an advantage for biological species able to more effectively utilize surplus energy to maximize power output than their competitors; they are selected for in evolution. Howard Odum (1971; see also1983, and with Elizabeth Odum 1981) suggested this "maximum power principle" as the fourth law of thermodynamics.

Almost a century after Lotka, anthropologist Leslie White (1943) extended Spencer's evolutionary complexity but focused more explicitly on energy:

> Culture is a kind of behavior. And behavior, whether of man, mule, plant, comet or molecule, may be treated as a manifestation of energy. Thus we see, on all levels of reality, that phenomena lend themselves to description and interpretation in terms of energy. (P. 335)

White defines energy as the capacity for performing work, and develops a formula to express the relationship of energy to "human-need-serving product:" E x T = P, where E is the amount of energy expended per capita per unit of time, T is the technological means of its expenditure, and P is the magnitude of the product per unit of time. By exchanging T for F, the efficiency of the mechanical means with which the energy is expended, and expanding on P as the degree of cultural development, White produces the law of cultural evolution:

> culture develops when the amount of energy harnessed by man per capita per year is increased; or as the efficiency of the technological means of putting this energy to work is increased; or, as both factors are simultaneously increased (P. 338)

It is, then, the ability to efficiently harness increasing amounts of energy that are directly responsible for intra-societal development, as White explains the relative stagnation of "the great civilizations of China, India, Egypt, the Near East, Central America and Peru," they reached limits of growth and transformation of energy. This situation can occur from natural factors such as lack of available resources, or can occur because of the extraction of surplus [stored energy] by the ruling elite, effectively stifling incentive for production and innovation (here White uses China since the Han dynasty as an exemplar). The rise and fall of civilizations, from endogenous causes, is thus a product of energy capture and transformation.

Fred Cottrell (1955) also places energy as the base for understanding social evolution. Cottrell states his argument plainly: …the energy available to man limits what he *can* do and influences what he *will* do (p. 3). In his study of human social evolution, Cottrell differentiated societies based on their energy use. Low energy societies were dependent upon animal and human energy in labor, or later in ships using sails to harness wind energy. High energy societies, on the other hand, primarily utilized coal and then oil for their energy needs. While low-energy societies that were best able to exploit what were very limited energy surpluses by later standards flourished, such as in ancient Egypt, they were much less complex and productive than those that harnessed higher-intensity sources, such as Britain during industrialization in the 18th and 19th centuries. As the high energy societies continued to distance themselves socially, economically, and politically from the low-energy societies—when not conquering the latter—there was a hierarchy created between the two levels of energy users.

Gerhard Lenski (2005) and Patrick Nolan and Lenski (2006) consider energy flow in their ecological-evolutionary framework as a primary factor in societal development and change:

> One of the most important of the variable characteristics of societies is the amount of energy its members consume. No human activity – not even thought – is possible without energy, and the quantity and nature of the energy available to the members of a society profoundly influences their patterns of life. (Lenski 2005:20)

At its most basic, energy as means of human sustenance is a source of difference between societies and a basic human need (cf. Harris 1979; Sanderson 2007). Of course, their focus on subsistence technology as their dependent variable is directly related to the amount of energy that is expended and that can be acquired for social life:

> *Subsistence technology* is the term used to refer to those elements of a society's store of information that enable it to obtain the energy its members require, and it is no exaggeration to say that subsistence technology provides the key to understanding societal growth and development. Specifically, *advances in subsistence technology are a necessary precondition for any significant increase in either the size or complexity of any society*. (Nolan and Lenski 2006:57, emphasis theirs)

For Nolan and Lenski, improvements in subsistence technology allow for a society to grow in size, defining "the limits of what is possible for a society" (ibid, 57) by reducing the costs of development. The division of labor can increase because new niche space opens, following Durkheim ([1893] 1984). The wealth of the society grows, as does the potential for inequality. And the ability to conquer other societies, or defend the society from others also increases. These changes then feed back to create the potential for further advances in subsistence and other technologies, generating self-sustaining development. Energy, then, is the prime mover in social evolution.

These factors are also at the core of inter-societal relations, particularly the conquest of one society of another. David Kaplan (1960) in an edited volume with a foreward by Leslie White, states “The Law of Cultural Dominance,” as “cultural systems which more effectively exploits the energy resources of a given environment will tend to spread in that environment at the expense of less effective systems” (p. 75). The view of cultural dominance here is specific to a given environment or niche and is therefore territorial. After noting the possibility of hunting and gathering in resource rich environments outyielding agriculture in others, Kaplan details the fate of both the Plains Indians in the United States at the hands of European agriculturalists and the northern Chinese from the invading pastoral steppe nomads as equal instances of a society superior in energy management of an environment triumphing over one less effective at the same task.

Extending this principle to more modern societies, Adams (1988) argues that “it seems hard to avoid the conclusion that ’development’ like ‘progress’ before it, has been inherently dedicated to the increase of energy consumption, both at home and abroad” (P. 235). Moreover, energy consumption is necessary for greater regulatory control that is required for the emergence and maintenance of complex societies. The increase in energy use “also created much greater nonlinearity and indeterminacy” (P. 241). This is due to the non-linear dynamics inherent in energy flow—issues we will return to shortly.

Energy-dependence in the explanation of the rise and fall of societies is also important in the work of Joseph Tainter (1988). Relying on case-studies from archaeological and anthropological data, and following Spencer, Tainter asserts energy flow is necessary for sociopolitical organization and complexity (evinced by larger and heterogeneous societies, with more governmental control over population and provision of defense and distribution of surplus). But rising complexity, outcomes of institutional responses to perceived problems—what Jonathan Turner (1995) calls "Spencerian selection pressures" for institutional change—require energy and the amount increases together with population size. However, and this is Tainter's key proposition, there are decreasing marginal returns for the cost of each additional unit of complexity. Without new energy acquisitions (often through territorial expansion), increasing costs of complexity occur just to maintain the current level, not growth. If a society does not have excess capacity to handle unexpected stress (climate, invasion, etc.) the system becomes destabilized, weakened and can decline in complexity. Furthermore, the awareness of declining marginal returns to complexity can also lead to a desire to voluntarily reduce it, reducing the services and advantages of being a member of the society, while often increasing taxes to support it, leading to revolt at both the upper and lower strata. Ultimately, energy shortages create less flexibility for complex societies to maneuver when faced with stress.

World-Systems Analysis

Informing much of the dissertation that follows is the theoretical perspective called world-systems analysis. In the simplest terms, world-systems analysis asserts that the modern world, since at least the 16th century, consists of a system of states interacting on unequal terms. An extension of dependency theory's focus on the negative impact of the Global North's penetration of the Global South through means such as foreign direct investment (cf. Amin 1974; Emmanuel 1972; Frank 1967), world-systems analysis was originally developed by Immanuel Wallerstein (1974). As envisioned by Wallerstein, the interstate system consists of a division of labor that takes place across core, semiperiphery, and periphery zones. Countries in the core have economies organized primarily around capital-intensive production with "skilled" and better-paid workers, countries with peripheral economies have economies that are primarily labor-intensived with "unskilled" and lower-paid workers who are often coerced, and countries in the semiperiphery have economies that have aspects of both types of production processes and labor characteristics (Chase-Dunn 1988:77; see also Arrighi and Drangel 1986).

The dynamics of the modern world-system, given its capitalist underpinnings, are driven by conflict occurring over competition for scarce resources; whether those resources are material, financial, or geopolitical power. These sources of conflict are often intertwined with the need for energy at their core. For example, Jason Moore (n.d.) considers cheap energy resources as one of the "four cheaps" (including food, raw materials, and labor) that was essential for the profitability of the modern world economy.

Similarly, Bruce Podobnik (2006a, 2006b) sees energy as fundamental in the competition for economic and geopolitical hegemony over the last four hundred years. Using a world-systems perspective, Podobnik reveals the patterns in the production, transportation, and consumption of primary energy resources that have fueled intra-societal growth and inter-societal competition, Podobnik's unifying concept is an energy shift: "the process whereby a new primary energy resource is harnessed for large-scale human consumption" (p. 4). The resource becomes the basis of an energy regime that includes technology, infrastructure, and the social, economic, and political structures. Podobnik then traces geopolitical rivalry through attempts by city-states and states to obtain energy sources from outside their borders. For example, conquests for wood, one of the earliest primary energy resources, were conducted by fifth-century C.E. Athens, the Roman Empire, and China, India, North Africa, and Western Europe during the pre-modern period. The use of force to obtain energy, or prevent another from it, continued between Britain and France during the Napoleonic Wars and between the powers in WWI and WWII. The winner of these struggles achieved power, wealth, and sometimes hegemony, as the U.S. did by replacing Britain's coal-based dominance by an oil-based system. The losers are consigned to second place, or lower among the hierarchy of nations. Seen in this manner, Podobnik tells the conflict over oil, which pits those who control it or seek to against those struggling to meet their demands, as part of the story of declining U.S. hegemony. Similarly, the future of the world-system will be told as another energy shift, and the success and failure of states to exploit new energy sources as oil availability declines.

Like Podobnik, Bunker and Ciccantell (2005) assign energy flow as a critical factor in hegemonic sequences. They also provide explanations for the material intensification (energy throughput) and the spatial expansion of production and trade, utilizing the concept of generative sectors (technological and organizational innovations various political, economic, and social spheres) and a dialectic of increasing economies of scale in production and diseconomies of space in the extraction and transport of raw materials that have shaped the world-system for at least the last 500 years. The state that has been able to foster the growth of generative sectors has been able to utilize its advantage to reconstitute the world-system in its favor and become the hegemon. Thus, the Dutch did it with wood and ship building in the 17th century, the British with coal that fueled steam engines in factories and on ships in the 19th century, and the United States with timber, iron, copper and rail and steel production in the 20th century. They then explain the rise of Japan as a story of raw material access throughout South Asia and Australia that fueled steel production that coupled with the production of massive ships and deep-water ports to support trade (see also Bunker 1985, 2007).

The semiperiphery of the modern world-system is the location for much of the energy-based change. While Wallerstein's semiperiphery is underdeveloped theoretically, he does suggest that countries in the semiperiphery can benefit during economic downturns when profit-strained core-production is shifted to the lower-cost semiperiphery (1976). This shift in the location for production would necessarily entail a shift in the energy profile within the world-system as industrialization of the semiperiphery would likely increase its energy use since industrialization is energy dependent and energy intensive, while deindustrialization in the core would likely decrease the energy use of the core as it shifts toward less energy-intensive sources of economic activity. Yet this could be tempered somewhat if the growth in production took place under a different energy regime and/or with different technology, a possibility considered by Chase-Dunn and Hall (1997a) who see the semi-periphery as the location for much of the world-system dynamics. This occurs because countries in the semiperiphery, relative to the core, have more incentives to implement new technologies and forms of organization, such as a new lead industry (Modelski and Thompson 1996) because they are less invested in the maintenance of the current system and have the "advantage of backwardness" (Gerschenkron 1962); i.e., and they do not have to overcome the friction of an older infrastructure. Additionally, societies in the semiperiphery, relative to the periphery, often have enough resources for upward mobility into the core. Societies in the semiperiphery, then, are materially and structurally positioned to make the most radical changes in the system and are often the location for progressive social movements (Chase-Dunn and Boswell 2009).

A "green energy" revolution, in which social and/or technological innovation fosters the growth of more sustainable energy use may occur, then, not in the wealthy core, where environmentalism is the most formalized, but in the semiperiphery where the possibilities for dramatic change or greater (Lawrence 2009b; see also Kaneshiro, Lawrence, and Chase-Dunn, Forthcoming). These possibilities are discussed here in more detail in the last chapter.

1.3 COMPLEXITY THEORY AND THERMODYNAMICS

While many important processes in physical, biological, and social evolution have been driven by energy flows, the effects have often been non-linear. For example, while not a consensus position, evolutionary biologist Stephen J. Gould argued that biological evolution is marked by punctuated equilibrium in which speciation occurs relatively rapidly (Gould 2002; Gould and Eldridge 1977), and in chemical and physical evolution, bifurcation and phase transitions appear between unique states, such as in the formation of stars (cf. Chaisson 2001; Prigogine 1997). In human social evolution chiefdoms cycle between rising and declining complexity (Anderson 1994; see also Liverani 2006; Spencer 1990),[2] and over the long term and across multiple world regions, we see what researchers led by Christopher Chase-Dunn call "upward sweeps" in which the size of settlements, cities, and empires grow over time through sharp rises—and declines—that are over a third larger than previous heights (Inoue, Álvarez, Lawrence, Roberts, Anderson, and Chase-Dunn 2011). Similarly, Immanuel Wallerstein (1998, 2004) argues that the modern world-system reaches bifurcation points in which the extant system reaches contradictions that jeopardize its continued survival able to survive and is replaced by a system built on a different foundation. Indeed, the greater the complexity of the system the more vulnerable it is to various shocks (cf. Homer-Dixon 2006; Tainter 1988). In his study of societies that have succeeded or collapsed during climate changes, anthropologist Brian Fagan (2004) calls this scalar effect the result of a society "trading up on the scale of vulnerability."

Complexity theory provides a generalizable explanation for the role of energy flow in these seemingly disparate evolutionary events. In complex adaptive systems, increases in energy can produce self-emergent transformations from one state to another.

---

[2] While not an example of state formation, David Anderson (1994:15-18) has a punctuated equilibrium explanation of the evolution of chiefdoms that is worth noting. Anderson argues that pristine chiefdoms occur gradually, as "resource control, alliance, and exchange networks, and supporting ideologies" emerged slowly and sometimes as risk-management strategies that generated legitimate authority for the best practitioners. But secondary chiefdoms formed quickly, as a reaction from threats from neighbouring chiefdoms or other societies.

The process creates discrete jumps—a series of punctuated equilibriums—as thresholds are crossed (cf. Chaisson 2005; Gunderson and Holling 2002; Prigogine 1997; Prigogine and Stengers 1984). The most mundane of these events may be the phase transitions that occur as H_2O changes from ice to water to steam. Similar jumps are also found in the evolution of ecosystems. Ecological science tells us that organisms reach energy-based limits on their growth—e.g., lions are only as big and as numerous as their niche allows, further growth would be energetically and thus evolutionarily disadvantageous (Colinvaux 1978). Moreover, the overall mass of species' form discrete trophic levels that take the shape of a pyramid (known as the Eltonian pyramid) with discrete steps as you move up the food chain. This is due to the net loss of energy that occurs during the process of capturing, consuming, and metabolizing prey.

Studying a chimpanzee troupe, hunters and gatherers, pastoralists, a village of horticulturalists, a village of those practicing agriculture with chemicals, and post-industrial, fossil-fuel based Japan, Mario Giampietro and David Pimental (1991) calculated the energy expenditures and inputs necessary for a particular level of societal mass and density, finding that energy increased in orders of magnitude at each step up in complexity. This is consistent with the history of our species over the past 50,000 years. Nomadic hunting and gathering, which was the dominant mode of production until at least the last 12,000 years, relied almost exclusively on human power. According to David LePoire (2007), the average human intake of calories is 2,500 per day, which generates about 100 watts of power. The average current energy use per capita in the United States, in a post-industrial or knowledge-based economy, is 15 kilowatts, or 150 times a hunter and gatherer. This works out to about 3.5 factors of the Feigenbaum number, a mathematical constant that indicates the increase in the ordering parameter necessary for bifurcation, ~ 4.7. For increases in energy flow, this corresponds to the point at which phase transitions to higher ordered states take place (Prigogine 2000). LePoire's calculation of 3.5 Feigenbaum numbers from hunting and gathering to modern post-industrial society suggests that there may have been three to four energy transitions in the past. Like Podobnik (2006a, 2006b), LePoire ties the three energy shifts that have previously taken place, from natural renewables (animal power, wind, and wood) to coal to oil, to leadership transitions. But LePoire points out an additional transition that has been taking place since the mid 1970s—a result of increases in conservation and efficiency—yet a new world-system leader remains to be seen (cf. Devezas, LePoire, Matias, and Silva 2008).

The existence of discrete steps from energy flow is also found by Howard Odum (1996), who developed an energy accounting method for ecosystems, including human societies. He began by distinguishing between energy as the potential to do work and "emergy" (with an "m") as the measure of all previously used energy that went into the transformed product. At each step in the transformation there is an order of magnitude decline in the available energy. For example, in a simple system such as an aquarium, sunlight enters the system (tank) at 2000 x10^3 Joules/day, is reduced by a factor of 1000, to 2 x10^3 Joules/day as it is captured by the plants, then an even small amount of energy is released by the plants, .002 x10^3 Joules/day.

Odum also created “National Emergy Indices” that depict the Empower, Import/Export Ratio of emergy, and Emergy/Money (how much “real wealth” is leaves the country via trade and finance). He explains uneven development as both outcome and cause of unequal exchange. This occurs in two primary ways: people leaving from underdeveloped to developed countries—i.e., a brain drain; and, net exports of emergy resources from underdeveloped to developed countries. As emergy accumulates in the developed countries, capital “autocatalytically” continues to drain the underdeveloped countries, including via colonialism and neocolonialism from economic power. Price as a reflection of value—which does not accurately account for emergy—and loaning money instead of recognizing the need for emergy resources also contributed (2007:303, see also 273-278). Uneven trade occurs when money is exchanged for undervalued resources (i.e., they contain more emergy than the money accounts for). For oil producers, Odum estimates they provide 3-12 times more real wealth emdollars to the purchaser than they receive in return with dollars. The oil producers would develop faster and more evenly if they were to use the emergy-containing resources internally (2007:274, see also Table 7.3 on p.201 and Figure 7.16 on p. 206). Odum also predicts that competition for resources, including war between societies, would occur when energy use is expanding. The most successful energy users take a greater share than others. Somewhat counterintuitively, when fewer resources are available, he predicted that peace and trade will emerge (2007:304-10).

It must be noted that punctuated change in human societal evolution is on a much longer timescale than many are accustomed to. For example, in their study of state formation in Mesopotamia Douglas Kennett and James Kennett (2006) take the long view of human sociocultural evolution—i.e., ~ 80,000 years—arguing that state formation that took place from ~ 6000 to 3000 BCE was a single punctuated event, "a dynamic interval of human cultural evolution" (ibid, 85). The shift from feudalism to capitalism is another example (Wallerstein 1980). Again, the rapid pace of change is relative: human organization looked the same for nearly 4 million years, but in the course of 10,000 years has changed rapidly (Klein and Edgar 2002). Taking a broader view, Claudio Cioffi-Revilla (2006) argues that between 7500 and 1500 BCE:

> …[the Near East evolved] from a disconnected region of simple and isolated societies (pre-pottery Neolithic period) to a network of chiefdoms, to a highly interconnected and interdependent network of politically complex polities at stately and imperial levels. (P. 83).

Cioffi-Revilla contends that this same punctuated evolutionary sequence—simple societies to chiefdoms to local and regional world-system—occurred not only in the West Asian region but also in the Mesoamerican, Andean, and East Asian world-systems. In contrast to the "Big Bang" that explains the expansion of the universe from singularity, he calls his model the "Big Collapse" because by the nineteenth century the four world systems had merged into one—the modern world system—the most complex human system ever created.

Norman Yoffee (2006) also offers a story of punctuated evolution, emphasizing cities: "In every region of the world where the first states appeared, cities were the collecting basins in which long-term trends toward social differentiation and stratification crystallized" (p. 60). This reflects Yoffee's "growth" model of state evolution: urbanization and population growth led to the formation of cities, city-states, and states, based on the expansion of interaction spheres. Yoffee points out that the growth of cities was "revolutionary" because it transformed all social life. Moreover, their growth occurred rapidly in "phase transitions," and are thus fitting of a punctuated equilibrium model: from 4000 BCE few villages in Mesopotamia were larger than 10 hectares/a few hundred people, yet by 3300 BCE Uruk was around 250 hectares (2.5km2) with around 20,000 people (ibid. 210-211, 230).

One of the reasons for the growth of cities stems from an energy shift from the countryside to urbanizing areas. As mentioned earlier, this is captured in the Marx's concepualization of the "metabolic rift." In short, Marx described the rupture that occurred, first as soil was degraded under agricultural intensification and the application of chemical fertilizers, which then continued to deteriorate as urbanization and industrialization created more pollution while robbing the countryside—and the laborers in both the city and country—of the nutrients necessary for sustainability. As an example of the metabolic rift due to capitalist imperialism, John Bellamy Foster, Brett Clark, and Richard York (2010) tell a fascinating story of the international trade in guano from Peru. The Guano, a rich fertilizer, was extracted by imported Chinese labor to meet the agricultural needs of Britain and the United States. They link the War of the Pacific at least partially to this demand for resources as a British-backed Chile and Peru fought for control of the islands containing guano.

A recent attempt at integrating natural laws with sociocultural processes was made by Lee Freese (1997). Following Lotka on energy flow and incorporating complexity theory, Freese's model depicts a biosociocultural regime as it evolves over time, ultimately leading to change that is similar to speciation. The regime has seven interaction process assemblies: ecosystem energy production, human energy expropriation, ecosystem sustainability/disorganization, human subsistence organization, sociocultural-demographic development/dissolution; biosociocultural reorganization, and human subsistence reorganization. The interaction process assemblies interact in five triads, but the model basically forms a geometric shape in which biological processes and human social processes interface. As the first triad reaches a critical threshold, it triggers a transition into the second triad, which becomes dominant, although interactions flow through both sets, amplifying each other. As the fifth triad crosses a threshold, the system shifts into a new biosociocultural regime, with new initial conditions. Over time, biosociocultural regimes in the present should have few, if any, residues left from earlier forms. While Freese's theoretical model has many interesting components, it suffers from lack of clarity.

Although not specific to energy flows, Abrutyn and Lawrence (2010) build upon the work of Turner (1995) and Chase-Dunn and Hall (1997b; updated in Fletcher, Apkarian, Hanneman, Inoue, Lawrence, and Chase-Dunn Forthcoming) utilize the idea of thresholds and phase transitions from complexity theory and punctuated equilibrium in their own theory of the evolution of the polity. In their theory, population increases, particularly when combined with circumscription (Carneiro 1970) create selection pressures for innovation. Under the right conditions and after social forces have crossed thresholds, entirely new social structures and organizational patterns can be created. Part of the explanation for the existence of thresholds in societal evolution comes from the principle of least effort (Zipf 1949). This principle describes the empirical regularity in which people do not immediately respond to pressures; it is only after the costs of stasis reach a relatively high level that inertia can be overcome and action taken. For example, the adoption of agriculture sometimes took hundreds of years after initial exposure because the amount of net energy required for farming was higher than for foraging (Smil 1994:23; see also Cohen 1977). Indeed, necessity is often the mother of invention – innovation is often a response to declining resources and population increases (Boserup 1965; Johnson and Earle 2000).

The Second Law of Thermodynamics

While complexity theory and punctuated equilibrium provide us with an explanation of the discrete jumps in evolution, it is the Second Law of Thermodynamics that offers a general law. From the Second Law of Thermodynamics, which reveals time's arrow and irreversibility, we know that the amount of free energy—that which is "available to us for producing some mechanical work"—dissipates over time (Georgescu-Roegen 1971:5). As energy is used for work, a portion of the free energy is lost as heat as it is transformed from low entropy; i.e., an ordered state such as the energy in coal, to one that has high entropy; i.e., a disordered state such as steam. Because of this dissipative nature of structures not in an equilibrium stat—which from an energy perspective would be the inability to perform any work or a state of death, increasing inputs of free energy are necessary to keep the process going—the consequence is increasing amounts of waste. Energy flows are therefore dialectical—they can generate greater complexity but at the same time greater disorder.

According to ecologist Paul Colinvaux (1980, see also 1978), Charles Elton was right about the discrete-stepped pyramids but wrong about the reason why the upright pyramid exists. Lindeman and Hutchinson discovered the correct explanation in the 1940s, over a decade after Elton's pyramid was revealed: the Second-Law of Thermodynamics. In each step up the pyramid of body mass, energy, originally from the sun, is lost to entropy as heat. Plants are only able to fix about one to two percent of the available energy from the sun, and use much of it during respiration, herbivores capture only about ten percent of the plant energy, meat eaters probably less than that percentage of the animals they eat.[3] Large meat eating animals, those at the top of trophic webs, are only able to capture a portion of the total energy in the system. At each step of the food chain, energy is lost due to entropy from the transformation of energy necessary to produce (catch, harvest, cook) and then utilize the energy as nutrition by those at the next higher level. Large animals are only as big as possible to survive in their niche, but no more. Lions cannot get any bigger because their hunting efficiency is low (all other sources of energy use in their niche must be considered as well). Those are the reasons "why big fierce animals are rare." But there are exceptions, such as some very large herbivores (e.g. baleen whales, elephants). The reason for their unpredicted size, as Colinvaux explains, is that they have "cut out the middleman" in the pyramid by eating low on the food chain but are able to support such a large body mass because they are efficient predators. Tyrannosaurus rex crawled.

---

[3] Colinvaux estimates that wolves on Isle Royale in Lake Superior only about 1.3% of calories theoretically available to them due to the inefficiency of hunting (1980:61-62)

Niche space and complexity, then, are dependent upon energy, and the expansion of niche space and complexity requires increasing energy supply and/or efficiencies in its transformation. The largest consumers of energy, the core states, cannot maintain their standards of living without increasing energy flows (barring population decline). Colinvaux predicts that aggressive war will take place capture resources, and ultimately energy, particularly when the expansion created during the fossil fuel age wanes.

Applying a more socio-ecological perspective, Hornborg (2001), after defining power as "a social relation built on an asymmetrical distribution of resources and risks" (p.1), explains industrialization as resting on unequal exchange in both ideas and materials. Drawing on classic Marxist concepts of use-value and exchange-value, the laws of thermodynamics, and also from chaos/complexity theory, Hornborg describes the theory that was the impetus for my research in this area. Simply put, there is a transfer of entropy in the energy flows of the world-system. The core states, the most powerful states using Hornborg's definition, are able to increase their wealth (and I would add complexity following Tainter) by importing energy in the form of raw materials from the weaker periphery. For Hornborg, the core increases its negative entropy, or order, at the expense of the periphery where entropy, disorder, is increased. Because machine technology is able to create higher exchange values for finished products than the use-values of the materials from which they were transformed, due to what Hornborg calls "machine fetishism" (ibid 84-87), there is a perverse incentive for the wanton exploitation of nature. According to the author, the process results in the "ecological and socioeconomic impoverishment of the periphery" (p.11); energy use is therefore at the heart of intersocietal inequality.

Following Hornborg, Andre Gunder Frank (2007) was developing an application of the concept of entropy to the interactions of core and peripheral states in the world system. Frank contended that imbalances of trade and consequent development in the structure and functioning of the interstate system have, since at least the nineteenth century, allowed powerful states in the global North to import negative entropy and export or transfer entropy to the weaker states in the global South. The North extracted and accumulated capital while some places in the South became environmental wastelands.

Applying the logic of the physics of energy flows developed in this section, I argue that the core states, are able to maintain a relatively high standard of living by using their power to extract the high-energy resources from the peripheral states, which transfers the energy the periphery could use for development. The core states are then capturing a disproportionate share of the energy in the system. They also must continue to capture energy to support their relatively high level of complexity. The low-energy periphery has relatively lower levels of complexity and standards of living.

This energy-inequality can be measured by the ecological footprint, which measures the amount of productive land necessary to generate the resources and store the wastes produced by the economy of a state (Wackernagel and Rees 1996). If a state was using resources solely from its own land, and its biosphere was absorbing all of its pollution, the footprint would be proportional to its size. But when a state is benefiting from unequal exchange by importing its resources to make up for its own shortfalls and its waste is being absorbed beyond its borders, its footprint becomes disproportionately large. A body of research supports the existence of this phenomenon. For example, Jorgenson (2003, 2004, 2005) finds that states with large ecological footprints also tend to have relatively lower levels of ecological degradation than those with smaller footprints. Furthermore, Jorgenson and Rice (2005, 2007) have found that non-core countries with high levels of exports to the core (in the latter study using weighted export flows) have lower ecological footprints, suggesting that these countries are sacrificing development while simultaneously suffering a disproportionate share of environmental ills (cf. Bunker 2007; Eisenmenger and Giljum 2007; Hornborg 2007; Martinez-Alier 2007; Muradian and Giljum 2007).

1.4 ENERGY AND ECONOMIC GROWTH

Within the field of economics, economic growth is traditionally viewed as bring driven by inputs of capital and labor. As large quantities or higher qualities of capital and labor are employed, or are employed more efficiently with technological improvement, neoclassical economic models predict that the rate of economic growth will increase all else held constant. Energy is typically considered as a form of natural capital that acts as an intermediary in the production process, suggesting that it can be substituted for by other forms of capital, labor, or its usage rate changed through technological development (Ockwell 2008; Stern and Cleveland 2004).

For a goal of increasing profits, all else held constant, there is an incentive to find the cheapest means to perform the work necessary to create and sell goods and services.

If an energy resource becomes too costly, a cheaper resource will be substituted for it; if there are none available, technological innovation will be sought to increase efficiency by obtaining more output for the same amount of energy usage. Human labor was the most plentiful—and only—resource for thousands of years. The use of draft animals and tools such as the plow were then substituted for human labor in agricultural production. Water, wind, and wood were also employed. Wood, for example, fueled growth from the time fire was used to burn wood for cooking, heating, and light over 50,000 years ago. The use of steam engines and then the combustion of coal in furnaces became primary energy resources for early industrializing countries in the eighteenth and nineteenth centuries CE due to their high energy content, relative abundance, and reduced (visible) air pollution. In the twentieth century oil began to replace coal for the same reasons that coal replaced wood; oil produced the most for the least cost (Smil 1994, 2008a)

In much of neoclassical economics, energy is a non-limiting factor as substitutes or technological change will occur to meet any constraints (Foster et al. 2010; Stern 2003:10-12). Given the assumptions of available substitutes and limitless technological change that is common in mainstream economics, then, growth has no limits. This is not dissimilar to the model proposed by Boserup (1965) but of utmost concern to Malthus (2003), of course. But given current technology, many energy resources are finite and even renewable resources are exhaustable. These are limits to growth that are not considered as such by traditional economics.

In contrast, ecological economics treats energy as a non-reproducible input (Stern and Cleveland 2004). The economy is also considered an open system as part of the larger environment in which it exists in ecological economics—in contrast to its treatment as closed in traditional economics. By thinking of the economy in this way, the laws of thermodynamics are (re)introduced. The first and second laws of thermodynamics tell us that economic growth can only continue with continual inputs of energy. The transformation of energy produces heat and other waste products that must be dealt with for the environment to survive. Yet this outflow of the production process to the environment is often not part of the traditional economic model or is treated as external to the costs of production if it is. And we have yet to find substitutes for many of the benefits of the natural world. Moreover, energy is not completely substitutable at our current level of technology; machines, animals, and humans all consume energy and remain necessary in production of goods and services in all economies.

As we enter, or continue in, the peak-oil era in which oil consumption outpaces supply (Deffeyes 2001), or the possibility of "peak everything" where all resources are under stress (Heinberg 2007), it is imperative that we adequately assess the costs and benefits of our energy use. Indeed, Nobel Prize-winning chemist Paul Crutzen (2002) argues that we are now in a new Epoch, having left the Holocene due to human-causes environmental changes. Yet intersocietal competition for resources and differences in demands and needs for energy for development have thus far led to little progressive movement toward solutions (Roberts and Parks 2007). This has led to a "world impasse" in which ecological constraints are preventing future U.S.-style development trajectories (Taylor 1996).

These issues inform the remainder of the manuscript. The literature covered here begins to reveal the essential contribution that energy makes to fundamental natural and social processes. The next chapter builds a general theory from the relationships that have been discussed, and the chapters following reveal empirical analyses designed to test hypotheses suggested by the literature and theory. Energy and ecological sustainability, one of the most serious challenges we face in the years ahead, are the foci of the final two chapters.

Chapter 2

Toward a Theory of Ecological Rent: Energy, Power, and Environmental Degradation in the Evolution of World-Systems

2.1 INTRODUCTION

In this chapter, a general theory of energy, power, and environmental degradation in world-systems evolution is developed and discussed. Covered in two parts, the theory then acts as the frame for the work that follows. In section 2.2, I develop a more general theory of intersocietal energy-environment dynamics through the concept of ecological rent, which is defined as the real and/or perceived value generated from the quality of the environment. This concept is the outcome of a process in which intersocietal power is leveraged to degrade distant environments in support of local production and consumption, providing the more powerful with both the benefits of resource use and a higher quality environment than their domestic territory would otherwise allow. The theory explains: 1) the *value* of ecological rent as a function of the marginal quality and total quantity of high quality environments, and the perceived need to protect the environment; and, 2) the *ability to extract* ecological rent as a function of intersocietal imbalances of political, military, and/or economic power. This provides a much-needed formal theoretical explanation for the phenomenon of power, resource use, and unequal ecological exchange. In section 2.3, I discuss a model of the basic energy-related processes that are the specific subject of this dissertation. This model portrays power as a function of energy control and transformation, and the levels of technology and ecological degradation. As in the more general model, the level of ecological concern and availability of resources provide both the constraints and possibilities for the growth in power and sustainability. In Section 2.4., I describe and discuss the hypotheses that emerge from the theory discussed here and from the literature in the prior chapter. The theory and the hypotheses then guide the quantitative research that follows.

2.2 TOWARD A THEORY OF ECOLOGICAL RENT[4]

There is a growing body of research that considers the ecological impact of human social evolution. This includes historical studies that uncover the recurring pattern of resource depletion and environmental pollution as human societies expand in size and scale. For example, Chase-Dunn and Hall (1997b) assert that environmental degradation has been endemic to social evolution in world-systems since at least the Mesolithic period twelve thousand years ago, while Chew (2001) finds evidence of the negative ecological effects of human engagement with the non-human world from at least 3,000 B.C.E. (cf. Elvin 2004; McNeill 2000; Moore 2003; Pointing 2007). In the historical present, industrial societies impact the environment at an unprecedented tempo and scale (Foster 1999a; Schnaiberg and Gould 1994).

While some degree of environmental degradation is typically associated with societal dynamics related to variables such as population size and density, level of technology, and consumption level (York, Rosa, and Dietz 2003), a society's depletion of the environment is not necessarily constrained to its geographic boundaries, an idea captured in the calculation of a society's total ecological footprint (Wackernagel and

---

[4] Much of section 2.2 that appears here is rewritten from a paper co-authored with Seth Abrutyn, currently under review at the journal *Social Forces* (Lawrence and Abrutyn 2011).

Rees 1996). Instead, it is possible to expand, shift, or displace the domestic impact of resource extraction, production, consumption, and waste assimilation/disposal. This can result in the relative cleanliness of a society's environment despite its high level of consumption and waste production since the overconsumption is negatively impacting the ecology of other societies. This phenomenon has become known as the Netherlands Fallacy" since the Netherlands can only sustain their high population and consumption rates by importing food, energy, and goods from other countries (Ehrlich and Ehrlich 1990).

Historically, displacement of environmental degradation emerges in three ways: 1) bigger groups segment into smaller units with some of them migrating to virgin or lesser-degraded resource environment—when available (Turner and Maryanski 2009); and/or 2) a relatively equal exchange of resources can take place between societies according to their "comparative advantage," with associated degradation occurring for both exporters according to their unique geography and cost structure (cf. Ricardo [1817] 1951); and, 3) if there is an unequal distribution of power between societies the more powerful societies can exploit the resources and degrade the environment of the less powerful, thus limiting local degradation. Degrading other's environment can occur directly by force in a process deemed ecological imperialism (Crosby 1986; Foster, Clark, and York 2010) or less directly through unequal ecological exchange (cf. Bunker 1984; Bunker and Ciccantell 2005; Hornborg 2001; Jorgenson, Austin, and Dick 2009; Rice 2007a, 2007b).

While each of these processes are important in their own right and have received attention from scholars, they lack a formal general theory explaining the underlying societal and intersocietal dynamics. This section provides the framework for such a theory, building up through a synthesis of work in classical political economy, sociological theory, and environmental sociology.

Rent, as defined in classical political economy, is the amount of money (or goods/services) paid to the owner for the use of land. It is my contention that there exists an *ecological* rent markedly different from the meanings attributed to *economic* rent by classical political economy. Ecological rent, in contrast to the economic calculation, considers the real or perceived value from the environment—that is, issues of health and well-being that are related to a more global conceptualization of 'standard of living'. Ecological rent, then, provides a means of calculating a sustainable rent instead of one based on monetary profit. Moreover, like Fredric Lane's (1979) concept of protection rent, ecological rent is not just generated between, and extracted from, individuals or organizations; it also occurs at the intersocietal level.

Ecological Rent: Profiting from Displaced Degradation

In his canonical treatment, David Ricardo ([1817] 1951: 67) considered *rent* to be: the "portion of the produce of the earth, which is paid to the landlord for the use of the original and indestructible powers of the soil." Rent is derived from the use of the natural environment and is a transfer from the user to the owner; and, rent is possible only because of differences in the quality or limitations in the quantity of the resource, otherwise the supply and demand function would not operate:

> If all land had the same properties, if it were unlimited in quantity, and uniform in quality, no charge could be made for its use, unless where it possessed peculiar advantages of situation. It is only, then, because land is not unlimited in quantity and uniform in quality, and because in the progress of population, land of an inferior quality, or less advantageously situated, is called into cultivation, that rent is ever paid for the use of it. When in the progress of society, land of the second degree of fertility is taken into cultivation, rent immediately commences on that of the first quality, and the amount of that rent will depend on the difference in the quality of these two portions of land. (Ricardo [1817] 1951:70)

For Ricardo it is not just the size of the plot that determines its value, the productiveness also matters: the greater is the demand for foods and other goods that can be extracted from the land, the higher is the value of the land.

While Ricardo was speaking about agricultural—productivity being the qualitative determinant of value—his understanding of rent as reflecting the marginal difference between lands of different qualities is a key insight for the development of our concept, ecological rent. This is because land, or more generally the natural environment, has increasingly become valued for its quality in many non-monetary senses. While the valuation of the environment for non-economic purposes has been taking place for centuries (Grove 1995), the value of high-quality environments increases as their availability declines.

While Ricardo and other economists often consider land a free gift that is indestructible, we know degradation of land is possible and, in fact, typical. All societies degrade their environments to some degree, despite the narrative of the "noble savage" (Hames 2007; Krech III 1999). As the environment becomes degraded from resource extraction and the production of waste from resource use, the quality of the land will continually decrease in the absence of innovations for sustainability (Chase-Dunn and

Hall 1997b). Air and water can suffer as well; and, it has become clear over the last half century the scale of degradation can reach an entire ecosystem and the biosphere (Brown 2010; Lovelock 2006).

Minimizing the costs of environmental degradation and maximizing the benefits of its protection are thus a source of value. From a practical standpoint, sustainable use of natural resources and the creation of sanitary and pollution-free living environments prolong people's lives and raise their standards of living. And the greater the importance of environmental protection of these and other reasons previously mentioned, the greater is its perceived value. Additionally, as the quantity of higher quality environments diminishes due to population expansion, resource use, and waste production, the value of environmental protection also increases.

I define *ecological rent* as *the real and/or perceived value generated from the quality of the environment*. The amount of value is a function of the supply and demand of environmental quality, with the quality calculated by objective measures such as an environment that provides for the physical health of its inhabitants and subjective measures such as a the perceived importance of unaltered landscapes. A basic equation for the value of ecological rent takes the following form:

$$ER = MQE(1/TQE)EP$$

> where ER is the value of ecological rent, MQE is marginal quality of the environment under consideration, TQE is the total quantity of high quality environments available, and EP is the perceived need for environmental protection for the society under question.

The equation depicts the input of both quantity and quality of environment in ecological rent, as well as the level of the perceived need for environmental protection. An environment of higher quality than others available, that is to say the marginal difference in environmental quality, will generate a certain amount of rent. This amount of ecological rent will increase as the quantity of high quality environments decreases. This product is multiplied by the perceived importance of a high quality environment. The equation therefore considers both the supply of and demand for environmental quality, creating not just a quantity of ecological rent but a valuation for that quantity.

