INFORMATION AND COMMUNICATION TECHNOLOGY DEVELOPMENT AND ANTHROPOGENIC GLOBAL WARMING: A CROSS-NATIONAL PANEL STUDY OF ICT DEVELOPMENT ON CARBON DIOXIDE EMISSIONS 1990-2009

By

JOSEPH MICHAEL SIMPSON

Bachelor of Science in Sociology
Cameron University
Lawton, Oklahoma
2005

Master of Science in Sociology
Oklahoma State University
Stillwater, Oklahoma
2008

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Dissertation Approved:

Dr. Riley E. Dunlap

Dissertation Committee Chair

Dr. Andrew Fullerton

Dissertation Advisor

Dr. Beth Caniglia

Dr. David Knottnerus

Dr. Jacqueline Vadjunec

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This dissertation is dedicated to the memories of Sarah Belusko, my lost love and colleague, and Matthew Simpson my late older brother. I think of you both often and wish I could share this with you both.

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Abstract:

Policy makers and ecological modernization scholars have begun to focus attention on the application of information and communications technologies (ICTs) to the mitigation of CO_2 emissions, the primary cause of anthropogenic global warming. This begs the question. Does ICT development increase or decrease CO_2 emissions? Two schools of thought provide competing hypotheses on this question. On one hand, Ecological Modernization Theory and its associated perspectives offer an optimistic appraisal of the impact of ICT development on CO_2 emissions. On the other hand, World Systems Theory, Treadmill of Production Theory and Structural Human Ecology Theory offer a pessimistic view of the potential for ICT development to reduce CO_2 emissions. This dissertation investigates the impact of ICT development on CO_2 emissions and resolves which school of thought is most appropriate. The analyses of six dependent variables (total CO_2 emissions, per capita CO_2 emissions and CO_2 emissions from electricity, buildings, manufacturing, and transportation) are conducted using a multilevel growth model that examines both changes over time (level-1) and differences between countries (level-2). The analyses cover the years 1990-2009 and uses three samples of nations: a global sample of all countries that data are available for (N=1926, n=121), a developed countries sample (N=461, n=26) and a less-developed countries sample (N=1465, n=95). Four key ICT development indicators are included as independent variables: fixed telephones per 100 people, mobile telephones per 100 people, the leapfrogging ratio of mobile telephones to fixed telephones and Internet users per 100 people. Population size, GDP per capita, urbanization, trade, and service economy are included as controls. The results of the analyses support the pessimistic view of ICT development. Fixed telephones per 100 people is the most consistent driver of increased CO_2 emissions globally. Mobile telephones do not have a significant impact on CO_2 emissions. Globally, the Internet does not have a significant effect on CO_2 emissions; however, in developed countries the Internet does increase CO_2 emissions.

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CHAPTER 1

INTRODUCTION

All Watched Over by Machines of Loving Grace

I like to think (and
the sooner the better!)
of a cybernetic meadow
where mammals and
computers
live together in mutually
programming harmony
like pure water
touching clear sky.

I like to think
(right now, please!)
of a cybernetic forest
filled with pines and
electronics
where deer stroll peacefully
past computers
as if they were flowers
with spinning blossoms.

I like to think
(it has to be!)
of a cybernetic ecology
where we are free of our labors
and joined back to nature,
returned to our mammal
brothers and sisters,
and all watched over
by machines of loving grace.

-Richard Brautigan 1967

The poetic dreamscape evoked by Brautigan is representative of a widely held belief about the development of advanced technology; a belief in the capacity for these technologies to elevate humanity to a new level and protect us from the uncertainty of the natural world. There are real dangers facing humanity. Anthropogenic global warming is arguably the single most important problem humanity faces. To face this problem head on humans have brought to task their most advanced technologies. In the contemporary era that means information and communication technologies, primarily telecommunications and the Internet; however, the development and application of technology to human problems involves a degree of uncertainty and there may be unintended consequences. This dissertation seeks to examine the potential for global information and communication technology development to slow CO_2 emissions.

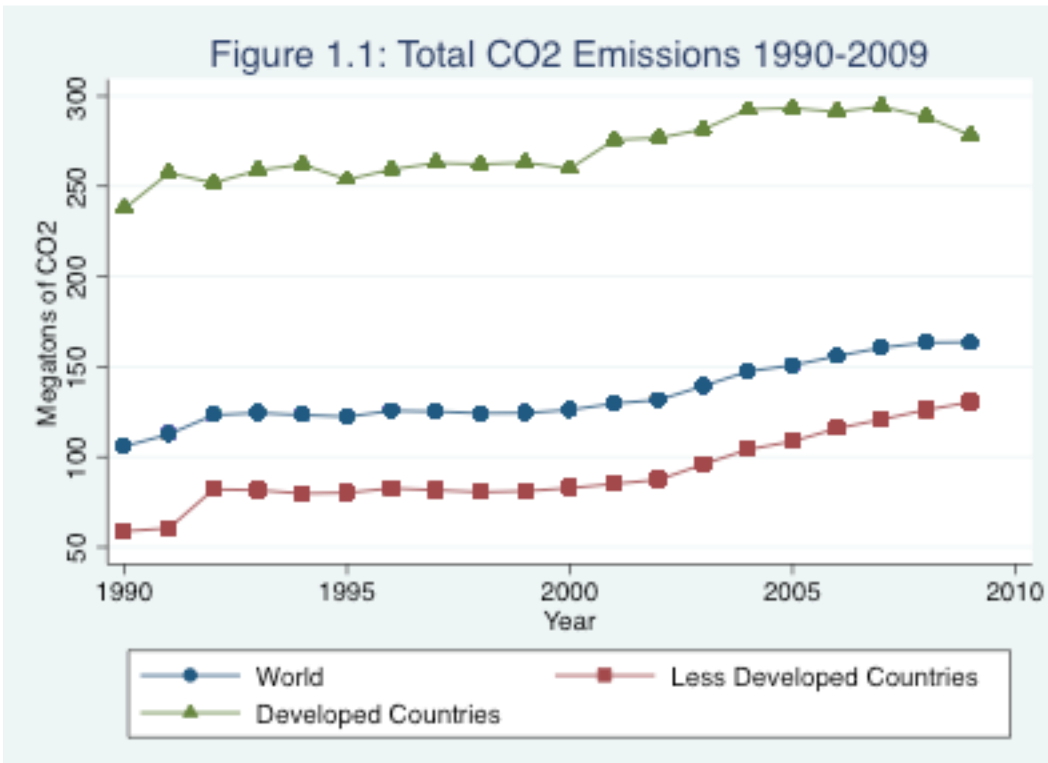
1.1 Anthropogenic Global Warming and Climate Change

The central question of this dissertation is whether CO_2 emissions have been slowed or accelerated by the global development of information communication technologies. This question is only important because CO_2 emissions play a major role in the warming of the Earth's atmosphere (IPCC 2007). When CO_2 is in the atmosphere, it absorbs solar radiation that would have otherwise reflected off the Earth's surface, trapping the heat energy and increasing the overall temperature of the atmosphere. This is similar to the effect created in a greenhouse so it is called the greenhouse effect and CO_2 is often a greenhouse gas (Mann and Kump 2009). The discovery of the heat absorbing properties of atmospheric gasses by Joseph Fourier in 1824 and their later isolation by John Tyndall allowed Svante Arrhenius, a Swedish chemist, to first calculate the approximate relationship between CO_2 in the atmosphere and global temperatures in 1896 (Powell 2011). He calculated that a doubling of CO_2 would raise global temperatures 5-6° C (9-11°F). The contemporary estimate from the Intergovernmental Panel on Climate Change (IPCC) is with a doubling of CO_2 temperatures are likely to rise 2.5-5.8°C (3-8°F), a slight revision of the original estimate by Arrhenius (IPCC 2007; Powell 2011:36-37).

Even in his time, Arrhenius knew that the burning of fossil fuels was the largest source of CO_2 emissions, and that if continued such emissions could have dramatic effects on the Earth's climate system. The key implication of the discovery of global warming and the greenhouse effect is that humans primarily cause the warming. The Mauna Loa Observatory has been measuring atmospheric concentrations of CO_2 since 1958. The record shows that the concentration of CO_2 has increased steadily every year (IPCC 2007). Additionally, the analysis of CO_2 in tree ring samples show an increasing ratio of CO_2 isotopes from the burning of fossil fuels and other plant matter (Francey et al. 1999). By the mid 1990s models were developed that could analyze the causal mechanisms of global climate shifts accurately. When human factors are left out of those models they no longer make accurate predictions and fail to model existing observations (Mann 2012:15). The increase of CO_2 in the atmosphere is unequivocally anthropogenic—human caused.

The science academies from 33 nations and regions along with dozens of national and international science organizations from nearly every field of science, notably the American Association for the Advancement of Science, the American Geophysical Union and the World Meteorological Organization (for a complete list see Powell 2011:191) affirm anthropogenic global warming as a scientific reality. Predictions from the IPCC 4th assessment report (2007) are presented as a range of possible outcomes based on a low emissions scenario, a business-as-usual emissions scenario and a high emissions scenario. Low emissions models predict a warming of 1.1 to 2.9 °C (2 to 5.2 °F) while the highest emissions models predict a warming of 2.4 to 6.4 °C (4.3 to 11.5 °F) in the 21st century. McMullen and Jabbour (2009) find that emissions on average increased 1.1% per year over the years 1990 to 1999 while from the year 2000 to 2009 CO_2 emissions increased on average 3 percent a year, exceeding the growth in emissions estimated by many of the IPCC models. All of the warming expected for the amount of CO_2 already in the atmosphere has not yet happened and every year emissions increase more warming is coming.

Figure 1.1 shows the emissions trajectories for total CO_2 emissions from 1990-2009 for developed countries, less developed countries and the world. The figure was created based on data from the World Bank (2013) and are the data for the analyses reported late in this dissertation. The steady upward trend of CO_2 emissions for the world, accelerating around the year 2000, is apparent.



*Data comes from the World Bank 2013.

It is difficult to deny that anthropogenic global warming (AGW) is happening, even though many do. However, as Arrhenius noted almost a century ago, a warmer climate might actually be welcome, particularly if you live in a cold climate (Powell 2011:38). Unfortunately, a warmer Earth does not simply mean warmer weather. The term *climate change* has come to be used almost interchangeably with *global warming,* but they are not the same thing. Warmer surface temperatures impact the natural variability in weather and climate systems and "load the dice" toward more extreme weather events and long-term changes in climate—collectively this is called climate change (IPCC 2007; Revkin 2008).

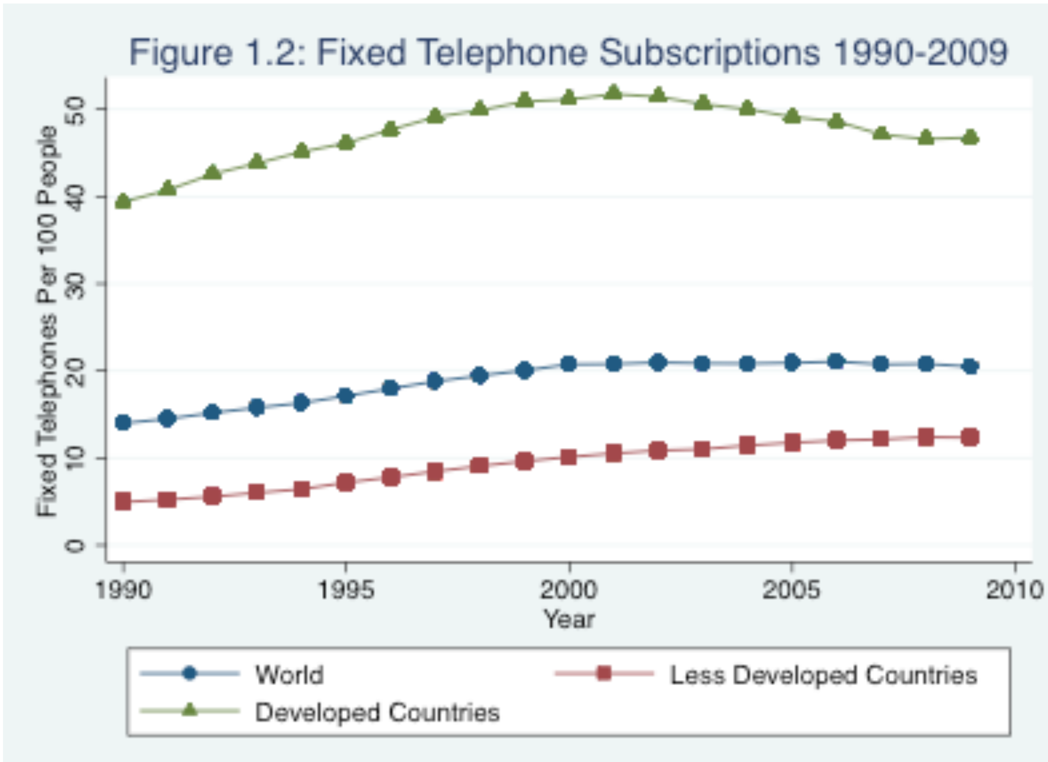
Confusing global warming with climate change can lead to erroneous conclusions when a severe cold weather event happens. What Arrhenius could not have known when he concluded that a warmer world might be better was the cascade of effects that have a degrading impact on natural systems, ecological systems, and human social systems, including rising sea levels, glacier retreat, increase in climate extremes (cold and hot days), increases in precipitation and draught, more frequent and severe storms, declines in arctic sea ice, species extinction, desertification, ocean acidification, increased disease territory (i.e., malaria, West Nile Disease), increased food and water insecurity and human habitat inundation via coastal and island flooding (Mann & Kump 2009). Many of these effects are being observed now and adaptation strategies are being deployed—when they can be—to prevent some of the worst affects. Many of these effects are absorbed as damages due to severe weather extremes impacting insurance rates and national budgets for adaptation strategies (Powell 2011).

While adaptation is certainly an important component of the response to AGW, it cannot be the only response. Each year that CO_2 emissions go unabated it becomes more difficult to slow emissions gradually and more drastic measures will be required. The prospects are bleak given that energy-related CO_2 emissions were at their highest recorded level in 2010 (IEA 2011b). While the potential for reductions strategies may be bleak, their necessity is extreme. This dissertation seeks to examine the potential for global information and communication technology development to slow CO_2 emissions and offer a support system for an overall emissions reduction strategy that includes changes in energy use.

1.2 Information and Communication Technologies

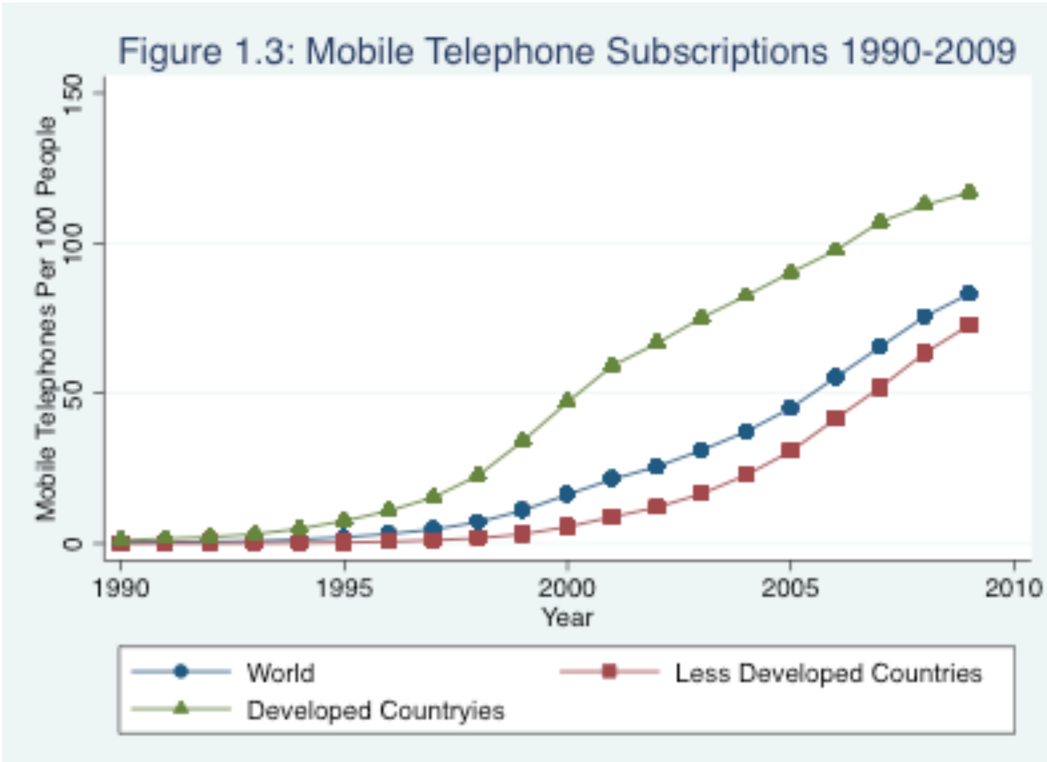
Information communication technologies (ICTs) are extensions of human sensory capacity and cognition (McLuhan 1964). As such, information technologies are as old as human civilization, including cuneiform clay tablets, papyrus and ink and the moveable-type printing press. Epochs of human civilization can be marked by the implementation of new ways of extending the human capacity to communicate, retain, and process information. Because of this broad scope, it is necessary to narrowly define ICTs for this dissertation. The focus of this dissertation is on the period of the late 20th century and early 21st century (1990-2009). This period has many monikers: post-industrial society, the information age, the new economy, the network society, and the digital society all refer to the transformative capacity of new ICT developments (Bell [1999] 1973; Castells 2000; Tapscott & Williams 2010). "All new communication means belong to one product constellation that is the driver of the new economy: [fixed] main telephone lines, mobile phones, personal computers and the Internet, they are significantly correlated with each other" (de Mooij 2003:122).

Three primary technologies associated with the information age (fixed-mainline telephones, mobile telephones, and the Internet accessible personal computer) were all developed or refined in the late 1960s and early 1970s and implemented throughout the world over the subsequent decades. Of these technologies the fixed-line telephone appears as an anachronism next to the more recent inventions of mobile telephony and the Internet; however, during the same incubation period that produced the Internet and mobile telephony (the 1960s and 1970s) fixed-line telephones incorporated the development of touch-tone dialing, digital electronic switching and common channel switching (AT&T 2012). Early switching was manual and then electromechanical. Digital electronic switching introduced the use of computers to call switching and advanced a century old technology for the new, more global and information intensive economy of the late 20th century.



*Data comes from the World Bank 2013.

Figure 1.2 shows the development trajectory of fixed telephone subscriptions for the period of the study, 1990 to 2009. The most notable feature of fixed telephone development is that in the developed countries subscriptions for fixed telephones began to fall after around the year 2000. In less developed countries fixed telephone subscriptions have been steadily increasing. Globally, the development of fixed telephones seems to have leveled off around 2000 when developed nations began to eschew fixed telephone subscriptions.

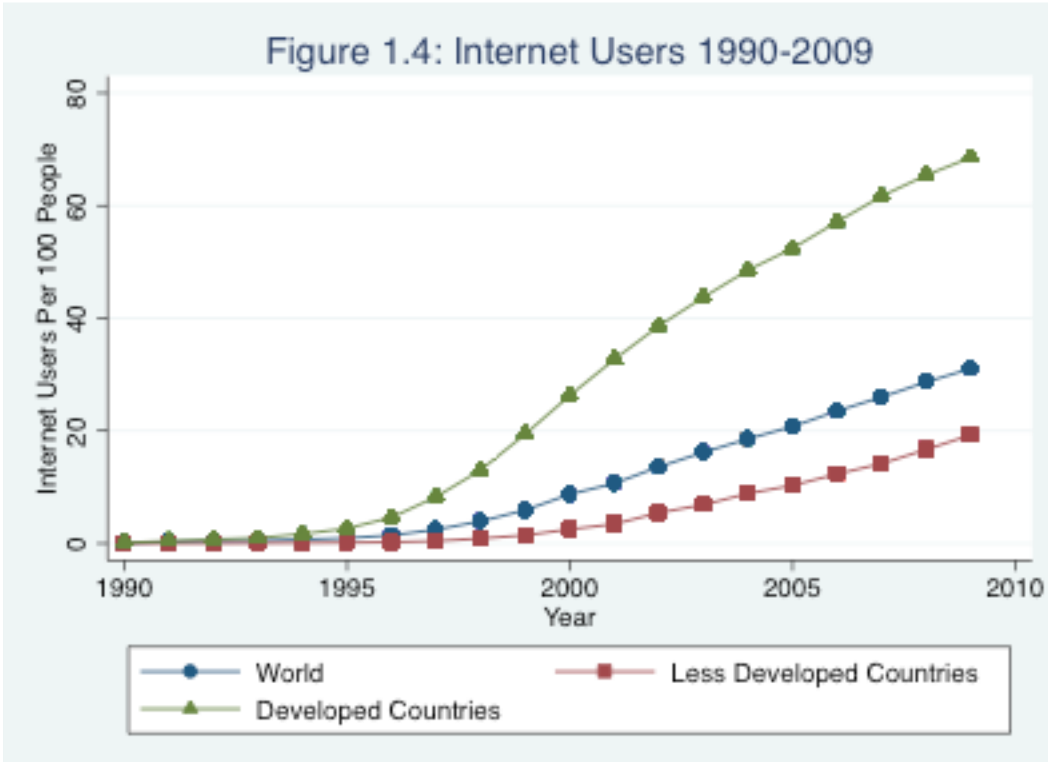


*Data comes from the World Bank 2013.

Mobile cellular-technology based phones are a 40-year-old consumer technology in 2013, first demonstrated from a car on April 3rd 1973 in New York City (Motorola 2013). Mobile telephony was made possible by the development of a cellular radio tower structure that could relay sender and receiver signals from tower to tower and through the fixed-line telephone switchboard system, seamlessly integrating the two technologies. Over subsequent decades the mobile telephone system has gone through several generations of system architecture and data transmission. The first generation (1G) networks were clunky by modern standards requiring lots of bandwidth with very little security; a police scanner could easily pick up a call. By the 1990s the second generation (2G) of networks relied solely on digital transmissions and incorporated data services such as SMS text messaging, audio downloads and eventually full Internet services. In the early 2000's the demand for more data and Internet functionality drove the development of the third generation (3G) network towards using Internet protocol packet switching to handle the increased volume of data transmissions. By 2009 the demand for data pushed the development of fourth generation (4G) network technology that removed circuit switching entirely by carrying voice over a packet switching service (Motorola 2013).

Figure 1.3 shows the dramatic growth in mobile telephones over the period of investigation. In 1990 there were very few cell phones present in any part of the world. By 2009 the average number of mobile telephones per 100 people in the developed world exceeds 100, meaning that almost everyone in a developed country has a mobile telephone and many have more than one. The change is no less dramatic for less developed countries, as by 2009 more than a majority of people in less-developed countries had access to Mobile telephones.

What is called the Internet is really a constellation of inventions. The first computer network was the ARPANET, developed by the U.S. Department of Defense; it developed a standard (TCP/IP) for how information would be processed over the network using binary packets (Howe 2012). These early developments allowed specialized users and then general consumers to access remote files and transmit electronic text, audio, and images. The Internet most people are familiar with relies on these basic principles but utilizes the World Wide Web system of HTTP application protocols and HTML files developed by Tim Berners-Lee's engineering team in the mid 1990s. Advances in user generated content and interactivity in the early 2000s, often called "Web 2.0" denotes the shift from Internet service provider content to user-generated new content (O'Reilly 2005).



*Data comes from the World Bank 2013.

Figure 1.4 shows the growth trajectory of Internet users from 1990 to 2009. As with mobile telephones there has been rapid growth during this period. The gap between developed countries and less-developed countries is wider than for mobile telephones and the level of penetration maxes out around 75 percent. In less developed countries barely 20 percent of people were Internet users by 2009. The global average at that time was around 35 percent.

When the terms *ICT, ICT development* or *ICT development indicator* are used in this dissertation I will be specifically referring to fixed line telephones, mobile telephones and the Internet. All three of these technologies have evolved over recent decades to become global technologies and drivers of global economic development, which begs the question: has this significant level of development had any impact on carbon dioxide emissions and if so, is the effect positive or negative? Answering this question will inform a core debate within environmental sociology, namely the sustainability of human societies.

1.3 Structure of the Dissertation

Chapter 2 presents an overview of the relevant literature and theory on ICT development and CO_2 emissions. There are two competing schools of thought about technology and the environment and each hinge on its orientation to the future. On one hand, optimistic perspectives such as Ecological Modernization Theory put forward the idea that technological development—including ICT development—is the key to reducing the impact of humans on CO_2 emissions (Mol 2006). On the other hand, pessimistic perspectives such as Treadmill of Production Theory and Structural Human Ecology are extremely skeptical about new technological developments such as ICTs changing the direction of societies' exploitation of the environment, including CO_2 emissions. Using these two opposing perspectives, a set of competing research hypotheses are developed.

Chapter 3 presents the data from the World Bank (2013) and quantitative methods for the investigation of the research question and the testing of the research hypotheses developed in chapter 2. Chapter 3 details the specification of a multilevel model for growth for total CO_2 emissions, per capita CO_2 emissions for countries and source-specific CO_2 emissions from electricity, buildings, manufacturing and transportation. Multilevel growth models will be specified for three samples: a global sample including all countries for which data are available, a developed country sample of countries in the top quartile of GDP per capita and a less-developed country sample for countries below the top quartile of GDP per capita. The general research hypotheses from Chapter 2 are expanded to generate an analytical set of hypotheses for all three samples. Variable descriptions and statistics are included for the six dependent variables as well as for the following independent variables: fixed telephones per 100 people, mobile telephones per 100 people, leapfrogging ratio of mobile to fixed telephones, Internet users per 100 people, population size, GDP per capita, urbanization, trade, and service economy.

Chapter 4 provides the results for the analyses of the global sample of 121 countries for the period of 1990 to 2009. Results from four growth models are presented for each of the outcome variables: total CO_2 emissions, per capita CO_2 emissions for countries, and source-specific CO_2 emissions from electricity, buildings, manufacturing and transportation. After presentation of the findings, a discussion of their implications for the research question and hypotheses is offered. Chapters 5 and 6 follow the same structure as Chapter 4, with Chapter 5 presenting the results for the developed country sample and Chapter 6 the results for the less-developed sample.

Chapter 7 is the discussion and conclusion chapter. A discussion of the findings across all three samples and their implications for the research hypotheses are discussed. The role for each ICT development indicator in CO_2 emissions will be examined individually and a general summation of their effect is made. The implications for theories are made clear, particularly for Ecological Modernization Theory, Treadmill of Production Theory and Structural Human Ecology Theory (Mol 2001; Schnaiberg 1980; York, Rosa, and Dietz 2003a). Some limitations of the study are discussed, unanswered questions and future research needs are outlined and final concluding remarks are made.

1.4 Conclusion

This dissertation situates ICTs within the context of environmental sociology broadly and quantitative human ecology studies more specifically (Catton and Dunlap 1978, Dunlap and Catton 1979; York, Rosa, & Dietz 2003a). This dissertation is not grounded in an overly simplistic view of technology, an antagonistic view of humans, or a Luddite technology phobia. Rather, a passion for explaining some of the complexity of the relationship between technology and the environment drives this research. What follows is an investigation of the potential beneficial and detrimental impacts of information and communication technologies on carbon dioxide emissions and thus global warming.

CHAPTER 2

THEORY AND LITERATURE REVIEW

"I would feel more optimistic about a bright future for man if he spent less time proving that he can outwit Nature and more time tasting her sweetness and respecting her seniority."

E. B. White

There are many perspectives on how information and communication technologies (ICTs) may impact society and the environment. This chapter provides a framework for organizing the literature on ICTs and the environment into two broad categories: *optimistic* and *pessimistic*. To facilitate this goal the chapter will be broken into four sections. Section one offers a brief overview of anthropogenic global warming (AGW). Section two offers a brief discussion about ICTs and the different genres of ICT research and how they can inform research on environmental degradation. Section three examines two sets of divergent perspectives on technological development and environmental degradation. The first set consists of the generally optimistic perspectives in which technological development and modernization are seen as pathways to reducing, mitigating, or eliminating environmental degradation, in this case CO_2 emissions. The second set consists of generally pessimistic perspectives that reflect doubts that technological development and innovation alone can halt environmental degradation. In the final section, I take stock of the theories presented and provide a set of corresponding and divergent hypotheses regarding the potential of ICTs to reduce environmental degradation, specifically CO_2 emissions which contribute to AGW.

The greatest crisis facing humanity in the 21st century is the threat of runaway global warming. The unabated release of greenhouse gases, CO_2 in particular, into the atmosphere has caused the global climate system to slowly warm. Without mitigation and with business-as-usual practices the planet-wide global warming may reach a point of no return. The direst predictions of runaway global warming (e.g. sea level rise, ocean acidification, food insecurity, see Mann and Kump 2009 for more) are not a certainty yet; however, the level of CO_2 already in the atmosphere will lead to additional global warming. It is also certain that the increased level of CO_2in the atmosphere results from human activity, primarily the burning of fossil fuels (IPCC 2007).

Problems that are seen as intractable are often labeled as "wicked problems" indicating their intransigent nature. AGW has been labeled as a "super-wicked problem" (Levin, Cashore, Bernstein and Auld 2007). In addition to the difficulty of developing straight-forward solutions, as with a merely wicked problem, AGW is "super" wicked for four reasons: 1) because time is running out for a solution, 2) there is no central authority to enforce a solution, 3) those seeking to end the problem are also its cause, and 4) it is prone to hyperbolic discounting (Levin et al. 2007). To tackle such a super-wicked problem society must bring to bear its most powerful problem-solving technology: the networked computer. In the Information Age any and all solutions involve the application of ICTs and the vast human capital of the networked world. It is the hope of many wellintentioned actors to utilize ICTs to reduce greenhouse gas emissions through as many possible avenues of mitigation as possible (Mol 2008; Tapscott and Williams 2010)

2.1 Orientations Toward the Future, ICTs and the Environment

Fixed-line telephones, mobile phones and Internet technologies have had profound impacts on economic development and social change more broadly. The transformative abilities of these three technologies have been the focus of much speculation, research and debate. Similarly, in the debate about environmental impacts, particularly CO_2 emissions, there has been much speculation, wishful thinking, and outright misinformation, because of this, it important to categorize the literature in a readily comprehensible fashion.

Kling (1994) outlines five genres of research on computerization and ICTs. Even though these genres emerged from the literature on ICTs the framework he develop seems to apply quite well to relevant literature in environmental sociology. The first two genres, *technological utopianism* and *anti-utopianism*, identify the brightest dreams and darkest nightmares respectively of a digital world. Useful because they explore ideas that cannot be verified, they are often hyperbolic and disconnected from the reality of technological development. The final three genres, *social realism*, *social theory*, and *analytical reduction* are anchored in empiricism rather than speculation. Social realism counters the hyperbolic nature of utopianism and anti-utopianism by focusing on "…empirical data to examine computerization as it is actually practiced and experienced" (Kling 1997:162). Studies in the social realism genre are case studies and generally employ more ethnographic methods. Social theory transcends single cases to test and develop general concepts that can be applied across many settings. The final genre, analytical reduction, works "…within a tightly defined conceptual framework [and] completely quantitative studies represent the ideal example of this genre" (Kling 1994:164).

There is a diverse set of perspectives and theories that can help explain the relationship between ICT development and CO_2 emissions. Applying Kling's genre framework as a guideline, a pattern appears in the literature. Research on technology and the environment is often oriented toward the future, concerned with the successes and pitfalls of human management of the natural environment. While this literature certainly has apocalyptic discourses as well as utopian musings, most of it is more tempered (see Grimes 1999 for an example of apocalyptic discourse and for a utopian discourse see Kurzweil 2005). The two general orientations of research or writings on technology and the environment set up two broad categories into which several perspectives can be fit. To refrain from over-emphasis on extreme positions these categories are labeled *optimistic perspectives* and *pessimistic perspectives*, rather than utopian and anti-utopian. Kling's model has additional value when examining this body of literature in that optimistic perspectives tend to fall in the social realism genre, utilizing more case studies, while the pessimistic genre often employs analytical reduction (York and Rosa 2003). The general conceptual models of the social theory genre seem to be found in equal measure in either category. Finally, using Kling's genre framework this dissertation can be categorized as a mix of analytical reduction and social theory, having both a general theoretical conceptual model and a specific analytical strategy. Whether it is optimistic or pessimistic in character remains to be seen.

2.2 Optimistic Perspectives

To begin the section on optimistic perspectives a selection of studies and reports on the relationship between CO_2 and ICTs will be reviewed. One of the earliest white paper reports to investigate the link between ICTs and climate change was Romm, Rosenfeld, and Herrmann's (1999) report, *The Internet and Global Warming.* In that report the authors outline the basic arguments for a reduction in energy demand brought about through the widespread adoption of ICTs. While the report is focused on the United States, its argument and method would be used later in subsequent national and international reports.

Romm et al. (1999) argue that over the period of 1997 to 1998 there was a 3 percent improvement in energy intensity (energy per dollar of GDP), with roughly one-third from "structural" improvements in energy intensity brought about by an increase in growth of economic sectors that are less energy intensive, in this case the ICT sector. The remaining two-thirds came from efficiencies across economic sectors, some of which would be ICT based efficiencies (Romm et al. 1999). The authors acknowledge the limitations in available data at the time and offer their report as one possible scenario, not a prediction (Romm et al. 1999:7). Additionally, Romm and co-authors acknowledge that ICTs are also energy consumers.