Since ecological rent is possible due to the importance placed on environmental quality and the diminishing supply of higher quality environments, rent seeking by interested individuals, organizations, and nation-states often occurs. Given space considerations and the substantive issue of concern in this paper, I will focus on rent-seeking at the macro, or intersocietal level. At that level, ecological rent is both cause and consequence of stratification between powerful societies, or parts of societies, and those dependent on, colonized by, or otherwise subordinate to them. The mechanism through which this works is displacement of ecological degradation, or what is more commonly known as unequal ecological exchange. Essentially, the more powerful actor can protect its environment by degrading the environment of the less powerful actor, thus displacing the costs of its environmental use by using its power to keep the location of the sources of its consumption and the assimilation of its wastes outside of its borders.

The idea of displaced ecological depletion was traced back to Marx by John Bellamy Foster (1999b) through the concept of the “metabolic rift” (see also Foster et al.

2010; Moore 2000). The rift occurred between the towns and their rural counterparts, as towns extracted rural resources while soil degradation hastened the country side's decline by destroying the quality of the local environment. The towns were capturing ecological rent.

Fossil fuel extraction, processing, and use provide a more modern illustration of the major components of ecological rent. Clearly, major oil exporters such as Saudi Arabia are able to profit from the production and sale of oil, exchanging resources for money—which is how Adam Smith tended to think of rent in contrast to Ricardo (Smith [1776] 1986:Chp.11). Yet Saudi Arabia pollutes their environment during the production for export, which lowers their ecological rent. Conversely, oil importers such as Japan and the United States are able to maintain higher quality environments, capturing ecological rent by displacing that portion of environmental degradation associated with their resource use in the oil exporting countries. And as more and more environments—or better, ecosystems—become degraded, the value of the higher quality environments increases; people with the ability to choose where to live will likely choose the higher quality environment, as preferences for environmental protection are reflected in environmental attitude polls (Dunlap 2006) and indicators such as clean air are used in popular rankings of the best places to live (e.g., CNNMoney 2010). Put another way, as demand exceeds supply, environmental protection becomes increasingly valued. Moreover, a happier, healthier, and therefore more productive populace is certainly attractive to the state as its tax base increases and political unrest over environmental problems decreases, which feeds back on ecological rent—e.g., economic prosperity is positively correlated with environmental concern (Franzen and Meyer 2010).

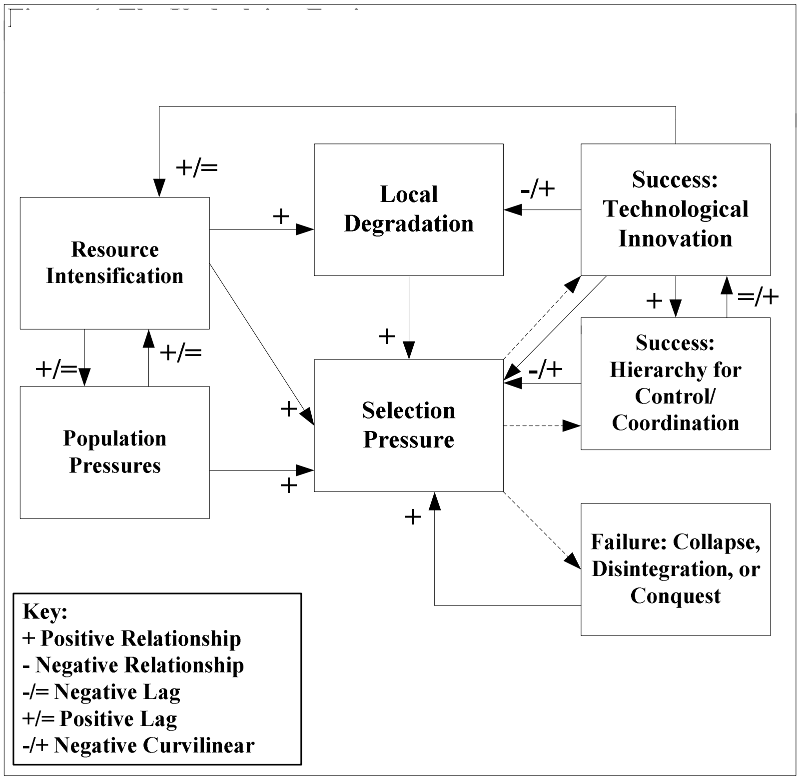
In the absence of domestic sustainable production, consumption, and waste assimilation, the possibility of a relatively clean local environment becomes realized only when those processes are located beyond the group's boundaries. Hence, more powerful societies externalize the costs of environmental harm to the less powerful while the benefits of resource use are exploited by the former. Empirical evidence supports these assertions. For instance, Jorgenson and Burns (2007) found that states with large ecological footprints—an estimation of the amount of productive land necessary to support the consumption and waste level of a population—also tend to have relatively lower levels of local ecological degradation than those with smaller footprints. Similarly, less-developed primary sector exporters tend to deforest faster and consume less than their more-developed importing counterparts, sacrificing development while simultaneously suffering a disproportionate share of environmental ills (Jorgenson et al. 2009).

A general theory must be able to account for ecological degradation regardless of time or place. This is a challenging task, as it is clear that the size and scale of degradation as well as the means to degrade the environment have radically grown over the last 200 years. Nevertheless, relatively dense conglomerations of people always produce waste and, at varying tempos, degrade their environments (Chase-Dunn and Hall 1997b). Thus, the theory below will employ an evolutionary framework because the decision to extract ecological rent from others is tightly tied to selection pressures generated by some basic macro-level exigencies. The variables and their valences will have to be adjusted when measuring empirical cases, but the processes remain the same.

The Engine of Change

In Figure 2.1 below, the dynamics underlying the emergence of ecological rent are presented. Building on Chase-Dunn and Hall's (1997a) interation model and Turner's (1995) conceptualization of societal selection pressures, at the heart of the process are two very important engines of change: population pressures and resource intensification. Essentially, degradation is a function of increases in group size and the concomitant intensification of productive capacities.

Figure 2.1 Ecological Rent, the Underlying Engine



Population Pressures and Intensification. Population pressures pose a ubiquitous problem for groups of all sizes (Turner and Maryanski 2009; Johnson and Earle 2000). Sometimes these pressures are obvious, though most of the time they are manifested indirectly. To be sure, carrying capacity, or the environmental limits imposed on population size, varies tremendously; and, as Mark Cohen (1977) has noted, the actual capacity is rarely reached before groups begin to trouble-shoot. Closely connected to population pressure is the intensification of resource production. More food, clothing, status, ideas, power, and other resources must be produced to meet the growing needs and demands of larger populations. The process often begins gradually. Where geographic mobility is limited by either natural barriers such as oceans or mountains, military barriers like hostile neighbors, or social barriers like ethnic, religious, or kin-based anchorage, the process will accelerate (Carneiro 1970).

Ecological Degradation. As resource intensification occurs, the environment is degraded. Extraction of natural resources, exhaustion of animal and vegetable supplies, and the production of waste all reduces the quality of the environment. Again, the scale of degradation depends upon the types of technologies available for productivity, the size and density of the population, the consumption level, and the degree to which a group exports its degradation. Yet all peoples, whether simple hunter-gatherers or complex post-industrial nations, eventually exhaust many of their local resources; in smaller societies, degradation is often one factor in the decision to migrate, segment into smaller groups, or invent new kinship organizational patterns—including a centralized, redistributive economy. However, in cases where groups are circumscribed by natural barriers—e.g., mountains or oceans) or social barriers—e.g., agricultural practices tie people to their land and walls and other city defenses coupled with external threats often limits mobility, degradation can become a pressure on par with or greater in magnitude than population pressures (Carneiro 1970). Either way, degradation accelerates the entire feedback loop as it challenges groups to innovate technologically and/or organizationally.

Selection Pressures. Selection pressures are pressures that must be met for a society to be sustainable. They are pressures that select *for* adaptive changes (Turner and Maryanski 2009). It is an empirical question whether or not individuals and/or groups (a) perceive a pressure at all, (b) can accurately identify the source of the pressure, (c) have the means to resolve the pressure, and (d) the solution is short- or long-term. The model assumes that as the feedback loop accelerates and degradation intensifies, the probability of failure, and, consequently, the chances of collapse, disintegration, or conquest, increases (Tainter 1988; Diamond 2005). Hence, poor decisions making, lack of information or understanding of the problem, structural conditions such as power-relations, and lack of perception may all hinder successful adaptation.

Successful Adaptation. Ecological degradation, more so than many other exigencies, amplifies the problems associated with potential failure because biotic systems are tenuously balanced and humans have a disproportionate ability at unbalancing them. Moreover, humans often think and act with short-term goals in mind and the pursuit of long-term goals often produces unintended and unanticipated consequences. As populations grow in size and density, resource bases are taxed, and local environments are degraded, selection pressures for adaptive responses increase.

Adaptive responses are quite varied because of ecological and environmental constraints, yet two generic responses can be delineated: organizational and technological.

Organizational responses involve the emergence and coordination of divisions of labor (Abrutyn and Turner Forthcoming). Eventually, with larger populations and intensified resource production hierarchies appear. The centralization of power helps manage risk as a chief or big man redistributes food or other important resources (Earle 2002). Later, the emergence of temple- and then palace-economies further facilitated the coordination of massive divisions of labor, the construction of complex public works—e.g., canals or irrigation systems, and the centralization of risk in trade and resource management (Lipinski 1979). However, problems stem from the conflict between individual and collective goals: it is easy for a ruler or the ruling elite to intensify resource production for their own benefit, even at the cost of degrading the environment quicker. Of course, the degradation of the environment may simply be the result of the unintended consequences of decision-making.

Closely linked to organizational responses are technological responses. Technology is more than just tools: the knowledge necessary to use natural and human-made resources and instruments is more important than the tools themselves. To be sure, the plow is a vital tool meant to expand the amount of food produced, but the tool itself means nothing without the knowledge of how to use, build, and improve it, as well as what it means to the group using it. A reciprocal relationship exists between technological and organizational innovation: Greater technological innovation often drives hierarchalization as problems of coordination and control grow in magnitude, while a ruling elite often drives technological change to enlarge their resource base. It is worth noting, however, that technologies become lost, group's de-differentiate when, for instance, a disease reduces population size, and the "values" of both variables can decline.

Thresholds and Bifurcation. In the theory of polity formation I previously published with Seth Abrutyn, we considered the application of complexity theory to shifts in the evolution of complexity in forms of political organizational (Abutyn and Lawrence 2010). In this theory, selection pressures created by challenges such as population increases, particularly when combined with circumscription (Carneiro 1970), environmental degradation, and others can create selection pressures for innovation. Under the right conditions and after social forces have crossed thresholds, entirely new social structures and organizational patterns can be created. Treating selection pressures as analogous to physical changes from increases in energy flow, such as when water is boiled, we predicted that the changes in polity forms could be non-linear, such as when water changes to steam at a certain point. This phenomenon is commonly called a “phase-transition” in complexity theory (cf. Prigogine and Stengers 1984; Prigogine 1997).

The Basic Engine. In conclusion the engine driving the eventual extraction of ecological rent begins with a generic feedback loop. Populations and resource levels are locked in an eternal struggle, with populations more often than not outstripping their resources. Humans are endowed with big brains and the societies which have survived have dealt found (temporary) solutions to the exigencies discussed above. While producing more allows a group to survive, it also allows the group to grow larger and has the unintended consequence of accelerating the level of local ecological degradation as humans process more natural resources at a quicker pace. All three of these forces, in varying valences calculable only through empirical case study, create selection pressures. While Herbert Spencer (1865) surely exaggerated the point that humanity was always on the precipice of doom, the feedback loop does increase the propensity for and the magnitude of failure.

Considering the fact that humans are still alive and have been successful as a species, some solutions have been invented that prevent total extinction and, in fact, have demonstrated the resilience of human societies, allowing them to not only survive but to grow beyond size and scales previously unimaginable (McAnany and Yoffee 2010). The most important for our discussion are technological innovation and hierarchalization of power structures. Both of these solutions do not necessarily slow the feedback loop down, but rather resolve immediate problems. Some innovations resolve one of the problems of the equation, such as resource scarcity, while exacerbating other variables in the equation such as ecological degradation. The "best" solution would be one which allows populations to grow, production to meet the needs of a population, and degradation to be reduced or made negligible. This "best" solution, though, can only be realized through either the sustainable use of one’s of resources or the degradation of some other group's environment such that the more dominant group can satisfy its needs and reap the benefits of intensification, while minimizing the effects on the quality of the local environment.

Social Structure: The Political Economy of Ecological Rent

Turning to the macro-structural dimensions driven by the feedback loop posited above, below I discuss the links from the feedback loop to the growth of political economy, power-dependency, and eventually, ecological rent.

Power. That hierarchy formation is a solution to various problems in the feedback loop alludes to the growth of a polity. Eventually, an autonomous polity that grows more and more spatially, temporally, and symbolically distinct from other spheres of social action such as kinship (Abrutyn 2009) appears replete with political actors pursuing increasingly discrete political goals and making political decisions (Eisenstadt 1963). Polities deal in power; power, as defined by Weber (1978) is the probability that a group or individuals commands will be obeyed, even in the face of resistance. Michael Mann (1986) delineates four important types of power: administrative, military, economic, and ideological; different types of power intersect in ways that make each polity in time and space unique in many regards. And while the base of authority in all state-like polities is military or coercive force, stable polities rely on all four types of power, even if the actual valences of any one type is historically contingent.

The actual level of natural resources available in a given environment will have important ramifications for power. Simply put, the greater the level of resources available, the greater the potential for the emergence of a polity and the expansion of its power and influence. The basic logic of this assertion is as follows. As the feedback loop intensifies, the types of technologies, the extraction of resources, and the pressure for vertical differentiation grow as well. The more resources available and the greater the complexity with which they are extracted, produced, and distributed, the more potential functions are available for political actors to assume control over. Typical roles of the polity include: management of resources, coordination of public works meant to produce or distribute resources, facilitation of long-distance trade networks as well as the creation and maintenance of prestige markets, centralized storage, protection of resources from external threats, maintenance of relationship between community and the supranatural in order to ensure material prosperity and/or avoid detriment (i.e., drought), and the resolution of conflict between social strata (Adams 1966; Yoffee 2005). Thus, the more resource rich the environment the more likely political structures will differentiate from other social structures to deal with the various problems associated with resources, production, and distribution. And due to the possibility of thresholds occurring due to a buildup of selection pressures, it is expected that bifurcation points can be reached where non-linear increases in the power of a society will occur.

Power-Dependency. Emerson (1962) and Blau (1964) both argued power is a function of imbalanced relationships between two individuals or two groups. Being resource rich, for example, produces leverage in relationships with those who desire your goods or services, but have little of equal value in return. A bargain is struck: in exchange for desired goods, the weaker partner "willingly" subordinates themselves and exchanges power.

With increasing levels of political, military, economic, and/or ideological power comes an increase in both the *means* to create power-dependent relationships—both within and between societies—and the *motivation* to do so. As ambitions grow faster than a given populous can reasonably support, rulers or the elite turn their attention outwards to potential sources of wealth or power, and the prestige that comes with successful domination. The variable "motivation" is added to create power-dependency because it is not obvious that people in power simply create the means to conquer or ensnare outsiders. Rather, the means are created as *reasons* to exploit neighbors grow. One reason comes from the level of natural resources: as the level of resources declines, the motivation to create power-dependent external relationships should increase. Indeed, the attempted subjugation of resource rich neighbors by resource poor "marcher" states (Collins 1981) or semi-peripheral groups (Chase-Dunn and Hall 1997a) is a fairly typical recurrence in history.

As power and the motivation to generate the means of power-dependency increases the search and successful creation of even greater means to secure and maintain power-dependent relationships expands a group's base of power. That is, war-like societies proudly display their weaponry, man-advantage, and military brilliance as a way of increasing and reinforcing their symbolic power internally; similarly, societies that claim to be the center of religious or other ideological power, always make sure to erect public works and hold massive ceremonies to reinforce these claims; as the networks of these four bases of power intersect in greater magnitude, the more they begin to support each other (Mann 1986).

The logic of power-dependency is implicit in much of the dependency and world-systems theoretical framework. Indeed, one of the most popular measures of world-system position was developed by Snyder and Kick (1979) to include membership in

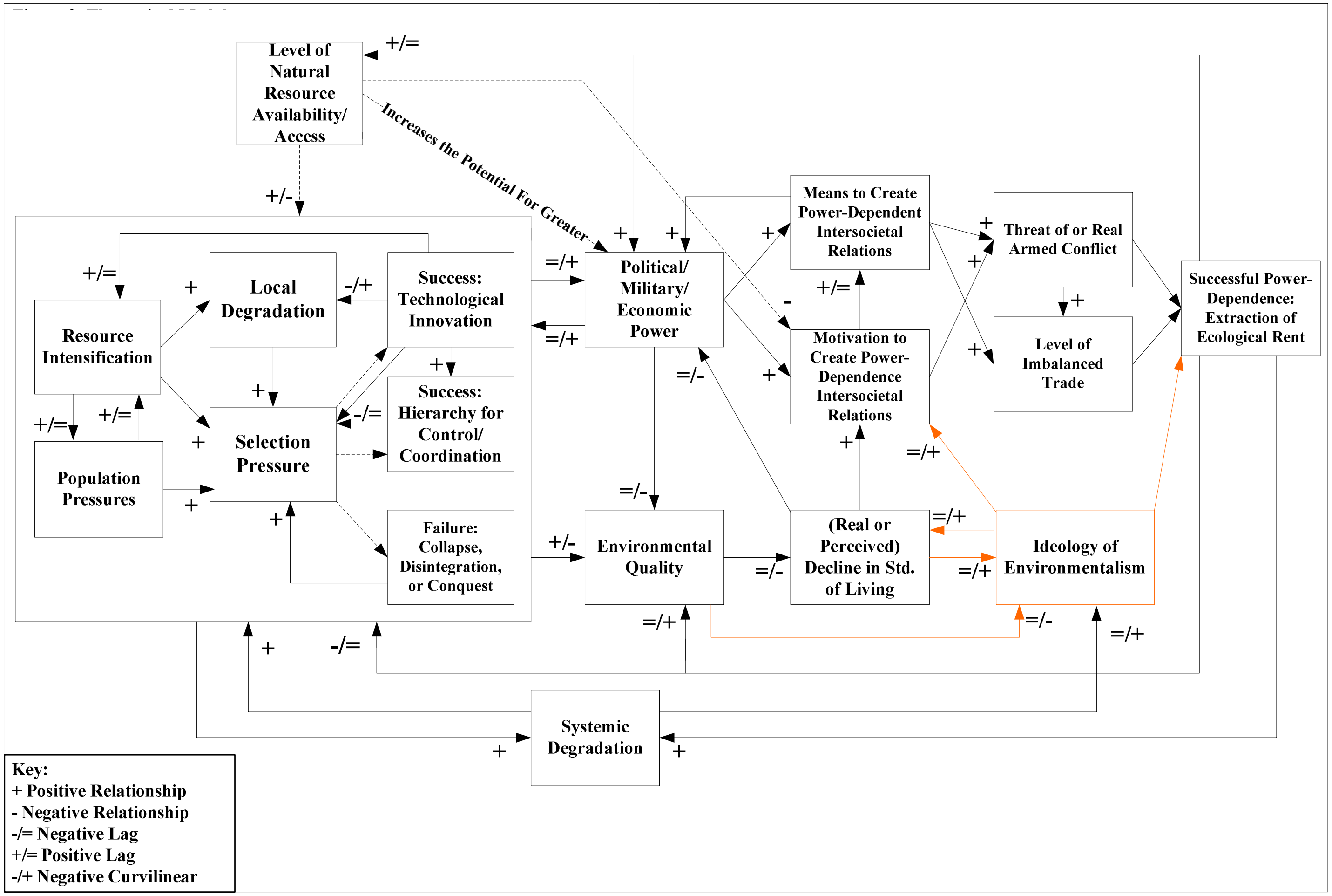
INGO’s, embassy locations, and trade. This has been updated by Kick, McKinney, McDonald, and Jorgenson (2011) to include arms transfers. The underlying argument is that countries at the center, or nodes, of international geopolitical and economic power networks are in the core of the world-system, while those in dependent positions are in the periphery or semiperiphery.

The Means of Extracting Rent. World-Systems analysts have studied the effects of imbalanced power and trade in the modern world economic system (Chase-Dunn 1998; Wallerstein 1974). Core nations, or those in the most dominant trade positions (Frank 2007), extract natural resources and obtain cheap labor and other benefits with greater ease than peripheral nations (e.g., much of Central and South America, Africa), while the latter provide the former with these valuable items. Indeed, Eduardo Galeano (1997) describes what he considers as five centuries of unequal exchange of resources and bodies from Latin America to the Dutch, British, and the United States, among others (see also Bunker 1985, 2005; Emmanuel 1972; Moore 2010; Tucker 2000).

Ecological Rent. Specific to the argument and this model, I propose that *as the motivation to create power-dependence increases because of resource depletion, environmental degradation, and/or environmentalist ideological pressures, the means to create power-dependency and, subsequently, power-dependent intersocietal relations generate greater potential for and the likelihood of acquiring ecological rent*. On the one hand, it is in the interests of the political and economic elite of a dominant group to exploit the environment of weaker groups, if only because it is cheaper. For example, Nina Eisenmenger and Stefan Giljum (2007) use material flow accounts to demonstrate that unequal trade benefits developed countries through their importation of goods produced through ecologically harmful methods in undeveloped countries. Further, they find that while the undeveloped countries experience the negative ecological effects of extraction, they receive little benefit from their exportation of the goods due to their relatively low-value. With this displaced degradation, ecological rent is generated for the more powerful states. Alongside the fact that the periphery provides natural resources and cheap labor, core nation-states as well as multinational corporations use economic power to leverage environmental laws in their favor (Woods 2006; see also Konisky 2008).

On the other hand, pressures from below in the form of environmentalism and the perception of declining standards of living become factors motivating political elite to exploit the environments of weaker nations, if only to sustain the legitimate right to rule and reduce grievances and protests. Humans prefer, when possible, to not soil their living spaces. Many strata appreciate unspoiled land—whether for hunting, outdoors activities, or simply for aesthetics. Moreover, mental, physical, and socio-emotional health are affected by the state of the environment. The desire to maintain a high quality local environment can generate movements which put pressure on the political economy. The full model follows in Figure 2.2 here.

Figure 2.2 Ecological Rent, the Full Model



Material and Social Psychological Forces

Figure 2.2 presents an expanded theoretical model by adding the processes discussed in the last section and four new variables to the model: *Environmental Quality*, (*Real or Perceived*) *Decline in Standards of Living*, *Ideology of Environmentalism*, and *Systemic Degradation*. For now, we will look at the ways in which the feedback loop may trigger the first three mechanisms which affect the political economy in ways that either amplify the search for ecological rent or may dampen it to some extent. Of course, the arrows do not always go in one direction—from the masses or segments of the population to the political economy—as they also flow from the top to the bottom as the ruling elite attempt to shape the ideas of the masses. The last variable—the *ideology of environmentalism*—will have to be explored in depth because this is not simply an ideology that segments of some populations come to hold and use to pressure the elite, it can become an ideological force effecting peripheral and semi-peripheral nations in ways that coerce environmentalist practices in exchange for legitimation in the world polity (Frank, Hironaka, and Schofer 2000). The effects of this imposed ideology when combined with the need and desire for resources without the associated ecological degradation, plus the growing realization that degradation cannot be easily contained in a specific location after all produces some tensions and potential problems for future research and humanity.

Environmental Quality. Environmental quality means the health of the bio- and geospheres; i.e., the air, water, and land, the flora and fauna and all other denizens. There are numerous measures of environmental quality that could be used to operationalize this concept. For example, the United Nations (2008) reports on a number of indicators under its Millennium Development Goal #7: “Ensure Environmental Sustainability,” including variables such as forest cover, fish stocks, total water and safe water use, and species protected and threatened (see also the U.N. Environment Programme). The World Resources Institute’s (2007) Earth Trends database also provides a wealth of information on a number of indicators. Another measure, the Biosphere Quality Index, suggests a number of variables such as population growth and resource consumption that can be used to create an index of ecological health at a global level (Trevors, Kevan, and Saier 2006).

It is proposed that as the primary feedback loop intensifies environmental quality will initially improve as food seems more abundant and the land more productive. Eventually, however, environmental quality will decline as intensification accelerates degradation, eroding either the entire local ecology or some aspects of the local ecology. Further exacerbating environmental quality is the level of power held by the ruling elite. At first, there is a lag or negligible effect coming from the powerful, but, as the power elite's capabilities and interest in harnessing the environment and its resources grow parallel with their ambitions and improving mechanisms of domination, degradation is likely to speed up as more and more resources are appropriated and the environment will increasingly suffer. Self-aggrandizement, the creation of public works such as irrigation and canals, and the coordination of a division of labor meant to intensify production to support a larger population all raise the values of every variable within the feedback loop and increase the likelihood that environmental quality will decline.

The Problem of Relative Deprivation. Anthropologist Marvin Harris (1979) argued that most people are motivated to act when they perceive their standard of living is in decline. The key to this particular variable is its roots in perception and not necessarily reality. One could, for example, measure standard of living by a whole host of empirical measures, such as those mentioned above, yet find people are subjectively satisfied and unaware; the inverse is just as plausible. The point is that as environmental quality declines, there should be an increase in the perception—and often times the reality—of a declining standard of living among some people in the population. Theoretically speaking, each society has a threshold by which we can say a *significant proportion* of the population experiences a decline; significant implying both a literal number of people as well as the proportion large enough to generate problems for the ruling elite, if only pressures and not real rebellion or resistance.

Notice in the bottom of Figure 2.2, the relationships with which a decline in the real or perceived standard of living effects. First, it has a lag effect that eventually erodes the legitimacy and power of the ruling elite. Each society's "significant proportion" is relative to its population size and density, and other related factors such as the amount of power and resources available to the elite or the proportion of people who make up the elite or are strongly beholden to them—e.g., the upper-middle class. The second relationship is a positive and direct one with motivation for power-dependency. Keep in mind that motivation refers to the elite's motivation to seek imbalanced relations externally, and not motivation on the part of the population whose standard of living is in decline. The motivation often plays out, where feasible, in fascinating ways. Take, for example, the gradual and then rapid move west in the U.S. during the nineteenth century. The desire to have land, 'make one's way in the world', and escape the trappings of urban society produced more than enough motivation for settlers to move repeatedly west in American history. Every move antagonized the native Americans, who would often attempt to make life miserable for the settlers. These problems often created vexing issues for both presidents and congress: on the one hand, it was not clear that they always wanted to intervene and attack the native Americans; on the other hand, elections, ambition, and a belief in Manifest Destiny generated strong motivations to side with the white population vis-à-vis the native population, muster up armed forces and/or create unfair (and unobserved) contracts, and gradually push the native Americans to the brink of extinction. Undoubtedly, the pressure to act was just as likely to emerge from below as it was to come from political ambition and expediency.

The final relationship is represented by a dotted line because it is a relationship likely to have emerged rather recently. That is, the ideology of environmentalism—in an organized form—has until relatively recently been a luxury of only the most dominant and richest polities, or among the most privileged classes within a society. Hence, it is typically evident where there is a strong middle to middle-upper class conservation for beauty and/or recreation has value. To be sure, elites have likely recognized the importance of draining neighbors' resources before tapping too deeply into one's own, but, again, this particular variable refers to environmentalist ideologies percolating among the masses and impacting the structural dimensions of the model. We propose that as people's standards of living decline or are perceived to decline, there is a point where conservation or environmentalist ideologies become pervasive both as a solution to the problem of scarce resources as well as recognition on the part of the moral community as to the importance of the environment to health and happiness, and the virtue of sustainability and/or conservation.

Ideology of Environmentalism. The origins of what could be called a large-scale environmental movement can be traced to the conservation movements in the nineteenth century that followed colonial expansion into resource-laden areas (Grove 1995). This was followed in the early-twentieth century by preservation and conservation movements that sprouted throughout much of the world—both in rich and poor countries and among the upper and lower strata—and continue to grow today (de Steiguer 2006; McNeill 2000). There are two sides to the impact of the perception that protecting the environment is important. First, the side we have already begun examining—the local, social psychological side. The second aspect of environmentalism is a much later dynamic that occurs as more people in more nation-states realize that there is a global ecology beyond one's local conditions. As organizations emerge and polities react to the pressure by creating environmental departments, a global ideology of environmentalism becomes a real force shaping the relationships between nation-states and patterns of legitimacy. Indeed, environmental protection has become a core value of the international regime (Frank 1997; Frank, Hironaka, and Schofer 2000; Schofer and Hironaka 2005). The regime consists of nation-states, international governmental and non-governmental organizations, scientists, and social movements. Hence, legitimate membership in the international community is predicated on a state developing environmental laws and agencies.

The effects of environmental ideologies are quite clear. As environmentalism gains traction and becomes a salient perspective in civil society, the potential for the perception of declining standards of living due to environmental quality should also increase. Not only does this ideology offer people a framework for defining and understanding their local ecology, it makes them more likely to be 'searching' for ecological degradation as well as fight for preventative measures that would restrict industrial/commercial, residential, or other types of growth which would potentially reduce the environmental resources available to them locally. Likewise, the presence and spread of such an ideology would likely produce associations or movements putting pressure on the polity and/or economy to take measures that improve environmental quality while also creating motivation for ecological rent and foreign degradation.

Systemic Degradation. As Figure 2.2 demonstrates, systemic degradation—or, the total amount of degradation across the entire Earth's bio- and geosphere—is accelerated both by the feedback loop and by the pursuit of ecological rent. On the one hand, local degradation can have regional and global effects. Air pollution in Los Angeles affects neighboring cities to the east and climate change is a global concern. Thus, systemic degradation has a feedback effect on the engine driving the whole model: as the entire system degrades, resource scarcity becomes even more pressing and the need to degrade one's local environment as well as others only grows. On the other hand, local and systemic degradation can also contribute to the ideology of environmentalism. The lag effect occurs because transportation/communication technologies and scientific knowledge of the extent and effects of pollution have not kept pace with the ability to degrade the environment. As the totality of the system becomes pervasively known, and the degradation of the system becomes clear to people, the need to conserve it grows salient.

Ultimately, the displacement of degradation creates a paradox: the level of domestic resource consumption can seem sustainable, masking the impact on the environment in the system as a whole, and thus providing little incentive for truly sustainable living. This is not a new phenomenon in human social evolution as environmental degradation has been occurring for millennia. What is different, however, is the amount of resource use and waste production, currently requiring one and a half Earths to assimilate (Global Footprint Network 2010). There are more people using more resources in a finite biosphere. And the type and degree of degradation have also increased due to technological innovation – chemicals, nuclear, cars, etc. In response, environmental and environmental justice movements have led efforts to protect both the biosphere in local and distant locations—even those that the person making that valuation will never actually visit.

Discussion

The above theory explains the macro-level dynamics applicable to the acquisition of ecological rent in the absence of sustainable use. A society's *perceived need* for ecological rent is a function of its level of environmental quality and the desire of its inhabitants for the protection or improvement of the local and/or distant environments. A society's *ability* to capture ecological rent is a function of its political, military, and economic power, which increases its potential to create power-dependence relationships and thereby degrade the environments of other societies while maintaining or increasing the standard of living of its own. The theory also recognizes that systemic degradation—global environmental problems—will reduce the solutions available to counter local degradation, creating a need for innovation for sustainability or otherwise increasing the likelihood of disintegration and collapse. In short, more powerful societies can use their power to create a relatively clean environment at the expense of less powerful societies, but those options are closing up as the number global environment becomes degraded.

Any discussion of geo-politics, world-systems, or globalization must also contend with the fact that it is not just the traditional resource flows characterizing the power-dependent relationships between core-periphery or dominant-subordinate societies. The location of environmental degradation is equally important, and while it has only recently become a heavily researched area of interest in the social sciences, the extraction of ecological rent has a long history. Thus, the theory of ecological rent herein is informed by interstate imperialism; states have historically oriented their geopolitical strategies toward resource acquisition and, in more recent history, although sometimes only a tertiary goal, to ecological health. States generally seek to maximize resource use and the economic power that accompanies it, while minimizing the degradation of their environments. By doing so, they can acquire ecological rent, *the real and/or perceived value generated from the quality of the environment*. Keeping environmental degradation outside of the state's borders maximizes the value of ecological rent for its populace. Military, political, and economic power are the conduits through which ecological rent is achieved since they are the bases for the domination or subordination states in the world-system.

2.3 ENERGY USE AND INTERSOCIETAL DYNAMICS

Having discussed the general model of ecological rent, I now turn toward a model specific to energy use. Considering systems of interacting societies as analogous to ecosystems, I posit that the development of societies and the dynamics of competition that generates hierarchy and instability in world-systems are fundamentally influenced by energy flows: the capture and transformation of useful energy sources and the processing of waste generated during that process. This process is shaped by the logics of complexity theory and thermodynamics and unequal exchange.

At the most abstract, the theory posits the following: 1) an increase of "local" order, or negentropy, societies experience as power is proportional to their levels of energy capture and transformation; 2) the increases in power may occur in a non-linear fashion as energy thresholds are crossed and bifurcations occur; 3) in closed systems such as our commercial energy supply the amount of energy is essentially fixed,[5] producing scarcity that fosters intersocietal competition and inequality; and, 4) the amount of entropy, or disorder, that will be experienced by societies as diminished levels of power varies inversely proportional to the level of energy capture and transformation.

At the societal-level, then, an increase in the control over energy sources, or an increase in the efficiency of their utilization, will increase the transformation of energy into use-value (for industry, transportation, etc) and/or exchange value (for export). This

---

[5] Technically, human social systems are open systems with respect to energy flows – sunlight continues to enter the system - however, the reliance upon sunlight as an energy source diminishes over the evolution of human societies, becoming a small portion of energy flows by the modern world-system. New energy sources and supplies can also be engineered and discovered, expanding the amount of available useful energy.

transformation can lead an increase in geopolitical and economic power, which is a measurable form of order/negentropy from thermodynamics. And as the level of geopolitical and economic power increases, so does the ability a society has to further increase its power in its world-system. Likewise, lower levels of energy control and transformation will likely result in lower levels of power; i.e., less order. Moreover, energy-fuelled power creates ecological degradation, another indicator of entropy/disorder, but due to the ability to utilize power to relocate the negative effects of the degradation, societies with more power can capture ecological rent, while societies with less power suffer the worst effects of energy use.

Definitions

Power: defined from Weber (1978: 926) as the ability for a society to achieve its will, even against the resistance of others. In world-systems, this occurs through both economic and political-military strength.

Useful Energy: a resource that can perform work, and that is economically and technologically available.

Energy Control: the ability to readily access useful energy sources through production, current stocks, and imports.

Energy Transformation: the consumption, barter, and/or and sale of useful energy sources.

Environmental Degradation: a reduction in the sustainability of the biosphere (including air, water, soil, species). The burning of fossil fuels contributes to global warming, primarily from the emissions of carbon dioxide. The clearing and burning of forests for the production of fuel sources such as corn and sugar cane (as ethanol) are also components, as is the burning of wood for fuel.

Formulas

In my theory, Power (P) is a function of the level of Energy Control (EC), the value of Energy Transformation (ET), and the impact of Environmental Degradation (ED). The equation for the relationship between Energy Control, Transformation, and Power takes the following form:

$$P = f\,(EC_{,}\,ET_{,}\,ED)$$

Additionally, the amount of energy available to transform is dependent upon the amount of energy control; i.e., a society must have energy under its control before it can be consumed, used for barter, or sold. This equation takes the following form (no lag between EC and ET):

$$ET_{=}\,f\,(EC)$$

There is also a positive feedback loop from power to energy control and transformation, more power allows for greater energy control and transformation. Energy comes first however, since without energy that can be transformed, power cannot emerge or increase. This relationship is found by Lise and Van Montefort (2005), who, using Granger co-integration analysis on data from Turkey from 1970-2003, find that GDP (2-year lag) predicts energy consumption. They also leave open the possibility that the causal relationship is bi-directional. The formulas are:

$$EC = f\,(P)$$

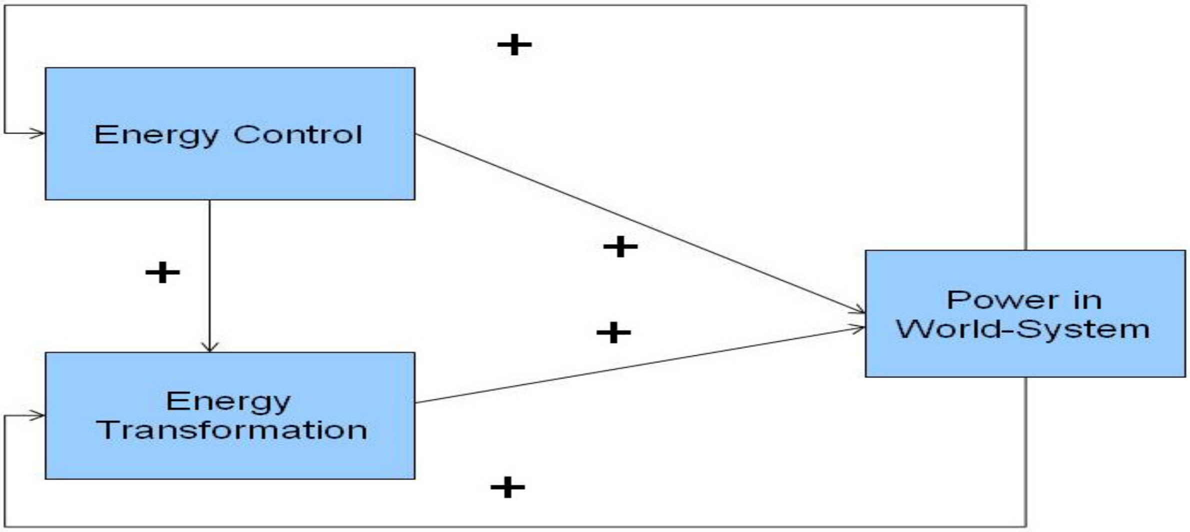
&

$$ET = f\,(P, EC)$$

Additionally, adding the concepts of thresholds and bifurcation from complexity theory as discussed earlier, the growth in power could be a non-linear process at times. When a certain level of energy flow is harnessed, societies may experience phase-transitions, or discrete jumps in their level of power.

The model is visually illustrated in Figure 2.3 below.

Figure 2.3 Power and Energy Control and Transformation in the World-System



The theoretical model also depicts the presence of a negative feedback loop to and from power and environmental degradation. This is because of a process called "unequal ecological exchange" (cf. Jorgenson and Clark 2009; see also Bunker 1985; Roberts and Parks 2007). The argument is that while powerful societies cause more environmental degradation than less powerful, the effects of that degradation are unequally experienced – the benefits accruing to disproportionately to the powerful and the costs disproportionately to the weak. For example, a powerful society that imports ethanol produced in weaker countries receives economy-powering fuel, while the less powerful producers suffer from the soil erosion and loss of refinery pollution associated with deforestation through emissions of pollutants. This is because the former can use their power to "export" the problems of environmental degradation to the latter, or to receive the energy source after it has been extracted and refined by a less powerful society; the negative effects of degradation on power would then remain localized while the positive outcome of transformation such as economic development are transferred to the more powerful society. And sometimes the local sources of degradation are controlled through foreign direct investment (Jorgenson 2007).