The most significant feature of the Romm et al. (1999) report is the organization of potential impacts by sector. Intuitively, ICTs may have differing trends in different economic sectors. Romm et al. discuss the impact of ICTs in four sectors: (1) energy, (2) buildings, (3) manufacturing and (4) transportation. This segmentation of effects will become a key feature in many future reports on the impacts of ICTs on CO_2 emissions. For example, the more recent report by the Climate Group and the Global e-Sustainability

Initiative, *Smart 2020: Enabling the Low Carbon Economy in the Information Age,* centers its argument on "smart" or ICT enabled motor systems, logistics, buildings and electrical grids (Webb 2008). Similar segmentation of impacts are found in most of the major reports on CO_2 and climate change (Buttazoni 2008; Erdman and Hilty 2010; Erdman et al. 2004; Hilty et al. 2006; Kuhndt al. 2003; Lainer and Koomey 2001; Labouze et al. 2008; Mallon et al. 2007; Matsumoto et al. 2005). The four sectors most often identified conform to four IPCC source categories: electricity and heat production, buildings, manufacturing, and transportation

The energy sector is at the heart of anthropogenic global warming. When humans choose to burn coal and other fossil fuels we emit CO_2 and other pollutants. ICTs utilize energy when they are operating, at rest, or charging. Their contribution to global energy consumption is estimated currently at 3 percent and is expected to increase to 6 percent by 2030 (Chan et al. 2012). Because of the connection of energy consumption to CO_2 emissions, "cloud computing" and other telecommunication services are often on the radar of organizations such as Greenpeace (Cook and Van Horn 2011). Big ICT firms such as Google, Apple, and Hewlitt-Packard have stylized themselves as "green" companies in what ways they can. For example, Google established several server farms or "cloud computing" centers in Oklahoma to take advantage of renewable wind resources in the panhandle (Google 2013).

Moore's Law correctly predicted in 1965 that the number of transistors on integrated circuits would double every eighteen months. What has come to be known as Koomey's Law states that "the electrical efficiency of computing (the number of computations that can be completed per kilowatt-hour of electricity) also doubled about every 1.5 years over that period" (Koomey et al. 2011:52). As computers get faster they have lower energy demands. As computers have gotten faster the number of people who have access to them has grown through laptops and mobile phones. Billions of people have now instant communication and access to a near infinite amount of content. Each of those users also has an increasing demand for more data and processing power—as evidenced by succeeding generations of mobile phones—and it is not clear that efficiency has outpaced demand. Correspondingly ICTs should have a decreasing demand on electricity production.

Optimistic Source Hypothesis 1: As ICT development increases, CO_2 emissions from electricity production will decrease.

Since its' beginning computing has been an indoor activity. Because of their size, materials, and sensitivity ENEAC and other early computers were kept in climate-controlled clean rooms to prevent dust and manage overheating. Mobile devices have made computing more of an anywhere activity; however, climate control and access to sockets for charging and operation are still the primary demands ICTs put on building infrastructure. Personal computers and laptops can become hot and increase the demand for air conditioning. Custom personal computers often come with additional aluminum heat-sinks, fans, or water-cooling to reduce heat output. Computer workstations take up square-footage and create demand for parking cars, all of which generate CO_2 emissions from concrete and other construction materials.

On the other hand, computer systems have enabled building operators to better manage their climate-control systems, thereby reducing energy demand. Other specialized building automations such as timed lighting and motion sensors also reduce this demand, but it is unclear that ICTs themselves contribute directly to this reduction. These systems often have remote control features that can be accessed through ICTs. ICT-enabled shopping reduces the demand for retail sales space. For example, all of the products sold on Amazon.com are warehoused but never shelved at a retail store. In contrast Wal-Mart, which has hundreds of retail stores and many warehouses, can expect to use more energy. Dematerialization can also reduce the demand for retail space. MP3s and e-books sold through online retailers such as Amazon.com and iTunes have had a dramatic impact on the retail sales of books and CDs. Brick and mortar stores such as Tower Records and Borders Books have gone out of business (USA Today 2011).

Optimistic Source Hypothesis 2: As ICT development increases, CO_2 emissions from buildings will decrease.

Computers also make manufacturing more productive by enabling automation, which makes production more efficient. ICTs along with automation processes allow on-demand production of goods. On-demand production matches retail demand more closely and requires less warehouse space as consumers and retail stores have products produced as needed, as opposed to a wholesale warehouse model. ICTs also impact manufacturing by providing more opportunities for retail and wholesale shopping, thus expanding the consumer base for small businesses.

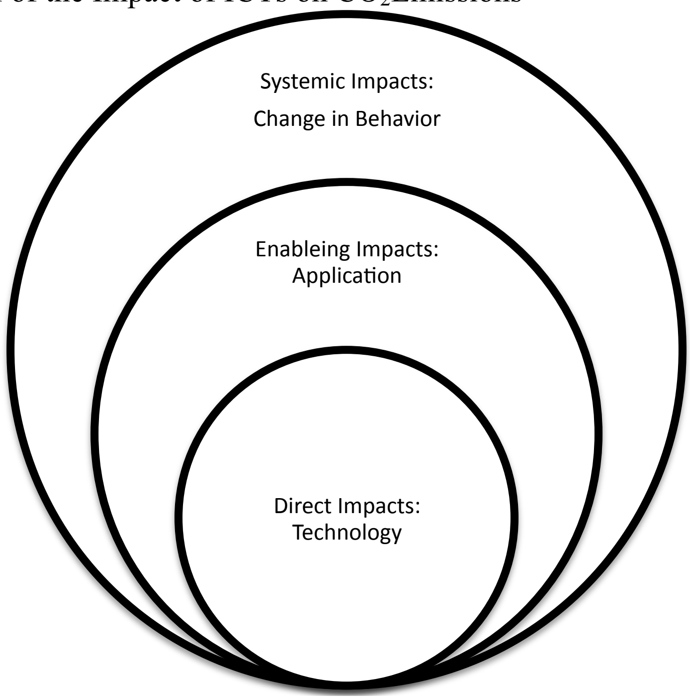
Optimistic Source Hypothesis 3: As ICT development increases, CO_2 emissions from manufacturing will decrease.

The potential for changes in transportation patterns are easy to see as ICTs provide an alternative to transportation. Work, education, healthcare, intimate relationships, sightseeing, job interviews and a vast number of other regular social activities now have ICT enabled alternatives. Services such as Skype can provide the imitation of real face-to-face interaction, and thus reduces the demand for real travel, reducing fuel usage.[1] The use of GPS systems and smart route planners can also reduce the demand for fuel, and with smart phones these technologies are more available than ever.

Optimistic Hypothesis 4: As ICT development increases, CO_2emissions from transportation will decrease.

Segmentation of effects is not the only commonality found in the ICT impacts literature. From Romm et al. (1999) on, explicitly or inexplicitly, a model of ICT impacts on the environment was developed. Hilty (2008) and MacLean and St. Arnaud (2008) explicitly model (Figure 2.1) the relationship of impacts as a series of nested effects beginning with direct impacts, leading to enabling impacts on through to systemic impacts. This model correlates with the International Telecommunication Union's (ITU) (2010) three-tier model of direct, indirect and systemic effects, as well as other common conceptions. Direct impacts are the real production-consumption costs of ICTs across the product lifecycle. Enabling, indirect or second-order impacts involve the application of ICTs in particular contexts such as telecommuting or e-commerce. Systemic or third order impacts are broad changes in behavior and across levels of social structure. The shift from an industrial economy to a post-industrial or information economy would be an example of this. The model is nested to indicate that each order of impact (first, second and third) is dependent on the level before it. Because of this feature direct, indirect, and systemic effects should be accessible through the level of adoption of ICTs in a given society.

Figure 2.1: Model of the Impact of ICTs on CO_2Emissions



The effect of ICTs on global development in general and their impact on the environment in particular can be viewed negatively or positively; however, the three-tier model assumes most of the negative consequences happen at the direct effect level with secondary and systemic level effects being generally viewed as beneficial. This understanding of the effects of ICT development is situated in the modernist worldview that shapes a great deal of public policy and institutional advancement. Within environmental sociology Ecological Modernization Theory reflects this train of thought.

2.2.1 Ecological Modernization Theory

Ecological Modernization Theory (EMT) is a prominent theory in environmental sociology and forms the core of optimistic perspectives. While often a catchall of optimistic green perspectives in addition to constantly shifting its theoretical foundations—EMT is now in its third wave—at its core EMT is concerned with social transformations that "transcend the ecology-economy divide" (Mol and Sonnenfeld 2000; Mol 2008; Mol, Spaargaren and Sonnenfeld 2009:6). EMT is squarely in the field of what Buttel (2003) calls the "sociology of environmental reform." EMT put forward the idea that corrections to the trajectory of environmental degradation should be "developed progressively from within the existing constellation of modernity in a way that reconstructed and redefined extant institutions so that environmental risks and side effects were addressed in a structural manner" (Mol, Spaargaren and Sonnenfeld 2009:6). To this end ICTs have been identified as a cornerstone of socio-environmental transformation, providing a pathway for structural change in behavior, politics, and resource use (Mol 2008; For a detailed discussion of Ecological Modernization Theory see Mol, Sonnenfeld, and Spaargaren 2009). Of course, technological development can be thought of as a structural change in and of itself (Kling 2000).

The explanations for this structural change can be divided into two camps, weak *ecological modernization* and *strong ecological modernization* (Christoff 2009). So-called weak EMT, the version that gets the most attention from American environmental sociology, is the application of technology to promote sustainable societies. In this sense EMT has been precisely defined "as the implementation of preventative innovation in production systems (processes and products), that simultaneously produces environmental and economic benefits" (Milanez and Bührs 2007:565). On the other hand, strong EMT is concerned with the broad institutional and systemic process of environmental governance and reform (Christoff 2009).

Strong EMT concerns the socio-political dimensions of environmental reform. Environmental public policy does not happen in a vacuum. Buttel (2000) considers ecological modernization as a primarily political sociology perspective that undervalues the technologic and economic arguments of the weak branch of EMT. The importance of the environmental movement and the structure of state-society relationships in generating incentives for green industrialization and green consumer practices cannot be overstated (Mol 2000; Gruber 2003; Cohen 2006). However, whatever the political realities may be—at the moment they are by no means favorable in the U.S. or globally—there must be technological alternatives for sustainable policy to be effective. In this dissertation the impact of ICTs on CO_2 emissions will be gauged by how widespread they are because a core assumption of modernization is that societies change when they have access to opportunity and resources for change. Here opportunity and resources are represented in the form of ICT development. Adherents of weak and strong ecological modernization would agree that the development of ICTs should reduce CO_2 emissions, through the technical applications noted above, their ability to transform social structures and their ability to amplify the impact of environmental governance (Mol 2008).

Mol outlines the praxis of informational governance in *Environmental Reform in the Information Age* (2008). He begins by noting the practical role that ICTs play in the surveillance of environmental harms. Satellites, weather stations, wireless communication, and new media such as blogs and YouTube all allow information on environmental harms to be recorded. The spread of governmental data such as the Toxics

Release Inventory are facilitated by ICTs (Mol 1995, 2008). Even at a more basic level the discovery of global warming and the advancement of climate science could not have occurred were it not for ICTs. In particular, data analysis software and super computers are needed to run complex climate models.

Mol (2008) argues the state, private sector nongovernmental organizations, and the media each have something to contribute to environmental informational strategies. The state provides regulatory mandates for private firms to collect data on their emissions that can be used as benchmarks for carbon reduction strategies. The state also adopts e-services such as e-filing for taxes. The state can also use incentive structures to encourage other organizations to adopt ICTs either for green purposes or for cost savings initiatives, electronic health records being one example. Businesses in the private sector are also driving the adoption of ICTs for carbon reductions and cost savings purposes (Tomlinson 2010).

Non-governmental groups can utilize ICTs in many ways that are beneficial to their missions and that could potentially save themselves energy. In particular environmental advocacy groups can better mobilize donors and activists through new media technology. In this same vein new media technologies allow research done at the community level to reach a much wider audience.

EMT asserts that through environmental reform, environmental consciousness, technological development and economic growth sustainable societies can be created (Mol 2001, 2002, World Economic Forum 2009). This process is primarily achieved through a process called *dematerialization*, or literally a reduction of the level of resource use by society. Dematerialization can come in the form of using lighter and more abundant materials such as the use of aluminum cans instead of steel cans. In the 21st century dematerialization is taken to mean the digitization of material products and services, as photons and electrons have little material substance. These claims must be considered hyperbolic to some degree. Text, images, video, and audio are readily digitized but make up a small portion the global economic product and represent only a small percentage of the industrial impact on CO_2 emissions. Agriculture, transportation, energy, buildings and construction are the most significant drivers of CO_2 emissions, and while dematerialization may reduce the heavy reliance on fossil fuels and other non-renewable resources from these sectors it is difficult to imagine completely immaterial versions of these sectors. However, technologists, policy makers and other like-minded ecological modernists contend that the energy savings potential form ICT development will significantly reduce CO_2 emissions.

Global Optimistic Hypothesis: As ICT development increases, CO_2 emissions will decrease.

2.2.2 ICTs and The Environmental Kuznets Curve

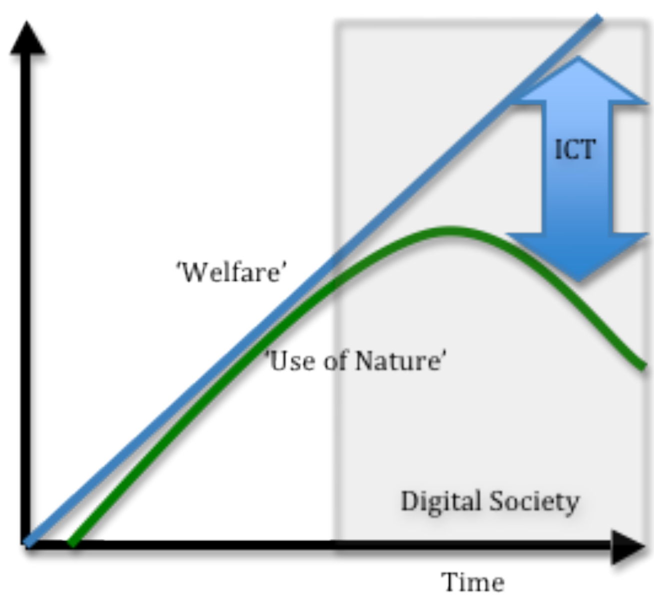
The Kuzenets curve is a well-known economic development hypothesis stating that income inequality initially increases as income per capita increases before hitting a turning point when inequality begins to decrease as per capita income increases (Kuzenets 1955). Graphically, the Kuzenets curve is an inverted U-shaped curve. The logic of the Kuznets curve hypothesis was first applied to the environment in the early 1990s through the International Bank for Reconstruction and Development (1992) report on the environment and development. Empirical research on the environmental impacts of economic development including the North American Free Trade Agreement suggested economic development was reducing environmental degradation (Grossman and Krueger 1994, 1995; Panayotou 1993, 1997; Shafik and Bandyopadhyay 1992). Proponents of the Environmental Kuznets Curve (EKC) suggested that environmental degradation would increase as gross domestic product (GDP) per capita increased until a turning point was reached; thereafter economic development would lead to a decrease in environmental degradation (See Figure 2.2).

This logic fits the basic arguments put forth by EMT well as the broader framework of sustainable development put forth in the World Commission on Environment and Development (1987) report, *Our Common Future.* The EKC hypothesis is attractive to policy makers and transnational corporations because it requires no compromise of liberal economic policy commitment to economic growth in order to reduce ecological degradation. In fact, one strong proponent suggested that "in the end the best—and probably the only—way to attain a decent environment in most countries is to become rich" (Beckerman 1992:482). The mechanisms of the EKC are assumed to be a mixture of political pressure from an affluent public along with advances in less degrading industrial technologies (Panayotou 1997). One of the key components of the EKC is "structural changes towards information-intensive industries and services…" that will supposedly decouple the economy from the environment, the central question of this dissertation (Panayotou 1993:1).

The empirical evidence for the Kuznets' inequality curve and the EKC has been called into question (Fields 2001; Stern 2004a). However, there is some evidence that an EKC exists for some individual pollutants such as SO_2 and resource depletions such as deforestation, though some of these findings could stem from measurement error or model specification issues (Stern 2004a). To date no EKC for CO_2 has been found, though there are interesting dynamics between developed and developing nations as reported in Stern (2004b:523):

> [In] tests of causality between CO_2 emissions and income in various individual countries and regions, the overall pattern that emerges is that causality runs from income to emissions or that there is no significant relationship in developing countries, whereas causality runs from emissions to income in developed countries… in each case, the relationship is positive, so that there is no EKC-type effect.

Figure 2.2: Potential Contribution of ICTs to Decoupling 'Welfare' from the Use of Natural Resources (Reproduced from Kuhndt et al. 2003:6)



While there is no empirical evidence of an EKC for CO_2 emissions, the literature on CO_2 emissions and ICT development often put forth the EKC argument based on ICT development rather than economic development. In particular, Kuhndt et al. (2003:6) begin their report with a figure (reproduced above) that models the potential environmental effects of ICT development over time. Two lines are drawn, one representing “welfare” over time and one representing “use of nature” over time. Welfare is not defined specifically in the report but can be interpreted as a mixture of economic development and social goods such as education, health care, and standard of living. The phrase “use of nature” does correspond to CO_2 emissions as the report focuses on these emissions as well as electricity use. The figure indicates that before the time frame of the “Digital Society” human welfare and use of the nature were linked, while during the “Digital Society” time frame the use of nature and human welfare decouple. ICTs are indicated as the causal mechanism of the decoupling, both reducing dependence on natural resources and increasing human welfare. The figure is not explicitly labeled as an EKC but the inverted U-shaped curve is indicative of the traditional EKC prediction; however, in this case economic development is replaced with ICT development as the key factor. The implications are clear for hypothesis testing.

ICT Driven Environmental Kuznets Curve Hypothesis: As ICT development increases, CO_2 emissions will decrease in developed countries.

2.2.3 Technological and Environmental Leapfrogging

The gradual development of technology from one phase of society to another (from industrial to post-industrial society for example) as described above is not the only possible pathway for the environment to decouple from the economy. There is the potential for less-developed countries to skip ahead or “leapfrog” to a less ecologically damaging level by adopting cleaner technologies already being gradually employed in developed countries (Perkins 2003). This argument differs from the EKC logic in that the mechanisms are not dependent on a less-developed country progressing incrementally before hitting a turning point. In essence the "turning point technology" developed in another country can be implemented in a less-developed country without proceeding through the dirtier intermediary stages necessary for an EKC.

Figure 2.3: Model of Environmental Leapfrogging

Incremental Progression

Dirtiest→ Dirtier→Dirty→Clean→Cleaner→ Cleanest

Transformative Progression: Leapfrogging

↗ Leapfrogging ↘

Dirtiest→ → Cleanest

The transition from telephone mainlines to mobile phones is a widely cited example of technological leapfrogging (James 2009). The development of fixed line telephones is dependent on domestic spending. As a result, GDP per capita is the most significant factor contributing to the spread of fixed line telephones, and for the less-developed world the price of infrastructure has been prohibitive (Looney 1998). Mobile telephone infrastructure has a lower entry cost for areas without fixed line development. In addition, mobile phones are more attractive to foreign direct investment and therefore are less dependent on a high GDP per capita for development (James 2012). Also important for this dissertation is the close association of the development of fixed-line telephones and the spread of electricity (Looney 1998). Because of the large material cost for a wired telephone network or an electrical grid, whenever one is installed the other is also likely to be installed. As a result, the development of mainline telephones is likely to increase CO_2 emissions. On the other hand, the development of a wireless mobile phone network that depends on cell towers and not pole-to pole lines does not stimulate the spread of electricity and likely does not increase CO_2 emissions as intensely. Countries that have a high number of mobile phones per fixed lines are likely to have lower emissions than those countries with a ratio closer to one.

ICT Leapfrogging Hypothesis: Countries with a high number of mobile telephones per fixed telephones will have lower CO_2 emissions.

From the perspective of EMT, the possibility of combating AGW through technological means seems reasonable. The modernization of governments and businesses in order to meet the challenges of CO_2 reductions is not simply a matter of discourse, law, and social movement pressure—although these factors are important—but also technological development. Modernization has always gone hand in hand with invention. ICTs are the latest technology and AGW is the latest human challenge to be solved with technological advances in the eyes of optimists. Human intelligence, often called the “ultimate resource” will ultimately provide a solution to any potential problems—natural or human caused (Simon 1983). EMT, the Kuznets Curve and environmental leapfrogging all fit into a generally optimistic worldview.

2.3 Pessimistic Perspectives

Pessimistic perspectives represent the other side of the coin. Where optimistic perspectives find encouraging trends either in technological solutions or socio-political change, or both, pessimists see a much different picture. They note that optimists often select cases that reflect successes in environmental governance (York and Rosa 2003).

For example, when Google teams with energy producers and state governments to incentivize wind power, this is viewed as ecological modernization at its best. However, cases such as this are often small scale, sporadically employed, or singular examples that do little to change the overall trends involved in modernization as a whole. Cases examined are sometimes at the country level—for example, the Netherlands has been often cited as an exemplar of green stewardship. However, EMT and other optimistic perspectives very rarely consider the global system in its entirety. When these cases are examined at the global level the "Netherlands' fallacy" becomes apparent, whereby the Dutch maintain a quality environment by degrading the environments of other countries through trade (Ehrlich and Ehrlich 1990; Rice 2007). There may be a parallel "Google fallacy" where certain ICT companies like Google can reduce their CO_2 emissions through adopting alternative energies while the industry and society as a whole increases its footprint directly or through systemic changes.

2.3.1 Political Economy: World Systems Theory, Treadmill of Production Theory and the Jevons's Paradox

World Systems Theory (WST) is a political economic perspective that looks at the structure of economic inequality at the global level (Wallenstein 1979, 1999). WST in its simplest terms suggests that nations close to the center of economic activity, or core nations, draw resources and cheap labor from nations farther away from the center of economic activity, or periphery nations. In the middle are semi-periphery nations that act as a supply and labor depots for core nations, but are themselves exploiters of periphery nations. Multinational industries housed in developed countries also take advantage of weak environmental regulations in less-developed countries and use their political power to prevent regulations from being put into place (Roberts 1996; Meyer et al. 1997).

This structural relationship can be equated to the distinction between developed countries (core) and less-developed countries (periphery and semi-periphery). While not a perfect corollary, those countries with developed country status are typically in an advantaged position over less-developed countries that allows them to leverage cheap resources, cheap labor, and a cheap repository for waste as core nations do (Roberts and Grimes 2002). Less-developed countries are not homogenous. The majority of the world does not meet Organization for Economic Cooperation and Development or United Nations classification of developed status. Generally included in the classification are nations such as Brazil, Russia India, and China—so called BRIC countries—that have large industrial cores, large populations, yet relatively low GDP per capita. These countries and a few others may better be classified as emerging economies or simply semi-periphery countries. However, for analytical purposes (expounded upon later) and parsimony this dissertation will use the developed country and less-developed country distinction.

The emergence of global environmental problems such as AGW necessitates a more global analytical perspective. It is also important because viewing a nation's environmental impact in isolation is not very useful given the globalized nature of the economy. Insights from WST have been used by numerous scholars in developing research programs on global environmental problems like AGW (Roberts 1996; Roberts and Grimes 2002; Jorgenson 2003, 2006; Jorgenson and Burns 2007; Pellow 2007; Rice 2007; Roberts and Parks 2007; Jorganson, Austin and Dick 2009; Jorgenson, Clark and

Kentor 2010; Jorgenson, Rice, and Clark 2010; Jorgenson and Clark 2009, 2010, 2012; For an extensive overview of WST and the environment see Goldfrank, Goodman, and Szasz 1999 or Jorgenson and Kick 2006).

A recent development in this framework has been the theory of ecological unequal exchange (Jorgenson 2006; Rice 2007). Developed countries reduce their relative ecological impact by exporting ecological damaging production and waste products to less-developed countries. There are certainly examples of this in the ICT world. Apple's production facilities in China, most notoriously FOXCONN, allow Apple to have a lower toxic footprint in the U.S. Also, electronic waste is exported from developed countries to less-developed countries to enter secondary markets before it winds up being scrapped for precious metals, releasing greenhouse gasses in the process (Byster and Smith 2006; Grossman 2006; Forbes 2012). WST relies on the basic political economy assumption that the structure of inequality serves those at the top and that upward mobility is unlikely because it is a threat to the existing power structure. Development has occurred in many of the less-developed countries over the last century, yet their relative position in the world economy has either remained stable or declined relative to developed nations (Roberts and Grimes 2002).

Pessimistic Developed Country Hypothesis: As ICT development increases in developed countries, CO_2 emissions in developed countries will either increase or be unaffected.

WST provides the theoretical framework for investigating the different roles that countries play in the global economy. Developed countries have always used whatever technologies were available to maintain their structural advantage in the world-system and the development of ICTs is no different.

> Now at last during this century of scientific investigation has yielded technologies that have enormously enhanced the power of capital against labor. These are, first, an infrastructure of telecommunications that allows for the remote control of multiple production sites and, second, the development of semi-intelligent machines that can potentially fulfill capital's ultimate dream of removing labor altogether. But an important cost of each of these developments has been an increase in the consumption of fossil fuel (Grimes 1999:32).

Telecommunications and ICTs more broadly facilitate the command and control of labor and natural resources in less-developed countries. This command and control comes at the cost of increased CO_2 emissions. Of course the structure of the world-system, and the mechanisms of exploitation and domination utilized to maintain that status are part of an institutional logic that demands ever-increasing accumulation of wealth through ever-increasing production.

Pessimistic Less-developed Country Hypothesis: As ICT development increases in less-developed countries, CO_2 emissions in less-developed countries will increase.

The institutional logic of profit accumulation through ever-increasing production has been labeled "the treadmill of production" (Schnaiberg 1980). Treadmill of Production Theory began as a societal-level theory that describes the role of labor, industry and the state in generating negative ecological impacts. The theory makes two basic predictions about the increased mechanization of society. First, as industry invests capital in mechanizing production, jobs are lost due to the increased output per unit of labor, burdening governmental resources needed for the displaced workers. The state needs more revenue, in part to cover expenses for displaced workers, workers demand jobs to replace the ones lost, and industry wants more profit, leading all three groups to support "growth" policies. Second, increases in output per unit of labor lead to increased resource extraction and pollution (Gould, Pellow and Schnaiberg 2008:7). From this standpoint the production process continually accelerates, increasing demands on the natural environment while at the same time leading to decreasing demand for labor. The pressures of job loss due to mechanization have been noted as one of the significant factors impacting weak job growth in the manufacturing sector. Wilson (2009) also notes this as one of the structural factors still forcing racial divides in employment related to the loss of unskilled labor.

Treadmill of production theorists consider production to be the prime mover of the treadmill and are dismissive of other dimensions such as consumption which they view as ancillary (Gould et al. 2008). Wright (2004) questioned this narrow focus and encouraged a systemic view that included consumption. Bell (2012) describes the logic of a "treadmill of consumption" that fills in the demand-side economic gap of the supply-side treadmill of production theory. The logic of the treadmill of consumption asserts that persons work hard to earn money (or credit) in order to purchase desirable goods that will provide a sense of fulfillment; however, the standard of fulfillment (keeping up with the Joneses) continually changes, thus requiring more hard work and more consumption (Bell 2012:79-80). In the information age there is no better example of the treadmill of consumption than the desire to have the latest and greatest ICT, and there is no better example of that than Apple.

In fact, Apple changed its corporate identity from Apple Computers to simply Apple to better reflect its market segmentation into music listening devices, mobile phones, streaming media, and tablets. Apple dominates the consumer ICT market not only through innovation but also through the incremental incorporation of features in successive devices (The Wall Street Journal 2012). Apple became famous for its shareholder meetings where, after showing updated versions of their current line, the company would announce that there was "one more thing" and then hype the newest product in their line ensuring that it would be the "must have" device during the holiday buying season. The iPhone, iPad, iMac, and iPod, were all "one more things."

While Apple's success demonstrates the demand side forces of ICT consumption in an illustrative way it must also be noted that all of the "one more thing" products were also announced to be shipping immediately or in time for holiday shopping, meaning production was running well in advance of expected consumption. Clearly, resource extraction and upstream pollution (the largest strains on the environment) had already occurred before consumers entered the picture (Williams 2004). Demand side forces cannot be ignored entirely; product failures do not see increased production in the next year. It makes sense to extend treadmill theory to include both production and consumption. Consumer success means that there are more devices in the hands of people, which mean more consumer energy demand downstream and more incentive for upstream energy consumption. The two logics work hand in hand. In fact, Foster, Clark, and York (2010) suggest using a more comprehensive term for the underlying capitalist structure, "the treadmill of accumulation."

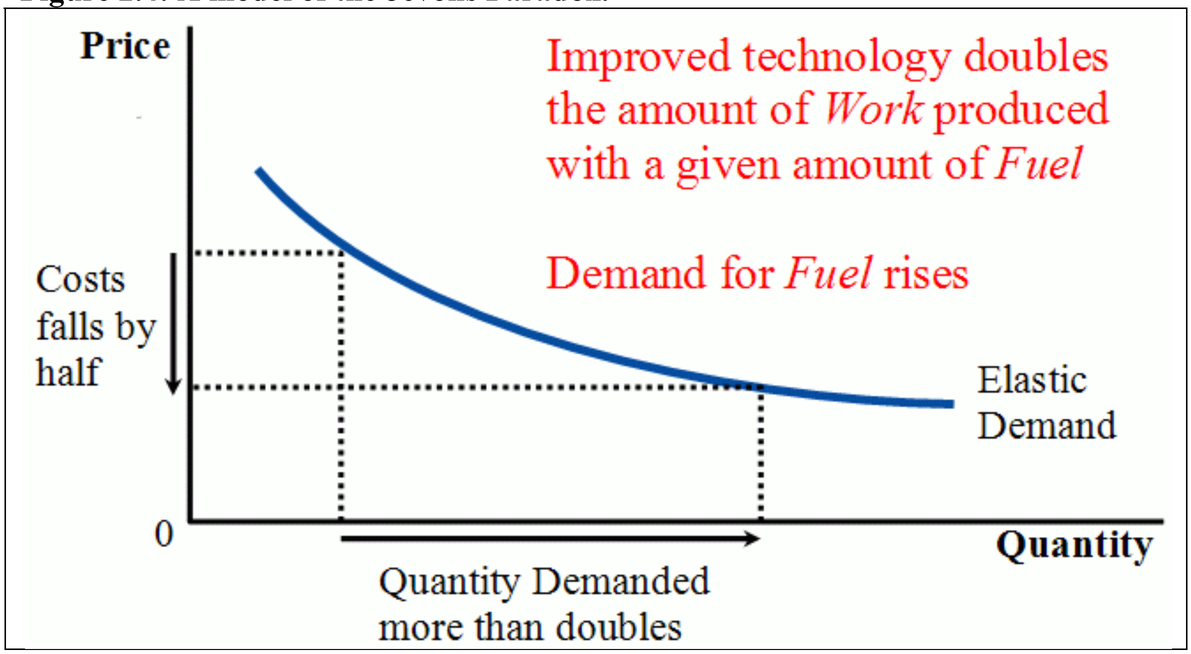
ICTs represent an integral component of the logic of the treadmill. Pellow and Park (2002) note this explicitly in *Silicon Valley of Dreams* by connecting the environmental impact of ICTs with the theorized growth of computing technology known as Moore's Law. "Gordon Moore's status has grown to the point of an icon, in large part because his prediction came true. Unfortunately, it is often the case that the greater the power and speed of electronic devices, the greater their toxicity" (Pellow and Park 2002:106). It may also be true for CO_2 emissions.

Underlying both the treadmill of production and WST is a Marxist tradition. Central to Marxian capitalist theory is the idea of capitalism's inherent internal contradictions; most famously that exploitation of workers will cause a revolutionary class-consciousness. A second, ecological contradiction was developed by O'Connor (1991), where by capitalism will collapse on itself if it overuses—or abuses—its' ecological resource base. AGW provides a prime example of this. Economic growth increases the concentration of CO_2 in the atmosphere causing unintended economic blows in the form of natural disasters, displaced human populations and disease (Roberts and Parks 2007).

Pessimistic Global Hypothesis: As ICT development increases, CO_2 emissions will increase.

Underlying the systemic ecological contradiction outlined by O'Connor (1991) are further contradictions in the development of technological efficiencies. The Jevons paradox (2001[1890]), like the optimistic Kuznets' curve, is essentially an economic theory based on the price function. While there is marginal evidence for the Kuznets's curve there is stronger evidence for a Jevons paradox effect (York 2003; York, Rosa and Dietz 2005). The paradox Jevons discovered was a discontinuity in the relationship between energy efficiencies and market forces. Essentially, Jevons noted that when the amount of energy (fossil fuels specifically) needed to produce a measure of work is reduced (real efficiency) any subsequent work becomes cheaper, thereby increasing demand for energy. If demand for a product doubles while its' costs fall by half, no real efficiency is gained and consequently no reduction in energy use is gained (Figure 2.4).

Figure 2.4: A model of the Jevons Paradox.



Source: Wikimedia Commons (http://commons.wikimedia.org/wiki/File:JevonsParadoxA.png)

As noted above, many theorists, scientists, NGO's and futurists are expecting the information revolution to lead to a renaissance in efficiency across all sectors of the economy. By far the biggest predicted impact of ICTs is their systemic effect on productivity. There are several negative social consequences associated with this development including technological unemployment, decreased job quality and increased surveillance to name a few (Brynjolfsson and McAffee 2011, Brancaccio 2012). There are, however, real questions that need to be raised about the nature of efficiency and its effect on the environment. For example, Kurzweil (2005) notes that the performance per watt for one million computational instructions per second (MIPS) has steadily decreased (see Kurzweil 2005:129). This phenomenon has been labeled Koomey's law after the lead researcher of the team that discovered the trend that energy demand for each computation was more than halved every eighteen months, outpacing Moore's Law of doubling computational power over the same time frame. Koomey's law is based on the *ceteris paribas* condition of stable computational demand (Koomey et al. 2011).