The causes and effects of environmental degradation are therefore mismatched. In my theory, the causes of environmental degradation are energy control and energy transformation; e.g., the burning of fossil fuels that produces the global warming gas carbon dioxide. The formula for the cause of environmental degradation (EDc) is:

$$EDc = f\ (ET, EC)$$

The effects of environmental degradation (EDe) reduce the power of a society by, for example, negatively impacting its income, level of development, and social costs for healthcare. There is then a negative feedback loop from the amount of power to the effects of environmental degradation; i.e., more powerful societies can displace the costs of environmental degradation to less powerful societies, the former achieving ecological rent, the latter suffering the negative ecological outcomes. The unequal ecological exchange equations are:

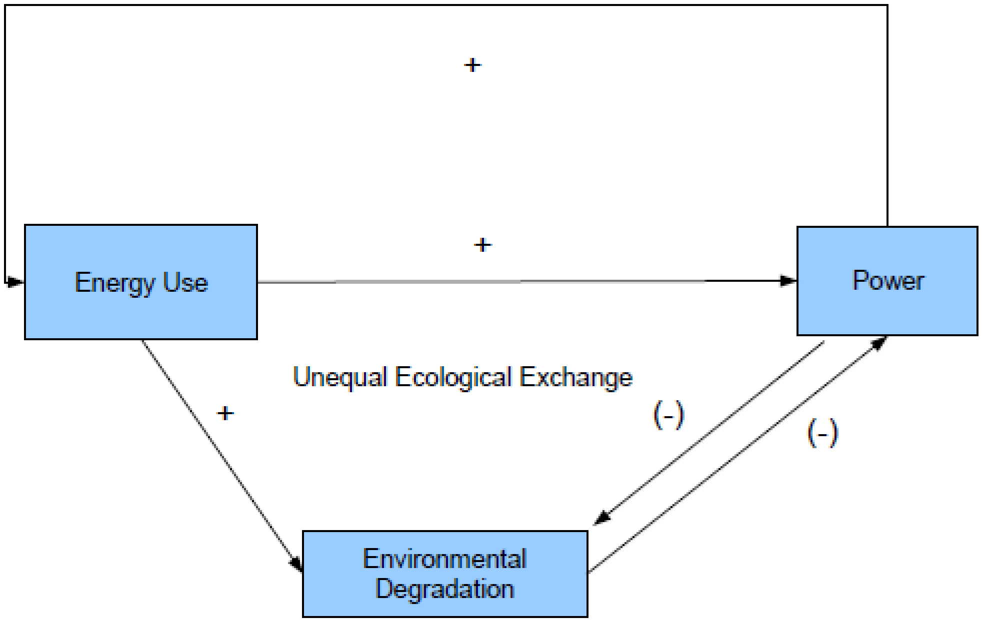
$$P = f(-EDe)$$

&

$$EDe = f(-P)$$

These relationships are illustrated in Figure 2.4 below.

Figure 2.4 Unequal Ecological Exchange and Power



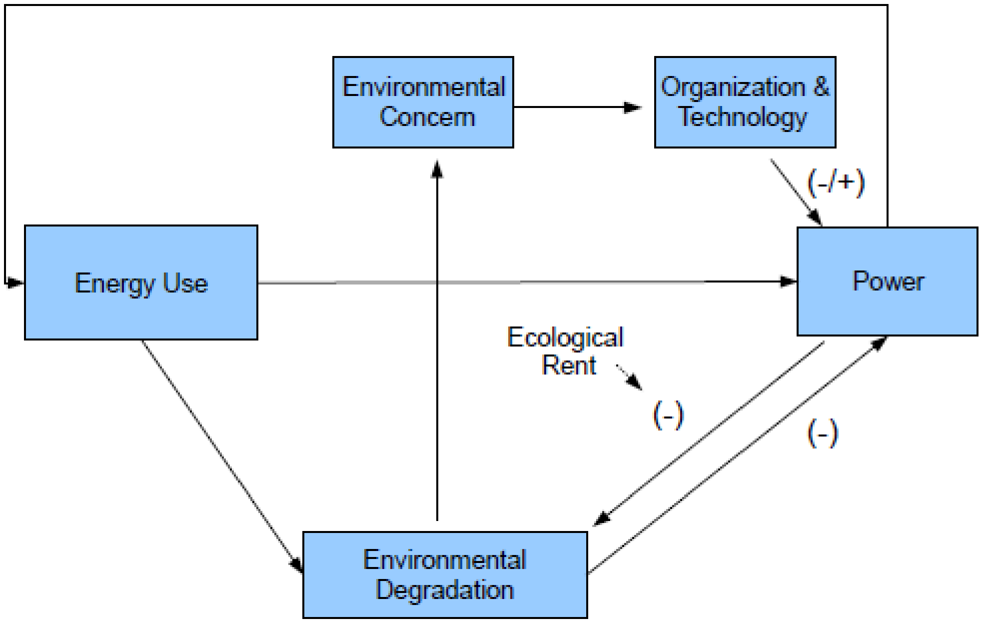
It is important to note the rather complex relationship between energy transformation, environmental degradation, and power. Environmental degradation from energy is dependent on the means of extraction, amount and type of energy transformed, and the technology used. For example, carbon efficiency (GDP/CO_2) or carbon intensity (CO_2/energy) are common measures of energy efficiency that point out that not all uses of energy have the same outcomes. We know from a number of studies indicated earlier that there is an unequal distribution of the sources and effects of environmental degradation. But we also know that countries vary on the mix of their energy sources and in their amount and types of pollution (e.g., carbon dioxide vs. nuclear waste) and that these sometimes do not correlate well with power (the Scandinavian countries are the classic example of relatively clean energy users and ecological modernization suggests that energy use and/or pollution will reduce with wealth and development).

The growth of environmentalism, either as an effect of "modernization," the result of a progressive social movement, or as an instrumental means for survival, can also affect the power-energy relationship. Some societies have the power to control and transform more energy but do not do so. As discussed earlier, the growth of environmentalism contributes to that outcome. Modernization theory suggests the existence of an "environmental Kuznets curve" in which environmental cleanliness will improve after a country reaches a certain level of development (Mol 2001). This has found little support in tests on recent data (York and Rosa 2003), as suggested by the "Lauderdale and Gevons' paradoxes" (Foster and Clark 2009) but is worth testing utilizing data from earlier in time. Similarly, a country's transition from an industrial to service-based economy may lower the amount of energy consumed and the emissions generated, but its GDP may still increase due to the higher-value added from services (cf. Chase-Dunn 1998; Hornborg 2001).

In my model, the impact of environmental degradation has a negative effect on power, while power reduces the effects of environmental degradation. But there is a disconnect between the sources of environmental degradation (such as CO_2) and the measurable effects. This is because the effects are difficult to measure and may not be felt for years, such as for carbon dioxide in the atmosphere and deforestation. Also, it is difficult to assign the source of pollution to a country if the pollution generating activity is being created by a foreign company. A relatively new measure deployed by the World Bank (2010; see Bolt, Matete and Clemens 2002; Hamilton and Clemens 1999), adjusts net income for the costs of environmental degradation, improving upon solely relying upon carbon-dioxide emissions. This measure will be utilized in chapter five.

Taken together, the energy control and power model and the unequal ecological exchange models are illustrated in the full model in Figure 2.5 below.

Figure 2.5 Energy, Power, and Ecological Rent: Simplified Theoretical Model*



* All relationships are positive unless indicated. A negative relationship is indicated by the symbol (-). Both negative and positive relationship, depending on the particular situation is indicated by the symbol (-/+).

In the theoretical model, environmental concern grows as energy-related environmental degradation increases. This creates selection pressures for organizational and technological solutions, which flow through power in a negative way in the search for less energy control and transformation or in a positive way by increasing the motivation to achieve ecological rent by locating the environmental degradation elsewhere.

It is important to note that my theory is not put forth as the only explanation for intersocietal power, nor is it intended to suggest that all societies with the same levels for energy or at the same levels for power would be replicas in other aspects. For example, the Chinese in the Song Dynasty burned their forests and used massive amounts of coal but were still conquered by nomads (Eugene Anderson, personal communication). France has a high percentage of energy from nuclear fission so lower carbon-dioxide emissions. The oil producing countries of the Middle East have large amounts of oil resources but less power than would be predicted. And some of the more powerful countries are becoming more efficient in their transformation of energy, resulting in lower levels of pollution than otherwise expected.

SECTION 2.4 HYPOTHESES

The literature and theory suggest a number of hypotheses to be analyzed. I have used a numbering convention that identifies the chapter in which the hypothesis is examined, followed by the order within the chapter. Since the specifics of the hypothesis testing will be described in the corresponding chapter, I will only discuss them briefly as they relate to the preceding literature and theory.

One of the predicted effects is the possibility that energy consumption will decrease over time due to pressures from environmental concern, and/or hierarchical or technological change. This effect is called “decoupling,” which will be discussed in the next chapter, but for now the related hypotheses are:

H3.1: The level of energy consumption per capita will decouple from GDP per capita over time for countries in the core

H3.2: The level of energy consumption per capita will not decouple from GDP per capita over time for countries in the semiperphery or periphery

H3.3: The amount of carbon-dioxide emissions will decrease after GDP reaches a certain level

H3.4: Reductions in energy consumed and emissions will emerge as a country moves from an industrial to service-based economy, while GDP will increase

The next hypothesis concerns the idea of energy-related bifurcation and phase-transitions from complexity theory and thermodynamics. If this phenomenon occurs, the theory would predict distinct levels of power across societies.

H4.1: The distribution of countries in the modern world-system occurs in discrete categories indentifying the core, semiperiphery, and periphery

Within the theoretical model for energy use, the first relationship posits that a society’s power will increase with its amount of energy use:

H4.2: A country’s power has a positive relationship with its energy consumption

The theory also predicts a positive feedback loop from the level of power to energy control and transformation, as more power allows for greater energy control and transformation. Considering world-system positions of core, semiperiphery, and periphery as differentiated based on power

H4.3: A country’s level of energy consumption has a positive relationship with its power

H4.4: Countries in the core have higher growth rates for energy consumption and power than the semiperiphery, and the semiperiphery has higher growth rates for energy consumption and power than the periphery

To test for theories of semiperipheral development, an alternative hypotheses examines if growth in the semipheriphery is outpacing the core and periphery.

H4.5: Countries in the semiperiphery have higher growth rates in energy consumption and power than the core, while the core has higher growth rates in energy consumption and power than the periphery

The final set of hypotheses concern environmental degradation. These mirror the hypotheses relating to energy consumption in above. These hypotheses are as follows:

H5.1: A country’s energy consumption has a positive relationship with its level of environmental degradation

H5.2: A country’s power has a positive relationship with its level of environmental degradation

H5.2: Countries in the core have higher levels and growth rates of environmental degradation than the semiperiphery, and the semiperiphery has higher growth rates for environmental degradation than the periphery

H5.3: Countries in the semiperiphery have higher growth rates in environmental degradation than the core, while the core has higher growth rates in environmental degradation than the periphery

The negative effects of environmental degradation, born disproportionately by the periphery as predicted by the theory, will not be directly tested here since, as indicated earlier, the available data has already been tested by others and evidence found for the effects.

Chapter 3

Two Centuries of Energy Dynamics

3.1 INTRODUCTION

Given my desire to explain the historical relationship between energy use, environmental degradation, and intersocietal power, but also given data limitations, the quantitative analyses in this dissertation has been undertaken in two distinct studies. In the first, appearing in this chapter, I discuss research conducted on a dataset consisting of countries with available data beginning in 1800 CE. Due to the small number of countries with data available on my variables of interest prior to the early 1970s, the quantitative analysis in this chapter will be limited to descriptive statistics. In the second study, which appears in the following chapter, I am able to dramatically increase the number of observations and countries by focusing on the recent period 1973-2008.

In section 3.2 that follows, I begin by discussing key issues expressed in extant research on the relationship between energy use, intersocietal power, and energy-related environmental degradation for the nineteenth and twentieth centuries. Hypotheses are developed to be examined in the remainder of the chapter. In section 3.3., I describe the data I have gathered and utilized for analysis of energy use (production, imports, exports, and consumption), GDP per capita, and carbon dioxide emissions per capita, for the period beginning in 1800 CE. After discussing the data set, in section 3.4 I present descriptive statistics and graphs on the countries with available data in the nineteenth- and early twentieth-century. I consider the hypotheses developed in section 3.2. In section 3.5, I close with a discussion of the results and future research possibilities.

3.2 THE NINETEENTH AND TWENTIETH CENTURIES

The nineteenth and twentieth centuries were a period of immense change in the relationship between energy and social evolution. Industrialization, beginning in England, and spreading to Western Europe and the United States, created one of the most rapid and dynamic periods of change human societies had ever experienced (Landes; Lenski and Nolan; Sanderson). The use of machine technology alongside and in replacement of animal and human labor led to huge production gains, but also greatly increased the consumption of resources and ecological degradation. Marx and Engels were keen observers of this dialectic of progress and destruction, of course.

As discussed in chapter one, changes in energy use have always been associated with dramatic evolutionary moments, and the industrial revolution was no different. The expanding use of coal to fuel steam engines and metallurgy ovens was essential in the development of industrialization since coal is much more energy intensive than wood and other sources previously in use (Smil 2008a) Those countries that had access to indigenous or external coal beds, such as in Great Britain and the United States were able to rise to the top of the interntional hierarchy of states, while those without coal lagged behind (Podobnik 2006b). The discovery of oil for commercial use in the United States in the early twentieth, century created another “energy shift.” Oil, with even higher energy intensity and potential applications than coal, fueled the continued expansion of industrial production, the growth of transportation, was a key ingredient in the “green” agricultural revolution as a source for fertilizer, and many other productive uses (Smil 2008a).

Decoupling for Sustainability

This growth in the extraction and consumption of fossil fuels was, also as previously discussed, a cause for the escalation of ecological degradation. This has important implications for the future of both energy use and sustainability. A key assumption in both energy and environmental economics is that economic growth and/or technological change will lead to a decoupling of energy use from further economic growth (Stern and Cleveland 2004). Decoupling in this case refers to the assumption that energy use will become less essential to economic growth due to one or more of the following reasons: 1) efficiency gains will be made in production that require less energy inputs; 2) less energy-intensive forms of production occur as societies will shift from agricultural to industrial and then service-based economies. Due to the high correlation between levels of energy use and production of pollutants—particularly carbon dioxide emissions from fossil fuel combustion—the decoupling assumption, then, creates a related assumption that economic growth and/or technological innovation will have a positive effect on the biosphere, an assumption at the foundation of modernization theories (Mol 2001).

But even service-based economies require energy to be used, in order to sustain labor or as electricity for example. (Stern and Cleveland 2004). In 2005, world electricity consumption for computer servers alone was 123 billion kilowatt hours, more than doubling the 58 billion kilowatt hours used five years earlier, although this still represented less than 1 percent of the world total electricity use of 15021 billion kWh in 2005 (International Energy Agency 2009a).

The evidence for decoupling is somewhat mixed. Lise and Van (2005) find evidence of decoupling in Turkey over the period 1970-2003 as the energy consumption per capita has a quadratic fit with GDP per capita. They suggest that decoupling depends on the "developmental phase" (India shifting a little toward services over the period) and after growth has occurred for many years. It should be noted that they do not find that overall energy use declines with economic growth, only that the rate of increase starts to level off.

In his research on the post WWII world-system, Chase-Dunn (1998: 263-267) found that the structure of the world-system had changed from 1960-1980: the proportion of world energy consumed by countries highest on per capita energy consumption and containing one-fifth of the world's population dropped from 83.3% to 69.9%; in the middle three-fifths of countries, the proportion of world energy consumed rose from 16.1 to 29.1%; the bottom one-fifth of countries remained essentially at the same low percentage of world energy consumption over the two decades, barely increasing from 0.9 to 1.0%. The distribution of GNP over the same period remained relatively the same across the three groups of countries, however. Chase-Dunn argued that these results provide a measure of changes in the makeup of the world-system hierarchy. In the core group, using a proxy of the top quintile of countries as measured above, deindustrialization and the shift to less energy intensive service-based economies provides at least a partial explanation of its declining share of the world's total energy consumption. In the semiperiphery, where the core's share went, the increase in energy consumption did not translate into efficient and profitable economic growth – a reflection of the industrialization of many semiperipheral countries. The periphery, suffering the continued combination of low GDP and energy consumption, was the only group that increased the percentage of the workforce in agriculture, from 33.2 to 40.4%. Similarly, Roberts and Parks (2007) found that leading export sectors mattered – controlling for a number of other variables, nations in which manufactured goods was the dominant export emitted the most carbon dioxide when compared to service and fuel exporters.

Taking a longer-term view, Podobnik (2006b) found evidence that to per capita commercial energy consumption was dropping in some core countries and regions over the period 1950-1980, particularly from the mid-1970s energy shocks. Energy consumption in Eastern Europe as a region dropped significantly after the fall of the Soviet Union in 1989, for example. Moreover, there was a shift starting in the 1950s in which the developed countries starting consuming more than they were producing where the two had been approximately equal, while in the less developed countries the relationship was the reverse – the less developed countries were exporting energy to the developed countries. Yet, from 1860-2000, the overall trend for the core, semiperiphery, and periphery has been of growth in energy consumption per capita

Andrew Jorgenson (2003, 2004) has found that nations with large ecological footprints—an estimation of the amount of productive land necessary to support the consumption and waste of a population, includes the assimilation of emissions from the burning of fossil fuels (Wackernagel and Rees 1996)—have lower levels of ecological degradation relative to nations with smaller footprints. And, contra modernization theory, the ecological footprint has grown for developed countries, even as they shift toward more service economies, and it is inversely proportional to manufacturing intensity (Jorgenson and Burns 2007; cf. Jorgensen and Rice 2005, 2007). Less developed countries dependent upon foreign investment in manufacturing have been found to emit higher levels of per capita noxious gases (cf. Grimes and Kentor 2003; Jorgenson 2007; Jorgenson, Dick, and Mahutga 2007; Kentor and Grimes 2006). Additionally, total population, level of development, and export intensity are positively associated with both total carbon dioxide emissions and emissions per unit of production (Jorgenson 2009). Moreover, the carbon intensity of countries CO_2 emissions per unit of GDP, were found to vary across the world-system, with semiperiphery and upper periphery countries operating least efficiently (Roberts, Grimes, and Manale 2003). Similarly, in an excellent study on energy flows and interstate inequality, J. Timmons Roberts and Bradley C. Parks (2007) found that total, per capita, and historical emissions of CO_2 reflect dramatic inequality between the Global North and South. Moreover, increases in CO_2 emissions are positively correlated with trade for poorer nations but negatively correlated for wealthier nations – an indication of unequal exchange. They also found that hope for an environmental Kuznets curve, in which development leads to decreasing emissions, is misplaced; carbon dioxide emissions continue to increase with wealth. Clearly, inequalities in the benefits of energy use and the costs of the pollution generated exist by location in the world-system hierarchy (Bunker 2003; 2007; also see the edited volume by Hornborg, McNeill, and Martinez-Alier 2007; the edited volume by Jorgensen and Kick 2006).

My own earlier research demonstrated that energy use and the emissions of pollutants generated from that use are disproportionately distributed across the core-periphery hierarchy (Lawrence 2009a). The core experienced relatively low growth in energy use and CO_2 emissions per capita, but larger gains in GDP. But its percentage of the world's total energy use, CO_2 emissions, and particularly GDP, are highly disproportional to its share of the world population. The semiperiphery had the largest increases in energy use, CO_2 emissions, and GDP per capita, reflecting its industrialization and the growth of China. The share of the world's energy use and CO_2 emissions for countries in the semiperiphery are relatively in line with its population percentage, but it lags in its share of GDP. The periphery, buoyed by India, had moderate growth in energy use and CO_2 emissions per capita, and its change in GDP per capita equaled the semipheriphery's. And it grew its share for the totals in the world-system, but they were still far below its percentage of the world's population. Finally, net energy importers had results similar to the core, while net energy exporters were most like the periphery.

The results demonstrated the inequality in the benefits of resource use and the results of unequal exchange that lead to the development of the core and the underdevelopment of the periphery. Countries in the periphery are unable to reap the benefits from energy use to the same extent as those in the semiperiphery and the core, using far less energy and receiving far less GDP for their energy use. Countries that are industrialized or industrializing, such as China and India, have relatively high observations and percentage changes for energy use, CO_2 emissions, and GDP, while the core and deindustrializing countries, such as the United Kingdom and the United States, have low percentage changes, indicating income is coming from non-energy intensive sources and possibly increased energy efficiency in the energy intensive processes. The bulk of the periphery shows low growth and is far behind the core. This supports claims discussed earlier that the core is able to outsource energy inefficient sources of income to semiperipheral and peripheral countries, increasing the order of the core and the disorder, or entropy, of the semiperiphery and periphery (cf. Bunker 1985; Hornborg 2001; Jorgenson 2009; Roberts and Parks 2007).

In my earlier work, large per capita differences in energy flows existed across the world-system, with the core using more energy, emitting more carbon dioxide, and reaping more economic gain. And net energy importers outpace net energy exporters, reflecting the reduction in entropy experienced by the core relative to the semiperiphery and both groups relative to the periphery. But gains are being made by countries in the semiperiphery and periphery relative to the core for both per capita and percentage of world total measures. This potential for development may place the planet in peril, however, as efficiency gains in the core are being offset by growth in emissions by the semiperiphery and periphery.

The analyses above, other than for Podobnik's work, suffer from two shortcomings. First, the analyses are not extended much further back in time than the middle of the twentieth-century. While this is no doubt due at least partially to data limitations, it is possible to find data that predates most analyses. This may provide a better understanding of the long-term trajectories of countries and the evolution of the world-system more generally. Second, extant studies are too narrow, mostly limited to one country, or too broad, analyzing all countries with available data as a block. I begin to try to correct for these issues in the analyses that follows in this chapter for countries with data available beginning in 1800, and in the next chapter for countries for the period 1973-2008.

For data on the longer-term in this chapter, a few hypotheses can be considered. First, related to the issue of decoupling, it is interesting to see if evidence exists for noticeable decoupling of energy consumption from GDP. Following earlier findings of decoupling varying across countries and world-system regions, two hypotheses are generated:

H3.1: The level of energy consumption per capita will decouple from GDP per capita over time for countries in the core

H3.2: The level of energy consumption per capita will not decouple from GDP per capita over time for countries in the semiperphery or periphery

Related to this is the suggestion from ecological modernization theory of an "environmental Kuznets curve" in which environmental cleanliness will improve after a country reaches a certain level of development (Mol 2001). This has found little support in tests on recent data (York and Rosa 2003), as suggested by the "Lauderdale and Jevons' paradoxes" (Foster and Clark 2009) but is worth analyzing utilizing data from earlier in time. The seventh hypothesis, then, is:

H3.3: The amount of carbon-dioxide emissions will decrease after GDP reaches a certain level

Similarly, a country's transition from an industrial to service-based economy may lower the amount of energy consumed and the emissions generated, but the GDP may increase from the value differences in the two types of income (cf. Chase-Dunn 1998).

> H3.4: Reductions in energy consumed and emissions will emerge as a country moves from an industrial to service-based economy, while GDP will increase

3.3 DATA AND METHODS

Energy Variables

Data for the primary commercial energy variables (consumption, imports, exports, and production) were compiled from two sources. From 1800-1960, the data come from a dataset compiled by Bruce Podobnik, and made available for my use by the author. Podobnik utilized a number of sources to create his dataset, including Etemad and Luciani's (1991) the United Nations (1952, 1997) Darmstadter et al. (1971), and Mitchell (1982, 1983, 1984, 1988, 1992, 1993).

For the period 1960-1971, Podobnik's data is used for countries that do not have similar data available from the IEA- primarily non-OECD countries, with the IEA data used when available. There were often mismatches between the data from the IEA and Podobnik, particularly since the latter's data does not capture all of the energy sources that the IEA does (such as wind, municipal waste, etc.). For those situations in which there was a large mismatch, I used linear interpolation to smooth the transition over the 10 years up to the beginning of the IEA coverage.

The original estimates are in million tonnes of oil equivalents so they were multiplied by one million to convert into tonnes of oil equivalents. The values are then divided by population to get per capita estimates.

Gross Domestic Product. Estimates for Gross Domestic Product per capita, a common indicator of national economic strength and level of development were obtained directly from the internet database originally maintained by Angus Maddison at The Groningen Growth and Development Centre at the University of Groningen in the Netherlands (Maddison 2008). The GDP estimates Maddison posted were in 1990 International Geary-Khamis dollars, also known as the international dollar, which is a Purchasing Power Parity (PPP) conversion to put all country values on a common base, in this case the 1990 amount of US dollars used to purchase a common basket of goods and services within each country. The effect is to show the standard of living within each country. Maddison's GDP estimate was used here since it is the only known estimate that extends further historically than the middle of the twentieth century. In chapter four, where I use data for the most recent decades, I use a foreign exchange rate (FX) conversion and data from the World Bank, which are now updated more often than Maddison's data and are a better indicator of international strength (see chapter four for a discsussion of FX versus PPP).

Carbon Dioxide Emissions. Carbon dioxide emissions, CO^2, from fossil fuels was gathered from the Carbon Dioxide Information Analysis Center (CDIAC 2011). The CDIAC estimate is multiplied by 1000 to get metric tons of carbon, then divided by population to get the per capita estimate. For scaling purposes, the quotient is then multiplied by 1000.

Data Availability

One of the difficulties for quantitative data analysis is historical data availability. That is true in this study as well. The earliest available data I have are for the year 1800, yet only seven countries have data available at that point, and only production data is available for that group. GDP from Maddison is available for four of those countries, and CO2 emissions for three of those. The picture gets brighter by 1850, where data on the three main variables are available for six countries, and it increases to 37 by 1945, and then 95 countries in 1950. By 1990 the number of countries with data available is 116 and there are 128 countries with data for 2008. For this chapter, again, I will be forced to limit the data analysis to basic descriptive statistics and graphs given my desire to reveal long-term trends.

3.4 DESCRIPTIVE STATISTICS AND GRAPHS

Table 3.1 below displays the mean values and country counts for those countries with estimates for all of the key variables at forty-year intervals over the period 1800-1970.

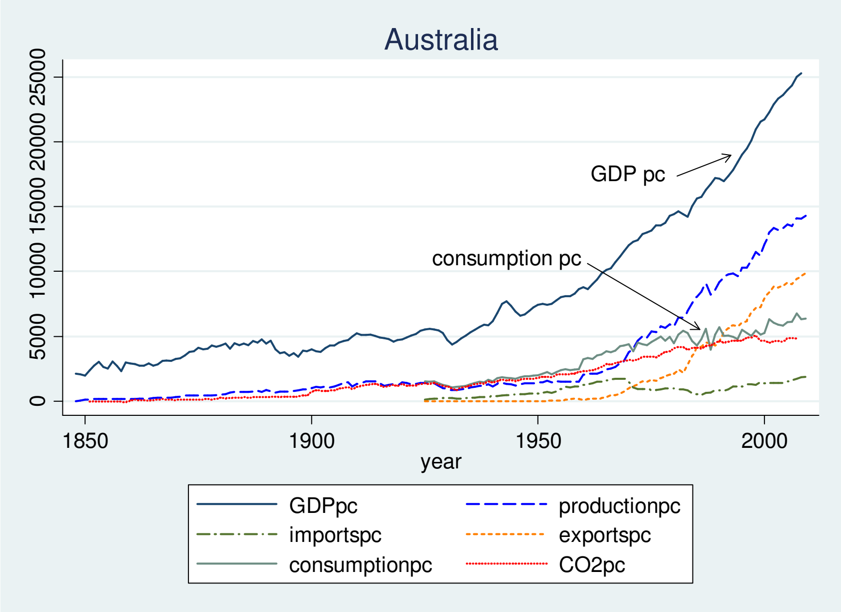
Table 3.1 Energy, GDP, and Carbon Dioxide, per Capita, 1800-2008

	1800	1840	1880	1920	1960	1980	2008
# of countries	4	8	18	21	30	106	128
Energy, p.c.							
Production	150	227	533	902	1720	5335	4926
Imports					769	1151	1518
Exports					922	4413	3619
Consumption					1573	2067	2857
GDP , p.c.	585	1445	2158	3141	6497	6272	9384
CO2, p.c.	133	220	550	1067	1268	1515	1696

Concerning decoupling, and hypotheses H3.1-H3.4, the aggregate-level are not that helpful due to the different number of countries at each time point. For example, in 1800, the proportion of production of energy per capita to GDP per capita was .26 and 1.13 for CO2 per capita. By 1920 this was .29 and .85, but it is impossible to say if those changes occurred due to underlying fundamentals within the countries or if it was due to countries with difference energy profiles joining the dataset.

Due to these data limitations, what is more revealing is to look at graphs from some of the countries for which long-term data are available. For example, in Australia, a country with huge coal reserves and the largest exporter of coal in the world (BP Statistical Review of World Energy 2010), there is evidence for the decoupling of GDP and CO2 from energy consumption, although not as much from production due to its exporter status, as revealed in Figure 3.1 below:

Figure 3.1 Energy Flows, Australia



In Japan and France, which have few of their own resources and a large nuclear energy regime, we also see decoupling of GDP per capita from all energy variables, as revealed in Figures 3.2 for Japan and 3.3 for France.

Figure 3.2 Energy Flows, Japan

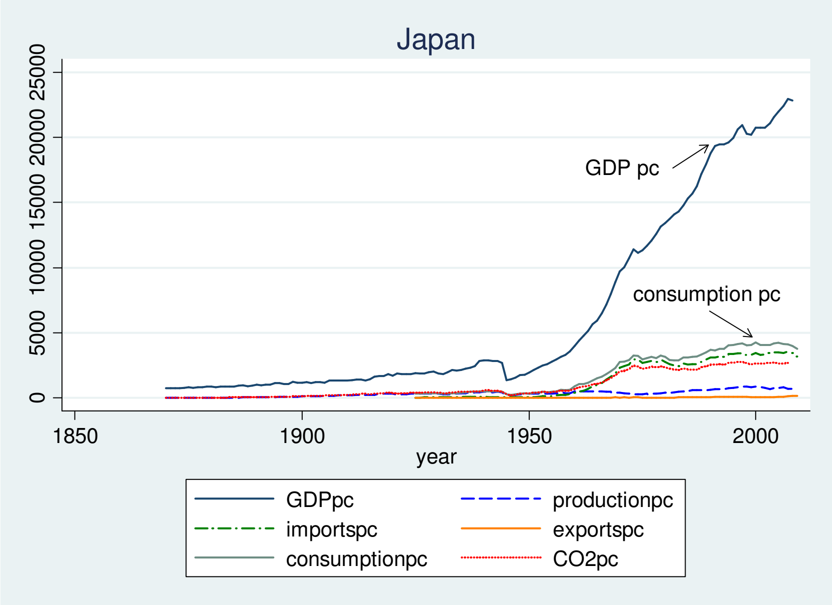
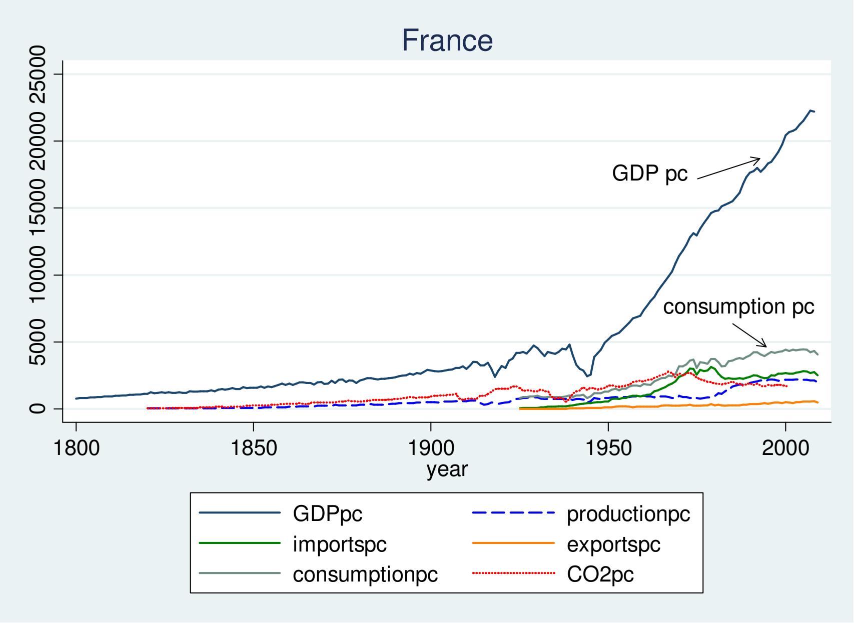
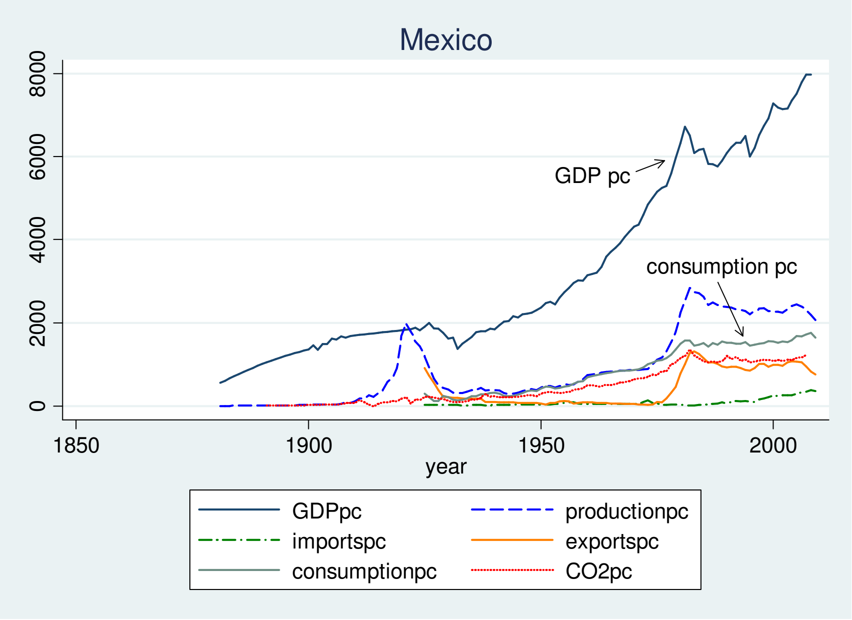


Figure 3.3 Energy Flows, France



In Mexico, a country in the semiperiphery, decoupling is also apparent.

Figure 3.4 Energy Flows, Mexico



The final set of graphs depict the energy profiles for the hegemon of the eighteenth and nineteenth centuries, the United Kingdom (Figure 3.5), and for the hegemon of the twentieth, the United States (Figure 3.6).

Figure 3.5 Energy Flows, United Kingdom

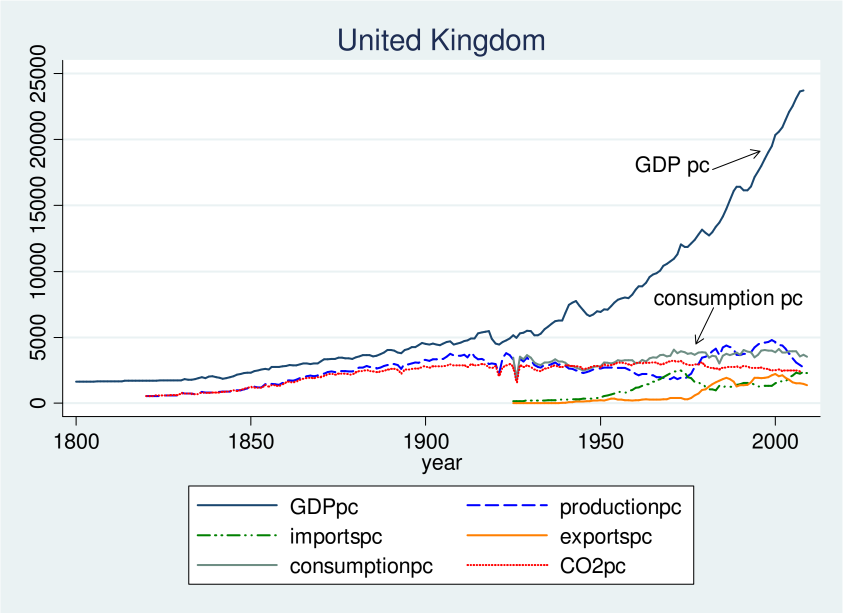
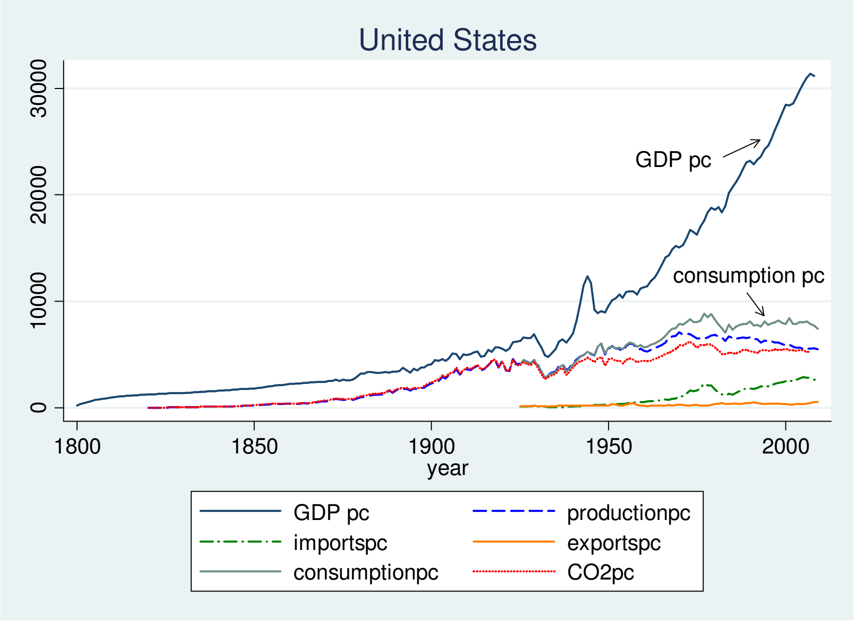


Figure 3.6 Energy Flows, United States



In the United Kingdom and the United States deindustrialization and a shift toward services has occurred, which is likely to be one of the causes of the decoupling witnessed.

3.5 DISCUSSION

While available data put limitations on the analysis that appears here, there is support for the decoupling of GDP per capita from the energy production (the only available data until 1925) and also for consumption, which is a better indicator for decoupling and available after 1925. In the above countries, there has been a shift away from industrialization toward services, although less so for Australia and even less so for Mexico, which likely explains some of the decoupling. The core countries make up all of the countries but Mexico, but decoupling is occurring in the latter as well.

Of course, each county has its own unique energy story, the details of which are beyond the scope of this project yet would be an interesting area for future research. Unfortunately, we will likely never have complete data much further back in time than the later part of the twentieth century on a large enough number of countries to facilitate more detailed analyses. In the next chapter, I focus on this most recent historical period in an attempt to over these limitations.

Chapter 4

Energy and Power in the Modern World-System, 1973-2008

4.1 INTRODUCTION

This chapter details the empirical data that has been gathered and analyzed as well as the methodology employed during quantitative research on a dataset of countries in the modern world system over the period 1973-2008. The analysis provided and discussed in this chapter is on a much shorter and more recent time frame than that presented in the previous chapter, but this time frame was selected for theoretical and methodological reasons. Theoretically, it can be argued that world-system significantly changed in the decades following WWII; e.g., the hegemony of the United States began to wane by the 1970s and the oil shocks of the 1970s altered the energy landscape from what had been a relatively stable period in the decades following WWII (Podobnik 2006b).

Methodologically, the time period's starting point in the early 1970s was necessary to more adequately cover the countries in the current world-system since data on many countries was unavailable through my primary sources, the World Bank and International Energy Agency, prior to 1971. The increase in the number of countries and observations occurring in the early 1970s affords the opportunity to substantially increase the number of observations and variables that can be analyzed, both of which increase the potential validity of the inferential statistics employed here.

The chapter is laid out in the following manner. In section 4.2, I revisit work I have previously published but that is germane for the research here; particularly for my attempt to reassess the applicability of thermodynamics to world-systems analysis. In the sections after 4.2 through the end of the chapter, I shift to an analysis conducted using more complex statistical techniques on an updated panel of countries for the key variables power, level of development, and energy consumption. There are three sets of models that are developed an analyzed, each with baselines of the key variables and second models with control variables: 1) models with Gross Domestic Product per capita (GDP pc) as the dependent variable; 2) models with a measure of world-system power as the dependent variable; and 3) models with energy consumption per capita as the dependent variable. In section 4.3, I discuss measures of interstate power in the modern world-system and discuss those that are utilized in this study. Section 4.4 describes the measure for energy use that is utilized. Section 4.5 describes the independent variables included in the study. In section 4.6, I discuss the specific hypotheses that will be tested. Section 4.7 discusses the methodology employed. In section 4.8, the models to be estimated are revealed. I then present the results of the statistical analyses in 4.9, and, finally, I discuss those results and suggest areas for further research in section 4.10.

4.2 AN ENERGY BASED WORLD-SYSTEM? EVIDENCE FROM AN EARLIER STUDY

In a study published in 2009 by the *International Journal of Comparative Sociology* (Lawrence 2009a), I began working through the applicability of thermodynamics to world-system dynamics. As I argued then, it seems that world-system categories should be analyzed on an energy basis, given the literature on the centrality of energy flows to the evolution of societal complexity and for establishing intersocietal power differences. Indeed, at the time I asserted that the world-system hierarchy should be more properly measured based on energy consumption rather than in more traditional ways such as income (GDP), since levels of energy consumption are causally prior to the income that was the outcome of that energy use. As I hope is or will become clear in my current thinking on the interrelationship between energy, development, and intersocietal power, I have subsequently rethought the logic of that argument such that development and power are the proper measures of world-system position. Yet, the centrality of energy in those outcomes remains one of the key, if not most important, inputs. Nonetheless, the earlier work continues to inform my current research, and, with all modesty, I think it remains an important early contribution to a slowly growing body of related research (as previously discussed).

One of the issues I sought to address was the shape of the world-system, particularly if it was a relatively continuous distribution of countries (or zones), as had been suggested by Chase-Dunn (1998: 207), or if it occurred in discrete categories, which was consistent with the work of Wallerstein (1974) and Arrighi and Drangel (1986). My hypothesis, although unstated formally at the time, was in support of the latter:

> H4.1: The distribution of countries in the modern world-system occurs in discrete categories indentifying the core, semiperiphery, and periphery

This hypothesis stems from the idea of bifurcation points based on differences in energy flow derived from thermodynamics and complexity theory (as previously discussed). Since countries have different levels of energy use, it seems logical to predict that, at certain levels there would be a shift or a jump in the level of complexity, reflected in development or power, however measured (as discussed earlier, this is more or less suggested by Giampietro and Pimental 1991, LePoire 2007, Podobnik 2006b, and in upward sweeps of city and empire size found in Inoue et al. 2011).

Data was gathered from the World Bank's "World Development Indicators" electronic database (2010, 2008 at the time) on a balanced panel of 87 countries for the period 1975-2005. The key variables were energy use (TPES, total primary energy supply, before transformation to other end-use fuels, million tonnes of oil equivalent), carbon dioxide emissions, (CO_2, from the burning of fossil fuels and the manufacture of cement, metric tons), GDP (exchange rate method, measured in constant 2000 US$), and population. I then used a population weighting method developed by Salvatore Babones (2005) to plot the distribution of countries. Briefly, the method weights country-level estimates by their population in order to demonstrate the share of the world population effected by the variable of interest. Smoothing of each country's observation is then employed by plotting the results over a normal distribution. A moving average is thereby created, with the intention of reducing the effects of random factors while allowing the underlying structure of the world-system to emerge naturally instead of by forcing countries into tiers.

Utilizing the natural logarithm of energy use per capita as the variable with which to establish the world-system structure, consistent with my argument about the centrality of energy, the key results of the population-weighting method are reproduced in Figures 4.1 and 4.2 below.

Figure 4.1 Population Weighted Energy Use per Capita, 1975

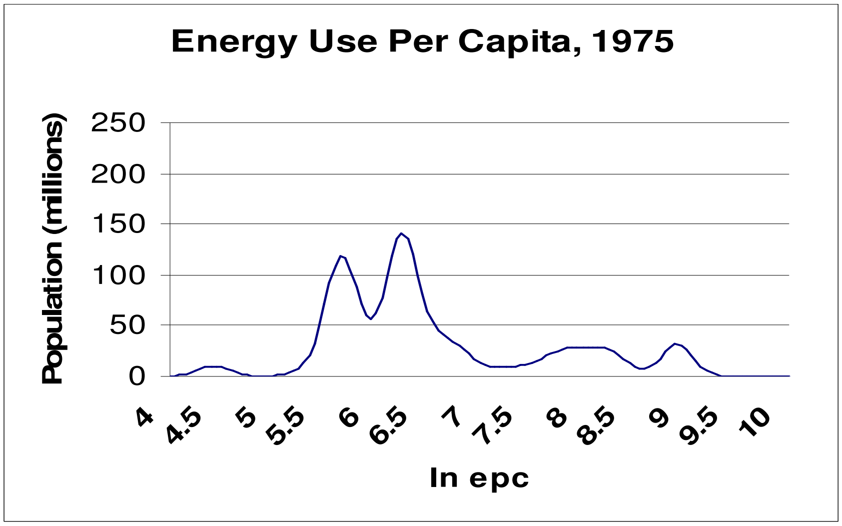
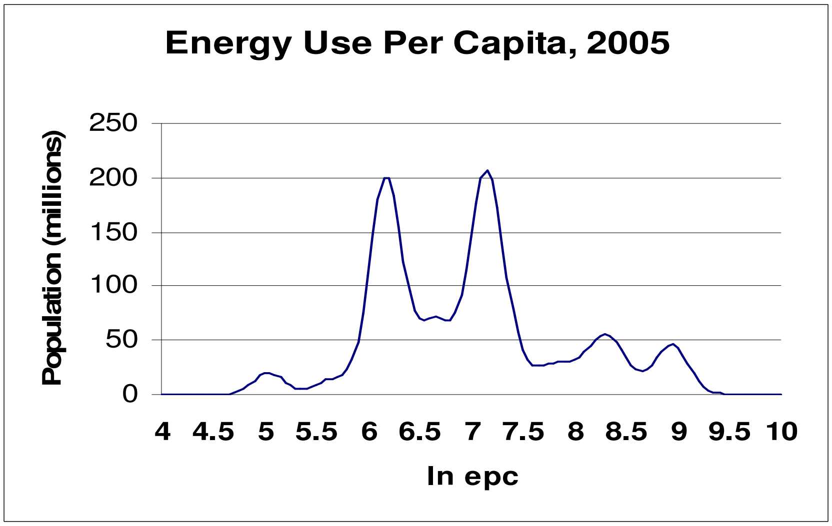


Figure 4.2 Population Weighted Energy Use per Capita, 2005



Data Source: World Bank, N =87. Reprinted with permission. The final, definitive version has been published in the *International Journal of Comparative Sociology*, Vol. 50, Issue 3-4 by Sage Publications Ltd., All rights reserved. © 2009 Sage Publications.

Figures 4.1 and 4.2 indicate a few interesting energy effects over the thirty-year period. First, the peaks are higher in the year 2005, reflecting population growth in the panel of countries. Second, the largest peaks in the middle of the distribution shifted toward the right, reflecting higher average energy use per capita; clearly, more total energy was being used in 2005 than in 1975. It was also being used differently by different countries, as those in the shifting peaks, heavily influenced by growths in energy consumption by China, the first large peak, and India, the second. Third, and more important for my hypothesis on the shape of the distribution of countries, both figures appear to confirm my hypothesis, H4.1: the world-system exists in discrete categories.[6]

But as I indicated then, the peaks and troughs are an artifact of the measurement methodology. The height of the peaks are strongly influenced by countries with large populations, such as the United States (the first peak at the highest level of energy use per capita), China, and India. There are a number of other countries around the largest that help form the shape of the peaks, but China, India, and the United States alone represented over 43% of the population of the total for the 87-country panel.

Moreover, the use of population-weighted data is intended to provide a better idea of the actual energy use by the people of the world. Yet we know that not everyone in countries with an unequal sharing of benefits and costs receives an equal amount of the item in question. This is true for energy consumption as well. For example, in China, despite the hopes of serving as a model for development (Frank 1998) small scale rural agriculture and other production are still practiced by a large number of people while large cities grow rapidly; energy use is obviously not the same per person. And nearly a third of the world's population does not have residential electricity at all (Smil 2008: 258-

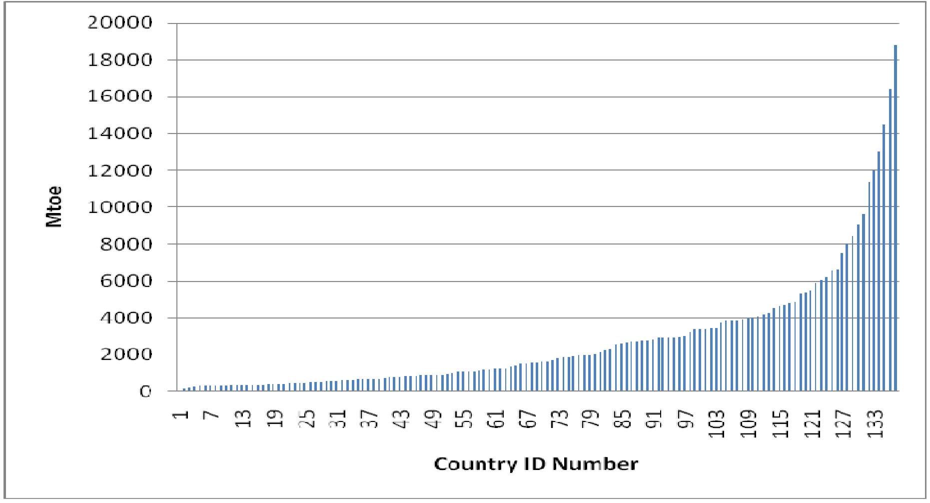
---

[6] Of course there are 5 peaks visible in both figures, which were collapsed into the typical tripartite core, semiperiphery, and periphery by merging the two at the top and bottom. It could be suggested, as Babones (2005) had and other have (Arrighi and Drangel; Mahutga and Smith 2011), that there may be upper and lower levels within each category. Exploring that possibility was beyond the scope of the paper then, as it is now.

259). Spreading the energy use over a normal distribution is intended to address that issue but is a generalizing assumption.

Plotting just energy use per capita from smallest to largest estimates, without the population weighting and smoothing—and even without the logarithmic transformation that compresses the range of the distribution—produces a distribution that seems to become more of a continuum. I did not display that visually in the earlier paper but it is worth including here:

Figure 4.3 Energy Use Per Capita, 2008, Unweighted and Unlogged[7]



Mtoe = Millions of tonnes of oil equivalent
Source: International Energy Agency, 2011

---

[7] It should be noted that these data were drawn from the total countries available in 2008, which is 137, instead of the 87 in my original study, but the distributions are nearly the same, with the key difference occurring due to the inclusion of a few oil producing countries with small populations here that were not available for the full panel study. These countries, including Qatar (the highest energy use per capita) Bahrain (fifth highest), and the Netherlands Antilles (sixth highest) in particular, generate the sharp spike in energy use per capita as the highest values are approached. Their inclusion in the earlier study would have slightly extended the front edge of the first peak (Qatar's energy use per capita (ln) is 9.84, while the next highest is Iceland at 9.71, which was included in the earlier study.

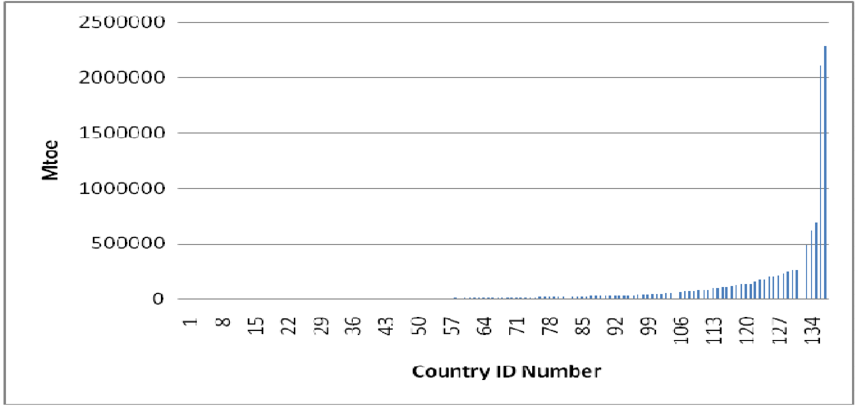
While there are large differences between countries at the bottom (Eritrea, 136.19) and the top (Qatar, 18,841.98) of the distribution, the only clearly noticeable breaks seem to be for the exponential-type rise for the top 11 countries (beginning with the United States at 7499.17, which is 12.95% higher than the next highest country, Finland at 6639.42).

But a closer examination of the data reveals the existence of a few other large percentage changes between countries next to each other in the distribution. For example, Gibralter is ranked at #119 (5291.7) is 9.2% higher than the Netherlands at #118 (4846.8), Poland at #84 (2567.7) is 11.9% higher than #83 Venezuela (2294.1), and Cuba at #54 (1071.7) is 10.2% higher than #53 Armenia (972.9). Similar to the top of the distribution (and predicted by the population weighted method), is spiky, with the lowest level (136.2, Eritrea) 57% smaller than the country at #5 from the bottom (Myanmar at 318.5).

As noted in my earlier paper, weighting each country equally has the drawback of failing to reflect the centers of gravity in the world-system—the impact on the largest percentages of the world's population may better approximate the world-system as it is more often experienced. But then comparing per capita measures across countries ignores differences in inequality levels *within* countries. Using population weights compounds that problem; however, accurate and longitudinal measures of within-country inequality are only now being developed (cf. Bornschier 2002; Firebaugh 2003; Milanovic 2005; Wade 2004) and are an area to explore in future research.

An additional problem with per capita weighting in general is that it can distort the largest contributors or users for the variable in question, which is of concern for scarce and valuable resources such as energy. Assessing the total energy use of countries provides another snapshot of the shape of the world system. That data are displayed in Figure 4.4 below:

Figure 4.4 Total Energy Use, 2008



Mtoe = Millions of tonnes of oil equivalent
Source: International Energy Agency, 2011

There is a much more dramatic exponential-type rise when mapping the total energy use compared to energy use per capita. Here you have countries that are more typically thought of as having power and located in the core of the world-system (top-five, ranked in order from the top): United States, People's Republic of China, Russian Federation, India, and Japan, with China using over 2-times as much energy as the Russian Federation (2,116,427 and 686,757, respectively), yet with the United States (2,283,722) using almost 8% more than China.

Yet there are still noticeable percentage change differences as you more from the highest to the lowest total energy users. Deciding, then, to find support for or reject my first hypothesis is impossible without a guideline for determining what constitutes a large enough percentage change, or the use of another measure I am unaware of, for the difference to be considered possible evidence for a categorical shift.

4.3 MEASURING INTERSTATE POWER IN THE MODERN WORLD-SYSTEM

Attempts to measure the core-semiperiphery-periphery structure is, then, in the first instance dependent upon the empirical characteristics on which it is constituted and maintained. Beyond my earlier energy-based approach, which is not at all typical, there are various scholars that have taken on the challenge. The logic of their methodologies tend to fall into three broad categories: income-based measures, network-based measures, and geopolitical power-based measures. Regardless of perspective, the measures seek to produce a ranking of countries that approximates their position within the interstate system.

In my additional empirical research that forms the remainder of this chapter, I focus on three measures that are representative of the three categores of empirically-assessing world-system position: in the income category, Salvatore Babones' (2005) population weighted GDP approach; in the network category, Matthew Mahutga and David Smith's (2011) analysis of trade; and in the geopolitical power category, Jeffrey Kentor's (2000) multivariate composite construction (for further review of other world-systems measures, see Babones 2005; Kentor 2000; Prew 2010). These measures were chosen for both theoretical and practical concerns. Theoretically, the three measures capture the main strands of thought on the measurable determinants of world-system position. Practically, all three use empirical data that were accessible for my reapplication.

The Income-Based Approach: Babones's Population Weighted GDP Approach

As mentioned in section 4.2, Salvatore Babones (2005) created a measure of world-system position that followed the income-based approach. These perspectives see the world-system as one in which capital flows largely determine the location of a country in the interstate system; countries with high incomes, with income level typically measured as GNP or GDP per capita, are likely to be engaged in more higher value-added economic processes than those with lower income levels. Ranking countries according to their location in the distribution of income for all countries should then more or less reflect Wallerstein's division of labor (see also Arrighi and Drangel 1986; Korzeniewicz and Martin 1994).

As discussed earlier as I detailed my replication of his method, Babones (2005) derived his measure from population-weighting, only instead of energy he used the more traditional GDP per capita, following the methodology that was developed by Giovanni Arrighi and Jessica Drangel (1986), but significantly updated the earlier authors' work. In both models, the value of a country's production—GNP per capita for Arrighi and Drangel—is the most important indicator of its position in the hierarchy of states. After weighting the logged estimates by population and smoothing the results over a normal distribution, Babones' results revealed three distinct tiers of states, albeit with a fair amount of mobility over time, providing empirical support for the world-systems concept of core, semiperiphery, and periphery.

The Network-Based Approach Mahutga and Smith's Network Analysis of Trade

The network-based approach to measuring world-systems position is represented in this study by Matthew Mahuta and David Smith's (2011) work on trade networks. In the network-based approach, countries are typically located within the core-semiperiphery-periphery structure by first determining their similarity or equivalence (regular or structural) with other countries and then determining the role or position of the groups or "blocks" of equivalent countries relative to the other blocks (see also Kick 1987; Lloyd, Mahutga, de Leeuw 2009; Nemeth and Smith 1985; Prew 2010; Smith and White 1992; Snyder and Kick 1979; Van Rossem 1996).

In an attempt to rethink the world-system as an international division of labor, consistent with Wallerstein's original idea if not his methodology, Mahutga and Smith introduce a network analysis of international trade to empirically describe the world-system hierarchy (see also Mahutga 2006; Boyd, Fitzgerald, Mahutga, and Smith 2010).

On a set of countries for the period 1965-2000, using regular equivalence in trade relationships, and hierarchal clustering and correspondence analysis to assign countries into groups, they found up to five minor groups (core, core contenders, upper-tier semiperiphery, strong periphery, weak periphery, and weakest periphery), which they then assign to core, semiperiphery, and periphery. They find that mobility is highest (although not uniform) for countries in the semiperiphery, and that the semiperiphery is converging with the core and diverging from the periphery on income and in the structure of economy.

The Geopolitical Power-Based Approach: Kentor's Composite World-System Measure

In the geopolitical power-based category, Jeffrey Kentor (2000, n.d.) created a composite measure of world-system position Geopolitical power measures typically include military expenditures and/or other indicators of political power in addition to financial strength (see also Terlouw 1992). As Kentor reveals, his measure he developed was derived from Charles Tilly's (1994; see also 1990) theoretical analysis of the emergence of nation states over the last millennium. Tilly argues that the most powerful states were those that had a balance between the concentration and accumulation of capital and coercive means; for the period 990 to 1990 AD, these were many of the national states in Europe and then the United States.

To construct a quantitative measure of this type of power, and for theoretical and practical concerns (available data), Kentor (2000, n.d.) settled on a formula that included the variables GDP, GDP per capita, and military expenditures. The raw scores for the variables were first divided by the averages of the variables for a stable set of 10 core countries in order to maintain a relative weighting since the countries in the sample varied over time and the available countries were systematically biased towards the core. The relative scores were then standardized by calculating z-scores and the z-scores were then added together. (Note: GNP per capita is used in place of GDP per capita in the reworking of his measure, Kentor n.d.).

Kentor found similarities in the power profiles of countries near the top, who had both economic and military power, while countries near the top, the "satellite core" had only high levels of economic power. In addition, the rankings of countries in the world-system remained relatively stable over the period 1930-1990, although the countries in the top of the distribution (the core) have higher average growth in their power score than those in the "satellite core," which has higher average growth in power than the bottom 50 percent. Interestingly, Kentor also found that economic growth had a significant positive effect on growth in military expenditures from 1910-1950, which then had a negative effect on future economic growth from 1950-1990, while foreign dependence, as measured by export partner and commodity concentration, had significant negative effects on economic power over the entire time period.

A Modified World-System Power Measure

Kentor's measure is of interest for replication in this study, both for the availability of data for its reconstruction, and given its theoretical correspondence with my definition of power, which again, following Weber (1978: 926), is a society's ability to exercise its will, even against the resistance of others. Yet Kentor's construction of his composition measure contains a few choices that I believe should be corrected to be utilized in this study. First, GDP and GDP per capita (or GNP per capita) for Kentor are derived from Maddison's (1995) or Grimes' (1996) data, or from the World Bank in the later working paper. It seems likely that data from both Maddison and the World Bank were in Purchasing Power Parity (PPP). This measure differs from a Foreign Exchange (FX) - based equivalent because FX adjusts GDP by the value of a country's currency in the international market, while PPP adjusts GDP by the costs of a basket of goods within the country in that country's currency. PPP, then, measures the relative strength of the consumer within the country instead of relative strength of the country within the world economy as FX does. Which GDP valuation to use is the subject of much debate for those assessing international inequality.[8] In this analysis, I am employing the commonly used FX-based GDP and GDP per capita, in constant 2000 US dollars, both taken from the World Bank (2010).

Kentor also chose not to use a logarithmic transformation to correct for skewness since it would reduce the magnitude of difference between countries. While that decision makes logical sense, for the statistical analysis that I am employing in the analysis that follows, I adjust GDP and GDP per capita using a natural log transform. While reducing the magnitude of difference between countries, "logging" the variables is necessary to approximate a normal distribution, which is a key assumption for parametric statistics but also a transformation that reduces the effects of outliers (Firebaugh and Beck 1994).

---

[8] When analyzing data on international inequality between states, Roberto Patricio Korzeniewicz and Timothy Moran 1997, 2000, 2005; Korzeniewicz, Angela Starch and Vrushali Patil 2004) use foreign exchange rates, and then adjust income to US Dollar equivalents. They claim that it is the most internationally accepted method. However, as the authors admit, FX measures market values only, it therefore fails to measure goods and services not sold in markets such as household labor. While arguably more important for international comparisons, FX fails to capture the relative purchasing power of a nation's currency within the country, instead reflecting the relative price in US dollars for domestic goods. It therefore captures the power of the US market position relative to other countries. Firebaugh Goesling (2004), in contrast, use PPP, which is intended to be based on national prices for a basket of similar goods and services. Korzeniewicz et al. claim that PPP data is contentious, if not invalid and unreliable, in part due to its reliance upon extrapolation from minimal benchmarks of cost bundles, dated data, and lack of data. For example, for China, a very important country for assessing international inequality as will be discussed below, PPP data come from limited price collection efforts and are years out of date. In fact, they claim that despite their widespread use, "the PPP data collection effort today stands on the verge of institutional collapse" (Korzeniewicz et al. 2004). Of course the most important difference between the two is in the result they produce; foreign exchange-based income results in rising inequality for Korzeniewicz et al. while PPP-based income has been the basis for Firebaugh et al.'s convergence. Neither FX nor PPP is perfect, but I am more convinced that, overall, FX is more accurate and reliable than PPP. This point may be mute however, if PPP does disintegrate as suggested.

Consistent with Kentor's original data, I extracted data on military expenditures from the Correlates of War electronic dataset (Correlates of War 2010). As the last available estimate at the time was 2007, I replicated the 2007 estimate for 2008.

The formula for the modified measure of world-system power is the same as Kentor's initial measure (2000: 66):

World-System Power = GDP + GDP per capita + Military Power

with each of the variables raw scores first divided by a stable set of 10 core countries to maintain equal weighting, then standardized into a z-score

Following, Kentor, the raw scores were not transformed so the magnitude of difference could be maintained; however, the resulting distribution is highly positively skewed (verified with normality plots and skewness test – sktest – in Stata), with the United States at the maxium, ranging from 15.46 in 1978 to 17.19 in 2008, while the average score for all years approximately zero (due to the standardization procedures) and the minimum score is -1.52 for the Democratic Republic of Congo (formerly Zaire) in 2003 and 2008. Due to the negative scores for the lower-ranked countries, a log transformation is not possible to reduce the positive skew since the natural logarithm of a negative number is undefined, but reducing the skewness is important in order to satisfy the assumption of normality for parametric tests such as linear regression. The data were therefore transformed by adding the absolute value of the most negative score to all numbers, and then conducting a log transformation.

The countries and their rankings across the three methods for the years 1978, 1988, 1998, and 2008 are listed in Appendix A-D. The data are first sorted by the

Babones GDPpc method, which was chosen for sorting solely on its position as the first column of countries. The descriptive statistics and bivariate correlations for the different ranking methods appear in Table 4.1 below.

Table 4.1 Descriptive Statistics and Bivariate Correlations, World-System Power Measures

N/n= 502/77*	Mean	SD**	1	2
1.Babones	1.98	.85		
2.Mahutga & Smith	2.32	.73	.62	
3. Kentor Modified	2.15	.80	.83	.72

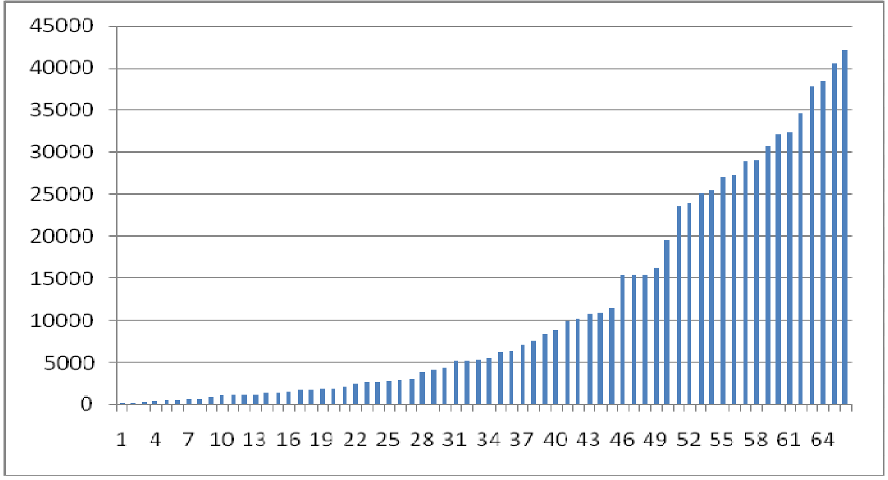
* N = the number of observations, n = the number of countries

* *Standard deviations are reported for the overall variation

The relatively high correlation between the Babones and Kentor Modified methods is for the large part driven by GDPpc; it is the entire basis for the Babones calculation, 1/3 of the Kentor calculation, and not included in Mahutga and Smith's operationalization. The Mahutga and Smith ranking also produces more countries in the periphery than the other rankings, which lowers the average rank.

Returning to the first hypothesis, H4.1, I plotted the distributions of countries in my dataset using the scores for each method. The results appear in the figures below. In Figure 4.5, the distribution of GDP per capita, the Babones method, reveals some "steps," Figure 4.6 reveals that Mahutga and Smith's method is relatively smooth, and the modified Kentor power data in Figure 4.7 has a few very large scores at the top, a set of relatively high scores, and then a drop to a relatively smooth range of values.

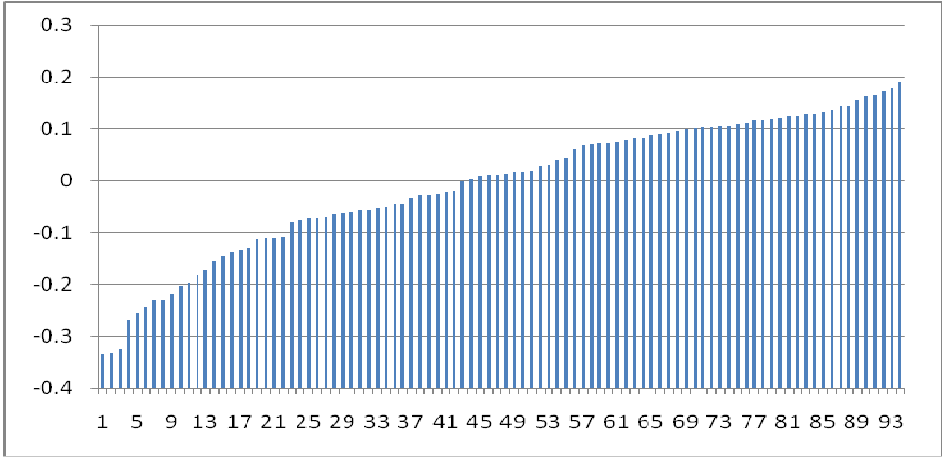
Figure 4.5 GDP per Capita Distribution, 2008*



Source: World Bank WDI, 2010

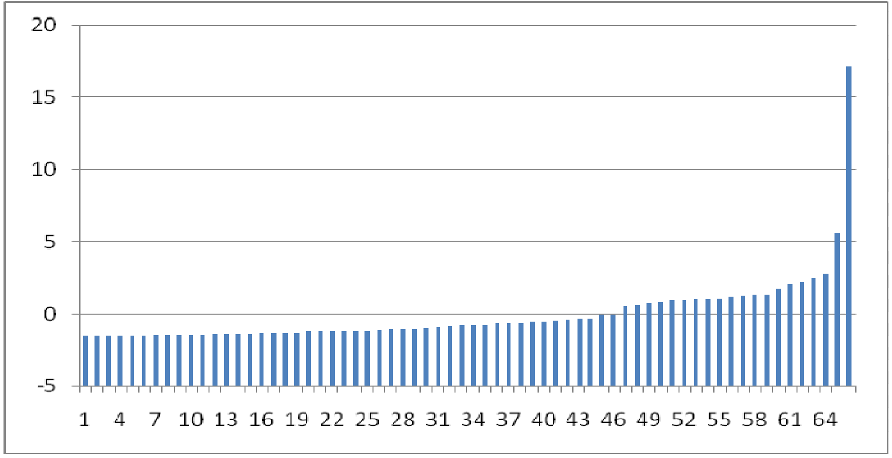
* GDP per capita is measured on a foreign exchange (FX) basis

Figure 4.6 Mahutga and Smith Country Distribution, 2000



Source: Mahutga and Smith, 2011

Figure 4.7 Kentor Power Modified, 2008



Source: Lawrence dataset

For the Kentor power method, it could be argued that there are points in which discrete shifts do occur in the data, most noticeably at the highest end in the Kentor power methodology (the United States is the highest with a score of 17.186, Japan is next with 5.59, while the next highest is the United Kingdom at 2.84), but also between Spain at 0.50 and Saudi Arabia at -.03 (the break around #46 on the chart). After that point, which could be a discrete jump between the core and semiperiphery, the data do not reveal as clear of a distinct semiperiphery-periphery break. The largest difference is between Algeria at -1.25 and Tunisia at -1.29 (between #19 and #20 on the chart). Overall, then, only weak support for hypothesis 4.1 is found.

4.4 MEASURING ENERGY USE

Energy in this study comes from sources of primary commercial energy, such as oil, coal, natural gas, nuclear, and renewables. Data on energy use was obtained from two sources. For the period 1971-2008—the years encompassing the period of study in this chapter—energy estimates were obtained from the International Energy Agency (IEA)

(2010b). Energy consumption, my main energy use variable, is calculated from the IEA as:

$$\text{Consumption} = \text{Production}+\text{Imports}-\text{Exports}+/-\text{StockChanges}$$

with each of the components measured in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis. This amount for consumption includes the amount before it is transformed into other sources of energy, such as electricity for consumer use, and does not subtract losses during transformation—such as when there is an energy loss as coal is burned to produce electricity. This measure of consumption is the "Total Primary Energy Supply" for the IEA, which differs from IEA's "Total Final Consumption" estimate, which subtracts transformation losses. Consumption as used here more accurately reflects the amount of energy actually used by each country, even if it is "lost" during transformation.

4.5 INDEPENDENT VARIABLES

*Industry Value Added as a Percentage of GDP (*INDUSTRY*)*. According to the World Bank World Data Indicators from which it comes, industry value added of GDP is the value of the net output of industrial production for an economy, divided by the total net output of the economy. The sectors include mining, manufacturing, construction, electricity, water, and gas (World Bank 2010: 229-233). This is a common control variable in models of growth (cf. Firebaugh and Beack). Industry value added is particularly important when considering energy due to the energy intensity of most forms of industrial production.

Tests for skewness (Shapiro-Wilk W test for normal data, swilk in Stata) and normality plots (histogram, pnorm and qnorm in Stata) were conducted on the independent variables. The tests for INDUSTRY demonstrated that the degree of skewness varied over time, from very little to moderate positive skew. No adjustment was made for skewness on INDUSTRY, however, the first difference is the ratio of change in order to maintain comparability across different size bases (Jackman 1980).

Secondary School Enrollment (SCHOOL). Education is deemed to be an important factor in economic growth by a "new neo-classical" theories of developmental economics and is commonly used in models of national and international development (Firebaugh and Beck 1994). A key component of human capital and a world polity measure, this is "the gross enrollment ratio, which is the ratio of total enrollment in secondary education, regardless of age, to the population of the age group that officially corresponds to secondary education" (World Bank 2010: 77).

Tests for skewness, as discussed for industry value added, revealed no consistent significant skew, therefore no adjustment was made for skewness on SCHOOL, however, the first difference is the ratio of change in order to maintain comparability across different size bases (Jackman 1980).

Trade level (TRADE). A common measure in macro-comparative research, trade level is the sum of exports and imports of goods and services, measured as a share of gross domestic product (World Bank 2010). Tests for skewness indicated positive skew (2.53), the estimates were therefore (natural) log transformed.

4.6 HYPOTHESES AND MODELS

Hypotheses

The data are analyzed with a set of hypotheses. Within the theoretical model for energy use, the first relationship posits that a society's power will increase with its amount of energy use:

H4.2: A country's power has a positive relationship its energy consumption.

The theory also predicts a positive feedback loop from the level of power to energy control and transformation, as more power allows for greater energy control and transformation, with the same 5-year lag. For example, the more GDP as society has the more energy they can purchase – import – and also the more advanced technology that can be purchased and then utilized to increase consumption as an input into industrial production.

H4.3: A country's energy consumption has a positive relationship with power

From this hypothesis, it is predicted that the core will have the highest amounts of energy and power, followed by the semiperiphery, and then the periphery.

H4.4: Countries in the core have higher levels and growth rates of power than the semiperiphery, and the semiperiphery has higher levels and growth rates of power than the periphery

To test for theories of semiperipheral development, an alternative hypothesis examines if growth in the semipheriphery is outpacing the core, while the latter is still outpacing the underdeveloped periphery:

H4.5: Countries in the semiperiphery have higher growth rates in energy consumption and power than the core, while the core has higher growth rates in energy consumption and power than the periphery

These hypotheses suggest not economies of scale (Firebaugh 1993) but advantages of scale in the acquisition of energy and the use of that energy for higher value-added means. However, following Tainter (1988), there could be diminishing returns from larger scales of income and power.

4.7 METHODOLOGY

The observations for the analysis were selected based on availability for the variables and time periods in question. For the period 1973-2008, that resulted in 502 total observations, in five year intervals, across 77 countries in total. It should be noted that although there were 77 countries that had estimates for all of the variables for at least two contiguous time periods, not all countries were available in any given time point, creating an unbalanced panel. The 77 total countries in my study represent from 24 to 79.6 percent of the total world population and from 69.4 to 93.4 percent of total world GDP, both from the World Bank World Development Indicators database (2010). The countries in my dataset also include from 55 to 82 percent of total world energy consumption, as produced by the International Energy Agency (2010). The relatively low percentages in 1973 reflect the unavailability of estimates for large world contributors such as China and India, with the Former Soviet Union/Russia unavailable for all of the time points. These statistics are reported below in Table 4.2, below, while the countries in 10-year time points are listed in the Appendices A-D.

Table 4.2 Country Counts and Percentage of World GDP and Energy Consumption

	1973	1978	1983	1988	1993	1998	2003	2008
# of countries	36	55	61	65	71	70	74	65
% of world population	24.00	49.89	75.22	76.00	77.53	77.33	79.57	74.56
% of world GDP	69.38	90.41	91.06	90.88	93.14	93.38	93.53	89.25
% of world energy consumption	55.07	64.55	70.73	71.40	77.19	80.29	81.95	76.25

As is common in international macro-comparative research, the countries that are not present in the study are systematically biased against countries in the semiperiphery and periphery that were not reporting annual data to the World Bank and IEA (such as Russia and Cuba and many small and poor countries) – which have relatively consistent and longer-term coverage for wealthy, core countries. Since the sample is non-random, and approximates the full population of countries for the key variables, this violates the logic of the sampling distribution upon which inferential statistics are based, calling into question the meaning of significance testing for what are essentially descriptive statistics (Mahutga 2008; Beckfield 2005). One suggested means to handle this situation is to treat the observations as a sample "quasi-randomly drawn from the (unknown) universe of past, present and future cases" (Ebbinghaus 2005: 135; as quoted in Mahutga 2008: 80). For the statistical analyses reported in this dissertation, I will indicate statistical significance according to the standard probability values from two-tailed t-tests, with a minimum confidence level of 95% (p<..05). But the values for the coefficients can also be analyzed by the reader as important effects for the observations in the study, particularly when they are relatively large on a standardized basis, although the actual effect may not be different from zero in the full population.

Statistical analysis is conducted using Stata (Version 11) software to estimate ordinary least-squares (OLS) regression analysis of panel data (cf. Frees 2004; STATA 2007; Wooldridge 2002). The sample size was maximized by using countries with available data, adding and subtracting countries as data is available. This creates unbalanced panels, which can be handled in the regression estimation (Jorgenson 2007).

First Difference Models

First Difference (FD) models are utilized for their ability to remain robust in the presence of non-stationarity, a problem that compromises Fixed effects (FE) models. Both can be employed to correct for heterogeneity bias, which can occur in the presence of unmeasured variables that are time-invariant for each case (country in this analysis), but that vary across cases within each year, such as geography (Jorgenson and Clark 2010; Jorgenson, Clark, and Kentor 2010; see also Jorgenson, Dirk, & Mahutga 2007; Mahutga 2008; see also Allison 2009; Frees 2004; Greene 2000; Hsiao 2003; Wooldridge 2002).

The general first-difference equation is:

$$(y_{it+1} - y_{it}) = (x_{it+1} - x_{it})\beta + (z_{it+1} - z_{it})\beta + (\varepsilon_{it+1} - \varepsilon_{it})$$

which is equivalent to:

$$\Delta y_{it} = \Delta x_{it}\beta + \Delta z_{it}\beta + \Delta\varepsilon_{it}$$

In the models above, y is the dependent variable observed for unit i at time t, x is a vector of time- and unit-variant regressors, z represents a vector of unobserved time-invariant, but-specific variables, and ε is the error term. In the models utilized in this study, the unit of analysis, *i*, is a country. Because *z* represents variables that do not differ over time but that do differ by country—such as topography and longitude and latitude—there is no change to estimate, therefore they are removed during the differencing process and are not present in the model predicting the difference in the dependent variable. Because they are removed from the model, the time-invariant, unit-specific variables are allowed to be arbitrarily correlated with *x*, thereby not violating the assumption of uncorrelated errors and indepdendent variables; i.e., $\text{cov}(\varepsilon, x) = 0$ (Firebaugh and Beck 1994; Mahutga 2008).

I am using difference models here because of their strength in panel analysis not only for their ability to eliminate spurious results from omitted time-invariant variables and also from time trends (Babones 2009). Since the time periods are the same for all difference periods, the effect of time is held constant. Indeed, Babones (ibid) argues that difference models are often more appropriate for long-term, macro-comparative analysis than the more popular fixed and random effects models due to the this strength, despite their relatively low power for finding statistical significance.

Growth Rates, Economies of Scale, and "Scale Entropy"

The estimates for the variables are logged[9] before differencing. Log transforming the variables in a difference model produce growth models of change (Firebaugh 1983;

---

[9] The natural logarithmic transformation, ln(x) generates a value indicating the exponent to which the constant *e* (≈ 2.72) must be raised to equal x. The natural log of a value below zero is undefined, the natural log of values between 0 and 1 is negative, and is positive for numbers greater than zero. Since energy consumption per capita (thousand tonnes of oil equivalent (ktoe) divided by the population) produces pre-transformation values that are between 0 and 1 for all of the countries, the pre-log estimates had 10000

Jackman 1980). This reduces the problem of comparability of growth that occurs since, at the same rate of growth, larger countries will have larger absolute rates of growth. This correlation with the level (i.e., size) of the variable increases the possibility of heteroscedasticity of the errors due to skew since the absolute levels will differ by size and time. Concerns of heteroscedasticity aside – my use of robust errors clustered on the country adjusts for heteroscedasticity, as indicated later in this section – the advantage of differences of logs generates a rate of change that is comparable across countries of different size. According to Jackman (1980: 6) "...since the difference in the logarithms on the left-hand side [log Y_t-log Y_0] is equivalent to the logarithm of the ratio of Y_t to Y_0, this specification identifies percentage rates of growth, as conventionally defined." To verify the accuracy of this statement, I ran the bivariate correlation (Pearson's r) on the difference of logs (($\ln(Y_t) - \ln(Y_{t-1})$) and the log of the ratio of Y_t to Y_{t-1} (ln(Yt / Yt-1)), using the variable GDPpc for Y. The correlation is a perfect, r = 1.00. Moreover, the correlation of the logged ratio with the logged lag of the level (($\ln(GDPpc_{t-1})$) is very low, r = .0358, which, then, is equal to the correlation of the latter with the difference of the logs, r = .0358. The difference of logs is not exactly the same as the typical percentage change ((New-Old)/Old), particularly for large positive or negative changes, but it is a close approximation in most situations. The correlations were over .90 for tests on my variables, with the exception of FDI, which remained high at .71, but had a lower correlation due to some large declines in FDI at various points for some countries. Nonetheless, the log transformation was still valuable due to the significant positive skew

---

added to prevent confusion about signs; the resultant log transformation produced only positive values but the scale of difference remained approximately the same.

of the estimates.