While there may be real efficiencies in the technical sense they may be practically unrealistic. Central processing units (CPUs) may have increased efficiency but graphics processing units (GPUs) have been increasing in energy consumption (Atwood 2006). These benchmarks also do not account for energy used during idle periods or extreme over-clocking (running at a higher energy demand). Furthermore, factors such as temperature effects on component efficiency, overall lifecycle costs from production through disposal, and climate control are often not taken into account (Chin 2007). Even relative to these issues it is clear that the market demand for more data and computational power places increasing demands on ICT hardware, with no signs of slowing (Cisco Systems 2012a, 2012b).

The potential of ICTs to mitigate climate change is based on their ability to generate efficiencies in direct effects, indirect effects and systemic effects. The Jevons Paradox reveals the underlying structure of accumulation. If UPS only used 1,000 trucks and would only deliver 10,000 packages then fuel savings from the GPS mapping of delivery routes and real time package tracking would be real savings. However, UPS does not limit its profit potential and will use fuel saving to buy more trucks so it can deliver more packages and thus make more profit. The source of the CO_2 emissions is irrelevant; any source or sector is subject to these same forces.

> Pessimistic Source Hypothesis: Regardless of the source of CO_2 ICT development increases CO_2 emissions.

From a political economy perspective it makes sense to view the development of ICTs via a pessimistic lens. Developed countries continually seek to increase their status through profit accumulation. There are two forces at play. First, developed countries are able to use their ICT development to advance the efficient use of available resources. These increased efficiencies in developed nations are often relative; absolute resource use almost always increases, as per the Jevons paradox (York, Rosa, and Dietz 2005). Second, developed countries are able to exploit resources in other countries increasing the resource use profile of less-developed nations with little of the benefit going to less-developed countries (Rice 2007).

2.3.2 Structural Human Ecology

A human ecology perspective provides a useful model for examining the unique dimensions of anthropogenic impact on the environment. The key factors of human impact on the environment are put forth by the I=PAT identity, where environmental impact (I) is a product of population (P), affluence (A), and technology (T) (Ehrlich and Holdron 1971). This early formulation assumed that each factor affected environmental impacts proportionally. There have been other attempts at describing the structural relationship of human society to the condition of the environment, most notably Duncan's (1959) POET model of population, organization, environment and technology

(Dunlap and Catton 1983). The structural human ecology (SHE) framework conceptualizes the relationship between society and the environment as consisting of four interrelated parts: population, social organization, environment, and technology (Knight 2009).

Dietz and Rosa (1994) modified the IPAT identity to eliminate the proportionality assumption and instead put forth the stochastic impacts by regression on population, affluence, and technology model or STIRPAT. This new model provides error terms for each factor and does not assume proportionality (Rosa and Dietz 1994). Essentially STIRPAT transforms the IPAT equation into a stochastic regression model making it more suitable for social science investigation and more flexible for dealing with the complexities of society-environment relationships. SHE focuses on the role of social structure in driving ecological impacts and has thus offered one of the most fruitful research programs in sociology for the analysis of environmental problems as exemplified by the analysis of deforestation, CO_2 emissions, other greenhouse gas emissions, resource consumption, and ecological footprints (Jorgenson and Clark 2010, 2012; Rosa and Dietz 2012; York 2007, 2008, 2010; York, Rosa and Dietz 2003a, 2003b, 2005, 2009. For a comprehensive review of SHE see Rosa, Diekmann and Dietz 2010). SHE is not fundamentally pessimistic; rather it is an attempt to quantify the most important variables impacting environmental degradation. However, when data consistently show that increases in population and GDP strongly contribute to environmental degradation, and population and GDP have been trending up for decades (if not centuries), it is easy to understand why SHE leads to pessimistic views.

Incorporating a SHE theoretical framework with a political economy framework helps highlight the potentially central role that technology can play in environmental degradation. From the early conceptions of IPAT to STIRPAT models it has been difficult to quantify the impact of technology in broad terms. Technology was initially considered directly proportional to population and affluence and was typically left undefined, making it essentially the efficiency of resource use, as defined by population and affluence. The development of the STIRPAT model allowed for the inclusion of additional variables such as urbanization, trade, and percent service economy. While these variables certainly represent technological aspects of society they also aggregate the impact of any specific technological development. It is reasonable for SHE scholars to focus on these variables; however, to answer the research question at hand more specific analyses are needed.

This is not to say that SHE scholars have not investigated the relationship between technology and environmental degradation. SHE scholars have used specific technological developments as dependent variables. York's (2010) investigation of absolute contributions of different energy technologies for CO_2 emissions is one example. In general however, SHE studies the effects of technology through the broad umbrella of modernization. The lack of scholarship on technological change is not unnoticed. In *Human Footprints on the Global Environment*—a recent collected volume complied as the culmination of SHE scholarship—it is noted that

> [T]echnological change… is omitted [from this volume] not because it lacks importance, but because of the difficulty of harnessing the complex and proximate effects of technological change…[this] pinpoints one of the most serious gaps in human dimensions research and the one, perhaps most desperately in need of concerted attention (Rosa, et al. 2010:5).

In line with the mission of SHE, this dissertation's primary goal is to provide an empirically grounded assessment of the impacts of ICT development on explaining environmental degradation—namely CO_2 emissions.

One last note: while SHE and political economy have different origins they do have an elective affinity. Both perspectives are grounded in a materialist view of human-environment relationships and in a realist worldview that sees the world as it is not as one wants it to be (York and Mancus 2009). As a consequence both perspectives are pessimistic of technological solutions that do not resolve the underlying structural issues be they population and affluence or social stratification and power.

2.4. Conclusion

Separating the literature on ICT development and the environment into divergent optimistic and pessimistic perspectives provides a pathway for clearly testable hypotheses. While the theoretical perspectives presented above provide a handy dichotomous theoretical structure there is room for complexity (See Table 2.1). The impact of ICT development on CO_2 emissions may have completely different trajectories in developing nations compared to less-developed nations as noted above. Additionally ICTs may have a stronger impact on certain CO_2 source sectors than on others; however, the basic divergence of technological optimism or technological pessimism still holds as the central hypothesis.

Table 2.1: Optimistic and Pessimistic Hypotheses.

Optimistic Hypotheses	
Optimistic Source Hypothesis 1:	As ICT development increases, CO_2 emissions from electricity will decrease
Optimistic Source Hypothesis 2:	As ICT development increases, CO_2 emissions from buildings will decrease.
Optimistic Source Hypothesis 3:	As ICT development increases, CO_2 emissions from manufacturing will decrease.
Optimistic Source Hypothesis 4:	As ICT development increases, CO_2 emissions from transportation will decrease.
Global Optimistic Hypothesis:	As ICT development increases, CO_2 emissions will decrease.
ICT Driven EKC Hypothesis:	As ICT development increases, CO_2 emissions will decrease in developed countries.
ICT Leapfrogging Hypothesis:	Countries with a high number of mobile telephones per fixed telephones will have lower CO_2 emissions.
Pessimistic Hypotheses	
Pessimistic Source Hypothesis:	Regardless of the source of CO_2 ICT development increases CO_2 emissions.
Pessimistic Global Hypothesis:	As ICT development increases, CO_2 emissions will increase.
Pessimistic Developed Country Hypothesis:	As ICT development increases in developed countries, CO_2 emissions in developed countries will increase.
Pessimistic Less-developed Country Hypotheses:	As ICT development increases in less-developed countries, CO_2 emissions in less-developed countries will increase.

Ecological Modernization Theory, the Kuznets curve and technological leapfrogging perspectives fundamentally suggest that structural changes in the way humans interact with the environment can be made by the development of ICTs. On the other hand, the political economy perspectives World Systems Theory, Treadmill of Production and Structural Human Ecology suggest that the current structure of environmental degradation is facilitated by increased ICT development. Clearly, these two perspectives cannot both be accurate.

This chapter has presented these two divergent views in order to frame the following empirical analysis in stark terms. ICTs may either reduce or increase CO2 emissions. As straightforward as this sounds, presenting such a black and white perspective may create difficulties when making a final determination about which view of the impact of ICTs is more reliable. First, ICTs are not a single entity. The technologies under investigation range from the more than a century old fixed-line telephone to the more recent developments of mobile telephones and the Internet. Such disparate technologies are unlikely to have the same effects. This complexity is partially captured by the leapfrogging hypothesis. Second, the effects of ICT development may not be homogeneous across countries. Results from the analyses of developed countries may support one view while those from the analyses of less-developed counties support another. Finally, ICTs may also have positive or negative CO2 emissions impacts across different source sectors. Such complexities often arise in the examination of empirical data, and their explanation is necessary for providing a realistic model of ICT development's impact on CO_2 emissions.

CHAPTER 3

DATA AND METHODS

This chapter serves as a road map for the analyses of the relationship between ICT development and CO_2 emissions. It is divided into four sections. First is a review of the multilevel model for change and then an explanation of the models developed for the analyses including a discussion of additional statistical components. Second is review of the general research hypotheses and the analytical hypotheses for each model. Third, dependent and independent variables are discussed and tables with descriptive statistics are presented. In the last section I will outline the subsequent chapters presenting analyses made to test the hypotheses and summarize the methodological approach employed for this dissertation.

3.1 The Multilevel Model for Growth

This study will use repeated cross-sectional national-level data on 121 countries from the World Bank (2013) made available through their open data initiative and partnership with STATA (World Bank 2012b). Data was retrieved through the STATA 11.2 statistical software using the *wbopendata* command line. Raw data were collected for six dependent variables: total CO_2 emissions, per capita CO_2 emissions, CO_2 emissions from electricity, CO_2 emissions from buildings, CO_2 emissions from manufacturing, and CO_2 emissions from transportation. Nine independent variables are used: year, population, GDP per capita, urbanization, trade, service economy, fixed telephones per 100 people, mobile telephones per 100 people, and Internet users per 100 people. Detailed descriptions of each dependent and independent variable are presented below as well as two additional variables that were derived from the raw data: less-developed country status and leapfrogging ratio.

Three samples will be used in the analyses. The first sample consists of the years 1990 to 2009, with 1926 country-years (level 1) nested within 121 countries (level-2). This will be labeled the "global sample" as it includes as many countries as possible given the available data. This time frame was selected for two reasons 1) to facilitate the inclusion of Internet users per 100 people as a variable and 2) to focus on the period of time most associated with the Information Age. The second sample is the subset of developed countries from the first sample. The developed sample consists of the years 1990-2009, with 461 country-years nested within 26 countries. This sample was selected to analyze both the differences between and changes within developed nations but also the divergent pattern of ICT development in developed countries. The third and final sample is the subset of less-developed countries from the global sample. The less-developed sample consists of the years 1990-2009, with 1465 country-years nested within 95 countries. This sample was selected to analyze the differences between and changes within less-developed countries and track the impact of ICT development in less-developed countries. Developed countries are those countries in the top quartile of GDP per capita and less-developed countries that are in the bottom three quartiles of GDP per capita.

Table 3.1: The Unconditional Means Model and the Unconditional Growth Model

	Level-1 model	Level-2 model	Composite Model
Unconditional Means Model	$Y_{ij} = \pi_{0i} + \varepsilon_{ij}$	$\pi_{0i} = \gamma_{00} + \zeta_{0i}$	$Y_{ij} = \gamma_{00} + (\varepsilon_{ij} + \zeta_{0i})$
Unconditional Growth Model	$Y_{ij} = \pi_{0i} + \pi_{1i}TIME_{ij} + \varepsilon_{ij}$	$\pi_{0i} = \gamma_{00} + \zeta_{0i}$ $\pi_{1i} = \gamma_{10} + \zeta_{1i}$	$Y_{ij} = [\gamma_{00} + \gamma_{10}TIME_{ij}]$ $+[\zeta_{0i} + \zeta_{1i}TIME_{ij} + \varepsilon_{ij}]$

Data for all three samples are unbalanced. When panel data are unbalanced it means that there are not an equal number of observations for each country. Usually, in longitudinal analyses it is important to construct balanced data so that cases with fewer observations do not skew results; however, one of the benefits of using a multilevel growth model is that it can adequately account for unbalanced data (Raudenbush and Bryk 2002; Singer and Willet 2003). This is useful in cross-national analyses as there are a limited number of countries in the population from which to draw a sample. It also allows for the inclusion of more independent variables because the selection criteria are less restrictive, allowing for more cases at level-2. Table 3.1 presents the countries in the sample, their development status and the years of observation for each country.

To model the impact of ICT development on CO_2 emissions over time, a multilevel model for growth will be utilized (Raudenbush and Bryk 2002; Singer & Willett 2003). The multilevel model for growth consists of two components, the level-1 model for individual change and the level-2 model for interindividual heterogeneity in change (Singer & Willet 2003:45). In the following analyses the level-1 unit of analysis is country-years, or to put it another way, the observation for each year for each country. The level-1 model examines questions about changes within countries over time and models are specified to include variables that explain change in CO_2 emissions over time within countries. The level-2 unit is the country. The level-2 model examines questions about: 1) time-invariant differences in the average level of CO_2 emissions between countries and 2) differences in CO_2 emissions trajectories over time between countries. Table 3.1 presents the specifications for the unconditional means models and the unconditional growth model, which are the base on which each full explanatory model is built.

Using the multilevel model for growth, both change over time within countries and differences between countries can be examined. To develop any model for change three criteria must be met (Singer & Willet 2003:9). First, there must be three or more waves of data. This study will use 20 years of repeated cross-sectional data. The period from 1990 to 2009 provides three key milestones that make it relevant to this analysis. At the beginning of this period the Internet and mobile telephone technologies were in their infancy and this point in time represents a symbolic initial status. Even though ICTS have a longer history they were not globally popularized until well after 1990. Next, the millennium has significant symbolic value representing the end of an eon. The year 2000 also coincides with the height of the "Internet" financial bubble as well as other important industry milestones. Finally, 2009 is near the end of the first decade of the 21st Century, a decade characterized by the growing importance if ICTs in everyday life.

Second, there must be an acceptable measure of time. This analysis will measure time from year to year. This is reasonable for practical reasons as most of the data comes only in annual format, but is also sensible in that the dynamics under consideration are likely to have more subtle effects if a shorter timescale were used.

Table 3.2: Countries included in the analysis by development status and years of observation for the Global, Developed, and Less-Developed Samples

Less-Developed		
Albania ‘90, ‘95-‘09	Jamaica ’94-‘97	Tunisia ’90, ’94-‘09
Algeria ‘90, ‘94-‘09	Jordan ’90, ’95-‘09	Turkey ’90, ’93-‘09
Angola ‘90. ‘96-‘09	Kazakhstan ’94-‘09	Turkmenistan ’99-‘09
Argentina ‘90, ‘92-‘06	Kenya ’90, ’95-‘09	Ukraine ’93-‘09
Armenia ‘94-‘09	Kyrgyz Rep. ’98-‘09	Uruguay ’90, ’94-‘09
Azerbaijan ‘94-‘02, ‘05-‘09	Latvia ’96-‘09	Uzbekistan ’96-‘09
Bangladesh ’90, ’97-‘09	Lebanon ’95-‘09	Venezuela ’90, ’92-‘09
Belarus ’94-’02, ’06-‘09	Libya ’02-‘08	Vietnam ’90, ’96-’04, ’06-‘09
Benin ’90, ’96-‘09	Lithuania ’96-‘09	Yemen, Rep. ’90, ’96-‘09
Bolivia ’90, ’95-‘09	Macedonia, FYR ’95-‘09	Zambia ’90, ’94-‘09
Bosnia & Herzegovina ’96-‘09	Malaysia ’90, ’92-‘09	Zimbabwe ’90, ’94-’00, ’04-‘09
Botswana ’90-’91, ’95-‘09	Mexico ’90-‘09	
Brazil ’90-‘09	Moldova ’94-‘09	
Bulgaria ’90, ’93-‘09	Mongolia ’90, ’95-’02, ‘08-‘09	**Developed**
Cambodia ’97-‘09	Morocco ’90, ’96-‘09	Australia ‘90-’01, ’05-‘09
Cameroon ’90, ’97-‘07	Mozambique ’90, ’97-‘09	Austria ’90-‘09
Chile ’90, ’92-‘09	Namibia ’95-‘09	Belgium ’90-‘09
China ’90, ’93-‘09	Nepal ’90-‘09	Canada ‘90-‘08
Columbia ’90, ’94-‘09	Nicaragua ’94-‘09	Cyprus ’04-‘08
Congo, Rep ’90, ’96, ‘98-‘09	Nigeria ’02-‘07	Denmark ’90-‘09
Congo, Dem. Rep. ’90, ’96-‘09	Oman ’90, ‘96-‘04	Finland ’90-‘09
Cote d'Ivoire ’90, ’95-‘09	Pakistan ’90, ’95-’99, ’01-‘09	France ’90-‘09
Croatia ’95-‘09	Panama ’90, ’94-‘09	Germany ’91-‘09
Cuba ’90, ’95-‘09	Paraguay ’90, ’96-‘09	Hong Kong, China ’00-‘09
Czech Republic ’93-‘09	Peru ’90, ’94-‘09	Ireland ’90-‘09
Dominican Rep. ’90, ’95-‘09	Philippines ’90, ’94-‘09	Italy ’90-‘09
Ecuador ’02-‘09	Poland ’90-‘09	Japan ’90-‘09
Egypt, Arab Rep. ’90, ’93-‘09	Romania ’90, ’93-‘09	Korea, Rep. ’90-‘09
El Salvador ‘90. ‘96-‘09	Russian Federation ’92-‘09	Kuwait ’95-‘03
Eritrea ’94-‘09	Saudi Arabia ’90, ’95-‘09	Netherlands ’90-‘09
Estonia ’95-‘09	Senegal ’90, ’95-‘09	New Zealand ’90-‘06
Ethiopia ’90, ’95-‘09	Serbia ’06-‘09	Norway ’90-‘09
Gabon ’96-‘09	Slovak Rep. ’93-‘09	Portugal ’90-‘09
Georgia ’95-‘09	South Africa ’90-‘09	Singapore ’90-‘09
Ghana ’90, ’95-‘09	Sri Lanka ’90, ’94-‘09	Slovenia ’93-‘09
Guatemala ’01-‘09	Sudan ’90, ’94-‘07	Spain ’90-‘09
Honduras ’90, ’95-‘09	Syria.’90-’06, ’08-’09	Sweden ‘90-‘09
Hungary ’90-‘09	Tajikistan ’99-’05, ’07-’09	United Arab Emirates ’01-‘09
India ’90, ’92-‘09	Tanzania ’90, ’96-‘09	United Kingdom ‘90-‘09
Indonesia ’90, ’94-‘09	Thailand ’90-‘09	United States ‘90-‘09
Iran, Islamic Rep. ’90, ’94-‘07	Togo ’90-‘09	