Consistent with the common treatment of long-term panel-data structure, I included a lagged level dependent variable as a predictor in the models. This provides a basis for assessing reciprocal causality since the coefficient on the independent variable is independent of the effect of the lagged dependent variable on itself (Chase-Dunn 1975). Since I am estimating a first-difference growth model of the panel data, these are not "pure" difference/change models then since the lagged variable are not differenced; however, the inclusion of the lagged level variable controls for the size of the variable at time t-1, which can uncover floor or ceiling effects; i.e., larger economies cannot grow infinitely large and smaller economies cannot get much smaller (Firebaugh and Beck 1994). As Firebaugh (1983) found, countries with larger economies had slower growth rates, an effect of "scale entropy" that countered the economies-of-scale arguments, but that is suggested by Marxist Crisis Theory. A negative coefficient on a lagged level dependent variable when the dependent variable is a growth rate, then, is an indication of diseconomies to scale while a positive coefficient would indicate that larger size produces greater growth. Since my theoretical model asserts a positive feedback loop between power and energy use, including the lagged variables is warranted. For the same substantive reasons, the lagged levels of each of the independent variables are also included.

Multicollinearity. The correlations reveal that multcollinearity is a concern given the high correlation between the levels of GDP pc and Energy Consumption pc for all countries (r = .91) and for Mahutga and Smith's semipheriphery (r = .92) and periphery (r

= .85). Likewise, multicollinearity is a potential issue for Kentor Power Modified and Energy Consumption pc, both for all countries (r = .85). The correlations are greatly reduced when the countries are split into the core, semiperiphery, and periphery for all of the other rankings. But these also are only problematic for the level variables since, as discussed earlier, the high correlations disappear when using the difference calculation. For example, although not a muticollinearity issue anyway since the two variables are not both on the right side of a regression equation, the highest correlation between the level variables that occurred in the Mahutga and Smith semipheriphery is a much smaller correlation between differences, (r = .550). Multicollinearity can cause three main problems: 1) it makes it difficult to estimate the independent contribution of the variables that have high correlation since they are each likely accounting for the same variance in the outcome; 2) the size of the standard errors increase, creating unstable coefficients; and, 3) it is difficult to assess the importance of the highly correlated predictors (Field 2009:223-4). To test for the presence of multicollinearity, I used the variance inflation factor (VIF) diagnostic test (vif in Stata). There are varying ranges for indicators of concern, ranging from above a maximum VIF of 5 to above 10 with averages above 1 possibly concerns (Field 2009).

Testing the VIF level reveals maximum VIFs approaching 10 for Mahutga and Smith's semipheripheral countries in the models containing the control variables (VIF = 8.85 for (ln) Energy Consumption pc, with a VIF of 7.45 for (ln) GDP pc, with an average VIF of 3.24 (models explained below). The second highest maximum VIF came for the second model for all countries, with the VIF for (ln) GDP pc of 8.08 and (ln)

Energy Consumption pc VIF of 7.18, with an average VIF of 2.92. All other runs with different rankings of countries produce much smaller VIFs, below 4, but the averages remain over 1. This may produce invalid results, as mentioned.

Moreover, the VIFs increase when the dummy variables are added, rising to a maximum of 11.49 for the lag level of GDP pc and 8.40 for the lag of energy consumption pc for the runs including dummies for Babones rank (average VIF = 3.55). This is due to the Babones ranking being based on GDP pc, but it raises even more concern about multicollinearity. To address this increasing concern, I ran a test to see if there would be a noticeable effect of dropping the energy consumption pc level, which highly correlated with GDPpc but is almost never significant in any of the models. The result proved interesting. For the Babones dummy run on all countries, the maximum and average VIF dropped appreciably for the model after dropping the lagged level of energy consumption pc, decreasing to 8.58 on the level of GDP pc (although still relatively high due to the Babones dummies) and 2.67, respectively. The R-squared value only decreased slightly, from .2872 to .2868; i.e., the variance explained by the model dropped by .04 percentage points.

I then generated a Bayesian Information Criterion (BIC) test (estat ic as a post-regression test in Stata 11) of the strength of the model, a test developed to measure the “goodness of fit” for the model to the observations, using maximum likelihood criteria for a given the number of observations and parameters estimated. The BIC formula is:

$$BIC = -2*\ln(likelihood) + \ln(N)*k$$

where N are the number of observations and k are the number of parameters.

The smaller the BIC value, the better the fit of the model to the data (Stata 11 help)[10]. The BIC for the model with the lag level of energy consumption pc dropped is -509.71, while the model including the variable has a BIC of -503.92 (again, the lower, or the more negative in this case, the better fitting model).

The effect on the coefficients reveals that multicollinearity was having an effect on the standard error and coefficients for many of the variables, although it was small and did not change the results of the t-tests. However, for the lagged level of GDP pc it did produce significant retults (p=.019) where it previously had not (p=.061). Similar effects were found for the other all countries models.

Conversely, dropping the lagged level of GDPpc in the Babones dummy test case reduces the R-squared to .2634, a drop of an additional 2.34 percentage points than when dropping energy consumption pc in the prior test. And although the VIF max dropped to 6.27, with an average of 2.37, the BIC is lower at -496.17. This demonstrates that, while correlated, the lagged level of GDP pc is a better predictor of the current level of GDP pc than the lagged energy consumption pc. It should be noted, however, that the coefficient for the lagged level of energy consumption pc becomes statistically significant (p=.021)_ and has a larger negative coefficient (-.040 compared to -.008) when you drop its co-correlate GDP pc. So the larger the prior level of energy consumption pc, the smaller the

---

[10] Stata 11's "Help" on the Baysenian Information Criterian formula suggests that Akaike information criterion (AIC) may be better due to concerns about what "N" is in the BIC calculation. If N equals the number of observations, which Stata assumes, then it can produce a conservative estimate compared to an N of number of groups, such as in panel data. When the correlation between observations within groups is high, as it is in panel data, then using the number of groups may be better. AIC does not use N at all (AIC = -2*ln(likelihood) + 2*k), therefore it should at least be considered along with BIC, if not using AIC only. In this case, AIC is also better for the model with energy consumption dropped, -544.15 compared to -542.40 when it is included.

growth rate, a ceiling or scale entropy effect. Note: the lag level of FDI also becomes statistically significant (p=.020) and the coefficient increases (.114).

Dropping the lagged level of energy consumption pc, then, demonstrates the problematic effects of multicollinearity. Similar issues occurred in almost all of the variations of test runs, with the exception of the Mahutga and Smith semiperiphery, where dropping the lagged level of energy pc actually lowered the BIC from -298.61 to -281.59 and the R-squared from .4924 to .4162. The key difference for these countries is the significant effect of energy consumption on economic growth. Even when the lagged level of GDPpc is included, the lagged level of energy consumption pc is still significant (p=.009) and has a *positive* coefficient (the only time that is the case when controlling for other variables). The positive coefficient indicates that the larger the level of energy consumption pc, the *larger* the GDP pc growth rate. Energy use is being transformed into economic growth in the semiperiphery. These are countries that are growing rapidly, like China, and consuming energy to do so. This is likely to be an effect of industrialization.

Despite this finding, due to the substantive reasons to drop the lagged level of energy consumption pc in the other models, I am removing it from the models and runs that follow. There were non-significant but negative coefficients on the lagged level in almost all cases, indicating that the typical effect is for larger levels of energy use to have lower growth rates, as expected. The results of the tests are available upon request.

Time lags. There is likely to be a time lag between the consumption of energy and associated economic and power effects – the energy must be transformed into value (e.g. the use of labor, machinery, and technology to create raw materials, goods, and services that can be sold), which takes time. In the regression models that follow, 5 years was selected as the difference and lag period. This occurred for two reasons; first, 5 years is a common lag time in quantitative, cross-national studies (see Jorgenson, Dick, & Mahutga 2007); second, lags of 10, 15, and 20 years were found to weaken the effectiveness of the models—i.e., the R^2 and coefficients were lower and were only significant for the key independent variable for 10-year difference and lag periods, and then at a much smaller coefficient and lower level of significance compared to the 5-year period.

Dummy variables. Country-rank “dummy variables” are employed in the first sets of the regression runs. These variables are dichotomous (0/1), with the coefficient on the dummy variables indicating the predicted value for the variable in relation to the constant, which, as the intercept, is the value for the dependent variable when all other coefficients are zero (Kohler and Kreuter 2005). In this study, dummy variables were created for countries ranked as core and periphery by the different methods. The semiperiphery is omitted as the reference category (always 0), a decision made since it is in the middle of the three rankings, offering one-level comparisons (core to semiperiphery and periphery to semiperiphery) and thus the ability to determine if there are significant differences between the tiers; i.e., if the core were the reference category, a direct estimation of the difference between the semiperiphery and periphery would not be possible.

Slope dummy variables were also employed. Slope dummy variables are the combination of a categorical dummy variable and a continuous measurement variable. The advantage of slope dummy variables is that you can estimate the differences in the slope of a given independent variable compared to the base category of the dummy variable (Hamilton 2004: 180-181). In the models that follow, I include slope dummy variables of the world-system zone and energy consumption per capita, as follows:

Core Dummy X first difference of energy consumption per capita

Periphery Dummy X first difference of energy consumption per capita

The semiperiphery remains the base. The coefficient for each of the slope dummy variables will then be its difference in energy consumption compared to the semiperiphery, while the semiperiphery's slope is indicated by the term energy consumption per capita.

I also tested the effects of dummy variables for oil importing and oil exporting countries, in order to test for "mean dependence" effects based on oil; i.e., oil exporting countries as a group may differ in a similar way from oil importing countries. This form of statistical control is recommended by Babones (2009) explicitly for this situation. The results when including the "oil dummies" were not significantly different then when the dummies were excluded. For parsimony's sake, they were removed as variables in the models.

Error Structure. Robust cluster standard errors corrections were employed, clustered on the country identification number (a unique non-zero positive integer assigned to each country). The option of robust standard errors does not require the assumption of homoskedasticity of the error terms. Clustering occurs when the observations within groups are correlated with each other but are not correlated between groups, which violates the assumption that the errors are "iid," or independent and identically distributed. This is often the case in panel data. While first difference will adjust for the effects of unmeasured time invariant variables, the use of robust clustering on group (in this case country) adjusts for serial correlation. Failure to adjust for clustered errors can lead to biased standard errors and thus invalidate significance testing (Nichols and Schaffer 2007; Wooldridge 2002).

4.8 MODELS

For each dependent variable, there are two models. Model one is the baseline with includes the lagged dependent variable, Power, as a predictor and the first difference for the key independent variable, energy consumption per capita. Model 2 adds the first differences of the control variables to the baseline model.

Baseline Models

The general formula for the baseline models is:

$$(Y_{it} - Y_{it-5}) = Y_{it-5} + (X_{it,} - X_{it-5}) + e_{it}$$

where Y is the dependent variable and X is the key independent variable, and e is the error term

For the prediction of world-system power, the baseline model is:

$$(P_{it} - P_{it-5}) = P_{it-5} + (EC_{it} - EC_{it-5}) + e_{it}$$

where P is power, assessed using Kentor Modified power and EC is energy consumption.

Model 2

The second model includes the control variables. The general formula is

$$(Y_{it} - Y_{it-5}) = (X_{it,\,1\ldots k} - X_{it-5,\,1\ldots k}) + e_{it}$$

where Y is the dependent variable and $X_{1\ldots k}$ are the independent variables 1 to the kth parameter, and e is the error term

For predicting power, the model is:

$$(P_{it} - P_{it-5}) = P_{it-5} + (EC_{it}\text{-}EC_{it-5}) + (IND_{it}\text{-}IND_{it-5})$$

$$+ (SC_{it}\text{-}SC_{it-5}) + (TR_{it}\text{-}TR_{it-5}) + e_{it}$$

where IND is industry value added as a percentage of GDP, SC is secondary school enrolment, and TR is trade as a percentage of GDP.

4.9 RESULTS

Tables 4.3 & 4.4, below, report the means, standard deviations, and bivariate correlations (pairwise) for the variables analyzed. Table 4.3 includes the level of the variable while Table 4.4 the first differences (“D) and 5-year lags. Each table reports results for all of the countries in the dataset, and for the countries ranked by each of the three methods (Babones, Mahutga and Smith, and Kentor Modified).

Table 4.3 Descriptive Statistics and Bivariate Correlations*

	Mean	SD***	1	2	3	4	5
All countries							
(N/n =502/77)**							
1.GDP pc	8.22	1.50					
2.Energy Consump. pc	2.67	1.04	.91				
3.Industry %	3.45	.326	.23	.31			
4. Secondary School %	4.10	.573	.78	.74	.21		
5. Trade %	4.08	.573	.15	.20	.10	.18	
6. Kentor Power Mod.	-.577	1.60	.92	.85	.28	.72	-.07

	Mean	SD***	1	2	3	4	5
Core							
Babones							
(N/n=186/29)							
1. GDP pc	9.78	.41					
2. Energy Consump. pc	3.74	.43	.48				
3. Industry %	3.45	.28	-.25	.20			
4. Secondary School %	4.55	.26	.35	.24	-.40		
5. Trade %	4.14	.57	-.02	.11	-.11	-.01	
Mahutga & Smith							
(N/n = 77/11)							
1. GDP pc	9.92	.29					
2. Energy Consump. pc	3.84	.35	.35				
3. Industry %	3.42	.18	-.52	-.27			
4. Secondary School %	4.58	.16	.40	.38	-.52		
5. Trade %	3.92	.59	-.26	.11	-.25	.46	
Kentor Power Mod.							
(N/n = 128/33)							
1. GDP pc	9.89	.53					
2. Energy Consump. pc	3.79	.40	.58				
3. Industry %	3.46	.26	-.37	-.02			
4. Secondary School %	4.57	.23	.38	.28	-.45		
5. Trade %	4.05	.57	.08	.04	-.22	.05	
6. Kentor Power Mod.	1.26	.53	.32	.28	-.05	-.11	-.65
Semi-Periphery							
Babones							
(N/n = 142/31)							
1. GDP pc	8.27	.51					
2. Energy Consump. pc	2.59	.64	.69				
3. Industry %	3.59	.30	.20	.46			
4. Secondary School %	4.19	.33	.35	.39	-.02		
5. Trade %	4.11	.67	.03	.32	.07	.29	
Mahutga & Smith							
(N/n = 188/32)							
1. GDP pc	8.61	1.31					
2. Energy Consump. pc	2.84	.87	.92				
3. Industry %	3.47	.25	-.19	-.05			
4. Secondary School %	4.31	.41	.80	.84	-.05		
5. Trade %	4.03	.65	.32	.34	-.18	.35	
Kentor Power Mod.							
(N/n =172/43)							
1. GDP pc	8.66	.89					
2. Energy Consump. pc	3.01	.76	.74				
3. Industry %	3.56	.31	-.04	.24			
4. Secondary School %	4.30	.36	.56	.50	-.18		
5. Trade %	4.09	.68	.42	.55	.17	.37	
6. Kentor Power Mod	-.093	.54	.60	.48	-.09	.23	-.07

	Mean	SD***	1	2	3	4	5
Periphery							
Babones							
(N/n = 174/33)							
1. GDP pc	6.51	.74					
2. Energy Consump. pc	1.60	.42	.60				
3. Industry %	3.33	.34	.44	.51			
4. Secondary School %	3.53	.56	.47	.39	.34		
5. Trade %	3.99	.48	.28	.17	.27	.16	
Mahutga & Smith							
(N/n = 237/43)							
1. GDP pc	7.36	1.26					
2. Energy Consump. pc	2.15	.95	.85				
3. Industry %	3.44	.40	.59	.62			
4. Secondary School %	3.77	.62	.66	.56	.36		
5. Trade %	4.17	.48	.40	.44	.37	.35	
Kentor Power Mod.							
(N/n = 202/39)							
1. GDP pc	6.79	.85					
2. Energy Consump. pc	1.67	.43	.72				
3. Industry %	3.35	.35	.44	.50			
4. Secondary School %	3.62	.58	.59	.51	.31		
5. Trade %	4.09	.47	.31	.38	.23	.31	
6. Kentor Power Mod.	-2.16	1.03	.88	.60	.49	.48	.08

* All variables are log transformed (natural)

** N = the number of observations, n = the number of countries

* **Standard deviations are reported for the overall variation

Table 4.4 Differences & Lags,† Descriptive Statistics and Bivariate Correlations*

	Mean	SD***	1	2	3	4	5	6	7	8
All Countries										
(N/n = 420/74)**										
1. D. GDP pc	.09	.14								
2. D. Energy Consump. pc	.07	.17	.36							
3. D. Industry %	-.01	.14	.22	.12						
4. D. Secondary School %	.10	.14	-.08	.12	.06					
5. D. Trade %	.08	.23	.18	.07	.45	-.07				
6. D. Kentor Power Mod.	-.01	.20	.70	.27	.12	-.03	.06			
7. Lag GDP pc	8.19	1.49	.04	-.04	-.22	-.31	-.01	.07		
8. Lag Energy Consump. pc	2.64	1.04	.03	-.11	-.19	-.31	-.00	.04	.92	
9. Lag Kentor Power Mod.	-.55	1.58	.10	-.01	.23	-.29	.02	.06	.92	.86
Core										
Babones										
(N/n = 159/28)										
1. D. GDP pc	.09	.11								
2. D. Energy Consump. pc	.06	.14	.15							
3. D. Industry %	-.05	.08	.31	.00						
4. D. Secondary School %	.05	.12	-.28	.21	-.24					
5. D. Trade %	.07	.14	.03	-.19	.21	-.22				
6. Lag GDP pc	9.72	.41	-.18	-.32	.07	-.23	-.02			
7. Lag Energy Consump. pc	3.70	.45	-.23	-.44	.08	-.18	.05	.56		

	Mean	SD***	1	2	3	4	5	6	7	8
Mahutga & Smith										
(N/n = 67/11)										
1. D. GDP pc	.09	.05								
2. D. Energy Consump. pc	.02	.08	.48							
3. D. Industry %	-.06	.05	.34	.20						
4. D. Secondary School %	.04	.09	-.15	.11	-.13					
5. D. Trade %	.08	.13	-.20	-.27	.18	-.16				
6. Lag GDP pc	9.87	.28	-.15	.03	-.08	-.20	.17			
7. Lag Energy Consump. pc	3.82	.35	-.14	-.19	.03	-.11	.16	.36		
Kentor Power Modified										
(N/n = 112/23)										
1. D. GDP pc	.11	.10								
2. D. Energy Consump. pc	.03	.12	.22							
3. D. Industry %	-.04	.08	.30	.07						
4. D. Secondary School %	.04	.12	-.16	.18	-.28					
5. D. Trade %	.08	.14	-.01	-.10	.19	-.28				
6. D. Kentor Power Mod.	.01	.10	.80	.06	.19	-.03	-.09			
7. Lag GDP pc	9.81	.60	-.54	-.27	-.03	-.27	.04	-.42		
8. Lag Energy Consump. pc	3.76	.43	-.37	-.42	.09	-.28	.08	-.27	.65	
9. Lag Kentor Power Mod.	1.24	.55	-.25	-.15	-.16	-.09	.03	-.29	.39	.32
Semi-Periphery										
Babones										
(N/n = 117/29)										
1. D. GDP pc	.11	.14								
2. D. Energy Consump. pc	.09	.16	.52							
3. D. Industry %	.01	.14	.19	.20						
4. D. Secondary School %	.10	.12	-.19	-.05	-.00					
5. D. Trade %	.10	.22	.12	.02	.50	.03				
6. Lag GDP pc	8.20	.52	-.20	-.06	-.00	-.21	.04			
7. Lag Energy Consump. pc	2.54	.62	-.06	-.04	.09	-.26	.02	.67		
Mahutga & Smith										
(N/n = 158/31)										
1. D. GDPpc	.13	.11								
2. D. Energy Consum. pc	.10	.13	.55							
3. D. Industry %	-.01	.10	.18	.20						
4. D. Secondary School %	.08	.11	-.02	.17	.06					
5. D. Trade %	.11	.19	.04	-.02	.29	.01				
6. Lag GDP pc	8.56	1.29	-.27	-.20	-.20	-.34	-.09			
7. Lag Energy Consump. pc	2.81	.86	-.12	-.23	-.15	-.37	-.05	.91		
Kentor Power Modified										
(N/n = 146/41)										
1. D. GDP pc	.10	.14								
2. D. Energy Consump. pc	.11	.22	.33							
3. D. Industry %	-.03	.13	.33	.08						
4. D. Secondary School %	.09	.12	-.19	.13	-.03					
5. D. Trade %	.08	.22	.21	-.06	.52	.02				
6. D. Kentor Power Mod.	.02	.20	.66	.35	.20	-.07	.01			
7. Lag GDP pc	8.55	.93	-.27	-.02	-.13	-.16	-.18	-.16		
8. Lag Energy Consump. pc	2.90	.77	-.26	-.14	-.11	-.21	-.20	-.20	.76	
9. Lag Kentor Power Mod.	-.14	.59	-.34	-.08	-.21	-.02	-.09	-.39	.65	.55

	Mean	SD***	1	2	3	4	5	6	7	8
Periphery										
Babones										
(N/n = 144/31)										
1. D. GDP pc	.065	.18								
2. D. Energy Consump. pc	.066	.21	.37							
3.D. Industry %	.03	.18	.25	.10						
4. D. Secondary School %	.15	.16	.11	.15	.07					
5. D. Trade %	.07	.30	.25	.16	.50	-.06				
6. Lag GDP pc	6.48	.73	-.03	.08	-.01	-.04	-.08			
7. Lag Energy Consump. pc	1.55	.41	.05	-.15	-.00	.00	.00	.59		
Mahutga & Smith										
(N/n = 195/39)										
1. D. GDP pc	.05	.18								
2. D. Energy Consump. pc	.06	.22	.29							
3. D. Industry %.	.01	.18	.28	.08						
4. D. Secondary School %	.13	.17	-.03	.11	.01					
5. D. Trade %	.05	.27	.22	.11	.55	-.06				
6. Lag GDP pc	7.31	1.24	.02	.09	-.12	-.13	-.08			
7. Lag Energy Consump. pc	2.09	.93	-.03	-.04	-.10	-.14	-.07	.86		
Kentor Power Modified										
(N/n = 162/36)										
1. D. GDP pc	.06	.16								
2. D. Energy Consump. pc	.06	.15	.47							
3.D. Industry %	.03	.17	.22	.19						
4. D. Secondary School %	.14	.16	.09	.10	.07					
5. D. Trade %	.07	.27	.20	.25	.49	-.06				
6. D. Kentor Power Mod.	-.04	.26	.71	.26	.12	.05	.10			
7. Lag GDP pc	6.74	.82	.08	.08	.02	-.06	.00	.09		
8. Lag Energy Consump. pc	1.63	.42	.07	-.07	.12	-.01	.08	.03	.72	
9. Lag Kentor Power Mod.	-2.16	1.00	.13	.17	.04	-.10	.01	.05	.89	.62

† D = 5-year difference of the estimates, Lag = 5 year lag of the estimates
* All variables are log transformed (natural) before differencing
** N = the number of observations, n = the number of countries
* ** Standard deviations are reported for the overall variation

The statistics reveal some interesting results. First the core, semi-periphery and periphery maintain a distinct ordering in their means for the levels of GDP per capita and energy consumption per capita, with the highest levels in the core and the lowest in the semi-periphery—and this holds regardless of the ranking methodology used. This is not unexpected, of course; the core countries are considered to be core because they have the highest levels of success, regardless of how that success is measured (GDP per capita, trade centrality, or a composite power measure) and, as my theory predicts, they achieved and maintain their core membership through energy use. (Mahutga and Smith’s (2011) trade network measure does not directly include GDP per capita, as the other methods do, but there is support here for their claim that GDP per capita is effected by trade network structure.) Therefore, energy use per capita would be expected to be highest in the core countries where there are the highest levels of development since large amounts of energy are consumed for transportation use and electricity production, in addition to the industrial production more often associated with countries in the semiperiphery, with lowest levels of industrialization and other energy use in the periphery. Again, this expected ranking holds

It should be noted that the GDP per capita and energy consumption per capita ordering holds, with the exception of Babones periphery energy consumption, when both variables are measured for total use; i.e., prior to dividing by population size. However, the mean energy consumption for Babones’s periphery is just slightly higher than for the semiperiphery (9.53 and 9.50, respectively, log transformed). The difference stems mostly from the location of India, whose 2008 total energy consumption of 626531.1 kilotonnes of oil equivalent (13.35 logged) is the third highest in the sample (behind the United States and China), but whose GDP per capita of 724.38 (6.58 logged) is seventh from last (between Nicaragua and Pakistan). Since Babones’s ranking methodology uses GDP per capita, India is thus ranked as a peripheral country, increasing the average relative to the semiperiphery, where it is ranked in Mahutga & Smith and Kentor modified methods.

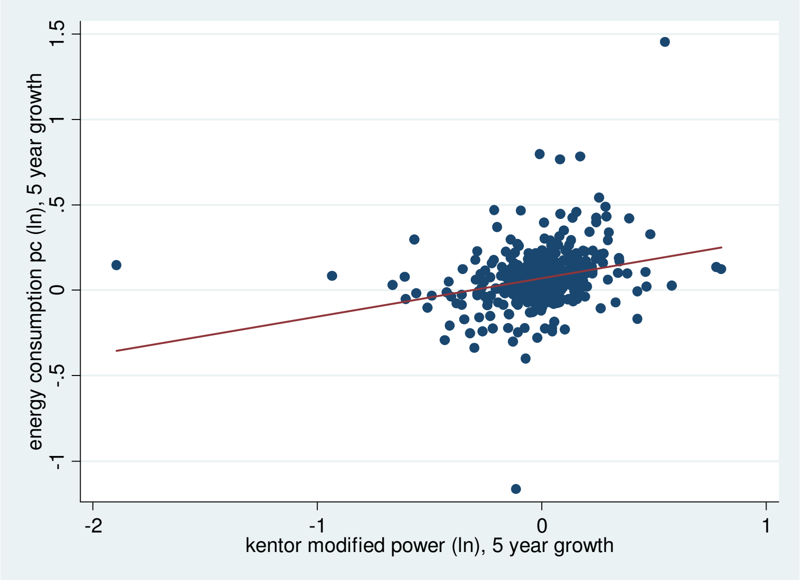
But the correlations better reveal the dynamics going on between the tiers. For the relationship between energy use per capita and GDP per capita, the semiperiphery and periphery have much higher correlations than the core, with the semiperiphery having the largest correlation in all three measurement methodologies: (.71 in Babones, .92 in Mahutga & Smith, .74 in Kentor Modified, respectively). This is surely and indicator of the industrialization taking place in the semiperiphery, but also that that industrialization is being transformed into GDP more efficiently than for the periphery. The core, while having high levels of energy consumption per capita, is finding GDP in other ways—which can be from higher-value contributions, such as financial services, and/or from more efficient energy use, since the same energy is resulting in a non-linear GDP growth.

The ranking of world-system tiers when considering first difference and percentage change statistics reveals a different picture than for the mean levels. The change/growth means are almost uniformly highest in the semiperiphery, with the exception of Kentor Modified ranking on GDP pc (first difference) slightly lower in the semiperiphery than the core (.103 and .106, respectively), although the percentage change for GDPpc is slightly higher in the semiperiphery than the core (.119 and .118, respectively). A more unexpected result is that energy change (both first difference and percentage change) in the periphery, while lower than the semiperiphery, is higher than for the core in all ranking methods. This likely reflects the industrializing of some countries in the periphery such as India and the deindustrialization and energy efficiencies of some members of the core, such as the Skandinavian countries.

For the correlations between the growth rates of energy consumption and power the relationship above holds again, with the semiperiphery the highest, then the periphery, then the core (.35/.26/.06, respectively). But the correlations for levels reveal the highest score for the periphery, followed by the semiperiphery, and then the core. Countries in the periphery, on average, have a higher amount of power coming from energy consumption, which may be an indication of their reliance upon energy intensive production for development while the semiperiphery and periphery may be more diversified.

Figure 4.8 displays the scatterplots of the 5-year growth in power and energy consumption. The table reveals a clumping of countries around zero growth in either indicator, and some outliers, but the overall relationship is positive and linear between the variables.

Figure 4.8 Growth in Kentor Power Modified and Energy Consumption per Capita



The outliers can be identified by sorting the data on the 5-year growth in Power and also on the 5-year growth in Energy Consumption per capita, displayed in the tables that follow: Tables 4.5 and 4.6 display the results for the sorts on highest and lowest Power scores, respectively, along with each country's Energy Consumption level and world-system region (1 = core, 2 = semiperiphery, 3 = periphery); Tables 4.7 and 4.8 display the results for the sorts on highest and lowest Power scores, respectively, along with each country's Energy Consumption level and world-system region.

Table 4.5 Highest 5-Year Growth in Power, with Energy Consumption per Capita

Country	Period	Power 5-Year Growth	Energy Consum. 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Angola	2003-2008	0.80	0.13	3	3	3
People's Rep. of China	1988-1993	0.78	0.13	3	2	2
Dem. Rep. of Congo	2003-2008	0.58	0.03	3	3	3
Islamic Rep. of Iran	1973-1978	0.55	1.45	3	3	2
Ethiopia	2003-2008	0.49	0.33	3	3	3
Malta	1973-1978	0.47	0.02	2	3	2
Indonesia	1998-2003	0.46	0.11	3	2	2
Ethiopia	1993-1998	0.43	-0.01	3	3	3
Kuwait	1988-1993	0.43	-0.17	1	3	2
Thailand	1988-1993	0.39	0.42	3	2	2

Table 4.6 Lowest 5-Year Growth in Power, with Energy Consumption per Capita

Country	Period	Power 5-Year Growth	Energy Consum. 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Dem. Rep. of Congo	1998-2003	-1.89	0.14	3	3	3
People's Rep. of China	1983-1988	-0.93	0.08	3	2	2
Kuwait	1978-1983	-0.66	0.03	1	3	1
Islamic Rep. of Iran	1983-1988	-0.61	0.08	3	3	2
Dem. Rep. of Congo	1988-1993	-0.61	-0.05	3	3	3
Islamic Rep. of Iran	1988-1993	-0.57	0.30	3	3	2
Togo	1988-1993	-0.56	-0.02	3	3	3
Dem. Rep. of Congo	1973-1978	-0.51	-0.10	3	3	2
Saudi Arabia	1983-1988	-0.49	-0.03	1	3	2
Kuwait	1973-1978	-0.43	-0.29	1	3	1

Table 4.7 Highest 5-Year Growth in Energy Consumption per Capita, with Power

Country	Period	Power 5-Year Growth	Energy Consum. 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Islamic Rep. of Iran	1973-1978	0.55	1.45	3	3	2
Malta	1998-2003	-0.01	0.80	1	3	3
Algeria	1973-1978	0.17	0.78	3	3	2
Malta	1983-1988	0.08	0.76	2	3	2
Korea, Rep. of (South)	1988-1993	0.26	0.54	1	2	1
Korea, Rep. of (South)	1983-1988	0.28	0.49	2	2	1
Saudi Arabia	1978-1983	-0.21	0.47	1	3	3
People's Rep. of China	2003-2008	-0.09	0.47	2	2	2
Malaysia	1973-1978	0.15	0.46	3	2	2
Cyprus	1988-1993	0.08	0.45	1	3	3

Table 4.8 Lowest 5-Year Growth in Energy Consumption per Capita, with Power

Country	Period	Power 5-Year Growth	Energy Consum. 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Islamic Rep. of Iran	1978-1983	-0.11	-1.16	3	3	2
Gabon	1993-1998	-0.07	-0.40	2	3	2
Panama	1993-1988	-0.30	-0.34	2	2	3
Bolivia	1998-2003	-0.13	-0.30	3	3	3
Kuwait	1973-1978	-0.43	-0.29	1	3	1
Australia	1983-1988	-0.02	-0.28	1	2	1
Gabon	1983-1988	-0.32	-0.25	2	3	2
Tunisia	1983-1988	-0.11	-0.25	3	3	3
Peru	1988-1993	-0.26	-0.24	3	3	3
Malta	1993-1998	0.05	-0.24	2	3	3

The results for the first-difference models of regression of 5-year growth—the first difference—in the Power variable, 1973-2008 are reported in Tables 4.9 & 4.10 that follow. Model 1 includes the lagged dependent variable as an independent variable, and the first difference of the key independent variable, the first difference of energy consumption per capita. Model 2 adds the first difference of the control variables.

Table 4.9, below, reveals the effects of the models for all countries, and then with intercept dummies. For the models without world-system position dummies, the significant positive coefficient on energy consumption per capita indicates that it is having a significant effect on the growth in power for all countries, holding all else constant. For the models with world-system position dummy variables, the coefficients for the core and periphery indicate the change in the mean value for the growth in power, for any given level of growth in energy consumption per capita (Model 1) and for any given level of the combination of growth in energy consumption per capita, industry %, secondary school %, and trade % (Model 2).

Table 4.9 Unstandardized and Standardized Coefficients for the Regression of 5-Year Growth in Kentor Power Modified, 1973-2008

	No Rank Dummies		Babones Rank Dummies		Mahutga & Smith Rank Dummies		Kentor Rank Dummies	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
L. Kentor Modified Power	.008 [.065] (.009)	.010 [.078] (.011)	-.000 [.002] (.016)	-.001 [.006] (.016)	-.006 [-.045] (.013)	-.004 [-.030] (.015)	-.026 [-.202] .023	-.025 [-.195] .024
D. energy consum. p.c. (ln)	.316*** [.267] (.051)	.309*** [.261] (.050)	.312*** [.263] (.050)	.305*** [.257] (.050)	.306*** [.258] (.046)	.297*** [.251] (.046)	.318*** [.268] .053	.306*** [.258] .054
D. industry % GDP (ln)		.167 [.114] (.120)		.170 [.116] (.117)		.184 [.126] .118		.195 [.133] .111
D. second. school % (ln)		-.069 [-.048] (.090)		-.063 [-.044] (.090)		-.053 [-.037] (.090)		-.052 [-.036] .085
D. trade % GDP (ln)		-.014 [-.015] (.054)		-.016 [-.017] (.054)		-.034 [-.037] (.055)		-.025 [-.028] .054
Core Dummy			-.010 (.030)	-.005 (.027)	-.011 (.022)	-.009 (.021)	.050 (.038)	.049 (.037)
Periphery Dummy			-.047 (.027)	-.048 (.027)	-.076*** (.021)	-.078*** (.021)	-.101** .036	-.108** .036
R^2	.075	.088	.080	.094	.095	.108	.097	.113
N observations (clusters) 420 (74)								

<.05 **p<.01 ***p<.001 (two-tailed); (ln) = the variable was transformed using the natural logarithm; L = lagged estimator, D = differenced estimator; standardized regression coefficients in brackets; robust clustered standard errors (country-level clusters) in parentheses; all F-statistics were significant at p<.001.

The significant negative coefficients on the Periphery dummy for Models 1 and 2 in both the Mahutga and Smith and the Kentor ranking indicate that the countries in the periphery of the world-system have lower average power than countries in the semiperiphery, which is the base (not estimated due to multicollinearity). The non-significant coefficient on the Core dummy indicates that countries in the core of the world-system do not differ significantly from the semiperiphery on the growth in power.

(Additional tests, not shown here, reveal that the periphery is significantly different than the core for the Kentor-ranking methodology but not for Mahutga & Smith ranking.)

It is also possible to estimate the effects of energy consumption across world-system zones by using slope dummy variables. As discussed in the earlier methods section, the slope dummy is an interaction term between a dummy variable and a continuous variable. In this case, I wish to model the effect of energy consumption on the growth in power across the different world-system zones. This is accomplished by including the Core and Periphery dummy variables (semiperphery as base), as in the previous table, but also including the interaction terms of the world-system zone (core and periphery, semiperiphery as base) times energy consumption per capita.

With the semiperiphery as the base, the value for its slope of energy consumption per capita is the value with the Core and Periphery interaction terms are zero, which will therefore be the coefficient on the first difference of energy consumption per capita.

Table 4.10, below, reveals the effects of the models for all countries, and then with intercept and slope dummies. For the models without world-system position dummies, the significant positive coefficient on energy consumption per capita indicates that it is having a significant effect on the growth in power for all countries, on average.

Table 4.10 Unstandardized and Standardized Coefficients for the Regression of 5-Year Growth in Kentor Modified Power, 1973-2008

	No Rank Dummies		Babones Rank Dummies		Mahutga & Smith Rank Dummies		Kentor Rank Dummies	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
L. Kentor Power Modified	.008 [.065] (.009)	.010 [.078] (.011)	-.004 [-.034] (.016)	-.004 [-.028] (.017)	-.005 [-.038] (.013)	-.003 [-.025] (.015)	-.030 [-.234] (.023)	-.029 [-.226] (.025)
D. energy consum. pc (ln)	.316*** [.267] (.051)	.309*** [.261] (.050)	.385*** [.325] (.105)	.355** [.300] (.106)	.433*** [.365] (.074)	.413*** [.349] (.076)	.301*** [.254] (.064)	.293*** [.247] (.060)
D. industry % GDP (ln)		.167 [.114] (.120)		.167 [.115] (.117)		.181 [.124] .119		.193 [.132] (.108)
D. second. school % (ln)		-.069 [-.048] (.090)		-.058 [-.041] (.088)		-.054 [-.037] (.090)		-.052 [-.036] (.086)
D. trade % GDP (ln)		-.014 [-.015] (.054)		-.024 [-.027] (.054)		-.033 [-.037] (.055)		-.040 [-.044] .054
Core Dummy			.016 (.034)	.018 (.032)	.005 (.021)	.006 (.021)	.064 (.040)	.063 (.040)
Periphery Dummy			-.052 (.028)	-.055 (.029)	-.061* (.024)	-.064* (.025)	-.120** (.036)	-.127** (.037)
Core X D. energy consum. pc			-.287* [-.125] (.115)	-.250* [-.109] (.119)	-.357*** [-.058] (.098)	-.366*** [-.060] (.098)	-.274* [-.084] .125	-.270* [-.083] (.118)
Periphery X D. energy consum. pc			-.007 [-.004] (.142)	.020 [.012] (.141)	-.154 [-.114] (.094)	-.137 [-.101] (.093)	.178 [.084] (.097)	.168 [.080] (.107)
R^2	.075	.088	.090	.102	.099	.112	.110	.124
N observations (clusters) 420 (74)								

<.05 **p<.01 ***p<.001 (two-tailed); (ln) = the variable was transformed using the natural logarithm; L = lagged estimator, D = differenced estimator; standardized regression coefficients in brackets; robust clustered standard errors (country-level clusters) in parentheses; all F-statistics are significant at p<.001.

For the models with world-system position dummies, the significant coefficient on the first difference of energy consumption pc indicates the effect of the variable on the growth in power only for the semiperiphery; since it is the base world-system position in the models, this is the effect of energy consumption pc when the core and periphery dummies are both zero. Energy consumption per capita in the semiperiphery has a significant and positive effect on the growth in power across all zones.

The interaction terms for the slope dummies of world-system position times consumption per capita (Core X D.energy consum. pc, Periphery X D. energy consum. pc) reveal that energy consumption per capita in the core has a significantly smaller effect on the growth in power than in the semiperiphery, while the periphery is not significantly different from the semiperiphery.

While the sign on the coefficient for the core-energy interaction term is negative, the overall effect is still positive since the coefficient must be added to the first difference of energy consumption pc coefficient for the semiperiphery. For example, the effect for the Babones- ranking core is .098, which is (.385 + -.287). Since, in all models, the negative interaction coefficient is smaller than the positive base coefficient, the effects are all positive, despite being smaller than the semiperiphery. This indicates that the slope of energy consumption per capita in the core is flatter/shallower than the slope in the semiperiphery.

The interaction coefficients can also be utilized to test if the effects of energy consumption pc on the growth in power differ from zero across world-system zones; i.e., does the slope of the growth in energy consumption per capita have a significant effect when predicting the growth in the dependent variable, conditional on world-system zone?

It is possible to use the command “lincom” in Stata (version 12.0) to generate the post-estimation conditional coefficients and standard errors from linear combinations of coefficients. A simple t-test is then performed to test the null hypothesis that the slope is not different than zero.

Table 4.11 Conditional Effects, Power and Energy Consumption per Capita

Growth in Kentor Power Modified	Conditional βeta Coefficient (Conditional Standard Error)	
	Model 1	Model 2
Babones Ranking		
Core D. energy consum. pc	.098 (.077)	.105 (.080)
Semiperiphery† D. energy consumption	.385*** (.105)	.355** (.106)
Periphery D. energy consum. pc	.378*** (.091)	.375*** (.088)
Mahutga & Smith Ranking		
Core D. energy consum. pc	.077 (.067)	.047 (.072)
Semiperiphery† D. energy consumption	.433*** (.074)	.413*** (.076)
Periphery D. energy consum. pc	.279*** (.051)	.276*** (.053)
Kentor Ranking		
Core D. energy consum. pc	.027 (.104)	.023 (.102)
Semiperiphery† D. energy consumption	.301*** (.064)	.293*** (.060)
Periphery D. energy consum. pc	.479*** (.088)	.461*** (.102)

† The coefficient and standard error for the semiperiphery are from the preceding table since it was the base zone it is the first difference of energy consumption pc when the rank dummies are zero

The table shows the t-tests for the slope of energy consumption per capita, conditional on world-system position. It reveals that the slope of the 5-year growth in energy consumption per capita is significantly different from zero in both the semiperiphery and periphery, but that is not the case in the core.

4.10 DISCUSSION

Countries in the periphery of the world-system have had significantly lower growth in power than the semiperiphery for two of the three ranking methodologies, while the core is not significantly different than the semiperiphery on this indicator. The 5-year growth of energy consumption per capita and power have a significant and positive relationship in the semiperiphery and in the periphery, but not in the core of the world-system. Based on the size of the coefficients, the relationship is the strongest for both Model 1 and 2 in the semiperiphery when ranking countries using the Mahutga & Smith methodology, and in the periphery when using the Kentor methodology. For the Babones methodology, the semiperiphery has a stronger relationship than the periphery in Model 1 but the periphery has a stronger relationship than the semiperiphery in Model 2.

The results suggest that the semiperiphery is the site for the strongest growth of energy-based power, which is expected given industrialization that is taking place in countries like India, South Korea, and Brazil. This supports hypotheses 4.4 and 4.5. The periphery also has a significant positive relationship between the main variables, although its power is growing slower than the semipheriphery, all other things held constant. Energy consumption per capita is increasing for countries in the periphery, but, as discussed earlier, its average value is lower than for the semiperiphery, and the semiperiphery is lower than the core. This could be an indication of convergence on energy consumption, as countries in the core continue to deindustrialize and seek less energy-intensive growth, while the semiperiphery and the periphery start to catch up.

Chapter 5

Power and Environmental Degradation, 1973-2008

5.1 INTRODUCTION

In this chapter I discuss the results of empirical analyses relating to the effects of energy, power, and world-system position on environmental degradation. In section 5.2 I discuss the data and hypotheses. In section 5.3, I discuss the results of quantitative analyses. The models are designed in the same was as in chapter four so I will not recap the methodology and other components that are exactly the same here. Instead, I will only discuss the differences. In section 5.4, I revisit the idea of decoupling first mentioned in chapter 3, only this time with data for the period 1973-2008. I test this using three fairly simple measures: "energy efficiency," which is measured as GDP pc/Energy Consunption pc, and "carbon-intensity," which is measured as CO2 emissions pc/GDP pc, and "carbon-efficiency," which is measured as CO2 emissions pc/energy consumption pc. I close with a discussion of the results in section 5.5.

5.2 DATA AND HYPOTHESES

The data set used for the following analyses are the same as in the previous chapter, with the following exceptions.

Key variable

Environmental Degradation: The amount of adjustments to net savings from environment indicators (carbon dioxide damage, net forest depletion, mineral depletion, and energy depletion). Positive numbers are reductions in net savings – an indicator of unsustainability from environmental degradation (from the World Bank 2010; see Bolt, Matete and Clemens 2002; Hamilton and Clemens 1999). The sum of the indictors is then divided by population, and log transformed to reduce positive skew (7.38 to .38). As in Chapter 4, the 5-year difference is therefore a growth rate.

Hypotheses

H5.1: A country's energy consumption has a positive relationship with its level of environmental degradation

H5.2: A country's power has a positive relationship with its level of environmental degradation

H5.2: Countries in the core have higher levels and growth rates of environmental degradation than the semiperiphery, and the semiperiphery has higher growth rates for environmental degradation than the periphery

To test for theories of semiperipheral development, an alternative hypothesis examines if growth in the semipheriphery is outpacing the core and periphery:

H5.3: Countries in the semiperiphery have higher growth rates for environmental degradation than the core, while the core has higher growth rates in environmental degradation than the periphery

5.3 RESULTS

The descriptive statistics for the variables are listed in Table 5.1 and 5.2 below.

Table 5.1 Descriptive Statistics and Bivariate Correlations*

	Mean	SD***	1	2	3	4	5	6
All Countries								
(N/n =493/77)**								
1. Environment Degradation pc	4.03	1.81						
2. Energy Consumption pc	2.67	1.04	.65					
3. GDP pc	8.22	1.50	.54	.91				
4. Kentor Power Modified	-.58	1.61	.50	.85	.92			
5. Industry %	3.44	.32	.58	.31	.23	.29		
6. Secondary School %	4.09	.60	.46	.74	.78	.72	.19	
7. Trade %	4.07	.56	.20	.19	.14	-.07	.06	.17

	Mean	SD***	1	2	3	4	5	6
Core								
Babones Ranking								
(N/n =184/28)**								
1. Environment Degradation pc	4.78	1.56						
2. Energy Consumption pc	3.74	.43	.64					
3. GDP pc	9.79	.41	.30	.48				
4. Kentor Power Modified	1.01	.60	.09	.35	.65			
5. Industry %	3.45	.28	.32	.21	-.23	.01		
6. Secondary School %	4.55	.26	-.06	.23	.35	.03	-.40	
7. Trade %	4.13	.56	.20	.19	.31	-.53	-.14	-.01
Mahutga and Smith Ranking								
(N/n =77/11)**								
1. Environment Degradation pc	4.54	1.12						
2. Energy Consumption pc	3.84	.35	.52					
3. GDP pc	9.92	.29	.39	.35				
4. Kentor Power Mod.	1.44	.61	.15	.25	.53			
5.Industry %	3.42	.18	-.39	-.27	-.52	-.01		
6. Secondary School %	4.58	.16	.18	.38	.40	-.25	-.52	
7. Trade %	3.92	.59	.13	.11	-.26	-.83	-.25	.46
Kentor Power Modified Ranking								
(N/n =128/23)**								
1. Environment Degradation pc	4.86	1.48						
2. Energy Consumption pc	3.79	.40	.47					
3. GDP pc	9.89	.53	.25	.58				
4. Kentor Power Modified	1.26	.53	.05	.28	.32			
5. Industry %	3.46	.26	.19	-.02	-.37	-.05		
6. Secondary School %	4.57	.23	-.04	.28	.38	-.11	-.45	
7. Trade %	4.05	.57	.13	.04	.08	-.65	-.22	.05
Semiperiphery								
Babones Ranking								
(N/n =136/30)**								
1. Environment Degradation pc	4.53	1.74						
2. Energy Consumption pc	2.58	.65	.67					
3. GDP pc	8.26	.50	.38	.68				
4. Kentor Power Modified	-.63	.59	.22	.45	.74			
5. Industry %	3.56	.30	.72	.48	.20	.24		
6. Secondary School %	4.18	.33	.19	.37	.34	.08	-.05	
7. Trade %	4.07	.66	.20	.31	-.02	-.41	-.00	.26
Mahutga and Smith Ranking								
(N/n =188/32)**								
1. Environment Degradation pc	4.10	1.43						
2. Energy Consumption pc	2.84	.87	.57					
3. GDP pc	8.61	1.31	.48	.92				
4. Kentor Power Modified	-.03	.91	.42	.82	.82			
5. Industry %	3.47	.25	.20	-.05	-.19	-.11		
6. Secondary School %	4.31	.41	.53	.84	.80	.67	-.05	
7. Trade %	4.03	.65	.18	.34	.32	.03	-.18	.35

	Mean	SD***	1	2	3	4	5	6
Kentor Power Modified Ranking								
(N/n =166/42)**								
1. Environment Degradation pc	4.69	1.74						
2. Energy Consumption pc	3.00	.76	.57					
3. GDP pc	8.65	.90	.21	.74				
4. Kentor Power Modified	-.09	.55	-.03	.49	.61			
5. Industry %	3.54	.30	.59	.25	-.05	-.08		
6. Secondary School %	4.29	.36	.08	.49	.56	.24	-.20	
7. Trade %	4.05	.67	.38	.56	.42	-.06	.12	.36
Periphery								
Babones Ranking								
(N/n =173/32)**								
1. Environment Degradation pc	2.83	1.50						
2. Energy Consumption pc	1.59	.42	.54					
3. GDP pc	6.51	.74	.40	.61				
4. Kentor Power Modified	-2.21	1.16	.41	.54	.67			
5. Industry %	3.33	.34	.64	.51	.44	.49		
6. Secondary School %	3.53	.56	.34	.40	.47	.42	.34	
7. Trade %	3.99	.48	.09	.16	.28	-.20	.27	.16
Mahutga and Smith Ranking								
(N/n =228/41)**								
1. Environment Degradation pc	3.79	2.21						
2. Energy Consumption pc	2.12	.95	.79					
3. GDP pc	7.32	1.25	.69	.85				
4. Kentor Power Mod.	-1.71	1.37	.67	.81	.95			
5. Industry %	3.42	.40	.79	.61	.58	.59		
6. Secondary School %	3.75	.62	.46	.55	.56	.56	.33	
7. Trade %	4.14	.46	.32	.41	.22	.22	.32	.30
Kentor Power Modified Ranking								
(N/n =199/37)**								
1. Environment Degradation pc	2.95	1.51						
2. Energy Consumption pc	1.66	.43	.55					
3. GDP pc	6.78	.85	.44	.72				
4. Kentor Power Modified	-2.17	1.03	.42	.60	.87			
5. Industry %	3.34	.34	.69	.48	.43	.47		
6. Secondary School %	3.62	.58	.36	.51	.59	.47	.29	
7. Trade %	4.08	.46	.15	.36	.30	.06	.19	.30

* All variables are log transformed (natural)
** N = the number of observations, n = the number of countries
* **Standard deviations are reported for the overall variation

The core countries have the highest mean level of environmental degradation per capita, the semiperiphery the second highest, and the periphery the lowest levels. This order remains the same in all three ranking methods. Notably, the mean of Industry percentage of GDP is highest in the semiperiphery, then the core, and then the periphery. This will be important as we look at the regression analysis later in this chapter.

Although not included in the analysis here, it should also be noted that the correlation between the *levels* of environmental degradation and agriculture percentage of GDP is -.66 and the correlation between the levels of environmental degadation and service percentage of GDP is .02, while the correlation between the *growth* of environmental degradation and agriculture % is -.32 and with service % is -.05.

Table 5.2 Differences & Lags,† Descriptive Statistics and Bivariate Correlations*

	Mean	SD***	1	2	3	4	5	6	7
All countries									
(N/n =413/73)**									
1. D. Enviro. Degradation pc	.36	.71							
2. D. Energy Consumption pc	.07	.17	.18						
3. D. GDP pc	.09	.14	.31	.38					
4. D. Kentor Power Mod.	-.01	.20	.29	.28	.70				
5. D. Industry %	-.01	.14	.42	.12	.22	.12			
6. D. Secondary School %	.10	.14	.04	.13	-.08	-.03	.06		
7. D. Trade %	.08	.23	.14	.06	.18	.06	.45	-.07	
8. Lag Enviro. Degradation pc	3.82	1.71	-.10	-.02	-.05	-.01	-.09	-.17	-.08
Core									
Babones Ranking									
(N/n =157/27)									
1. D. Enviro. Degradation pc	.34	.56							
2. D. Energy Consumption pc	.05	.12	-.20						
3. D. GDP pc	.09	.11	.10	.16					
4. D. Kentor Power Mod.	.00	.11	.24	.14	.92				
5. D. Industry %	-.05	.08	.35	.02	.32	.29			
6. D. Secondary School %	.05	.12	-.13	.22	-.29	-.17	-.24		
7. D. Trade %	.07	.14	.08	-.20	.02	-.03	.22	-.23	
8. Lag Enviro. Degradation pc	4.58	1.46	-.15	-.13	-.31	-.27	.05	.11	-.18
Mahutga and Smith Ranking									
(N/n =67/11)									
1. D. Enviro. Degradation pc	.29	.58							
2. D. Energy Consumption pc	.02	.08	-.39						
3. D. GDP pc	.09	.05	-.07	.48					
4. D. Kentor Power Mod.	-.01	.04	.22	.15	.61				
5. D. Industry %	-.06	.05	.16	.20	.34	.20			
6. D. Secondary School %	.04	.09	-.12	.11	-.15	-.05	-.13		
7. D. Trade %	.08	.13	.04	-.27	-.20	-.34	.18	-.16	
8. Lag Enviro. Degradation pc	4.40	1.03	-.22	-.05	-.04	-.03	.04	.10	.01

	Mean	SD***	1	2	3	4	5	6	7
Kentor Modified Power Ranking									
(N/n =112/23)									
1. D. Enviro. Degradation pc	.39	.61							
2. D. Energy Consumption pc	.03	.12	-.15						
3. D. GDP pc	.11	.10	.06	.22					
4. D. Kentor Power Mod.	.01	.10	.11	.06	.80				
5. D. Industry %	-.04	.08	.31	.07	.30	.19			
6. D. Secondary School %	.04	.12	-.07	.18	-.16	-.03	-.28		
7. D. Trade %	.08	.14	.00	-.10	-.01	-.09	.19	-.28	
8. Lag Enviro. Degradation pc	4.62	1.32	-.02	-.04	-.17	-.07	.18	.06	-.11
Semiperiphery									
Babones Ranking									
(N/n =112/28)									
1. D. Enviro. Degradation pc	.43	.67							
2. D. Energy Consumption pc	.09	.15	.36						
3. D. GDP pc	.10	.13	.42	.61					
4. D. Kentor Power Mod.	.01	.15	.42	.48	.85				
5. D. Industry %	.01	.14	.46	.22	.18	.11			
6. D. Secondary School %	.10	.12	-.19	-.03	-.21	-.24	-.03		
7. D. Trade %	.10	.23	.17	-.01	.13	.06	.50	.01	
8. Lag Enviro. Degradation pc	4.27	1.58	.01	-.07	-.18	-.14	.15	-.09	-.09
Mahutga and Smith Ranking									
(N/n =158/31)									
1. D. Enviro. Degradation pc	.43	.56							
2. D. Energy Consumption pc	.10	.13	.10						
3. D. GDP pc	.13	.11	.11	.55					
4. D. Kentor Power Mod.	.03	.16	.17	.36	.51				
5. D. Industry %	-.01	.10	.38	.20	.18	.08			
6. D. Secondary School %	.08	.11	-.08	.17	-.02	-.02	.06		
7. D. Trade %	.11	.19	-.03	-.02	.04	-.15	.29	.01	
8. Lag Enviro. Degradation pc	3.91	1.27	.02	-.07	.00	-.04	.05	-.17	-.01
Kentor Power Modified Ranking									
(N/n =140/40)									
1. D. Enviro. Degradation pc	.38	.61							
2. D. Energy Consumption pc	.10	.21	.24						
3. D. GDP pc	.10	.15	.37	.36					
4. D. Kentor Power Mod.	.02	.20	.40	.38	.65				
5. D. Industry %	-.02	.14	.49	.09	.34	.21			
6. D. Secondary School %	.09	.12	-.11	.15	-.18	-.07	-.04		
7. D. Trade %	.09	.23	.20	-.07	.21	.02	.52	.02	
8. Lag Enviro. Degradation pc	4.43	1.65	-.17	-.15	-.36	-.24	-.04	-.08	-.22
Periphery									
Babones Ranking									
(N/n =144/31)									
1. D. Enviro. Degradation pc	.33	.87							
2. D. Energy Consumption pc	.07	.21	.25						
3. D. GDP pc	.07	.18	.35	.37					
4. D. Kentor Power Mod.	-.04	.30	.28	.27	.62				
5. D. Industry %	.03	.18	.46	.10	.25	.11			
6. D. Secondary School %	.15	.16	.23	.15	.11	.10	.07		
7. D. Trade %	.07	.30	.14	.16	.25	.07	.50	-.06	
8. Lag Enviro. Degradation pc	2.64	1.39	-.22	.09	.04	.05	-.10	-.13	-.07

	Mean	SD***	1	2	3	4	5	6	7
Mahutga and Smith Ranking									
(N/n =188/38)									
1. D. Enviro. Degradation pc	.33	.85							
2. D. Energy Consumption pc	.06	.21	.25						
3. D. GDP pc	.05	.18	.41	.31					
4. D. Kentor Power Mod.	-.05	.26	.34	.25	.74				
5. D. Industry %	.02	.18	.48	.09	.29	.16			
6. D. Secondary School %	.14	.17	.12	.14	-.02	.02	.00		
7. D. Trade %	.05	.27	.22	.11	.23	.12	.56	-.06	
8. Lag Enviro. Degradation pc	3.53	2.11	-.13	.01	-.12	-.02	-.10	-.12	-.13
Kentor Power Modified Ranking									
(N/n =161/35)									
1. D. Enviro. Degradation pc	.33	.84							
2. D. Energy Consumption pc	.06	.15	.27						
3. D. GDP pc	.06	.16	.36	.49					
4. D. Kentor Power Mod.	-.05	.25	.28	.27	.71				
5. D. Industry %	.03	.17	.47	.19	.21	.12			
6. D. Secondary School %	.14	.16	.18	.10	.08	.05	.07		
7. D. Trade %	.07	.28	.15	.25	.20	.09	.49	-.06	
8. Lag Enviro. Degradation pc	2.73	1.39	-.19	.15	.03	.00	.04	-.06	-.03

† D = 5-year difference of the estimates, Lag = 5-year lag of the estimates

* All variables are log transformed (natural)

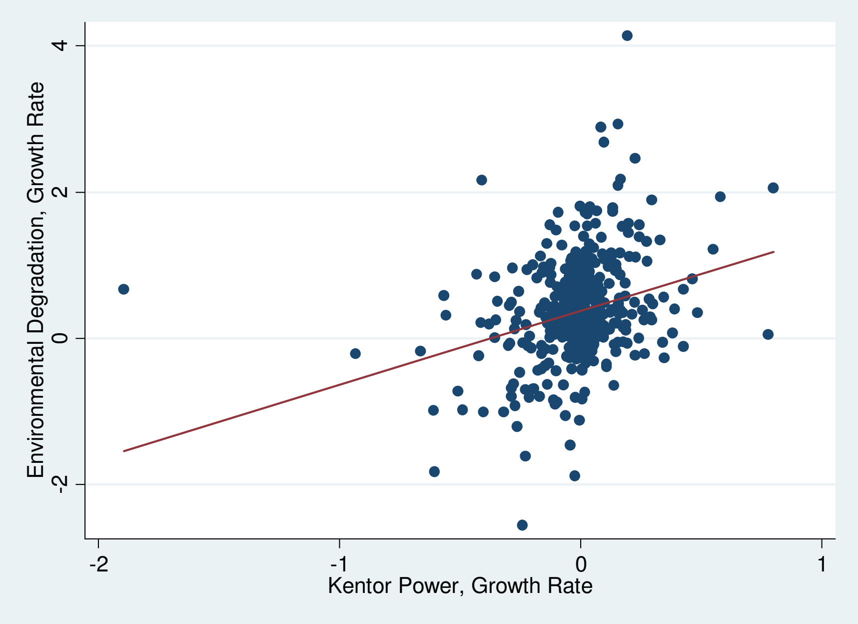
** N = the number of observations, n = the number of countries

* **Standard deviations are reported for the overall variation

In Table 5.2, the mean for growth of environmental degradation (the first difference) is highest in the semiperiphery, then the core, and then the periphery. This is true across all ranking methods except Kentor's Power Modified, where the core was slightly higher than the semiperiphery (.39 to .38, respectively). The mean for growth of industry percentage of GDP was highest in the periphery, then the semiperiphery, and followed by the core, where it was negative across all ranking methodologies.

In Figure 5.1 below, the scatterplot of the growth rate of environmental degradation and the modified Kentor power measure reveals a positive linear fit between the two variables. Positive growth in geopolitical power is occurring together with positive growth in environmental degradation. This is not surprising given the high correlation between energy use, GDP, environmental degradation and power. Also, the environmental degradation measure's inclusion of carbon dioxide emissions, which is highly correlated with energy consumption, is likely contributing to this relationship.

Figure 5.1 Environmental Degradation and World System Power



As in Chapter 4, it is possible to identify the outliers by sorting on environmental degradation. Table 5.3 displays the highest scores for 5-year growth in Environmental Degradation, with the Power score for each country, while Table 5.4 does the same for the lowest scores in 5-year growth in Environmental Degradation.

Table 5.3 Highest 5-Year Growth in Environmental Degradation, with Power

Country	Period	Enviro. Degrad. 5-Year Growth	Power 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Zambia	2003-2008	4.13	0.20	3	3	3
Cameroon	1978-1983	2.93	0.16	3	3	3
Morocco	2003-2008	2.89	0.08	3	3	3
Norway	1973-1978	2.68	0.10	1	2	1
Peru	2003-2008	2.46	0.23	2	3	2
Jordan	2003-2008	2.17	0.17	2	3	3
Cote d'Ivoire	1978-1983	2.16	-0.41	3	3	3
Malaysia	1973-1978	2.09	0.15	3	2	3
Angola	2003-2008	2.06	0.80	3	3	3
Democratic Rep. of Congo	2003-2008	1.93	0.58	3	3	3

Table 5.4 Lowest 5-Year Growth in Environmental Degradation, with Power

Country	Period	Enviro. Degrad. 5-Year Growth	Power 5-Year Growth	Babones	Mahutga & Smith	Kentor Modified
Zambia	1988-1993	-2.56	-0.24	3	3	3
Honduras	1988-1993	-1.88	-0.02	3	3	3
Democratic Rep. of Congo	1988-1993	-1.83	-0.61	3	3	3
Zambia	1973-1978	-1.61	-0.23	3	3	3
Germany	1983-1988	-1.47	-0.04	1	1	1
Peru	1988-1993	-1.21	-0.26	3	3	3
Benin	1998-2003	-1.13	-0.00	3	3	3
Morocco	1988-1993	-1.06	-0.06	3	2	3
Gabon	1983-1988	-1.01	-0.32	2	3	2
Zambia	1993-1998	-1.01	-0.40	3	3	3

In Table 5.5 below, the results of regression analyses on the growth in environmental degradation per capita are displayed. Again, the regression analysis here followed the same structure as in the previous chapter, so the first table includes the intercept dummies for world-system position (semiperiphery as base), while Table 5.6 that follows includes the slope dummies for the interaction of world-system position and energy consumption.

Table 5.5 Unstandardized and Standardized Coefficients for the Regression of 5-Year Growth in Environmental Degradation, 1973-2008

	All countries No Ranking		Babones Ranking		Mahutga & Smith Ranking		Kentor Modified Ranking	
Growth in environmental degradation, pc	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Lag Enviro. Deg., pc Level	-.041* [-.099] (.018)	-.027* [-.066] (.014)	-.056* [-.134] (.023)	-.063** [-.152] (.021)	-.041* [-.097] (.018)	-.032* [-.077] (.015)	-.056* [-.133] (.023)	-.069** [-.167] (.022)
D. Kentor Power	.909*** [1.28] (.230)	.796** [.229] (.233)	.883*** [.255] (.229)	.731** [.211] (.231)	.905*** [.261] (.236)	.741** [.214] (.235)	.872*** [1.23] (.228)	.679** [.956] (.226)
D. Energy Consumption p.c.	.439* [.107] (.191)	.272 [.066] (.182)	.434* [.106] (.191)	.267 [.065] (.182)	.425* [.104] (.191)	.260 [.063] (.178)	.462* [.113] (.190)	.275 [.067] (.177)
D. industry % GDP		2.09*** [.412] (.379)		2.30*** [.455] (.413)		2.21*** [.436] (.402)		2.38*** [.471] (.414)
D. secondary school %		.013 [.003] (.291)		.169 [.034] (.314)		.110 [.022] (.316)		.198 [.039] (.317)
D. trade % GDP		-.205 [-.065] (.166)		-.279 [-.089] (.173)		-.263 [-.084] (.178)		-.321 [-.102] (.176)
Core Dummy			-.052 (.062)	.079 (.069)	-.047 (.075)	.024 (.077)	.056 (.068)	.104 (.067)
Periphery Dummy			-.137 (.083)	-.220* (.084)	-.017 (.063)	-.125 (.068)	-.069 (.078)	-.258** (.095)
constant	.500*** (.072)	.487*** (.069)	.622*** (.115)	.662*** (.109)	.514*** (.080)	.554*** (.086)	.564*** (.116)	.711*** (.123)
R^2	.105	.251	.110	.273	.105	.258***	.109	.281
N observations (clusters) 413(73)								

<.05 **p<.01 ***p<.001 (two-tailed); L = lagged estimator, D = differenced estimator; standardized regression coefficients in brackets; robust standard errors (country-level clusters) in parentheses; first difference estimation with lagged dependent variable, all countries, all variable logged before differencing ; F-statistics are all significant at p<.001.

The models include the 5-year lag of the level of the dependent variable to see ceiling and floor effects. The lag level of power was not significant in any model so it was removed. The VIF when it was included reached a high of 4.77, with an average of 1.96 (Model 2, with dummies); removing it also reduces potential multicollinearity issues (VIF max after removal = 1.83, with average of 1.34). Standard errors improved. This slightly lowered the R-square from .281 to .280, the BIC slightly improved (806.14 from 811.63), while the AIC also improved (769.92 from 771.39), all model 2 results.

The growth in power is positive and significant predictor of the growth in environmental degradation (an indicator of unsustainability of growth), while the negative coefficient on environmental degradation indicates a ceiling effect: slower growth rates in environmental degradation occur for countries with already higher levels of environmental degradation, as expected.

The Core and Periphery intercept dummy variables are not significant in most of the models, indicating that their growth in environmental degradation is not significantly different from the semiperiphery. The exceptions are for the Periphery in Model 2 for Babones and also for Kentor rankings. In both cases, the negative coefficient on the Periphery indicates that its average environmental degradation is lower than the semiperiphery at any given levels of the other variables. Countries in the periphery of the modern world-system are generating less environmental degradation, which may be indicative of its low level of industrialization.

What may be most interesting are the effects of the growth in energy consumption per capita and industry %. In all of the first models, the coefficient on energy consumption per capita is positive and statistically significant. This is to be expected given that two of the components of the dependent variable are energy-related (CO^2 emissions and energy depletion). Yet, the significance disappears when the control variables are added in Model 2, while industry % becomes significant. This suggests that industrial production is the source of environmental degradation, holding energy consumption constant. This is likely due to the differences in the level of degradation associated with different types of energy use. For example, some core countries, such as France, consume a relatively greater share of their energy use from nuclear power, which does not produce CO^2 emissions.

In Table 5.6, below, the slope dummy variables are added. The ceiling effects for the lag level of environmental degradation on growth, and also the positive effect of growth in power remain. Industry percentage remains positive and significant in all models, while trade percentage becomes negative across all models and is statistically significant in the Kentor Power Modified ranking. This could be an indication of a world-polity effect; i.e., the more integrated a country is in the world-system the more environmental protection is valued.

The slope dummy variables were positive and significant for the periphery in all of the second models, and in Model 1 for the Kentor ranking. This indicates that countries in the periphery have a steeper positive slope for the growth in energy consumption and environmental degradation than the semiperiphery, which is the base. This is an effect of industrialization in the growth of industrialization in the periphery. The core is not statistically different than the semiperiphery.

Table 5.6 Unstandardized and Standardized Coefficients for the Regression of 5-Year Growth in Environmental Degradation, 1973-2008

	Babones Ranking		Mahutga & Smith Ranking		Kentor Modified Ranking	
Growth in environmental degradation, pc	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Lag Enviro. Deg., pc Level	-.035** [-.150] (.013)	-.032** [-.173] (.011)	-.024 [-.102] (.013)	-.026* [-.083] (.012)	-.032* [-.150] (.016)	-.039** [-.185] (.014)
D. Kentor Power	.783** [.232] (.216)	.650** [.191] (.224)	.849** [.258] (.236)	.683** [.209] (.237)	.797*** [.234] (.214)	.622** [.178] (.219)
D. Energy Consumption p.c.	1.19** [.287] (.392)	.800* [.187] (.383)	.101 [.000] (.427)	-.241 [-.077] (.410)	.373* [.087] (.179)	.230 [.052] (.175)
D. industry % GDP		2.24*** [.457] (.403)		2.31*** [.454] (.392)		2.33*** [.474] (.398)
D. secondary school %		.329 [.044] (.322)		.243 [.021] (.319)		.335 [.040] (.326)
D. trade % GDP		-.303 [-.112] (.163)		-.340* [-.111] (.168)		-.337* [-.128] (.164)
Core Dummy	.046 (.064)	.157* (.071)	-.036 (.078)	.038 (.082)	.052 (.062)	.112 (.067)
Periphery Dummy	-.010 (.075)	-.105 (.071)	-.026 (.064)	-.175* (.075)	-.050 (.074)	-.222* (.088)
Core X D. Energy Consumption pc	-2.28*** (.523)	-.203*** (.535)	-2.99** (1.06)	-3.12** (1.02)	-1.13 (.682)	-1.19 (.674)
Periphery X D. Energy Consumption pc	-.413 (.498)	-.139* (.458)	.644 (.481)	.871 (.442)	.855* (.417)	.720* (.356)
constant	1.12*** (.279)	1.07*** (.233)	.955** (.286)	1.08*** (.266)	1.08** (.344)	1.30*** (.320)
R^2	.132	.288	.123	.289	.113	.281
N observations (clusters) 413(73)						

<.05 **p<.01 ***p<.001 (two-tailed); L = lagged estimator, D = differenced estimator; standardized regression coefficients in brackets; robust standard errors (country-level clusters) in parentheses; first difference estimation with lagged dependent variable, all countries, all variable logged before differencing; F-statistics were significant at p<.001.

The conditional effects of the growth in environmental degradation and the slope dummy variables are displayed in Table 5.7 below.

Table 5.7 Conditional Effects, Degradation and Energy Consumption

Growth in Environmental Degradation pc	Conditional βeta Coefficient (Conditional Standard Error)	
	Model 1	Model 2
Babones Ranking		
Core D. energy consumption pc	-1.09** (.327)	-1.23** (.351)
Semiperiphery† D. energy consumption pc	1.19** (.392)	.800* (.383)
Periphery D. energy consumption pc	.779* (.303)	.661* (.283)
Mahutga & Smith Ranking		
Core d. energy consumption pc	-2.89** (.945)	-3.36** (.929)
Semiperiphery† d. energy consumption pc	.101 (.427)	-.241 (.410)
Periphery D. energy consumption pc	.745** (.252)	.630** (.224)
Kentor Ranking		
Core D. energy consumption pc	-.754 (.678)	-.955 (.676)
Semiperiphery† D. energy consumption pc	.373* (.179)	.230 (.175)
Periphery D. energy consumption pc	1.23** (.356)	.950** (.297)

Again, the conditional effects reveal the results of the test to see if the slope is significantly different from zero. As expected from the intercept dummy tests, the slope of the growth of energy consumption and environmental degradation in the periphery is significant in all measurement methodologies, with the exception of the periphery for the Mahutga & Smith ranking in Model 2, but that is very close to significance (p=.065).

Notably, the core and periphery are also significantly different from zero in the Kentor ranking method and the core is also significant in the Babones method, while the results approach significance in all other tests. Yet the coefficient for the core is negative, indicating that, on average, as its growth in Energy Consumption increases its level of Environmental Degradation decreases. Energy consumption is driving environmental degradation in the semiperiphery and periphery of the world-system, but the effect is the strongest in the periphery. This is likely to be an effect of industrialization using less efficient technologies or more "dirty" fuel sources such as coal. But it also indicates that the periphery is the most dissimilar group in this respect, and the core is the most dissimilar on the negative side.

Another way to understand environmental degradation and world-system position is to look at the slope dummy variables and the conditional effects of environmental degradation and the interaction terms of world-system position and power (measured using the modified Kentor measure). Table 5.8 below reports the results for the core and periphery slope dummy variables, with the semiperiphery as the base for comparison. The results reveal that there is not a significant difference between world-system positions on environmental degradation, with the exception of the periphery's negative and significant results in the Babones ranking method for Model 2. Model 1 was very close to being statistically significant at the 95% confidence level as well, p=.052. For the Babones ranking, then, the periphery had a slope for its power and environmental degradation that was not as steep as the semiperiphery. The slope for the periphery was still positive, however, as revealed in the conditional effects table that will be discussed shortly.

Table 5.8 Slope Dummy Variables, Degradation and Power

Growth in Environmental Degradation pc	βeta Coefficient (Standard Error)	
	Model 1	Model 2
Babones Ranking		
Core X D. Kentor Power Modified	-.793 (.678)	-1.15 (.633)
Periphery X D. Kentor Power Modified	-.863 (.436)	-.938* (.422)
Mahutga & Smith Ranking		
Core X D. Kentor Power Modified	2.37 (1.42)	1.76 (1.50)
Periphery X D. Kentor Power Modified	.472 (.392)	.407 (.408)
Kentor Ranking		
Core X D. Kentor Power Modified	-.456 (.692)	-.575 (.625)
Periphery X D. Kentor Power Modified	-.077 (.434)	.051 (.438)

To test if the slopes are different from zero, the conditional effects were analyzed. Table 5.9 below reports these results for the slope dummy interaction terms. The conditional effects results reveal that the semiperiphery and periphery have slopes for the interaction of world-system position and power that are positive and significantly different from zero in all tests except for the Mahutga &Smith semiperiphery. For that ranking methodology, the core is also significant in Model 1, which is the only test in which that occurred. In all other cases, the growth in power in the core had little effect on the growth in environmental degradation. In fact, regressions including the intercept dummies for the core and periphery but not the slope dummies revealed only one significant difference in mean of the growth in environmental degradation, for the periphery in the Kentor ranking methodology in Model 2. In that case, the coefficient was negative, indicating that the periphery had a lower average environmental degradation per capita than the semiperiphery.

Table 5.9 Conditional Effects, Degradation and Power

Growth in Environmental Degradation pc	Conditional βeta Coefficient (Conditional Standard Error)	
	Model 1	Model 2
Babones Ranking		
Core D. Kentor Power Modified	.801 (.541)	.399 (.525)
Semiperiphery† D. Kentor Power Modified	1.59*** (.395)	.155*** (.371)
Periphery D. Kentor Power Modified	.731** (.255)	.614* (.263)
Mahutga & Smith Ranking		
Core D. Kentor Power Modified	2.86* (1.40)	2.14 (1.49)
Semiperiphery† D. Kentor Power Modified	.490 (.427)	.381 (.289)
Periphery D. Kentor Power Modified	.962** (.300)	.788* (.303)
Kentor Ranking		
Core D. Kentor Power Modified	.474 (.751)	.105 (.704)
Semiperiphery† D. Kentor Power Modified	.931** (.179)	.679* (.292)
Periphery D. Kentor Power Modified	.854** (.313)	.730* (.333)

Notably, in all cases the periphery had a statistically significant positive slope that also had larger effects (larger βeta coefficients) in the periphery than the semiperiphery, with the exception of Model 1 for Babones and Kentor ranking methods. This is an interesting outcome as it indicates a larger increase in Environmental Degradation per capita for a unit change in power in the periphery than the semiperiphery. This could be an effect of the severe underdevelopment of the slowest developing countries, and/or the relatively high development of the fastest developing countries in the periphery. Put another way, as a group the periphery is the most dissimilar in its relationship between Power and Environmental Degradation.

5.4 ENERGY TRENDS

While the descriptive statistics and regression analyses reported earlier are helpful for understanding relationships, on average and over the entire period under consideration, understanding the period-to-period changes can enhance our ability to perceive trends in per capita energy consumption, power, and environmental degradation. Closer examination of the trends also affords an opportunity to reexamine the existence of decoupling, as first discussed in Chapter 3, only here for the period 1973-2008. I test this using three fairly simple and common measures: “energy efficiency,” which is measured as GDP pc/Energy Consumption pc, and “carbon-intensity,” which is measured as carbon dioxide (CO2) emissions pc/GDP pc, and “carbon-efficiency,” which is measured as CO2 emissions pc/energy consumption pc. For each 5 year time point, the means for each of the measures for all countries and then for countries in each zone (Kentor Power Method) are displayed in Table 5.10 below. For ease of interpretation, only the difference statistics (indicated by the preceding “D.”) are log transformed and energy consumption and carbon dioxide have been transformed by multiplying the per capita measure by 10,000 to generate interpretable results.

Table 5.10 Mean Energy Efficiency, Carbon Intensity, Carbon Efficiency, 1973-2008, by World-System Position*

	1978	1988	1998	2008
All Countries				
# of countries	54	65	70	65
Energy Consumption	21.65	22.16	24.01	26.30
Growth Rate, EC	.10	.07	.09	.08
Power	1.70	1.42	1.43	1.51
Growth Rate, Power	.01	-.10	.02	.11
Environmental Deg.	245.64	166.71	168.51	1024.41
Growth Rate, ED	.81	-.18	-.03	1.07
GDP/EC	297.91	302.64	313.75	372.35
Growth Rate, GDP/EC	-.17	-.08	-.12	-.06
CO2/GDP	2.25	2.60	2.48	2.14
Growth Rate, CO2/GDP	-.01	.00	-.01	-.01
CO2/EC	591.19	576.20	548.03	551.10
Growth Rate, CO2/EC	-.22	-.10	-.15	-.12
Core				
# of countries	16	15	19	20
Energy Consumption	48.41	47.01	47.15	47.42
Growth Rate, EC	-.01	.09	.08	.03
Power	4.38	4.43	3.98	3.87
Growth Rate, Power	.00	.00	.03	.02
Environmental Deg.	628.68	178.76	217.61	1322.00
Growth Rate, ED	1.03	-.22	.00	.71
GDP/EC	396.54	478.12	526.03	602.56
Growth Rate, GDP/EC	.02	-.03	-.02	.00
CO2/GDP	1.91	1.40	1.59	1.27
Growth Rate, CO2/GDP	-.02	-.01	-.01	-.02
CO2/EC	701.69	620.07	599.46	548.39
Growth Rate, CO2/EC	-.01	-.06	-.06	-.05
Semiperiphery				
# of countries	14	21	26	26
Energy Consumption	19.22	27.37	25.10	24.96
Growth Rate, EC	.22	.12	.10	.12
Power	1.22	.99	.84	.71
Growth Rate, Power	.03	-.14	.03	.13
Environmental Deg.	179.13	332.53	275.96	1391.30
Growth Rate, ED	.87	-.27	.00	1.13
GDP/EC	381.01	307.49	297.50	325.40
Growth Rate, GDP/EC	-.23	-.13	-.08	-.06
CO2/GDP	2.39	3.90	3.19	2.80
Growth Rate, CO2/GDP	.00	.01	.00	-.01
CO2/EC	744.73	732.74	665.52	654.31
Growth Rate, CO2/EC	-.26	-.13	-.09	-.10

	1978	1988	1998	2008
Periphery				
# of countries	24	29	25	19
Energy Consumption	5.23	5.54	5.23	5.90
Growth Rate, EC	.13	.03	.09	.09
Power	.20	.17	.12	.11
Growth Rate, Power	.00	-.12	.00	.18
Environmental Deg.	29.08	40.40	19.43	209.11
Growth Rate, ED	.51	-.10	-.08	1.36
GDP/EC	183.68	208.37	169.31	194.27
Growth Rate, GDP/EC	-.35	-.06	-.23	-.13
CO2/GDP	2.40	2.28	2.40	2.14
Growth Rate, CO2/GDP	-.01	.00	-.01	-.02
CO2/EC	427.95	440.14	386.75	412.70
Growth Rate, CO2/EC	-.42	-.10	-.29	-.22

* All variables other than Power are per capita measures. Growth Rate = first difference of logged variables. The remaning variables were not log transformed. The Kentor Power method is used to assign world-system zone.