Third, there must be "an outcome whose values systematically change over time" (Singer and Willet 2003:9). CO_2 emissions have been on a gradual upward trend since they were first measured (IPCC 2007). Unfortunately, there is adequate evidence that a global downward trend in CO_2 emissions is highly unlikely anytime soon (IPCC 2007). Drastic differences between countries in CO_2 emissions result in an extremely skewed distribution. In quantitative analysis variables with these characteristics are often transformed using the natural logarithm. While a steady upward trend is noticeable for most countries, variation over time in the transformed variables is significantly reduced by the transformation. This can be viewed in table 3.3 which presents the intraclass correlation coefficients (ICCs) calculated based on the results from the unconditional means model with both the raw and log transformed outcomes for the global, developed, and less-developed samples.

The ICC indicates how much variation is found at level-2 in the outcome variable. In this case, for the global sample two percent of the variation in total CO_2 emissions is over time while 98 percent is between countries using the raw score and one percent of the variation in total CO2 emissions is over time and 99 percent between countries when using the logged score. Again, in the global sample for CO_2 emissions from electricity, nine percent of the variation in the raw score is over time. Using the logged variable reduces that to only two percent. Despite the small amount of variation in the logged outcomes over time, it is still important to explain these amounts over time as even a small increase in CO_2 emissions can have a significant impact on climate dynamics and make necessary reductions more difficult. To adequately account for the logarithmic distortion of the variation overtime, the data will be examined through the centering strategy described below and through aggregating all level-1 variables at level-2.

Table 3.3: Intraclass Correlation Coefficients For Six Outcome Variables both Raw and Natural Logged from Global, Developed, and Less-Developed Samples

Dependent Variable	Raw ICCs	Logged ICCs
Global		
Total CO2 Emissions	0.98	0.99
Per Capita CO2 Emissions	0.97	0.98
CO2 Emissions from Electricity	0.91	0.98
CO2 Emissions from Buildings	0.99	0.99
CO2 Emissions from Manufacturing	0.92	0.99
CO2 Emissions from Transportation	0.98	0.98
Developed Nations Sample		
Total CO2 Emissions	0.99	0.99
Per Capita CO2 Emissions	0.96	0.94
CO2 Emissions from Electricity	0.99	0.99
CO2 Emissions from Buildings	0.99	0.99
CO2 Emissions from Manufacturing	0.99	0.98
CO2 Emissions from Transportation	0.99	0.99
Less-Developed Nations Sample		
Total CO2 Emissions	0.87	0.98
Per Capita CO2 Emissions	0.94	0.98
CO2 Emissions from Electricity	0.82	0.98
CO2 Emissions from Buildings	0.97	0.98
CO2 Emissions from Manufacturing	0.89	0.98
CO2 Emissions from Transportation	0.88	0.97

In addition to the above features of a study of change over time, multilevel modeling requires the consideration of centering strategies (Singer and Willet 2003). Centering variables in any multilevel model gives their intercepts a precise meaning (Raudenbush and Bryk 2002:31). In a linear growth model, centering only effects the intercept. In other words, centering variables allow for a meaningful interpretation of the effects of time-invariant level-2 variables, because they are linked to the outcome through the level-1 intercept (see Raudenbush and Bryk 2002).

In multilevel models for growth, Level-1 variables within a given year are typically centered on the initial status, midpoint, or final status. However, because of the unbalanced structure, a meaningful year was not available for all cases and this strategy was not possible. Grand mean centering level-1 variables is also an option but was not useful for this analysis because of the high multicolinearity with the aggregated level-2 means. Uncentered scores were also not an option for the same reason. Because of these issues, group-mean centering was utilized for all level-1 variables. The most important benefit of group-mean centering is the generation of orthogonal variables at level-1. Group-mean centering fundamentally changes the structure of the data by removing the cross-level correlations between level-1 and level-2 independent variables.

In order to group-mean center a variable, one subtracts the level-2 mean from the level-1 variable. The values for the group-mean centered variable represent the number of units above or below the mean for a particular level 2 cluster. As a result, group-mean centering removes all of the between-country variation in level-1 independent variables. Group mean centering changes the interpretation of the intercept. It now represents the "unadjusted" cluster mean for country j. To further facilitate interpretation, the level-2 aggregates are grand-mean centered. Doing so makes the grand-mean (γ_{00}) the outcome for a country with average levels of independent variables instead of 0, which is neither realistic nor meaningful.

Autocorrelation is a common problem with variables used in cross-national environmental impact models, common in STIRPAT and World Systems analyses of environmental outcomes like CO_2 emissions (Jorgenson and Clark 2012). Autoregression process 1 or AR(1) helps alleviate issues of temporal auto correlation at level-1 by assuming the errors from one year are correlated with the following year. This helps reduce false positives and increases the reliability of the model. AR(1) errors will be calculated for all models.

One final consideration in multilevel analysis is the use of fixed or random coefficient models. Because of the number of parameters and the limited theoretical expectation for random coefficients, time will be the only variable allowed to have a random slope; no other random coefficients or cross-level interactions will be included in this analysis. However, this analysis will provide useful information about potential random coefficients and interaction effects that could be tested in future research.

3.2 Research Hypotheses.

The research hypotheses presented in Table 2.1 in Chapter 2 are the general research hypotheses and represent the aggregate expectations of ICT development for the optimistic and pessimistic perspectives. For analytical purposes a more detailed explanation and presentation of hypotheses is required. First, level-1 and level-2 outcomes address different kinds of hypotheses. Level-1 hypotheses refer to time-variant measures (changes over time) within countries while level-2 hypotheses refer to time-invariant measures and comparisons between countries. Level-1 hypotheses take the form of most of the hypotheses found in table 2.1. For example, as ICT development increases CO_2 emissions will increase. This hypothesis is about change over time. Level-2 variables are about time-invariant differences between countries. The leapfrogging hypothesis is an example of a time-invariant, between-countries measure. Countries with high numbers of mobile telephones per fixed telephones will have lower CO_2 emissions. This hypothesis is about differences between countries, not changes over time. In actuality, each hypothesis can be stated either way because all independent variables are included at both level-1 and level-2.

Second, the key concern of this dissertation, ICT development, is not based on a single measure. Three ICT development indicators are used to capture the concept of ICT development: fixed telephones per 100 people, mobile telephones per 100 people and Internet users per 100 people. The ratio of mobile to fixed telephones is also included as a separate measure of technological leapfrogging. Just as each of the 11 hypotheses could be stated using time sensitive or time-insensitive measures, each hypothesis could also be constructed for the three ICT development indicators (save for the leapfrogging hypotheses). That would be 62 research hypotheses! Additionally, there are control variables and three different samples to contend with. To facilitate the presentation and interpretation of so many hypotheses, Table 3.4 summarizes all of the expected relationships based on the perspectives presented in Chapter 2. Anticipated relationships for the control variables are also presented.

In general, the pessimistic view predicts that CO_2 emissions will *increase* when an independent variable *increases* for level-1. At level-2 the pessimistic view predicts that countries with a *higher* than average level of the independent variable will have *higher* CO_2 emissions. This is represented by "+" on the table. On the other hand, the optimistic perspective predicts that CO_2 emissions will *decrease* when an independent variable *increases* for level-1 and at level-2 it predicts that countries with a *higher* than average level of the independent variable will have *lower* CO_2 emissions. This is represented by the "–" on the table. There are two exceptions to this pattern. First, the effect of population is almost universally agreed to increase the use of natural resources, in this case the burning of fossil fuels leading to the release of CO_2 (Jorgenson and Clark 2010). Second, it is generally accepted that an increase in the size of the service economy is also decreases the dependence on natural resources, especially compared to a manufacturing based society (Salzman 2000; Jorgenson 2003).

Table 3.4: Hypothesized Relationships with to Log Total CO_2 Emissions, Log Per Capita CO_2 Emissions, and Log CO_2 Emissions from Electricity, Buildings, Manufacturing and Transportation for Optimistic and Pessimistic Perspectives.

Independent Variables	*Optimistic Perspectives*	*Pessimistic Perspectives*
Level-1		
Annual Rate of Change	−	+
Population (ln)	+	+
GDP per Capita (ln)	−	+
Urbanization	−	+
Trade (ln)	−	+
Service Economy	−	−
Fixed Telephones per100 (ln)	−	+
Mobile Telephones per100 (ln)	−	+
Leapfrogging (ln)	−	+
Internet Users per100 (ln)	−	+
Level-2		
Less-Developed Country	+	−/+
Mean Population (ln)	+	+
Mean GDP per capita (ln)	−	+
Mean Urbanization	−	+
Mean Trade (ln)	−	+
Mean Service Economy	−	−
Mean Fixed Telephones per100 (ln)	−	+
Mean Mobile Telephones per100 (ln)	−	+
Mean Leapfrogging Ratio (ln)	−	+
Mean Internet Users per100 (ln)	−	+

The less-developed country dummy variable also has some unique characteristics. First, the optimistic perspective predicts that less-developed countries will have higher emissions than developed countries because they are on the low end of the Environmental Kuznets Curve. The pessimistic perspective is less straightforward. Developed countries are predicted to have the highest emissions as their structural position affords them access to more of the world's resources; however, Unequal Ecological Exchange Theory explains that in addition to the consumption of their own domestic resources, developed countries will also use the resources of less-developed countries to offshore their own dirty manufacturing and waste (Rice 2007). Because of this, a political economy framework can support two possible outcomes: less-developed countries will have higher CO_2 emissions than developed countries (−) or developed countries will have higher emissions (+).

These hypotheses are straightforward in relation to our two perspectives. The Optimistic perspective predicts that ICT development will decrease CO_2 emissions and countries with higher than average ICT development will have lower CO_2 emissions. In contrast, pessimists expect that ICT development will increase CO_2 emissions and countries with higher than the average ICT development will have higher CO_2 emissions. The results for each of the analyses will be summarized at the end of each analysis chapter in a table similar to Table 3.4.

3.3.1 Dependent Variables

Global studies of CO_2 emissions typically utilize two measures: total CO_2 emissions and per capita CO_2 emissions for individual countries (Jorgenson and Clark 2012). Both measures will be used in this dissertation. The CO_2 emissions measure is based on the burning of fossil fuels and the manufacture of cement, including CO_2 produced during the consumption of solid, liquid, and gas fuels and gas flaring. The data were collected and compiled by the Carbon Dioxide Information Analysis Center, Environmental Sciences Division at the Oak Ridge National Laboratory in Tennessee

(World Bank 2012a). Total CO_2 emissions are measured in millions of metric tons and per capita CO_2 emissions are measured in metric tons per person in each country.[2]

In addition to the typical CO_2 emissions outcome variables, this study will utilize four additional source and sector-specific outcomes: CO_2 emissions from electricity and heat production, CO_2 emissions from buildings, CO_2 emissions from manufacturing and construction, and CO_2 emissions from transportation. All four of these are included in national total and per capita measures but are considered separately to highlight any potential sector-specific differences in CO_2 emissions from ICT development. All four subcategories also correspond directly to Intergovernmental Panel on Climate Change source/sink category designations and were compiled by the International Energy Association (IEA) based in IPCC guidelines (IPCC 2007; International Energy Agency 2011a; World Bank 2013). Both the typical and source-specific outcome measures are highly skewed and log transformed to correct for their skewed distributions.

CO_2 emissions from electricity and heat production are the sum of three components: public or private utilities, unallocated auto producers, and other energy industries such as fuel refinement. *CO_2 emissions from buildings and construction* represents all of the emissions from residential, commercial and public service buildings, including all emissions from fuel combustion in households. *CO_2 emissions from manufacturing and construction* represents the emissions from the combustion of fuels in industry (except auto producers). *CO_2 emissions from transportation* represents the combustion of fuel for all transport activity, including domestic aviation road, rail and pipeline transport, regardless of the sector. International marine bunkers (fuel oil) and international aviation are not included in this total. Descriptive statistics for all outcomes

and uncentered independent variables are in the following tables: the global sample in Table 3.5, for the developed country sample in Table 3.6, and for the less-developed country sample in Table 3.7.

Table 3.5: Descriptive Statistics for the Global Sample

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Dependent Variables				
Total CO_2 Emissions (ln)	10.54	1.95	5.21	18.8
CO_2 Emissions Per Capita (ln)	0.91	1.43	-3.53	3.58
CO_2 Emissions from Electricity (ln)	2.75	1.87	0	8.18
CO_2 Emissions from Buildings (ln)	1.73	1.55	0	6.42
CO_2 Emissions from Manufacturing (ln)	2.24	1.65	0	7.72
CO_2 Emissions from Transportation (ln)	2.39	1.51	0.04	7.50
Level-1 Independent Variables (Time-Varying)				
Population (ln)	16.53	1.41	13.8	21.0
GDP per capita (ln)	7.88	1.52	4.41	10.6
Urbanization	58.66	21.34	8.53	100
Trade as % of GDP (ln)	4.26	0.57	2.41	6.13
Service as % of GDP	55.23	12.58	15.9	92.8
Fixed Telephones per 100 (ln)	2.27	1.56	-5.16	4.28
Mobile Telephones per 100 (ln)	2.34	1.70	0	5.20
Leapfrogging (ln)	0.86	0.93	0	7.54
Internet Users per 100 (ln)	1.64	1.44	0	4.53
Level-2 Independent Variables (Time-Invariant)				
Less-Developed Country	0.76	0.42	0	1
Mean Population (ln)	16.53	1.41	13.8	20.9
Mean GDP per capita (ln)	7.88	1.51	4.60	10.5
Mean Urbanization	58.66	21.21	11.1	100
Mean Trade as % of GDP (ln)	4.26	0.49	3.04	5.90
Mean Service as % of GDP	55.23	11.82	22.9	90.6
Mean Fixed Telephones per 100 (ln)	2.27	1.51	-3.69	4.18
Mean Mobile Telephones per 100 (ln)	2.34	0.88	0.34	4.80
Mean Leapfrogging (ln)	0.86	0.49	0.09	3.37
Mean Internet Users per 100 (ln)	1.64	0.86	0.12	3.97

Data comes from the World Bank; N=1926 n=121

3.3.2 Level-1: Time-Varying Covariates

Because of the multilevel structure of the analyses, independent variables fall into level-1 (time-varying) or level-2 (time-invariant) categories. Level-1 variables include population, GDP per capita, urbanization, trade, service economy, fixed telephones per 100 people, mobile telephones per 100 people, leapfrogging ratio, and internet users per 100 people. These will be group-mean centered; therefore, these variables will only explain within-country differences. Aggregating the mean of the level-1 variables to level-2 allows for the remaining between county variations to be assessed at the same time. One level-2 variable of development status will be included as a control for the analysis of the global sample. Time is included centered on 1990, the initial status.