The results reveal that energy efficiency (GDP/EC), has remained relatively flat in the core after some decoupling in the 1970s, while energy efficiency declined at points during the 1980s, 90s, and in 2003 for the semiperiphery yet the 35-year change was close to zero (3.12 to 3.10). The periphery showed the opposite trend from the core; i.e., energy efficiency was the highest in the earlier time points and declined over time until showing growth again in 2008. Carbon intensity (CO2/GDP), an indicator of how much the economy is generating climate change gasses (CCG) is highest in the core, yet declining, while fluctuating quite a bit in the semiperiphery before declining in 2008, and remaining relatively flat over the time period for the periphery. Finally, carbon efficiency (CO2/EC) has improved in the core and semiperiphery, while fluctuating quite a bit in the periphery.

While the averages and growth rates are helpful for understanding trends, the totals and percentages of the total by world-system position are also revealing, as displayed in Table 5.11 that follows. For all countries in the dataset, population is increasing, as are per capita levels of energy consumption and environmental degradation. Power went down a bit from 1998 to 2008, however there are fewer countries in the dataset for 2008 so it is likely that power for a balanced panel would also show an upward trend over time The core has consistently remained at the highest levels for energy consumption per capita, power, and environmental degradation per capita. The core countries as a group, have “over consumed” energy by consuming more than their population share; e.g., in 2008, the core countries contained 44% of the sample population but 55% of the energy consumption per capita. The power is also disproportionately held by core countries—consistently over 70% of the total—in part due to the size of the United States military. Yet the core has a relatively lower level of environmental degradation per capita than the semiperiphery, with 40% of the total for the former compared to 54% of the latter. The semiperiphery is therefore “overdegrading.” The percentage share for the core has increased over the last 20 years, while the semiperiphery has declined, however. Part of this is due to the inclusion of China in the data set for the first time in 1988, then its shift from the semiperiphery in 1988 to the core for 1998 and 2008, and also India’s movement from periphery in 1978 to semiperiphery for the more recent decades. Meanwhile, the periphery has lagged far behind both the semiperiphery and the core, consuming at low levels, holding low levels of power, and generating low levels of environmental degradation. So while the growth rates for these variables in the periphery are positive, and the highest of the three zones for power and environmental degradation during the most recent 5-year period, countries in the periphery have a long way to go before approaching the levels of the semiperiphery and the core. It is conceivable, however, for the semiperiphery to converge on the core, particularly with the growth of countries like India; although a trajectory that places it in the core, similar to China's, would then produce divergence.

Table 5.11 Totals and Percentages of Totals for Key Variables by World-System Zone*

	1978	1988	1998	2008
All Countries				
# of countries	54	65	70	65
Population (000s)	2140760	3878190	4583970	4993790
Energy Consumption, pc	1169.16	1440.58	1679.20	1709.46
Power	91.96	92.17	100.46	97.95
Environmental Degradation, pc	13264.62	10836.13	11795.3	66586.89
Core				
# of countries	16	15	19	20
% of Total	.30	.23	.27	.31
Population (000s)	679740	715460	2025990	2220500
% of Total	.32	.18	.44	.44
Energy Consumption, pc	774.56	705.15	895.85	948.40
% of Total	.66	.49	.53	.55
Power	70.08	66.45	75.62	77.40
% of Total	.76	.72	.76	.79
Environmental Degradation, pc	10058.88	2681.40	4134.59	26440.00
% of Total	.76	.25	.35	.40
Semiperiphery				
# of countries	14	21	26	26
% of Total	.26	.32	.37	.40
Population (000s)	403550	2426700	1752680	2168920
% of Total	.19	.63	.38	.43
Energy Consumption, pc	269.08	574.77	652.60	648.96
% of Total	.23	.40	.39	.38
Power	17.08	20.79	21.84	18.46
% of Total	.19	.23	.22	.19
Environmental Degradation, pc	2507.82	6983.13	7174.96	36173.80
% of Total	.19	.64	.61	.54
Periphery				
# of countries	24	29	25	19
% of Total	.44	.45	.36	.29
Population (000s)	1057470	736030	805300	604370
% of Total	.49	.19	.18	.12
Energy Consumption, pc	125.52	160.66	130.75	112.10
% of Total	.11	.11	.08	.07
Power	4.80	4.93	3.00	2.09
% of Total	.05	.05	.03	.02
Environmental Degradation, pc	697.92	1171.60	485.75	3973.09
% of Total	.05	.11	.04	.06

* The Kentor Power method is used to assign world-system zone.

5.5 DISCUSSION

Support is found for hypotheses 5.1-5.3 as environmental degradation does have a positive relationship with power. The semiperiphery, as with energy consumption, is generating the highest growth in environmental degradation. Limited support is found for the decoupling hypotheses 3.1-3.4, as energy consumption and CO^2 emissions compared to GDP are declining or remaining relatively flat in recent time periods. But the core is generating negative growth in environmental degradation for its growth in energy consumption. The periphery has a larger effect size for its slope than the semiperiphery. There are likely to be significant differences across countries in those world-system zones.

For the most part, these are positive results from an ecological perspective. Fewer carbon-dioxide emissions are being generated for both GDP and energy consumption—all on a per capita basis. From an unequal economic exchange perspective, the core is receiving more value-added for the amount of energy it is consuming, while the periphery is receiving less. And the shifting percentages attributable to each world-system zone indicate that the semiperiphery has a disproportionate share of environmental degradation, even while it proportions of energy use and power are below the core. The periphery, despite its relatively high recent growth rates, lags far behind.

Chapter 6

Current Implications and Future Possibilities

6.1 INTRODUCTION

In this dissertation, I have examined the relevant literature and the theoretical and empirical relationships between the key variables of energy use, power, and environmental degradation for societies interacting within world-systems of economic, political, and military relations. My theory of energy, power, environmental degradation, and ecological rent explained power as the cause and consequence of energy use, with energy use positively associated with the sources of environmental degradation. The theory further asserted that more powerful societies can use their power to keep some of the effects of environmental degradation outside of their borders, achieving ecological rent by reaping the benefits of having relatively clean environments while the less powerful societies disproportionately suffer the ecological costs of energy use. In the primary empirical analyses, countries were assigned to a position within a three-tiered system of zones (core, semiperiphery, and periphery) that form a power-dependence hierarchy. Energy use was measured as the consumption of primary commercial energy resources, power was a composite of GDP, GDP per capita, and military expenditures, and environmental degradation was measured as the monetary cost of unsustainable economic activity. Growth rates and levels of each were analyzed for countries in the most recent four decades. Results revealed a number of interesting outcomes, discussed below, but the primary finding is that energy use and environmental degradation are important factors for understanding power in the modern world-system, but the effects differed by world-system position/zone, with the core having high levels for each of the variables but with higher growth rates occurring in the semiperiphery and periphery.

In this final chapter, I consider the theoretical and empirical implications of the findings from my research in section 6.2. In section 6.3 I discuss future research opportunities for this area of study. I then conclude with thoughts on sustainable energy use to meet the challenges we face in section 6.4.

6.2 THEORETICAL AND EMIPIRICAL IMPLICATIONS

At the most general level, my dissertation reveals that energy does have important societal and intersocietal effects but those effects occur in complex ways. On the whole and over the long term, energy use contributes to the growth in geopolitical and economic power, but also is associated with increases in environmental degradation. Energy use is therefore a variable that warrants continued inclusion in macrosociological research.

Yet the effects of energy use vary over time and by world-system zone. By definition, countries in the core have higher *levels* of power than the semiperiphery, and the semiperiphery has higher *levels* for each than the periphery. But, and for the remainder of this discussion I am referring to the use of the modified Kentor power method for assigning countries to world-system positions, the semiperiphery had higher *growth rates* for power, energy use, and environmental degradation, and the periphery had the second highest growth rates for energy consumption, exceeding those in the core. Moreover, the correlations between the growth rates of energy consumption and power were highest in the semiperiphery, followed by the periphery, while the correlation between the level of energy consumption and power were highest within the periphery followed by the semiperiphery. In addition, the core had a slope that is closer to zero, and thus flatter, than the other two zones for the growth rate of energy consumption as a predictor for the growth rate of power and for the growth rates of both energy consumption and power as predictors for the growth rate of environmental degradation. This indicates that the linear relationships between these variables are not statistically different than zero; i.e., knowing the growth rates of energy consumption and environmental degradation does not improve predictability of power over just using the mean as the estimated value for power at all levels of the independent variables. The periphery, meanwhile, had a steeper positive slope than the semiperiphery for the growth rate of energy consumption predicting the growth rate of power and—in Model 2 with the control variables—for both power and energy consumption predicting environmental degradation. This indicates that there is a stronger relationship between the variables in the periphery than the semiperiphery (and the core); i.e., growth in power and environmental degradation are energy intensive for those countries that do exhibit positive growth rates.

The periphery was a surprising source of growth in power, energy consumption, and environmental degradation. This could be due to low starting points or the rapid development of just a few countries; the data reveal fluctuations from 5-year period to period that could be an indication of both but could also be reporting problems. For example, the Democratic Republic of Congo had the lowest rate of growth in power, experiencing negative growth for the period 1998-2003, yet had the highest rate of growth rate for the next period ending in 2008. This occurs for other countries in the periphery and for the other key variables as well, yet this phenomenon of fluctuating positive and negative growth rates is not limited to countries in the periphery. For example, China also fluctuates between one of the highest and lowest growth rates for power between 1983 and 1993, when it was a ranked in the semiperiphery. More research is necessary to understand the details of both peripheral growth and also the fluctuations exhibited.

While countries in the semiperiphery and the periphery are the site of much of the growth in energy consumption per capita, power, and environmental degradation per capita, the core remains at the highest total levels for those variables despite having lower recent growth rates and the periphery lags far behind. Industrialization and the use of inefficient energy forms in the semiperiphery (and to a lesser extent in the periphery) are part of the explanation for these findings. High levels of electricity use and transportation are likely contributing factors to the energy use in the core.

The results complicate my theory of energy use and ecological rent. Countries in the core, on average, have benefitted from past energy use, reflected in its high levels for power, energy consumption, and ecological degradation. This provides support for the theory. The growth rates are slowing down for the core, however, while the growth rates in the semiperiphery and periphery are increasing, outcomes which were not predicted in the existing theory but that need to be incorporated.

In the last few decades the total levels of energy consumption and environmental degradation are increasing for the set of all countries in the dataset, but it is only in the core that both continue to increase as energy consumption per capita in the semiperiphery and periphery has shown some decline (although the panels are unbalanced so this could be an effect of the changing dataset). Total environmental degradation is increasing in all three zones, which is quite disconcerting given warnings about the unsustainability of that path. The net effect of these changes is some movement toward convergence for the energy variables; i.e., if the trend continues, over time all three zones will have more similar statistics. Yet that will take some time given the large differences between the core and the semiperiphery, and the even greater distance between those zones and the periphery, which remains far below the others. Meanwhile the overall total levels of energy consumption and environmental degradation continue to increase while the overall average growth rate of energy consumption per capita decreased slightly from 1998 to 2008, driven by the slowing growth in the core. Unfortunately, again, the average growth rates for environmental degradation per capita increased in each world-system zone.

While I considered the phenomenon of semiperipheral development in my hypotheses, it was not a relationship that was specified in the theoretical model. Neither was the growth of the periphery; in fact, a decline from the impact of environmental degradation was predicted for that zone. Furthermore, the possibility of convergence between zones is not adequately addressed in the theory. Rethinking the differences between world-system zones is necessary, including the possibility that causal relationships vary by zone.

These findings complicate what now appears as an overly simplified model of the relationships in the theory. Clearly, the type of economy (e.g., agricultural, industrial, post-industrial) has to be considered due to its differential impacts on energy use. In addition, the impacts of environmental degradation do not seem to be slowing down the semiperiphery, although it is possible that its relatively higher power compared to the periphery allows it to locate some of the negative effects in the latter zone. However, I was not able to assess that possibility. The relationship between energy use, environmental degradation, and environmental concern was also not measured, but could be contributing to the slower growth rates in the core.

Decoupling of energy use and GDP per capita has occurred in the limited number of countries for which data are available. More specifically, income has become less correlated with energy consumption over time for these countries. A shift away from industrial to financial economic growth is likely to be part of the story for countries such as the former and current hegemons, as discussed by Arrighi (1994). Arrighi argues that there is a global “systemic cycle of accumulation” in which the profit rate in the “real economy” of trade and production decreases and shifts investment into financial services as a strategy for maintaining the rate of profit. The centers of finance capital tend to be mainly located in the world cities of the core, though important “emerging markets” located in the world cities of the non-core have emerged in the most recent wave of global financialization. Financial services use less energy than production and trade, so the mushrooming proportion of the global economy that is composed of the financial sector could account for some of the observed changes in energy consumption. Analyses for countries in the semiperiphery and periphery, and for power, energy use, and environmental degradation will be possible as the years of data accumulate and would be an important contribution to our understanding of historical and future trends.

The bifurcations predicted by complexity theory—measured here as discontinuous distributions in energy use and power across countries ranked by highest to lowest values—are not as clear as predicted. There are points of large percentage changes between countries next to each other in rankings, but this occurs at more than three places and there is no scientific consensus about what size of a percentage difference should qualify as a bifurcation. Moreover, at the highest levels there are very high percentage differences from country to country, indicating much more dissimilarity within the core than usually understood. Part of the difficulty may stem from the absence of a useful measure of national complexity. Geopolitical and economic power is often assumed to be a general proxy for complexity, but it may not be adequate, particularly applications of non-linear dynamics. Developing an accurate and generally available indicator of the relative complexity of national societies was attempted early on in this research but was given up when little was found that would adequately capture the level of differentiation within countries or that was available for many countries at multiple time points. Further work on the development of a complexity indicator might help sort out some of the remaining issues regarding the relationship between energy usage, power and economic development, and world-system position.

The application of concepts from complexity theory and thermodynamics, such as bifurcation points and entropy, to issues of human sociocultural development bring both useful insights and conceptual complications. Consideration should be given to the net value added by their inclusion versus the confusion caused by the effort of translation.. At minimum, the concepts need to be better defined and operationalized.

The research in this dissertation also reveals that the different methods of assigning countries to world-system zones matter greatly. When using GDP per capita, countries like China and India—both with large populations and relatively high growth rates—have lower rankings than when considering the size of their economy (total GDP), as in the Kentor power method. Moreover, countries with high GDP per capita do not necessarily have high amounts of geopolitical power; e.g., the United Arab Emirates has one of the highest levels of GDP per capita in the world yet has little power. Due to these limitations, I relied primarily upon Kentor's method for producing a composite measure of world-system position based on GDP, GDP per capita, and military expenditures (which still has a correlation of .83 with the GDP per capita method due to the variable appearing in both indicators). It would also be fruitful to separately test the relationships between energy use and environmental degradation with GDP, GDP per capita, trade centrality, and military expenditures rather than by using various composite measures. And military power should be examined using both the global reach sea power measure developed by Modelski and Thompson (1996) and the more conventional war capability measure developed by the Correlates of War Project (2010).

The correlation between the rankings using Kentor's method and Mahutga and Smith's trade centrality method is even lower at .72, a result partially attributable to Scandinavian countries such as Norway, Finland, and Denmark assigned to the semiperiphery based on trade impact but in the core due to their relatively strong economies. Yet international trade networks are undoubtedly important in the operation of the modern world-system and centrality in those networks should be considered as a factor in geopolitical and economic power. The construction of a composite measure that includes trade in addition to the variables in Kentor's method would be an improvement. While a consensus regarding the best way to measure world-system position remains to be agreed upon, it would certainly be of great usefulness for the kind of comparative research undertaken in this dissertation.

Finally, it is worth reemphasizing that data used are not from a random sample of countries, nor does the sample consist of a stable set of countries across time. As with most comparative and historical research, data availability is increasingly limited the further back in time the values are estimated. The earlier time points are also biased toward larger, wealthier countries (i.e., core and semiperiphery). Moreover, even more developed countries do not consistently have data on all variables at all time points. All of these issues problematize the validity and interpretation of statistical significance. The most conservative approach is to treat the results as descriptive statistics for the countries for which data was analyzed without drawing any conclusions about the differences across world-system zones on the whole. Yet the high percentages of the world population, energy consumption, and GDP for countries within the sample (e.g., 75, 76, and 89% in 2008, respectively) give some degree of assurance that the world-system dynamics assessed were representative and would not be altered much even if a full population of all countries were to be analyzed.

6.3 FUTURE RESEARCH

The research here can be further developed in a number of ways. For example, averages and totals do not ever convey the information necessary to understand the effects of the individual units of analysis. In this case, the findings reveal that the periphery was an unexpected source of growth for the key variables, yet understanding which countries are having the biggest impact and, more importantly, why, requires digging deeper. Comparative and historical analysis incorporating qualitative data from case-studies for selected societies would therefore enrich the quantitative analysis offered here. Data are limited as you move further back in time from the middle of the twentieth century, but historical narratives, anthropology and archaeological research, and other similar work may shed some light on historical energy issues. Studies on the energy impacts of colonialization and for oil producers would also be interesting. The period following WWII through the early 1970s would also likely reveal interesting shifts in the world-system.

It is possible that there are system-level effects that are not the same at the country/societal level. A multi-level analysis could yield interesting results. Testing of the relationship between hegemony and energy use, as suggested and begun by Podobnik (2006b), was not performed here but may also reveal system-level effects.

The research did not directly analyze the effects of environmental degradation, only its sources. While other studies referenced have demonstrated the phenomenon of unequal exchange and ecological rent, this area is ripe for continued research. This will be important as more data become available for problems such as the effects of climate change, which are only now beginning to be experienced. Research into the growth of environmental concern and its impact on energy use and environmental degradation is also necessary as the ecological rent theory is further developed.

Breaking down energy into the components such as wind, water, the different types of coal, oil, and nuclear and doing so by country in the same five year intervals of the current study would add depth to the analysis. Additionally, each of the components of energy control and energy transformation, such as imports and exports, could be measured separately since their effects on power likely differ. For example, large oil reserves, such as in Saudi Arabia, certainly generate some power, but its amount of geopolitical and economic power is considered to be less than other countries that have few natural resources and import most of their energy, such as Japan. Analyzing the independent effects of each component of energy flow will therefore be an important part of the analysis.

One statistical tool to explore is structural equation modelling (SEM) (cf. Kline 2005). With this statistical procedure, it is possible to employ a latent growth modelling technique to test for covariance of a longitudinal dataset and using nonrecursive modelling allows for the testing of feedback loops. But the use of panel data in SEM analyses is difficult, if not impossible given existing tools. The econometric technique generalized method of moments (GMM) for analysis of latent effects of time series data (Hansen 1982) and the use of spatial coding in geographic information system (GIS) to plot the sources and destinations of energy flow, power, and environmental degradation could also be fruitful research projects.

6.4 CONCLUDING THOUGHTS

In rather remarkable announcement, China has set a target that caps energy consumption in 2015. The cap is not what could be considered aggressive as it is set at 4.1 billion tonnes of coal equivalent, which is over 25% higher than their 2010 level (Branigan 2011). But for a country that has seen a rapid rise in its development and power over the last decades, setting a cap that is not indexed to further development or based on emissions is an important move toward sustainability. It is a recognition that energy consumption itself, regardless of if the energy source is coal, oil, nuclear, or other, is problematic for ecological sustainability despite its importance for economic and geopolitical power.

In the mid-nineteenth century, the British economist William Stanley Jevons argued that increasing efficiency in resource use, coal in Jevons case, would lead to increased consumption rather than the decrease predicted by many economists. This paradox was due to the increased production that could take place with more efficient—and thus cheaper—use; e.g., more iron and steel could be manufactured in coal-fired plants (Foster et al. 2010). It will be critical that efficiency gains and the use of less ecologically damaging technology translate into less and not more use as we move forward.

Moreover, there is the “externalization” problem; i.e., the ecological costs of private activity are accrued to the public, or at best, to the state for cleanup. This is a significant issue for healthcare, as particulate emissions from fossil fuel combustion are known to increase asthma rates and other health problems. The oil “spill” in the Gulf and the ongoing nuclear disaster in Japan are only the most well-known of recent ecological costs that will likely be primarily borne by the public and nature.

Given the importance of energy to social evolution and its effects on the biosphere, it is imperative that we find a path to sustainability so that the future can be assured. It is estimated that we need five earths for everyone in the world to live like the average person in the United States (Global Footprint Network 2008), which would require a five-fold increase in global energy use (Smil 2008a). Humans have already had such a negative impact on the planet in the last two hundred years that scientists are saying we have left the Holocene and are now in the Anthropocene (Crutzen, 2002; see also Chase-Dunn and Hall 1997; Ponting 2007). As suggested by Peter Taylor (1996), we have reached a “world impasse” in which future development cannot be as ecologically harmful as in the past. We must internalize the ecological costs of our society and find solutions for their reduction.

Energy flow has been an essential component of biological, physical, and social evolution. The rise of complexity, the rise and demise of societies, and success or failure in intersystem competition are all impacted by energy capture, transformation, and waste management. We are now on the verge of a new energy regime as the fossil fuel era wanes. ‘What is next” should be a world-system with an energy base utilizing sustainable resources and with equally shared costs and benefits. Given current and projected technology, it is likely to have lower total energy use and higher costs per unit. Given the myriad crises we immediately face, including energy constraints and environmental degradation, we must begin planning for a world-system that will be more peaceful, equitable and just, while sustaining, and even improving our biosphere.

References

Abramsky, Kolya, ed. 2010. *Sparking a Worldwide Energy Revolution: Social Struggles in the Transition to a Post-Petrol World*. Oakland, CA: AK Press.

Abrutyn, Seth. 2009. "Towards a General Theory of Institutional Autonomy." *Sociological Theory* 27(4): 449-65.

Abrutyn, Seth and Kirk Lawrence. 2010. "Chiefdom to State: Toward an Integrative Theory of the Evolution of Polity." *Sociological Perspectives* 53(3): 419-442.

Abrutyn, Seth and Jonathan H. Turner. Forthcoming. "The Old Institutionalism Meets the New Institutionalism." *Sociological Perspectives*.

Adams, Robert McC. 1966. *The Evolution of Urban Society: Early Mesopotamia and PreHispanic Mexico*. Chicago, IL: Aldine Publishing Company.

Adams, Richard N. 1975. *Energy and Structure: A Theory of Social Power*. Austin, TX: University of Texas Press.

______. 1988. *The Eighth Day: Social Evolution as the Self-Organization of Energy.* Austin, TX: University of Texas Press.

Allison, Paul D. 2009. *Fixed Effects Regression Models*. Los Angeles, CA: Sage.

Amin, Samir. 1974. *Accumulation on a World Scale: A Critique of the Theory of Underdevelopment*. Vols 1 & 2. New York: Monthly Review Press.

______. 1976. *Unequal Development*. New York: Monthly Review Press.

______. 2009. "Capitalism and the Ecological Footprint." *Monthly Review* 61(6): 19-22.

Anderson, David G. 1994. *The Savannah River Chiefdoms: Political Change in the Late Prehistoric Southwest*. Tuscaloosa, AL: University of Alabama Press.

Arrighi, Giovanni. 1994. *The Long Twentieth Century: Money, Power, and the Origins of Our Times.* New York: Verso.

Arrighi, Giovanni and Jessica Drangel. 1986. "The Stratification of the World-Economy: An Exploration of the Semiperipheral Zone." *Review* 10(1): 9-74.

Babones, Salvatore J. 2005. "The Country-Level Income Structure of the World-Economy." *Journal of World-System Research* 11(1): 29-55. Available at: http://jwsr.ucr.edu.

______. 2009a. *The International Structure of Income: Its Implications for Economic Growth*. Saarbrücken, Germany: VDM Verlag Dr. Müller Aktiengesellschaft & Co. KG.

______. 2009b. "Modeling Error in Quantitative Macro-Comparative Research." *Journal of World-Systems Research* 15 (1): 86-114.

Blau, Peter M. 1964. *Exchange and Power in Social Life*. New Brunswick, NJ: Transaction Publishers.

Bolt, Katharine, Mampite Matete, and Michael Clemens. 2002. "Manual for Calculating Adjusted Net Savings." Environment Department, World Bank.

Bornschier, Volker. 2002. "Changing Income Inequality in the Second Half of the 20th Century: Preliminary Findings and Propositions for Explanations." *Journal of World-Systems Research* 8(1):100-127. Available at: http://jwsr.ucr.edu.

Bornschier, Volker, Christopher Chase-Dunn, Richard Robinson. 1978. "Cross-National Evidence of the Effects of Foreign-Investment and Aid on Economic Growth and Inequality: A Survey of Findings and Reanalysis." *American Journal of Sociology* 84: 651-83.

Boserup, Ester. 1965. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*. Chicago: Aldine Publishing.

Boyd, John, William Fitzgerald, Matthew C. Mahutga, David A. Smith. 2010. "Computing continuous core/periphery structures for social relations data using MINRES SVD." *Social Networks* 32(2): 125–137.

BP Statistical Review of World Energy. 2009. *BP Statistical Review of World Energy, June 2009*. London, United Kingdom: British Petroleum. Accessed June 2010. Available at: bp.com/statisticalreview

Branigan, Tania. 2011. "China to cap energy use in national low-carbon plan." The Guardian, UK edition. Accessed 8/19/2011. Available at: http://www.guardian.co.uk/environment/2011/aug/04/china-cap-energy-plan

Brown, Lester R. 2009. *Plan B 4.0: Mobilizing to Save Civilization*. New York: W. W. Norton & Co.

______. 2010. *World on the Edge: How to Prevent Environmental and Economic Collapse*. New York: W. W. Norton.

Bunker, Stephen G. 1985. *Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State.* Urbana, IL: University of Illinois Press.

______. 2003. “Matter, Space, Energy, and Political Economy: The Amazon in the World-System.” *Journal of World-Systems Research* 9(2): 219-258. Available at: http://www.jwsr.edu.

______. 2007. “Natural Values and the Physical Inevitability of Uneven Development under Capitalism.” Pp. 239-258 in *Rethinking Environmental History: World-System History and Global Environmental Change*, edited by A. Hornborg, J.R. McNeill, and J. Martinez-Alier. Walnut Creek, CA: AltaMira.

______. 2005. “How Ecologically Uneven Development Put the Spin on the Treadmill of Production.” *Organization and Environment* 18(1): 38-54.

Bunker, Stephen G. and Paul S. Ciccantell. 2005. *Globalization and the Race for Resources.* Baltimore, MD: Johns Hopkins University Press.

Burkett, Paul. 1999. *Marx and Nature: A Red and Green Perspective.* New York: St. Martin’s Press.

Burkett, Paul and John Bellamy Foster. 2006. “Metabolism, Energy, and Entropy in Marx's Critique of Political Economy: Beyond the Podolinsky Myth.” *Theory and Society* 35(1): 109-156.

Butzer, Karl W. 1971. Environment and Archeology: An Ecological Approach to Prehistory, 2nd ed. Hawthorne, NY: Aldine.

Carbon Dioxide Information Analysis Center. 2011. *Fossil-Fuel CO2 Emissions by Nation*. Available at: http://cdiac.ornl.gov/trends/emis/tre_coun.html.

Carneiro, Robert L. 1970. “A Theory of the Origin of the State.” *Science* 169: 733-8.

______. 1986. “On the Relationship between Size of a Population and Complexity of Social Organization.” *Journal of Anthropological Research* 42(3): 355-64.

Catton, William R. Jr. 1980. *Overshoot: The Ecological Basis of Revolutionary Change.* Urbana, IL: University of Illinois Press.

Chaisson, Eric J. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*. Cambridge, MA: Harvard University Press.

______. 2005. *Epic of Evolution: Seven Ages of the Cosmos*. New York: Columbia University Press.

Charvát, Petr. 2002. *Mesopotamia Before History*. New York: Routledge.

Chase-Dunn, Christopher. 1975. "The Effects of International Economic Dependence on Development and Inequality: A Cross-National Study." *American Sociological Review* 40: 720-738.

______. 1998. *Global Formation*: *Structures of the World Economy,* 2d ed. Lanham, MD: Rowman & Littlefield.

______. 2007. The World Revolution of 20xx. IROWS Working Paper # 35. Accessed 4/13/2010. Available at: http://irows.ucr.edu/papers/irows35/irows35.htm

Christopher Chase-Dunn and Terry Boswell. 2009. "Semiperipheral Development and Global Democracy" Pp. 213-232 in *Globalization and the 'New' Semiperipheries,* edited by O. Worth and P. Moore. New York: Palgrave MacMillan.

Chase-Dunn, Christopher and Thomas D. Hall. 1997a. *Rise and Demise: Comparing World-Systems.* Boulder, CO: Westview.

______. 1997b. "Ecological Degradation and the Evolution of World-Systems." *Journal of World-Systems Research* 3:403-431. Available: http://jwsr.ucr.edu

Chase-Dunn, Christopher, Jake Apkarian, Edwin Elias, Jesse Fletcher, Robert A. Hanneman, Hiroko Inoue, Kirk Lawrence, and Tony Roberts. 2009. "The Human Demographic Regulator." Working Paper #41. Available: http://jwsr.ucr.edu.

Chew, Sing C. 2001. *World Ecological Degradation: Accumulation, Urbanization, and Deforestation, 3000 B. C. – A. D. 2000*. Walnut Creek, CA: AltaMira Press.

______. 2007. *The Recurring Dark Ages: Ecological Stress, Climate Changes, and System Transformation*. Walnut Creek, CA: AltaMira Press.

Christian, David. 2004. *Maps of Time: An Introduction to Big History*. Berkeley, CA: University of California Press.

Cioffi-Revilla, Claudio. 2006. "The Big Collapse: A Brief Cosmology of Globalization." Pp. 79-95 in *Globalization and Global History*, edited by B. K. Gills and W. R. Thompson. New York: Routledge.

Cleveland, Cutler J., Robert K. Kaufmann, and David I. Stern. 2000. "Aggregation and the Role of Energy in the Economy." *Ecological Economics* 32: 301-317.

CNNMoney.com. 2010. *Best Places to Live.* Accessed 03/05/2011. Available: http://money.cnn.com/magazines/moneymag/bplive/2010/top25s/qualitylife/cleanair.html.

Cohen, Mark N. 1977. *The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture*. New Haven, CT: Yale University Press.

Colinvaux, Paul. 1978. *Why Big Fierce Animals are Rare: An Ecologist's Perspective.* Princeton, NJ: Princeton University Press.

Collins, Randall. 1981. "Long-Term Social Change and the Territorial Power of States." Pp. 71-108 in *Sociology Since Midcentury: Essays in Theory Cumulation*. New York: Free Press.

Correlates of War. 2010. National Material Capabilities, v. 4.0. Accessed 5.20.2010. Available at: http://www.correlatesofwar.org/

Cottrell, Fred. 1955. *Energy and Society: The Relationship between Energy, Social Change, and Economic Development*. New York: McGraw-Hill.

______. 1972. *Technology, Man, and Progress.* Columbus, OH: Charles E. Merrill.

Crosby, Alfred W. 1986. *Ecological Imperialism: The Biological Expansion of Europe, 900-1900*. Cambridge University Press.

Crutzen, Paul J. 2002. "Geology of Mankind." *Nature* 415: 23.

Daly, Herman E. 1981. *Energy, Economics, and the Environment*. AAAS Selected Symposium 64. Boulder, CO: Westview Press.

Darmstadter, Joel, with Perry Teitelbaum and Jaroslav Polach. 1971. *Energy in the WorldEconomy: A Statistical Review of Trends in Output, Trade, and Consumption Since 1925*. Johns Hopkins Press: Baltimore, Maryland.

Deffeyes, Kenneth S. 2001. *Hubbert's Peak.* Princeton, NJ: Princeton University Press.

De Landa, Manuel. 2000. *A Thousand Years of Nonlinear History.* Brooklyn, NY: Zone Books.

de Steiguer. Joseph E. 2006. *The Origins of Modern Environmental Thought*. Tucson, AZ: The University of Arizona Press.

Devezas, Tessaleno, David LePoire, João C.O. Matias, and Abílio M.P. Silva. 2008. "Energy Scenarios: Toward a New Energy Paradigm." *Futures* 40: 1-16.

Diamond, Jared. 1999. *Guns, Germs, and Steel: The Fates of Human Societies.* New York: W. W. Norton & Company.

______. 2005. *Collapse: How Societies Choose to Fail or Succeed.* New York: Viking

Dixon, William J. and Terry Boswell. 1996a. “Dependency, Disarticulation, and Denominator Effects: Another Look at Foreign Capital Penetration.” *American Journal of Sociology* 102(2): 543-62.

Dunlap, Riley E. 2006. “Show us the data: The questionable empirical foundations of "The Death of Environmentalism" thesis.*”* *Organization & Behavior* 19(1)*:* 88-102.

Dunlap, Riley E. and William R. Catton, Jr. 1978. “Environmental Sociology: A New Paradigm.” *The American Sociologist* 13(February): 41-49.

Durkheim, Émile. [1893] 1984. *The Division of Labor in Society*. Intro. L. Coser. Trans. W. D. Halls. New York: Free Press.

______. [1912] 1995. *The Elementary Forms of Religious Life*. Trans. and Intro. K. E. Fields. New York: Free Press.

Ehrlich, Paul R. and Anne H. Ehrlich. 1990. *The Population Explosion*. New York: Simon and Schuster.

Eisenmenger, Nina and Stefan Giljum. 2007. “Evidence from Societal Metabolism Studies for Ecological Unequal Trade.” Pp. 288-302 in *The World System and the Earth System: Global Socioenvironmental Change and Sustainability since the Neolithic*, edited by A. Hornborg and C. Crumley. Walnut Creek, CA: Left Coast Press.

Eisenstadt, S. N. 1993. *The Political System of Empires*. New Brunswick, NJ: Transaction.

Elvin, Mark. 2004. *The Retreat of the Elephants: An Environmental History of China*. New Haven, CT: Yale University Press.

Emerson, Richard M. 1962. "Power-Dependence Relations." *American Sociological Review* 27(1): 31-41.

Emmanuel, Arrighi. 1972. *Unequal Exchange: A Study of the Imperialism of Trade*. New York: Monthly Review Press.

Engels, Friedrich. [1884] 1978. “The Origin of the Family, Private Property, and the State.” Pp. 734-759 in *The Marx-Engels Reader*, 2nd ed. Edited by R. C. Tucker. New York: W. W. Norton & Company.

Erhardt-Martinez, Karen. Edward M. Crenshaw, and J. Craig Jenkins. 2002. “Deforestation and the Environmental Kuznets Curve: A Cross-National Investigation of Intervening Mechanisms.” *Social Science Quarterly* 83: 226-43.

Etemad, Bouda, and Jean Luciani. 1991. *World Energy Production, 1800-1985.* Centre National De La Recherche Scientifique & Centre D'Histoire Economique Internationale. Geneva, Switzerland: Librarie DROZ.

Fagan, Brian. 2004. *The Long Summer: How Climate Changed Civilization*. New York: Basic Books.

Field, Andy. 2009. *Discovering Statistics Using SPSS, 3d ed*. Thousand Oaks, CA: Sage.

Firebaugh, Glenn. 1983. Scale Economy or Scale Entropy? Country Size and Rate of Economic Growth, 1950-1977. *American Sociological Review* 48: 257-269.

______. 2003. *The New Geography of Global Income Inequality.* Cambridge, MA: Harvard University Press.

Firebaugh, Glenn, and Frank D. Beck. 1994. "Does Economic Growth Benefit the Masses? Growth, Dependence, and Welfare in the Third World." *American Sociological Review* 59: 631-653.

Firebaugh, Glenn and Brian Goesling. 2004. "Accounting for the Recent Decline in Global Income Inequality." *American Journal of Sociology* 110(2): 283-312.

Fletcher, Jesse, Jacob Apkarian, Robert A. Hanneman, Hiroko Inoue, Kirk Lawrence, and Christopher Chase-Dunn. Forthcoming. "Demographic Regulators in Small-scale World-Systems." *Structure* and *Dynamics: eJournal of Anthropological and Related Sciences.*

Foster, John Bellamy. 1999a. *The Vulnerable Planet: A Short Economic History of the Environment*. Monthly Review Press.

______. 1999b. "Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology." *American Journal of Sociology* 105(2): 366-405.

______. 2008. "Peak Oil and Energy Imperialism." *Monthly Review* July-August: 1-20. Available: http://www.monthlyreview.org/080707foster.php.

Foster, John Bellamy and Paul Burkett. 2008. "Classical Marxism and the Second Law of Thermodynamics." *Organization & Environment* 21(1): 3-37.

Foster, John Bellamy and Brett Clark. 2009. "The Paradox of Wealth and Environmental Destruction." *Monthly Review* 61(6): 1-18.

Foster, John Bellamy, Brett Clark, and Richard York. 2010. *The Ecological Rift: Capitalism's War on the Earth*. New York: Monthly Review Press.

Frank, Andre Gunder. 1967. *Capitalism and Underdevelopment in Latin America*. New York: Monthly Review Press.

______. 1978a. *World Accumulation, 1492-1789*. New York: Monthly Review Press.

______. 1978b. *Dependent Accumulation and Underdevelopment*. London: Macmillan.

______. 1998. *ReORIENT: Global Economy in the Asian Age.* Berkeley, CA: University of California Press.

______. 2007. "Entropy Generation and Displacement: The Nineteenth-Century Multilateral Network of World Trade." Pp. 303-316 in *The World System and the Earth System: Global Socioenvironmental Change and Sustainability since the Neolithic*, edited by A. Hornborg and C. Crumley. Walnut Creek, CA: Left Coast Press.

Frank, David J. 1997. "Science, Nature, and the Globalization of the Environment, 1870-1990." *Social Forces* 76(2): 409-435.

Frank, David J., Ann Hironaka, and Evan Schofer. 2000." The Nation State and the Natural Environment, 1900-1995." *American Sociological Review* 6(5): 96-116.

Franzen, Axel and Reto Meyer. 2010. "Environmental Attitudes in Cross-National Perspective: A Multilevel Analysis of the ISSP 1993 and 2000." *European Sociological Review* 26(2): 219-234.

Freese, Lee. 1997. *Advances in Human Ecology,* Supplement 1 (Part A). Greenwich, CT: JAI Press.

Freese, Edward W. 2004. *Longitudinal and Panel Data: Analysis and Applications in the Social Sciences.* New York: Cambridge University Press.

Fried, Morton H. 1967. *The Evolution of Political Society, an Essay in Political Anthropology*. New York: Random House.

Galeano, Eduardo. 1997. *Open Veins of Latin America: Five Centuries of the Pillage of the Continent*, 25th Anniversary Ed. Trans. by C. Belfrage, Fwd. by I. Allende. New York: Monthly Review Press.

Georgescu-Roegen, Nicholas. 1971. *The Entropy Law and the Economic Process.* Cambridge, MA: Harvard University Press.

Gerschenkron, Alexander. 1962. *Economic Backwardness in Historical Perspective.* Cambridge, MA: Harvard University Press.

Giampietro, Mario and David Pimental. 1991. “Energy Efficiency: Assessing the Interaction Between Humans and their Environment.” *Ecological Economics* 4: 117-144.

Global Footprint Network. 2010. “World Footprint.” Accessed 7/1/2010. Available: http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/.

Gould, Stephen Jay. 1987. *Time's Arrow/Time's Cycle: Myth and Metaphor in the Discovery of Geological Time*. Cambridge, MA: Harvard University Press.

______. 2002. *The Structure of Evolutionary Theory*. Cambridge: Belknap Press.

Gould, Stephen Jay and N. Elderidge. 1977. "Punctuated Equlibria: The Tempo and Mode of Evolution Reconsidered." *Paleobiology* 3: 115-51.

Green, Brian E. 2004. “Explaining Cross-National Variation in Energy Consumption: The Effects of Development, Ecology, Politics, Technology, and Region.” International Journal of Sociology 34(1): 9-32.

Grimes, Peter. 1996. “Economic Cycles and International Mobility in the World-System: 1790-1990.” Ph.D. dissertation. The Johns Hopkins University, Baltimore, MD.

Grimes, Peter and Jeffrey Kentor. 2003. “Exporting the Greenhouse: Foreign Capital Penetration and CO2 Emissions 1980-1996.” *Journal of World-Systems Research* 9(2):261-275. Available: http://jwsr.ucr.edu.

Grove, Richard H. 1995. *Green Imperialism: Colonial Expansion, Tropical Island Edens and the Origin of Environmentalism*. New York: Cambridge University Press.

Gunderson, Lance and C. S. Holling. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, D.C.: Island Press.

Hale, Cam. 1997. “More is Not Enough: National Energy and International Power.” *International Journal of Contemporary Sociology* 34(1): 17-38.

______. 1999. “Energy Quality: The Forgotten Factor in Energy-Society Relationships.” Pp. 271-91 in *Research in Social Problems and Public Policy*. Greenwich, CT: JAI.

Hall, Thomas D. and Christopher Chase-Dunn. 2006. “Global Social Change in the Long Run.” Pp. 33-58 in *Global Social Change: Comparative and Historical Perspectives*, edited by C. Chase-Dunn and S. Babones. Baltimore, MD: Johns Hopkins University Press.

Hames, Raymond. 2007. "The Ecologically Noble Savage Debate." *Annual Review of Anthropology* 36: 177-190.

Hamilton, H. J. 1977. "A Thermodynamic Theory of the Origin and Hierarchal Evolution of Living Systems." *Zygon* 12(4): 289-335.

Hamilton, Kirk and Michael Clemens. 1999. "Genuine Savings Rates in Developing Countries." *The World Bank Economic Review* 13(2): 333-56.

Hansen, Lars Peter. 1982. "Large Sample Properties of Generalized Method of Moments Estimators." *Econometrica* 50: 1029-1054.

Harding, Robert S. O. and Geza Teleki, eds. 1981. *Omnivorous Primates: Gathering and Hunting in Human Evolution*. New York: Columbia University Press.

Harris, Marvin. 1979. *Cultural Materialism: The Struggle for a Science of Culture.* New York: Random House.

Hawley, Amos H. 1984. "Human Ecology and Marxian Theories. *American Journal of Sociology* 89(4): 904-917.

______. 1986. *Human Ecology: A Theoretical Essay*. Chicago, IL: University of Chicago Press.

Herkenrath, Mark and Volker Bornschier. 2003. "Transnational Corporations in World Development—Still the Same Harmful Effects in an Increasingly Globalized World Economy?" *Journal of World-Systems Research* 9(1): 105-39. Available: http://jwsr.ucr.edu.

Heinberg, Richard. 2007. *Peak Everything: Waking Up to the Century of Decline in Earth's Resources*. Gabriola, BC, Canada: New Society Publishers.

Hillman, Gordon, Robert Hedges, Andrew Moore, Susan Colledge, and Paul Pettitt. 2001. "New Evidence of Lateglacial cereal cultivation at Abu Hureyra on the Euphrates." *The Holocene* 11(4): 383-93.

Hogg, Dominic. 2006. "A Changing Climate for Energy from Waste? Final Report for Friends of the Earth." Eunomia Research & Consulting Ltd. Accessed 6/15/ 2010.Available online at: www.foe.co.uk/resource/reports/changing_climate.pdf

Homer-Dixon, Thomas. 2006. *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization.* Washington, D.C.: Island Press.

Hopkins, Rob. 2008. *Transition Handbook: From Oil Dependency to Local Resilience.* Totnes, England: Green Books.

Hornborg, Alf. 2001. *The Power of the Machine: Global Inequalities of Economy, Technology, and Environment.* Walnut Creek, CA: AltaMira Press.

______. 2003. “Cornucopia or Zero-Sum Game? The Epistemology of Sustainability.” *Journal of World-Systems Research* 9(2): 205-16.

______. 2007. “Footprints in the Cotton Fields: The Industrial Revolution as Time-Space Appropriation and Environmental Load Dispacement.” Pp. 259-272 in *Rethinking Environmental History: World-System History and Global Environmental Change*, edited by A. Hornburg, J.R. McNeill, and J. Martinez-Alier. New York: AltaMira.

Hornborg, Alf, J. R. McNeill, and Joan Martinez-Alier, eds. 2007. *Rethinking Environmental History: World-System History and Global Environmental Change*. Walnut Creek, CA: AltaMira Press.

Hsiao, Cheng. 2003. *Analysis of Panel Data, 2nd ed*. New York: Cambridge University Press.

Inoue, Hiroko, Alexis Alvarez, Kirk Lawrence, Anthony Roberts, E.N. Anderson, and Christopher Chase-Dunn. 2011. “Polity Scale Shifts Since the Bronze Age: An Inventory of Upsweeps and Collapses.” Unpublished Manuscript. Institute for Research on World-Systems, University of California, Riverside.

International Energy Agency. 2009a. *World Energy Outlook, 2009*. Paris, France: OECD/IEA, 2009. See also: www.iea.org.

______. 2009b. *Coal Information*. Paris, France: OECD/IEA.

______. 2010a. World Energy Statistics and Balances. Accessed 18 January 2011.

______. 2010b. World Indicators. Accessed 18 January 2011.

International Energy Agency. Intergovernmental Panel on Climate Change. n.d. “IGCC Frequently Asked Questions.” Available online at: www.ipcc-nggip.iges.or.jp/faq/faq.html. See also: www.ipcc.ch.

IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate* Change, edited by Core Writing Team, R. K. Pachauri, and A. Reisinger. Geneva, Switzerland: IPCC. Available: http://www.ipcc.ch/ipccreports/ar4-syr.htm.

Jackman, Robert W. 1980. “A Note on the Measurement of Growth Rates in Cross-National Research.” *American Journal of Sociology* 86(3): 604-617.

Johnson, Allen W. and Timothy Earle. 2000. *The Evolution of Human Societies: From Foraging Groups to Agrarian State*. Stanford: Stanford University Press.

Jorgenson, Andrew K. 2003. “Consumption and Environmental Degradation in the World-Economy.” *Social Problems* 50: 374-394.

______. 2004. “Global Inequality, Water Pollution, and Infant Mortality.” *Social Science Journal* 41(2): 279-288.

______. 2005. “Unpacking International Power and the Ecological Footprints of Nations: A Quantitative Cross-National Study.” Sociological Perspectives 48 (3): 383–402.

______. 2006. “Global Warming and the Neglected Greenhouse Gas: A Cross-National Study of the Social Causes of Methane Emissions Intensity, 1995.” *Social Forces* 84(3): 1779-98.

______. 2007. “Does Foreign Investment Harm the Air We Breathe and the Water We Drink? A Cross-National Study of Carbon Dioxide Emissions and Organic Water Pollution in Less-Developed Countries, 1975 to 2000.” *Organization & Environment* 20(2): 137-156.

______. 2009. “The Transnational Organization of Production, the Scale of Degradation, and Ecoefficiency: A Study of Carbon Dioxide Emissions in Less-Developed Countries.” *Human Ecology Review* (16): 64-74.

______. 2009. The Sociology of Unequal Exchange in Ecological Context: A Panel Study of Lower Income Countries, 1975–2000. *Sociological Forum* 24 (1): 22–46.

Jorgenson, Andrew K. and Thomas J. Burns. 2007. “The Political-Economic Causes of Change in the Ecological Footprints of Nations, 1991-2001: A Quantitative Investigation.” *Social Science Research* 36(2): 834-853.

Jorgenson, Andrew K. and Brett Clark. 2009. “Ecologically Unequal Exchange in Comparative Perspective: A Brief Introduction.” *International Journal of Comparative Sociology* 50: 211-214.

______. 2010. “Assessing the Temporal Stability of the Population/Environment Relationship in Comparative Perspective: A Cross-National Panel Study of Carbon Dioxide Emissions, 1960-2005.” *Population and Environment* 32: 27-41.

Jorgenson, Andrew K. and Edward L. Kick, eds. 2006. *Globalization and the Environment*. Boston, MA: Brill.

Jorgenson, Andrew K. and James Rice. 2005. “Structural Dynamics of International Trade and Material Consumption: A Cross-National Study of the Ecological Footprint of Less-Developed Countries.” *Journal of World-Systems Research* XI(I): 57-77. Available: http://jwsr.ucr.edu

______. 2007. “Unequal Ecological Exchange and Consumption-Based Environmental Impacts: A Cross-National Comparison.” Pp. 273-288 in *Rethinking Environmental History: World-System History and Global Environmental Change*, edited by A. Hornburg, J.R. McNeill, and J. Martinez-Alier. New York: AltaMira.

Jorgenson, Andrew K., Kelly Austin, and Christopher Dick. 2009. “Ecologically Unequal Exchange and the Resource Consumption/Environmental Degradation Paradox: A Panel Study of Less-Developed Countries, 1970-2000. *International Journal of Comparative Sociolog*y 50(3-4): 263-84.

Jorgenson, Andrew K., Brett Clark, and Jeffrey Kentor. 2010. “Militarization and the Environment: A Panel Study of Carbon Dioxide Emissions and the Ecological Footprints of Nations, 1970–2000.” *Global Environmental Politics* 10(1): 7-29.

Jorgenson, Andrew K., Christopher Dick, and Matthew C. Mahutga. 2007. “Foreign Investment Dependence and the Environment: An Ecostructural Approach.” *Social Problems* 54(3): 371–394.

Kaneshiro, Matheu, Kirk S. Lawrence, and Christopher Chase-Dunn. (Forthcoming). “Global Environmentalists and their Movements at the World Social Forums.” Chp. 10 in *The Handbook of the World Social Forums*, edited by J. Smith, S. Byrd, E. Reese, and E. Smythe, eds. Boulder, CO: Paradigm.

Kaplan, David. 1960. “The Law of Cultural Dominance.” Pp. 69-92 in *Evolution and Culture*, edited by Marshall D. Sahlins and Elman R. Service. Ann Arbor, MI: University of Michigan Press.

Kennett, Douglas J. and James P. Kennett. 2006. "Early State Formation in Southern Mesopotamia: Sea Levels, Shorelines, and Climate Change." *Journal of Island and Coastal Archaeology* 1: 67-99.

Kentor, Jeffrey. n.d., “The Divergence of Economic and Coercive Power in the World Economy 1960 to 2000: A Measure of Nation-State Position.” Accessed 6.22.2011. Available at: http://irows.ucr.edu/papers/irows46/irows46.htm

______. 2000. *Capital and Coercion: The Economic and Military Processes that Have Shaped the World Economy 1800-1990.* New York: Garland.

Kentor, Jeffrey and Terry Boswell. 2003. "Foreign Capital Dependence and Development: A New Direction." *American Sociological Review* 68(2): 301-313.

Kentor, Jeffrey and Peter Grimes. 2006. "Foreign Investment Dependence and the Environment: A Global Perspective." Pp. 61–78 in *Globalization and the Environment*, edited by Andrew K. Jorgenson and Edward L. Kick. Boston, MA: Brill.

Kick, Edward L. 1987. "World-System Structure, Nationalist Development, and the Prospects for a Socialist World Order." Pp. 127-155 in *America's Changing Role in the World-System*, edited by Terry Boswell and Albert Bergesen. New York: Praeger.

Kick, Edward L., Laura A. McKinney, Steve McDonald, and Andrew Jorgenson. 2011. "A Multiple-Network Analysis of the World System of Nations, 1995-1999." Pp. 311-327 in *Sage Handbook of Social Network Analysis*. Thousand Oaks, CA: Sage Publications.

Klein, Richard G. and Blake Edgar. 2002. *The Dawn of Human Culture*. New York: John Wiley and Sons.

Kline, Rex B. *Principles and Practice of Structural Equation Modeling, 2nd Ed.* New York: The Guilford Press.

Kohler, Ulrich and Frauke Krueter. 2005. *Data Analysis Using Stata*. College Station, TX: Stata Press.

Konisky, David M. 2008. "Regulator Attitudes and the Environmental Race to the Bottom Argument." *Journal of Public Administration Research and Theory* 18(2): 321-44.

Korzeniewicz, Roberto Patricio and William Martin. 1994. "The Global Distribution of Commodity Chains." Pp. 67-91 in *Commodity Chains and Global Capitalism*, edited by Gary Gereffi and Miguel Korzeniewicz. Westport, CT: Praeger.

Krech III, Shepard. 1999. *The Ecological Indian: Myth and History*. New York: W. W. Norton & Company.

Lane, Frederic C. 1979. *Profits from Power: Readings in Protection Rent and Violence-Controlling Enterprises*. Albany, NY: State University of New York Press.

Lawrence, Kirk S. 2009a. "The Thermodynamics of Unequal Exchange: Energy Use, CO2 Emissions, and GDP in the World-System, 1975-2005." International Journal of Comparative Sociology 50(3-4): 335-359.

______. 2009b. “Toward a Democratic and Collectively Rational Global Commonwealth: Semi-Peripheral Development in a Post-Peak World-System.” Pp. 198-212 in *Globalization and the ‘New’ Semi-Peripheries*, edited by O. Worth and P. Moore. New York: Palgrave Macmillan.

Lawrence, Kirk S. and Seth Abrutyn. 2011. “A Theory of Ecological Rent: The Political Economy of Displaced Environmental Degradation.” Unpublished Manuscript.

Lenski, Gerhard. 1966. *Power and Privilege: A Theory of Social Stratification*. New York: McGraw-Hill.

______. 2005. *Ecological-Evolutionary Theory: Principles and Applications*. Boulder, CO: Paradigm.

LePoire, David J. 2007. “Exploration of Connections Between Energy Use and Leadership Transitions.” Presented at the Systemic Transitions Conference, May 11-13, Indiana University, Bloomington, IN.

Lipinski, Edward. 1979. *State and Temple Economy in the Ancient Near East*. Leuven, Belgium: Department Orientalistiek.

Lise, Wietze and Kees Van Montfort. 2005. “Energy Consumption and GDP in Turkey: Is there a Cointegration Relationship?” *ECN Policy Studies*.

Liverani, Mario. 2006. *Uruk: The First City*. Translated by Z. Bahrani and M. Van De Mieroop. London: Equinox.

Lloyd, Paulette, Matthew C. Mahutga, and Jan de Leeuw. 2009. “Looking Back and Forging ahead: Thirty Years of Social Network Research on the World-System.” *Journal of World-System Research* 15 (1): 48–85.

Lotka, Alfred J. 1925. *Elements of Physical Biology.* Baltimore, MD: Williams and Wilkins.

______. 1945. “The Law of Evolution as a Maximal Principal.” *Proceedings of the National Academy of Sciences* 8: 147-151.

Lovelock, James. 2006. *The Revenge of Gaia: Earth's Climate in Crisis and the Fate of Humanity.* New York: Basic Books.

Maddison, Angus. 1995. *Monitoring the World Economy 1820-1992*. Paris: OECD.

_____. 2006. *The World Economy Volume 1: A Millennial Perspective and Volume 2: Historical Statistics*. Paris, France: Development Centre of the Organisation for Economic Co-operation and Development.

______. 2008. “Statistics on World Population, GDP and Per Capita GDP, 1-2008 AD.” Accessed 6/27/2010. Available at: http://www.ggdc.net/MADDISON/oriindex.htm.

Mahutga, Matthew C. 2008. “Embedded Inequality in Global Production Networks: The Causes and Consequences of Production Network Formation.” Ph.D. dissertation. Department of Sociology, University of California, Irvine.

Mahutga, Matthew C. 2006. “The persistence of structural inequality? A network analysis of international trade, 1965–2000.” *Social Forces* 84(4): 1863–1889.

Mahutga, Matthew C. and David A. Smith. 2011. “Globalization, the structure of the world economy and economic development.” Social Science Research 40: 257-272.

Maisels, Charles Keith. 1990. *The Emergence of Civilization: From Hunting and Gathering to Agriculture, Cities, and the State in the Near East.* New York: Routledge.

Malthus, Thomas Robert. 2003. *An Essay on the Principle of Population*, 2d ed. Edited by P. Appleman. New York: W. W. Norton & Company.

Mann, Michael. 1986. *The Sources of Social Power: A History of Power From the Beginning to A.D. 1760*, vol. 1. Cambridge: Cambridge University Press.

Matias, J. C. de Oliveira and T. C. Devezas. 2007. “Consumption Dynamics of Primary-Energy Sources: The Century of Alternative Energies.” *Applied Energy* 84: 763-770.

Martinez-Alier, Joan. 2007. “Marxism, Social Metabolism, and International Trade.” Pp. 221-237 in *Rethinking Environmental History: World-System History and Global Environmental Change*, edited by A. Hornburg, J.R. McNeill, and J. Martinez-Alier. New York: AltaMira.

Marx, Karl. [1887] 1978. *Capital, Volume One*. Pp. 294-438 in *The Marx-Engels Reader,* 2d ed., edited by R. C. Tucker. New York: W. W. Norton & Company.

McAnany, Patricia A. and Norman Yoffee. 2010. *Questioning Collapse: Human Resiliance, Ecological Vulnerability, and the Aftermath of Empire*. New York: Cambridge University Press.

McNeill, J. R. 2000. *Something New Under the Sun: An Environmental History of the Twentieth-Century World.* W. W. Norton & Company.

Milanovic, Branko. 2005. *Worlds Apart: Measuring International and Global Inequality.* Princeton, NJ: Princeton University Press.

Mitchell, Brian. 1982. *International Historical Statistics: Africa and Asia*. New York: New York University Press.

______. 1983. *International Historical Statistics: The Americas and Australasia*. Detroit, MI: Gale Research Company.

______. 1984. *Economic Development of the British Coal Industry, 1800-1914*. New York: Cambridge University Press.

______. 1988. *British Historical Statistics*. New York: Cambridge University Press.

______. 1992. *International Historical Statistics: Europe, 1750-1988*. Third Edition. New York: Stockton Press.

______. 1993. *International Historical Statistics: The Americas, 1750-1988*. Second Edition. New York: Stockton Press.

Modelski, George and William R. Thompson. 1996. *Leading Sectors and World Powers: The Coevolution of Global Economics and Politics*. Columbia, SC: University of South Carolina Press.

Mol, Arthur. P. J. 2001. *Globalization and Environmental Reform.* Cambridge, MA: MIT Press.

Moore, Jason W. 2000. “Environmental Crises and the Metabolic Rift in World-Historical Perspective.” *Organization & Environment* 13(2): 123-157.

______. 2003. “The Modern World-System as Environmental History? Ecology and the Rise of Capitalism.” *Theory and Society* 32: 307-77.

______. 2011. “Transcending the Metabolic Rift: A Theory of Crises in the Capitalist World-Ecology.” *Journal of Peasant Studies* 38(1): 1-46.

______. n.d. “Cheap Food & Bad Money: Food Frontiers, and Financialization in the Rise and Demise of Neoliberalism.” Unpublished manuscript.

Muradian, Roldan and Stefan Giljum. 2007. Physical Trade Flows of Pollution-Intensive Products: Historical Trends in Europe and the World.” Pp. 307-325 in *Rethinking Environmental History: World-System History and Global Environmental Change*, edited by A. Hornburg, J.R. McNeill, and J. Martinez-Alier. New York: AltaMira.

Nemeth, Roger, and David A. Smith. 1985. "International Trade and World-System Structure: A Multiple Network Analysis." *Review* 8: 517–560.

Nichols Austin and Mark Schaffer. 2007. "Clustered Errors in Stata." *Research Papers in Economics*. Accessed 7 July 2011. Available: http://repec.org/usug2007/crse.pdf

Nissen, Hans J. 1988. *The Early History of the Ancient Near East, 9000-2000 B. C.* Trans. by E. Lutzeier, with K. J. Northcott. Chicago, IL: University of Chicago Press.

Nolan, Patrick and Gerhard Lenski. 2006. *Human Societies: An Introduction to Macrosociology*, 10th ed. Boulder, CO: Paradigm Publishers.

Ockwell, David G. 2008. "Energy and Economic Growth: Grounding our Understanding in Physical Reality." *Energy Policy* 36: 4600-04.

Odum, Howard T. 1971. *Environment, Power, and Society.* New York: John Wiley & Sons.

______. 1983. *Systems Ecology: An Introduction*. New York: John Wiley & Sons.

______. 1996. *Environmental Accounting : EMERGY and Environmental Decision Making*. New York: Wiley.

______. 2007. *Environment, Power, and Society for the Twenty-First Century: The Hierarchy of Energy.* New York: Columbia University Press.

Odum, Howard T and Elizabeth C. Odum. 1981. *Energy Basis for Man and Nature*. New York: McGraw Hill.

Pimental, David and Marcia H. Pimental. 2007. *Food, Energy, and Society*, *3rd Ed.* CRC Press.

Podobnik, Bruce. 2006a. "Global Energy Inequalities: Exploring the Long-Term Implications." Pp. 135-158 in *Global Social Change: Historical and Comparative Perspectives*, edited by Christopher Chase-Dunn and Salvatore Babones. Baltimore, MD: Johns Hopkins University Press.

______. 2006b. *Global Energy Shifts: Fostering Sustainability in a Turbulent Age.* Philadelphia, PA: Temple University Press.

Pointing, Clive. 2007. *A New Green History of the World: The Environment and the Collapse of Great Civilizations*. Penguin Books.

Polanyi, Karl. [1944] 2001. *The Great Transformation: The Political and Economic Origins of Our Time.* Boston, MA: Beacon Press.

Prigogine, Ilya. 1997. *The End of Certainty: Time, Chaos, and the New Laws of Nature*. New York: The Free Press.

______. 2000. “The Networked Society.” *Journal of World-Systems Research* 6(1): 892-898. Available at: http://jwsr.ucr.edu.

Prigogine, Ilya and Isabelle Stengers. 1984. *Order out of Chaos: Man’s New Dialogue with Nature.* New York: Bantam New Age.

Prew, Paul. 2010. World-Economy Centrality and Carbon Dioxide Emissions: A New Look at the Position in the Capitalist World-System and Environmental Pollution. *Journal of World-Systems Research* 16(2): 162-191.

Ricardo, David. [1817] 1951. “*On the Principles of Political Economy and Taxation*,” edited by P. Sraffa. Cambridge University Press.

Rice, James. 2007a. “Ecological Unequal Exchange: Consumption, Equity, and Unsustainable Structural Relationships with the Global Economy.” *International Journal of Comparative Sociology* 48(1): 43-72.

______. 2007b. “Ecological Unequal Exchange: International Trade and Uneven Utilization of Environmental Space in the World System.” *Social Forces* 85: 1369-92.

Rindos, David. 1984. The Origins of Agriculture: An Evolutionary Perspective. New York: Academic Press.

Roberts, J. Timmons and Bradley C. Parks. 2007. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy.* Cambridge, MA: MIT Press.

Roberts, J. Timmons, Peter Grimes, and Jodi L. Manale. 2003. “Social Roots of Global Environmental Change: A World-Systems Analysis of Carbon Dioxide Emissions.” *Journal of World-Systems Research* 9(2): 277-315. Available: http://jwsr.ucr.edu.

Rosa, Eugene A. and Gary E. Machlis. 1983. “Energetic Theories of Society: An Evaluative Review.” *Sociological Inquiry* 53(2-3): 152-178.

Rosa, Eugene A., Gary E. Machlis, and Kenneth M. Keating. 1988. “Energy and Society.” Annual Review of Sociology 14: 149-172.

Sahlins, Marshall D. 1960. “Evolution: Specific and General.” Pp. 12-44 in *Evolution and Culture*, edited by M. D. Sahlins and E. R. Service. Ann Arbor, MI: University of Michigan Press.

Sahlins, Marshall D. and Elman R. Service, eds. 1960. *Evolution and Culture*. Ann Arbor, MI: University of Michigan Press.

Sanderson, Stephen K. 1995. *Social Transformations: A General History of Historical Development*. Cambridge, MA: Blackwell.

______. 2007. *Evolutionism and Its Critics: Deconstructing and Reconstructing an Evolutionary Interpretation of Human Society*. Boulder, CO: Paradigm Publishers.

Schofer, Evan and Ann Hironaka. 2005. “The Effects of World Society on Environmental Protection Outcomes.” *Social Forces* 84(1): 25-47.

Service, Elman R. 1975. *Origins of the State and Civilization: The Process of Cultural Evolution*. New York: W. W. Norton and Company.

Shadra, John, Bruce London, Owen Wooley, and John Williamson. 2004. International Nongovernmental Organizations and Carbon Dioxide Emissions in the Developing World: A Quantitative, Cross-National Analysis.” *Sociological Inquiry* 74: 520-45.

Shiva, Vandana. 2006. *Earth Democracy: Justice, Sustainability and Peace*. London: Zed Books.

Simmons, Matthew R. 2005. *Twilight in the Desert: The Coming Oil Shock and the World Economy.* Hoboken, NJ: John Wiley and Sons.

Smil, Vaclav. 1994. *Energy in World History*. Boulder, CO: Westview Press.

______. 2008a. *Energy in Nature and Society: General Energetics of Complex Systems*. Cambridge, MA: MIT Press.

______. 2008b. *Global Catastrophes and Trends*: *The Next 50 Years.* Cambridge, MA: MIT Press.

Smith, Adam. [1776] 1986. *An Inquiry into the Nature and Causes of the Wealth of Nations,* edited by A. Skinner. Viking Penguin.

Smith, David A. and Douglas R. White. 1991. “Structure and Dynamics of the Global Economy: Network Analysis of International Trade 1965-80.” *Social Forces* 70: 857-893.

Snyder, David, and Edward Kick. 1979. “Structural Position in the World-System and Economic Growth, 1955-1970: A Multiple-Network Analysis of Transnational Interactions.” *American Journal of Sociology* 84: 1096–1126.

Spencer, Hebert. 1865. *First Principles of a New System of Philosophy.* New York: D. Appleton and Co.

Spencer, Charles. 1990. "On the Tempo and Mode of State Formation: Neoevolutionism Reconsidered." *Journal of Anthropological Archaeology* (9): 1-30.

STATA 2007. *Longitudinal/Panel-Data Reference Manual.* College Station, TX: STATA Press.

Stern David I. 1999. Is energy cost an accurate indicator of natural resource quality? *Ecological Economics* 31: 381-394.

______. 2000. A multivariate cointegration analysis of the role of energy in the U.S. macroeconomy. *Energy Economics* 22: 267-283.

Stern David I. and Cutler J. Cleveland. 2004. “Energy and Economic Growth.” *Rensselaer Working Papers in Economics* # 410. Accessed 6/22/2010. Available at: http://www.economics.rpi.edu/workingpapers/rpi0410.pdf

Taagepera, Rein. 1978a. “Size and Duration of Empires: Systematics of Size.” *Social Science Research* 7: 108-27.

Taagepera, Rein. 1978b. “Size and Duration of Empires: Growth-Decline Curves, 3000 to 600 B. C.” *Social Science Research* 7: 180-96.

Tainter, Joseph A. 1988. *The Collapse of Complex Societies.* New York: Cambridge University Press.

Taylor, Peter. 1996. *The Way the Modern World Works: World Hegemony to World Impasse*. New York: Wiley.

Terlouw, Cornelius P. 1992. *The Regional Geography of the World-System: External Area, Periphery, Semi-Periphery, Core.* Utrecht: Faculteit Ruimtelijke Wetenschappen.

Tilly, Charles. 1990. *Coercion, Capital, and European States, AD 990-1990.* Cambridge, MA: Basil Blackwell.

______. 1994. “Entanglements of European Cities and States.” Pp. 1-27 *Cities and the Rise of States in Europe AD 1000 to 1800*, edited by Charles Tilly and Wim Blockmans. Boulder: Westview Press.

Trevors, J. T., P. G. Kevan, and M. H. Saier, Jr. 2006. “Biosphere Quality Index (BQI).” *Water, Air, & Soil Pollution* 173(1-4): 1-3.

Tucker, Richard P. 2000. *Insatiable Appetite: The United States and the Ecological Degradation of the Tropical World*. University of California Press.

Turner, Jonathan H. 1995. *Macrodynamics: Toward a Theory on the Organization of Human Populations.* New Brunswick, NJ: Rutgers University Press.

Turner, Jonathan H. and Alexandra Maryanski. 2009. *On the Origin of Societies by Natural Selection*. Boulder, CO: Paradigm.

United Nations. 1952. *World Energy Supplies in Selected Years, 1929-1950*. New York: United Nations.

United Nations. 1997. *United Nations Energy Statistics Database, 1997 Edition*. Computerized version provided (to Bruce Podobnik) by the UN Energy Statistics Unit.

United Nations. 2008. “Millennium Development Goals Indicators.” Accessed 6/30/2010. Available: http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Indicators/OfficialList.htm.

Van Rossem, Ronan. 1996. “The World-System Paradigm as General Theory of Development: A Cross-National Test.” *American Sociological Review* 61: 508-527.

Wackernagel, Mathis and William E. Rees. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. Gabriola Island, B.C., Canada: New Society.

Wade, Robert Hunter. 2004. “Is Globalization Reducing Poverty and Inequality?” *World Development* 32(4): 567-589.

Wallerstein, Immanuel. 1974. *The Modern World-System I: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. New York: Academic Press.

______. 1976. “Semiperipheral Countries and the Contemporary World-Crisis.” *Theory and Society* 3: 461–484.

______. 1998. *Utopistics, or, Historical Choices of the Twenty-first Century*. New York: The Free Press.

______. 2004. *World-Systems Analysis*. Durham, NC: Duke University Press.

Wallis, Victor. 2008. “Capitalist and Socialist Responses to the Ecological Crisis.” *Monthly Review* November: 25-40.

Weber, Max. 1978. *Economy and Society*, *Vol. 2*. Edited by G. Roth and C. Wittich. Berkeley, CA: University of California Press.

Weiss, Harvey, ed. 1986. *The Origins of Cities in Dry-Farming Syria and Mesopotamia in the Third Millennium B. C.* Guilford, CT: Four Quarters Publishing Co.

White, Leslie A. 1943. “Energy and the Evolution of Culture.” *American Anthropologist* 45(3): 335-356.

______. [1959] 2007. *The Evolution of Culture: The Development of Civilization and the Fall of Rome.* Intro. by R. L. Carneiro & B. J. Brown. Walnut Creek, CA: Left Coast Press.

Wimberley, Dale W. and Rosario Bello. 1992. "Effects of Foreign Investment, Exports, and Economic Growth on Third World Food Consumption." *Social Forces* 70: 895-921.

Wittfogel, Karl. (1957). *Oriental Despotism: a Comparative Study of Total Power*. New Haven: Yale University Press.

Woods, Neal D. 2006. “Interstate Competition and Environmental Regulation: A Test of the Race to the Bottom Thesis.” *Social Science Quarterly* 87(1): 174–89.

Wooldridge, Jeffrey M. 2002. *Econometric Analysis of Cross Section and Panel Data.* MIT Press.

World Bank. 2010. *World Development Indicators.* Washington, D.C.: International Bank for Reconstruction and Development/The World Bank. Accessed 1/5/2011. Available at: http://data.worldbank.org/.

World Resources Institute. 2007. “Earth Trends.” Accessed 7/27/2010. Available: http://earthtrends.wri.org.

Yoffee, Norman. 2006. *Myths of the Archaic State: Evolution of the Earliest Cities, States, and Civilizations*. New York: Cambridge University Press.

York, Richard and Eugene A. Rosa. 2003. “Key Challenges to Ecological Modernization Theory.” *Organization and Environment* 16(3): 273-288.

York, Richard, Eugene A. Rosa, and Thomas Dietz. 2002. “Bridging Environmental Science with Environmental Policy: Plasticity of Population, Affluence, and Technology.” *Social Science Quarterly* 83(1): 18-34.

______. 2003. “STIRPAT, IPAT and ImPACT: Analytical Tools for Unpacking the Driving Forces of Environmental Impacts.” *Ecological Economics* 46: 351-365.

Zeder, Melinda A. 1994. “After the Revolution: Post-Neolithic Subsistence in Northern Mesopotamia.” *American Anthropologist* 96(1): 97-126.

Zipf, George K. 1949. *Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology*. Reading, MA: Addison-Wesley.

Appendices

Appendix A. Countries and World-System Rankings, 1978

1978	Babones	Mahutga & Smith	Kentor Modified
Kuwait	1	3	1
United States	1	1	1
Japan	1	1	1
Norway	1	2	1
Denmark	1	2	1
Sweden	1	1	1
Canada	1	1	1
United Kingdom	1	1	1
Netherlands	1	1	1
Saudi Arabia	1	3	1
France	1	1	1
Germany	1	1	1
Austria	1	2	1
Belgium	1	1	1
Australia	1	2	1
Finland	1	2	2
Italy	1	1	1
New Zealand	1	2	2
Ireland	1	2	2
Greece	1	2	2
Spain	1	2	2
Argentina	2	2	2
Venezuela	2	3	2
Portugal	2	2	2
Gabon	2	3	2
Mexico	2	2	2
Malta	2	3	3
Korea, Rep. of (South)	2	2	2
Brazil	2	2	2
Turkey	2	2	2
Chile	2	3	3
Peru	2	3	3
Islamic Rep. of Iran	3	3	2
Algeria	3	3	3
Colombia	3	3	3
Malaysia	3	2	3
Guatemala	3	3	3
Jordan	3	3	3
Tunisia	3	3	3
Paraguay	3	3	3
Bolivia	3	3	3
Honduras	3	3	3
Cote d'Ivoire	3	3	3
Philippines	3	2	3
Egypt	3	2	3
Thailand	3	2	3
Cameroon	3	3	3
Zambia	3	3	3
Sri Lanka	3	3	3

Togo	3	3	3
Pakistan	3	2	3
Benin	3	3	3
Dem. Rep. of Congo	3	3	3
Ghana	3	3	3
India	3	2	3

Appendix B. Countries and World-System Rankings, 1988

1988	Babones	Mahutga & Smith	Kentor Modified
Japan	1	1	1
United States	1	1	1
Norway	1	2	1
Denmark	1	2	1
Sweden	1	1	1
Canada	1	1	1
United Kingdom	1	1	1
Finland	1	2	1
Austria	1	2	1
Germany	1	1	1
France	1	1	1
Belgium	1	1	1
Netherlands	1	1	1
Australia	1	2	1
Italy	1	1	1
Ireland	1	2	2
Kuwait	1	3	2
New Zealand	1	2	2
Spain	1	2	2
Bahrain	1	3	2
Cyprus	1	3	2
Greece	1	2	2
Saudi Arabia	1	3	2
Portugal	1	2	2
Argentina	2	2	2
Korea, Rep. of (South)	2	2	2
Malta	2	3	2
Uruguay	2	3	2
Mexico	2	2	2
Venezuela	2	3	2
Trinidad and Tobago	2	3	2
Gabon	2	3	2
Brazil	2	2	2
Turkey	2	3	2
Costa Rica	2	3	3
Panama	2	2	3
Chile	2	2	3
Malaysia	2	2	3
Colombia	2	2	3
Peru	2	3	3
Jordan	2	3	3
Algeria	2	3	3

Tunisia	3	3	3
Guatemala	3	3	3
Paraguay	3	3	3
Morocco	3	2	3
Thailand	3	2	3
Islamic Rep. of Iran	3	3	2
Egypt	3	3	3
Honduras	3	3	3
Philippines	3	2	3
Bolivia	3	3	3
Angola	3	3	3
Cameroon	2	3	3
Cote d'Ivoire	3	3	3
Sri Lanka	3	3	3
Indonesia	3	2	3
Senegal	3	3	3
Pakistan	3	3	3
Zambia	3	3	3
People's Rep. of China	3	2	2
Benin	3	3	3
India	3	2	2
Togo	3	3	3
Dem. Rep. of Congo	3	3	3
Ghana	3	3	3

Appendix C. Countries and World-System Rankings, 1998

1998	Babones	Mahutga & Smith	Kentor Modified
Norway	1	2	1
Japan	1	1	1
Switzerland	1	2	1
United States	1	1	1
Denmark	1	2	1
Sweden	1	1	1
United Kingdom	1	1	1
Hong Kong, China	1	2	1
Netherlands	1	1	1
Austria	1	2	1
Germany	1	1	1
Canada	1	1	1
Finland	1	2	1
Ireland	1	2	1
Belgium	1	1	1
France	1	1	1
Australia	1	2	1
Italy	1	1	1
Kuwait	1	3	2
Spain	1	2	2
New Zealand	1	2	2
Cyprus	1	3	2
Portugal	1	2	2
Korea, Rep. of (South)	1	2	2
Saudi Arabia	2	3	2

Malta	2	3	2
Argentina	2	2	2
Uruguay	2	3	2
Mexico	2	2	2
Trinidad and Tobago	2	3	2
Czech Republic	2	2	2
Venezuela	2	3	2
Chile	2	2	2
Gabon	2	3	2
Hungary	2	2	2
Turkey	2	3	2
Costa Rica	2	3	2
Panama	2	2	2
Malaysia	2	2	2
Brazil	2	2	2
Colombia	2	2	2
El Salvador	2	3	3
Peru	2	3	3
Tunisia	2	3	3
Thailand	2	2	2
Algeria	2	3	2
Jordan	2	3	3
Guatemala	3	3	3
Islamic Rep. of Iran	3	3	2
Paraguay	3	3	3
Egypt	3	3	3
Morocco	3	2	3
Honduras	3	3	3
Bolivia	3	3	3
Philippines	3	2	3
People's Rep. of China	3	2	1
Sri Lanka	3	3	3
Indonesia	3	2	3
Nicaragua	3	3	3
Cote d'Ivoire	3	3	3
Angola	3	3	3
Cameroon	3	3	3
Pakistan	3	3	3
Senegal	3	3	3
India	3	2	2
Benin	3	3	3
Zambia	3	3	3
Togo	3	3	3
Ghana	3	3	3
Ethiopia	3	3	3
Dem. Rep. of Congo	3	3	3

Appendix D. Countries and World-System Rankings, 2008

Country	Babones Ranking	Mahutga & Smith	Kentor Modified
Norway	1	2	1
Japan	1	1	1
United States	1	1	1
Switzerland	1	2	1
Hong Kong, China	1	2	1
Denmark	1	2	1
Sweden	1	2	1
Ireland	1	2	1
Finland	1	2	1
United Kingdom	1	1	1
Netherlands	1	1	1
Austria	1	2	1
Germany	1	1	1
Belgium	1	1	1
Australia	1	2	1
France	1	1	1
Italy	1	1	1
Spain	1	1	1
Korea, Rep. of (South)	1	2	1
Greece	1	2	2
Cyprus	1	3	2
Portugal	1	2	2
Trinidad and Tobago	2	3	2
Malta	2	3	2
Saudi Arabia	2	3	2
Argentina	2	2	2
Uruguay	2	3	2
Libyan Arab Jamahiriya	2	3	2
Czech Republic	2	2	2
Mexico	2	2	2
Chile	2	2	2
Hungary	2	2	2
Panama	2	3	2
Turkey	2	2	2
Costa Rica	2	3	2
Malaysia	2	2	2
Brazil	2	2	2
Gabon	2	3	2
Jamaica	2	3	2
Colombia	2	3	2
Peru	2	3	2
Tunisia	2	3	3
El Salvador	2	3	3
Thailand	2	2	2
Jordan	2	3	3
Algeria	2	3	2
People's Rep. of China	2	2	1
Guatemala	3	3	3
Egypt	3	3	2
Morocco	3	3	3
Paraguay	2	3	3
Honduras	3	3	3

Angola	3	3	3
Philippines	3	2	3
Sri Lanka	3	3	3
Bolivia	3	3	3
Indonesia	3	2	2
Nicaragua	3	3	3
India	3	2	2
Pakistan	3	3	3
Senegal	3	3	3
Cote d'Ivoire	3	3	3
Zambia	3	3	3
Ghana	3	3	3
Ethiopia	3	3	3
Dem. Rep. of Congo	3	3	3