3.3.3 Key Level-1 Time Varying Covariates: Information Communication Technology Development Indicators

As noted earlier there are three ICTs that are the primary focus of this research: fixed telephones, mobile telephones and the Internet. Data for these ICTs all come from the International Telecommunications Union (World Bank 2013). The first two ICTs are typically collectively referred to as *telecommunications* and are often even measured together as they freely interact and each utilizes the capabilities of the other's infrastructure (James 2012). They will be examined separately here to examine for potential differences their development has had on CO_2 emissions. *Fixed telephones* refer to main-line telephones that connect a subscriber to a public switched telephone network with a port on a telephone exchange. Fixed telephones are measured here as the number of telephone main-line subscriptions per 100 people. Similarly, *mobile telephones* refer to a subscription to a public mobile telephone service using cellular technology, which provides access to the public switched telephone service. Post-paid and prepaid subscriptions are included. Mobile telephone subscriptions are also measured as subscriptions per 100 people. Both fixed and mobile telephone subscriptions have skewed distributions and are therefore log transformed.

Table 3.6: Descriptive Statistics for the Developed Country Sample

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Dependent Variables				
Total CO_2 Emissions (ln)	11.91	1.44	8.90	15.5
CO_2 Emissions Per Capita (ln)	2.27	0.40	1.44	3.52
CO_2 Emissions from Electricity (ln)	4.06	1.44	1.45	7.91
CO_2 Emissions from Buildings (ln)	2.83	1.69	0.08	6.42
CO_2 Emissions from Manufacturing (ln)	3.36	1.36	0.63	6.56
CO_2 Emissions from Transportation (ln)	3.63	1.41	1.09	7.49
Level-1 Independent Variables (Time-Varying)				
Population (ln)	16.55	1.36	13.83	19.5
GDP per capita (ln)	9.96	0.38	8.84	10.6
Urbanization	77.95	12.29	47.92	100
Trade as % of GDP (ln)	4.30	0.64	2.77	6.13
Service as % of GDP	67.20	7.80	40.30	92.8
Fixed Telephones per 100 (ln)	3.87	0.23	3.13	4.28
Mobile Telephones per 100 (ln)	3.33	1.44	0.06	5.20
Leapfrogging (ln)	0.65	0.48	0.00	2.05
Internet Users per 100 (ln)	2.73	1.53	1.66	4.53
Level-2 Independent Variables (Time-Invariant)				
Mean Population (ln)	16.55	1.36	13.86	19.4
Mean GDP per capita (ln)	9.96	0.35	9.24	10.5
Mean Urbanization	77.95	12.14	50.53	100
Mean Trade as % of GDP (ln)	4.30	0.63	3.07	5.90
Mean Service as % of GDP	67.20	7.29	45.43	90.6
Mean Fixed Telephones per 100 (ln)	3.87	0.19	3.17	4.18
Mean Mobile Telephones per 100 (ln)	3.33	0.40	2.91	4.80
Mean Leapfrogging (ln)	0.65	0.19	0.34	1.55
Mean Internet Users per 100 (ln)	2.73	0.43	1.66	3.97

Data comes from the World Bank; N=461 n=26

The development of mobile telecommunication in the last three decades provides one of the clearest examples of technological leapfrogging available. To capture the dramatic transition from fixed telephone use to mobile telephone use, particularly in the less-developed world, a “leapfrogging” ratio is calculated by dividing the number of mobile telephones per 100 people by the number of fixed telephones per 100 people. This ratio can be used to gauge the impact of rapid mobile telephone development (James 2009:995). The effect of leapfrogging has a skewed distribution. To correct for this, it is log transformed.

The Internet, arguably one of the most significant technological developments in the 20th century, is included as a measure of ICT development separate from telecommunications and is most representative of the new possibilities for ICTs. Unlike telecommunications, the Internet is measured in users rather than subscriptions. It is measured as the number of Internet users per 100 people. *Internet user* is defined as someone who has access to the worldwide network. Internet use, like telecommunications, is highly skewed and is logged to correct for this.

3.3.4 Control Variables

Several variables known to have an impact on CO_2 emissions are included as controls in the analyses: population, GDP per capita, urbanization, trade, and service economy. Population is the *de facto* definition of population, meaning all of the people living in a country in a given time. Data on population are compiled from several sources including: (1) United Nations Population Division (2) United Nations Statistical Division, (3) Census reports and other statistical publications from national statistics offices, (4) Eurostat, (5) Secretariat of the Pacific Community: Statistics and Demography

Programme, and (6) U.S. Census Bureau: International Database (World Bank 2013). Population, as noted in Chapter 2, is one of the most significant driving forces of environmental degradation (Ehrlich and Erlich1990; Rosa and Dietz 2012). The effects of population size on environmental impacts are stable over time for both less-developed and developed countries (Jorgenson and Clark 2010). Population is log transformed to correct for skewed distribution.

Second only to population size, affluence is one of the most significant driving factors of environmental degradation (Rosa and Dietz 2012; Jorgenson and Clark 2012). GDP per capita is gross domestic product divided by midyear population. GDP is the sum value added to the economy without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. It is measured in constant U.S. dollars for the year 2000, the midyear of the study. GDP per capita is log transformed to account for its skewed distribution.

Urbanization, another known predictor of environmental degradation, refers to the percentage of a country's population that lives within urban areas as defined by the national statistical office for each country (Jorgenson, Rice and Clark 2010, World Bank 2013). Urbanization is included as it is often used as a measure of modernization and is often found to have a positive relationship with CO_2 emissions (Rosa and Dietz 2012). Urbanization is also an important control variable, since the effects of ICTs likely vary for more rural versus more urban countries. Urbanization is close to a normal distribution and is not transformed.

Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product. Trade as a percentage of GDP is included as a control for the extent to which an economy is embedded in the world economy (Jorgenson and Clark 2012). Trade can have an impact on CO_2 emissions because competitiveness in the world economy puts pressure on nations to have lower environmental standards (Roberts 1996). Trade is also highly skewed, making a log transformation necessary.

The last control variable is a measure of the degree to which a nation has a service or post-industrial economy, indicated by service revenues as a percentage of GDP. Services include wholesale and retail trade, transport, government, financial, professional and personal services such as education, healthcare and real estate. *Service economy* represents the value added to GDP from these and other services as defined by the International Standard Industrial Classification (World Bank 2013). Service economy is important to include as a control variable because growth in the service sector is often cited as evidence of the growth of an ICT driven economy, even though they are not the same (Salzman 2000). Service economy is close to a normal distribution and is not transformed.

3.3.5 Level-2: Time-Invariant Covariates

As noted above, level-2 aggregates of all level-1 variables will be included in the analysis to account for the greater variation between countries. Aggregated time-varying variables are calculated by averaging the yearly observations for each country. Essentially, level-2 aggregates are the average level of the independent variable over the observed time. Level-2 aggregates are grand-mean centered. Descriptive statistics for level-2 aggregates are found in Tables 3.5, 3.6, and 3.7.

Table 3.7: Descriptive Statistics for the Less-Developed Country Sample

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Dependent Variables				
Total CO_2 Emissions (ln)	10.10	1.89	5.21	15.8
CO_2 Emissions Per Capita (ln)	0.48	1.37	-3.53	3.58
CO_2 Emissions from Electricity (ln)	2.33	1.79	0	8.18
CO_2 Emissions from Buildings (ln)	1.38	1.32	0	6.03
CO_2 Emissions from Manufacturing (ln)	1.89	1.58	0	7.72
CO_2 Emissions from Transportation (ln)	2.01	1.33	0.05	6.16
Level-1 Independent Variables (Time-Varying)				
Population (ln)	16.52	1.43	13.9	21.0
GDP per capita (ln)	7.23	1.10	4.41	9.30
Urbanization	52.60	19.93	8.53	93.0
Trade as % of GDP (ln)	4.25	0.49	2.41	5.40
Service as % of GDP	51.46	11.38	15.9	77.7
Fixed Telephones per 100 (ln)	1.76	1.46	-5.16	3.75
Mobile Telephones per 100 (ln)	2.03	1.66	0	5.17
Leapfrogging (ln)	0.92	1.03	0	7.54
Internet Users per 100 (ln)	1.30	1.24	0	4.30
Level-2 Independent Variables (Time-Invariant)				
Mean Population (ln)	16.52	1.42	14.0	20.9
Mean GDP per capita (ln)	7.23	1.09	4.60	9.13
Mean Urbanization	52.60	19.78	11.1	91.2
Mean Trade as % of GDP (ln)	4.25	0.44	3.04	5.23
Mean Service as % of GDP	51.46	10.37	22.9	75.2
Mean Fixed Telephones per 100 (ln)	1.76	1.39	-3.69	3.63
Mean Mobile Telephones per 100 (ln)	2.03	0.74	0.34	4.67
Mean Leapfrogging (ln)	0.92	0.53	0.09	3.37
Mean Internet Users per 100 (ln)	1.30	0.65	0.12	3.53

Data comes from the World Bank; *N*=1465 *n*=95

To control for differences in economic development in the global sample and to compare the impact of ICT development on less-developed and developed countries a development status dummy variable is used. *Development status* is calculated by dividing GDP per capita into quartiles. GDP per capita as noted above is a generally accepted measure of a country's economic development; however, there is no established convention for designating a country "developed" or "less-developed" and the categories used here are for statistical analysis only (United Nations Statistical Division 2013). Developed countries are those in the upper quartile of the GDP per capita distribution for all countries for which the World Bank (2013) provides data, and less-developed countries are those that fall below the upper quartile. A few nations move from the second to the top quartile over the time frame of the study. In these cases, countries with 50 percent or more of their observations in the top quartile will be coded as developed. Developed countries are the reference category (less-developed country = 1, developed country = 0). This will be referred to as the *less-developed country dummy*.

3.4 Structure of Analyses

The results for these analyses are presented across three chapters. Chapter 4, *The Global Impact of ICT Development on Carbon Dioxide Emissions,* presents the results from four models of the global sample for each of the six outcome variables: log total CO_2 emissions, log per capita CO_2 emissions, and log CO_2 emissions from electricity, buildings, manufacturing, and transportation. The four models are: (1) the unconditional growth model with time as the only variable, (2) the control model which adds log population, log GDP per capita, urbanization, log trade, service economy at level-1 and less-developed country dummy, mean log population, mean log GDP, mean urbanization, mean log trade, and mean service economy at level-2, (3) the leapfrogging model which includes all of the controls at level-1 and 2 in addition to the log leapfrogging ratio at level-1 and the mean log leapfrogging ratio at level-2, and finally (4) the full model which includes all the controls at level-1 and 2 in addition to the three ICT development indicators: log fixed telephones per 100 people, log mobile telephones per 100 people, and log Internet users per 100 people at level-1 and log mean fixed telephones per 100 people, log mean mobile telephones per 100 people, and log mean Internet users per 100 people at level-2. For the log per capita CO_2 emissions models population is left out as a variable because it is controlled for by the structure of the outcome variable. The leapfrogging ratio is left out of the full model as it is derived directly from two of the OCT development indicators, namely fixed telephones per100 people and mobile telephones per 100 people.

Chapter 5, *The Impact of ICT Development on Carbon Dioxide Emissions for Developed Countries*, and Chapter 6, *The Impact of ICT Development on Carbon Dioxide Emissions for Less-developed Countries*, follow the same structure as Chapter 4. Chapter 5 uses the developed country sample for the analyses and Chapter 6 uses the less-developed sample for its analyses. The level-2 control variable less-developed country is removed from the analysis as it is perfectly correlated with the outcome and is no longer needed as a control.

3.5 Conclusion

Utilizing a multilevel model for change will provide initial answers to my key research question: How does ICT development affect CO_2 emissions? Development is an inherently temporal concept and being able to control for and model the effects of time is invaluable for answering this kind of question. The following chapters will help reveal the effects of ICT development on global CO_2 emissions. Based on these analyses a clearer understanding will be developed about which orientation toward the future is most appropriate to take, optimism or pessimism.

CHAPTER 4

GLOBAL CARBON DIOXIDE EMISSIONS AND INFORMATION AND COMMUNICATION TECHNOLOGY DEVELOPMENT

Anthropogenic global warming (AGW) is truly a global problem, as every nation contributes something to the total aggregate of CO_2 (IPCC 2007). ICT development is also on a global scale, with every country invested in expanding their ICT capacity to generate economic development (World Economic Forum 2009). To evaluate the global impact of ICT development on CO2 emissions, countries from every region and level of economic development are included in the global sample (See Table 3.2 for a full list of nations in the analysis and years of observation). This chapter is organized into three sections. First, the theories being tested and the general research question will be briefly reviewed. Second, the results from the multilevel models for growth will be presented and explained. Finally, a brief discussion and summation of findings will be outlined.

4.1 Research Question and Theory

The models examined in this chapter provide insight in to the global dynamics of ICT development and CO_2 emissions. The dynamics under consideration may lead to increased or decreased CO_2 emissions. Ecological Modernization Theory and related optimistic perspectives predict that advances in ICT development can reduce the demand for energy in a variety of ways. The more opportunities generated by ICTs for people to avoid energy expenditures through telephone, mobile apps and websites, the less the usage of fossil fuels. Technological leapfrogging from fixed-line telephones to the relatively low infrastructure costs associated with mobile telecommunications reduces the impact of ICT development (James 2012). ICTs provide an infrastructure for e- governance with open-sourced social movements and businesses that are seemingly less energy demanding than traditional industry (Mol 2008). Optimistically, technological developments will replace outdated, energy intensive, top-down structures with fresh, carbon neutral, open-source structures.

The Treadmill of Production and associated pessimistic theories offer a different perspective on ICTs and CO_2 emissions (Gould et al. 2008). ICTs, like any technology, are developed and produced through industrial processes. Because of the global production paradigm companies like Apple often have many faces: one for tax and fiscal responsibilities, one for environmental regulation, and one for intellectual property rights. The state, labor and industry are all interested in economic growth and encourage infrastructure development, including ICT development, to spur economic development. It is well known that economic development (along with population) is one of the most significant factors impacting environmental degradation (Rosa and Dietz 2012). ICT development worldwide is fostered by promises of economic growth. What impact does ICT development have on CO_2 emissions? Do connected countries emit more than unconnected countries? Pessimistically, ICTs are the most recent chapter of the long duŕee of ecologically harmful industrialization (Grimes 1999).

Global trends are central to the examination of anthropogenic global warming. There are cases of exceptional engineering and bold behavior that can reduce organizational or community carbon foot prints. Ecological modernization rightly highlights these developments and affirms them as evidence of the ecological context of modernity (Hilty et al. 2006; Mol 2008; see Apple 2012 for a corporate example). However impressive, case studies do little to explain the structure of the global economy and the social forces that support a high fossil fuels demand. Taking a global perspective is essential for assessing the state of a planetary scale problem and any meaningful emissions reductions brought about by technological change.

As the results are discussed, keep in mind that even minute changes in these models can refer to millions of tons of carbon dioxide emissions (it is often difficult to scale the issue of climate change) 32,042 million tons of CO_2 were emitted in 2009 alone (World Bank 2013; Erdmann and Hilty 2010). Even a one percent change is significant in real terms because any increase CO_2 emissions increases the total atmospheric concentration that much higher. . Study after study on ICTs and climate change suggest potential reductions in CO_2 emissions (Erdmann and Hilty 2010).

4.2 Global Multilevel Growth Model

Six dependent variables will be examined in the multilevel model for growth, including two general outcomes (total CO_2 emissions and per capita CO_2 emissions) and four source specific outcomes (CO_2 emissions from buildings, electricity, manufacturing, and transportation). Models for total CO_2 emissions and CO_2 emissions from buildings, electricity, manufacturing, and transportation will include five controls (population, GDP, urbanization, trade, and service economy) and four key independent variables (fixed telephones, mobile telephones, leapfrogging ratio, and Internet users). For the level-2 portion of the model, less-developed country status (LDC) is also included as a control. The model for per capita CO_2 emissions includes all controls and key variables save population.

The number of parameters prohibits the presentation of results on a single page. As a consequence, results from each of the six outcomes will be presented across two tables. The first table (A) presents the level-1 and level-2 coefficients and standard errors. The second table (B) presents the variance components and goodness-of-fit tests for each model. Four models are presented for each dependent variable. Model 1 is the unconditional growth model. Model 2 is a control model including less-developed country, population, GDP, urbanization, trade, and service economy. Model 3 is the leapfrogging model that includes all controls in addition to the leapfrogging ratio. Model 4 is a full model including all controls and ICT development indicators (fixed telephones per 100 people, mobile telephones per 100 people, and Internet users per 100 people). AR(1) auto correlation correction is produced for each model. AR(1) correction controls for the assumption that the errors for one year are correlated with the error in a previous year. All interpretations assume that all other effects are held at a constant.

4.3 Global Total CO_2 Emissions

Results for a multilevel growth model with AR(1) errors for total CO_2 emissions are presented in Table 4.1A and Table 4.1B. The ICC for total CO_2 emissions is 0.98, indicating that 98 percent of the variation in logged total CO_2 emissions is between countries and only about 2 percent of the variation is over time within a country. The results from Model 1 show that there is still a significant effect of time. On average, a country's logged total CO_2 emissions increase 0.02 ($p<0.001$) units every year. The initial status is the unadjusted cluster mean of log total CO_2 emissions in 1990, the log total CO_2 emissions are 10.10 ($p<0.001$).

Model 2 introduces the control variables. The effect of time has now changed direction. Controlling for log population, log GDP per capita, urbanization, log trade, and service economy, total CO_2 emissions within countries are predicted to decrease by 0.02 ($p<0.001$) units every year on average. The control variables have the level-1 and level-2 outcomes expected by the structural human ecology perspective (Rosa and Dietz 1994). A 1 percent increase in log population is predicted to increase log total CO_2 emissions by 1.56 percent ($p<0.001$), holding all else constant. By far the largest effect, population is a well-established predictor that has a consistent significant positive effect (Jorgenson and Clark 2010). A 1 percent increase in log GDP per capita increases log total CO_2 emissions by 0.77 percent ($p<0.001$), holding all else constant. While not as large, the effect of log population, log GDP per capita is just as reliable a predictor of CO_2 emissions. A 1 percent increase in urbanization leads to a 0.02 unit ($p<0.01$) increase in log total CO_2 emissions, holding all else constant. The effect of urbanization is often seen as the clearest evidence that ecological modernization is not occurring, as urban living is one

Table 4.1A: Global Log Total CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.02***	-0.02***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		1.56***	1.54***	1.57***
		(0.17)	(0.17)	(0.17)
GDP per Capita (ln)		0.77***	0.76***	0.75***
		(0.05)	(0.05)	(0.05)
Urbanization		0.02**	0.02**	0.02**
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.01	-0.01	-0.01
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.04*
				(0.02)
Mobile Telephones per100 (ln)				-0.00
				(0.01)
Leapfrogging (ln)			-0.01	
			(0.01)	
Internet Users per100 (ln)				-0.02
				(0.01)
Level-2				
Initial Status	10.10***	10.14***	10.26***	10.43***
	(0.18)	(0.21)	(0.19)	(0.16
Less-Developed Country		0.82***	0.68***	0.43*
		(0.26)	(0.22)	(0.19)
Mean Population (ln)		1.11***	1.10***	1.08***
		(0.06)	(0.05)	(0.04)
Mean GDP per capita (ln)		0.97***	0.87***	0.46***
		(0.10)	(0.09)	(0.09)
Mean Urbanization		0.00	0.00	0.00
		(0.01)	(0.00)	(0.00)
Mean Trade (ln)		0.49**	0.60***	0.28*
		(0.17)	(0.15)	(0.13)
Mean Service Economy		-0.01*	-0.02***	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per100 (ln)				0.85***
				(0.14)
Mean Mobile Telephones per100 (ln)				-0.14
				(0.13)
Mean Leapfrogging Ratio (ln)			-0.77***	
			(0.12)	
Mean Internet Users per100 (ln)				0.14
				(0.16)

*** $p<0.001$, **$p<0.01$ *$p<0.05$; N=1926, n=121; ln = natural logarithm of the hallmarks of contemporary modernity. Neither log trade nor service economy had a significant effect on CO_2 emissions over time.

The average predicted log total CO_2 emissions is 10.14 ($p<0.001$) for a country with an average log population, log GDP per capita, urbanization, log trade and service economy. Slightly higher than the unconditional growth model, this represents the effect of including grand-mean centered control variables. The level-2 coefficients examine the between country variation in the model. Less-developed countries are predicted to have 0.82 ($p<0.001$) higher units of log total CO_2 emissions than developed nations, holding all else constant. Two of the largest CO_2 emitters are China and India, so it is not unexpected for less-developed countries to have higher average CO_2 emissions, particularly given the predictions of unequal ecological exchange theory (Rice 2007). A country with a 1 percent higher than average log population is predicted to increase log total CO_2 emissions 1.11 percent ($p<0.001$), holding all else constant. While not as large as the effect within countries, it is the largest between country effects. A country with 1 percent higher than average log GDP per capita is predicted to increase total CO_2 emissions by 0.97 percent ($p<0.001$), holding all else constant.

Interestingly, the effect of urbanization appears to be limited to differences over time within countries, as it has no significant effect between countries. Conversely, log trade appears to have a significant impact on between country variations but not within country variation. A country with 1 percent above average level of log trade is predicted to have 0.49 percent ($p<0.01$) higher log total CO_2 emissions. Similarly, service economy seems to have a small significant effect on between country variations in log total CO_2 emissions. For every 1 percent a countries service economy is above average, log CO_2 emissions are predicted to decrease by 0.01 units ($p<0.05$). Service based economies are less energy intensive than manufacturing based economies and, as expected, they have a negative coefficient. The shift from an industrial to a post-industrial economy or service economy is closely associated with the development of an information economy. Even though the effect is significant, it is small relative to the driving forces of population and GDP per capita.

Model 3 is the leapfrogging model including all controls and the leapfrogging ratio. The annual rate of change remains constant with the control model (0.02, $p<0.001$). The controls have a slightly less intense effect at level-1, with a 1 percent increase in log population predicted to increase log total CO_2 emissions by 1.54 percent ($p<0.001$) and a 1 percent increase in log GDP per capita predicted to increase emissions by 0.76 percent ($p<0.001$). Urbanization's predicted increase in log CO_2 emissions remains at 0.02 units ($p<0.010$) for a 1 percent increase. Trade and service economy remain insignificant. Finally adding the leapfrogging ratio to the level-1 model does not produce a significant effect.

At level-2 Model 3 produces differences in the effects of the control variables. Less-developed countries are predicted to have 0.68 units ($p<0.001$) greater log total CO_2 emissions than developed countries, rather than the initial 0.82 units in the control. A country with 1 percent above average log population has 1.10 percent ($p<0.001$) higher log total CO_2 emissions, which is not significantly diminished from the control model (1.11 percent). However, every 1 percent increase above average in log GDP per capita is only predicted to increase log total CO_2 emissions by 0.87 percent ($p<0.001$) across nations, compared to the 0.97 percent ($p<0.001$) predicted in the control model. Conversely, a 1 percent increase in log trade above average now predicts a 0.60 percent ($p<0.001$) increase in log total CO_2 emissions compared to 0.49 percent increase in the control model. Unlike the other controls, a 1 percent increase above average in service economy reduces CO_2 emissions by 0.02 units ($p<0.001$). Unlike at level-1 the effect of the leapfrogging ratio is significant at level-2. A country with 1 percent above average log ratio of mobile telephones to fixed telephones is predicted to have 0.77 percent ($p<0.001$) fewer log total CO_2 emissions. This is the first evidence for an ICT driven effect on CO_2 emissions. Countries that develop mobile communications faster or to a larger degree than their fixed telephones will have slower growth in their CO_2 emissions. This supports the optimistic leapfrogging hypothesis.

Model 4 adds all three ICT development indicators. At level-1 there are no significant changes to the effects of the controls from adding the ICT development indicators at level-1. This gives the first glimpse of the impact of ICT development over time. For every 1 percent increase in log fixed subscriptions, log CO_2 emissions are predicted to increase 0.04 percent ($p<0.05$). This is the only significant level-1 effect for the ICT development indicators. Countries that invest in fixed telephones will have higher CO2 emissions. This supports the general pessimistic hypothesis that ICT development will increase CO2 emissions.

At level-2 the control variables have a diminished effect in Model 4. Less-developed countries are predicted to have 0.43 units ($p<0.05$) greater log total CO_2 emissions than developed countries, rather than the initial 0.82 units in the control model. A country with1 percent above average log population has 1.08 percent ($p<0.001$) higher log total CO_2, which is not significantly diminished from the control model (1.11 percent). However, every 1 percent increase above average in log GDP per capita is only predicted to increase log total CO_2 emissions by 0.46 percent ($p<0.001$) across nations, opposed to the 0.97 percent ($p<0.001$) predicted in the control model. Similarly, a 1 percent increase in log trade above average now only predicts a 0.28 percent ($p<0.05$) increase in CO_2 emissions compared to 0.49 percent in the control model. Unlike the other controls, a 1 percent increase above average in service economy reduces CO_2 emissions by 0.03 units ($p<0.001$), a larger effect than the 0.01 unit ($p<0.05$) decrease in the control model.

At level 2 we see a similar pattern the for ICT development indicators. A country with 1 percent above average level of log fixed telephones is predicted to have 0.85 percent ($p<0.001$) higher log total CO_2 emissions. This is a much stronger predicted effect than at level-1. The development of telephones is a significant component of between country variations in log total CO_2 emissions. This is partly responsible for the reduction in the effect of less-developed country, log GDP per capita and log trade. There is not a significant effect for log mobile telephones per 100 people and log Internet users per 100 people on log total CO_2 emissions. The strong positive effect of fixed telephones matches the strong negative effect of the leapfrogging ratio. Countries that have underdeveloped fixed telephone lines are much more likely to have more mobile telephones. However the reduction in that ratio by increase fixed telephone development produces higher emissions.

Table 4.1B: Global Log Total CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	1.84	0.61	0.51	0.32
		(20.55)	(0.09)	(0.08)	(0.05)
	In rate of change	-0.02	-0.01	-0.01	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	18	20	24
Deviance		-2407	-2885	-2920	-2978
AIC		-2393	-2849	-2880	-2930
BIC		-2354	-2749	-2769	-2797
Pseudo R-sq (Level 2)		—	0.67	0.72	0.83
AR(1), ρ		0.99	0.87	0.87	0.86
		(0.02)	(0.03)	(0.03)	(0.03)
Error Variance		2.16	0.04	0.04	0.03
		(0.45)	(0.01)	(0.01)	(0.01)

N=1926, *n*=121

Turning to the variance components and model fit statistics in Table 4.1B, an image of ICT development emerges. There is virtually no within-country variation to be explained, but what variance there is does appear to be accounted for by the models, from .0005 in the unconditional growth model to 0.00027 and .00023 in the control and full model respectively. The real story is in the change in initial status variance. Starting without control variables there is 1.84 variance, the control model explains 57 percent of the variance, Model 3 explains 72 percent while Model 4 explains 83 percent. This is good evidence that the ICT variables add a good amount in explanatory power to the total CO_2 emissions model. AIC and BIC goodness-of-fit statistics also favor the full model (lower numbers are better). The selection of the full model and the increasing explanation of the variance between countries by the full model both indicate that the inclusion of the ICT development indicators helps explain about 11 percent more of the variation in CO_2 emissions between countries. Fixed telephones are the only significant effect of ICT development and they are predicted to increase emissions. Therefore the additional explained variation is from countries with higher emissions as a result of ICT development, specifically fixed telephones.

4.4 Global Per Capita CO_2 Emissions

Results for a multilevel growth model with AR(1) errors for log per capita CO_2 emissions are presented in Table 4.2A and Table 4.2B. The ICC for per capita CO_2 emissions is 0.98 indicating that 98 percent of the variation in per capita CO2 emissions is between countries and only about 2 percent of the variation is over time within a country. The results from Model 1 show that there is still a significant effect of time. On average, a country's logged per capita CO_2 emissions increase 0.01 (p<0.001) units every year. The unadjusted cluster mean of log per capita CO_2 emissions is 0.74 (p<0.001).

The control model for log per capita CO_2 emissions does not include log population as a control as it is figured into the outcome variable. The pattern of effects for log per capita CO_2 emissions is quite similar to the pattern found for log total CO_2 emissions. At level 1, log GDP per capita and urbanization have significant effects on emissions levels over time. A 1 percent increase in log GDP per capita within a country is predicted to increase log per capita CO_2 emissions by 0.74 percent (p<0.001), while a 1 percent increase in urbanization increases CO_2 emissions by 0.02 units within countries, holding all else constant. Trade and service economy do not have a significant effect on log per capita CO_2 emissions.

Table 4.2A: Global Log Per Capita CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01***	-0.01***	-0.01***	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
GDP per Capita (ln)		0.74***	0.73***	0.72***
		(0.05)	(0.05)	(0.05)
Urbanization		0.02***	0.02***	0.02***
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.01	0.00	0.01
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.04*
				(0.02)
Mobile Telephones per100 (ln)				-0.02
				(0.01)
Leapfrogging (ln)			-0.01	
			(0.01)	
Internet Users per100 (ln)				-0.02
				(0.01)
Level-2				
Initial Status	0.74***	0.50***	0.62***	0.77***
	(0.14)	(0.21)	(0.19)	(0.16)
Less-Developed Country		0.76**	0.60**	0.37
		(0.26)	(0.22)	(0.19)
Mean GDP per capita (ln)		0.96***	0.86***	0.46***
		(0.10)	(0.10)	(0.09)
Mean Urbanization		0.00	0.00	0.00
		(0.01)	(0.00)	(0.00)
Mean Trade (ln)		0.28*	0.42***	0.15
		(0.14)	(0.12)	(0.11)
Mean Service Economy		-0.02*	-0.02***	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per100 (ln)				0.65***
				(0.07)
Mean Mobile Telephones per 100 (ln)				-0.15
				(0.13)
Mean Leapfrogging Ratio (ln)			-0.77***	
			(0.12)	
Mean Internet Users per 100 (ln)				0.14
				(0.17)

*** $p<0.001$, ** $p<0.01$ * $p<0.05$; N=1926, n=121; ln = natural logarithm

The level-2 effects of control variables exhibit a different pattern. On average, less-developed countries are predicted to have 0.76 units more CO_2 emissions compared to developed countries. For a country with 1 percent above average log GPD per capita, log per capita CO_2 emissions are predicted to be 0.96 percent higher. As with total CO_2 emissions, urbanization appears to have a significant effect over time but not a significant between countries. Countries with 1 percent higher than average log trade have 0.28 percent higher log per capita CO_2 emissions. Finally, countries with 1 percent larger than average service economy have 0.02 units fewer log per capita CO_2 emissions. The log average per capita CO_2 emissions for the control model are 0.5 units.

In Model 3, the leapfrogging model, the control variables have virtually the same effect at level-1 as in the control model. As with the log total CO_2 emissions model leapfrogging does not appear to have an effect over time. The real effects are at level-2. The initial status is larger at 0.62 (p<0.001) units of log per capita CO_2 emissions. The effect of less-developed country status is lower. Less-developed countries are now predicted to have 0.60 (p<0.01) more units of log per capita CO_2 emissions on average, compared to developed countries. A country with 1 percent higher than average log GDP per capita is predicted to have 0.86 percent (p<0.001) fewer log per capita CO_2 emissions. The effect of trade increases notably with the addition of the leapfrogging ratio. A country with 1 percent more than average log trade is predicted to have 0.42 percent (p<0.001) higher log per capita CO_2 emissions. The confidence interval for service economy is higher but the effect remains the same, -0.02 (p<0.001). As with the log total CO_2 model the log leapfrogging ratio has a significant effect. A country with 1 percent higher than average log ratio of mobile telephones to fixed telephones is predicted to have 0.77 percent (p<0.001) higher log per capita CO_2 emissions.

With evidence from both the total and per capita emissions models an initial conclusion can be drawn about the leapfrogging hypothesis. The null hypothesis should be rejected in favor of the optimistic leapfrogging hypothesis. Countries with higher ratios of mobile telephones to fixed telephones have lower CO2 emissions on average than those with lower ratios.

Introducing the ICT development indicators in Model 4 does not change the effects of the controls at level-1. As with the total CO_2 model fixed telephone lines has a significant effect on per log capita CO_2 emissions. On average a 1 percent increase in the number of log fixed-line telephone subscriptions increases log per capita CO_2 emissions by 0.07 percent ($p<0.001$). Log mobile telephones and Internet users have no effect at level-1. At level-2 the effect of development status on per capita CO_2 emissions is significantly reduced in Model 4. The effect is almost halved, 0.43 ($p<0.05$) instead of 0.82 ($p<0.001$) in Model 2. Mean log GDP per capita also has a less intense effect in the Model 4. In a country with 1 percent above average log GDP per capita log per capita CO_2 emissions are predicted to increase by 0.44 percent ($p<0.001$) again, almost half the effect from Model 2. The effect of log trade on log per capita CO_2 emissions is similarly affected. A country with 1 percent higher than average log trade is predicted to have 0.23 percent ($p<0.05$) higher log per capita CO_2 emissions. The effect of service economy is bolstered. A country with 1 percent above average level of service economy is predicted to have 0.03 units ($p<0.001$) lower log per capita CO_2 emissions. The impact of ICT variables on per capita CO_2 emissions is similar to that of total CO_2 emissions. Fixed line telephones have the only significant effect. A country with 1 percent higher than average level of fixed telephones is predicted to have 0.64 percent ($p<0.001$) higher log per capita CO_2 emissions.

With both aggregate models (total and per capita) now described some initial conclusions about the research hypotheses can be made. At least for fixed telephones the null hypotheses should be rejected in favor of the global pessimistic hypothesis. As fixed telephones develop over time CO_2 emissions are predicted to increase. In addition, countries with higher than average fixed telephone development are predicted to have higher CO_2 emissions. For the effect of mobile telephones and Internet users at the global level these models fail to reject the null hypothesis.

{Table4.2B About Here}

Table 4.2B: Global Log Per Capita CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	0.90	0.69	0.57	0.33
		(0.51)	(0.10)	(0.09)	(0.05)
	In rate of change	-0.01	-0.01	-0.01	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	16	18	22
Deviance		-2512	-2874	-2908	-2965
AIC		-2498	-2842	-2872	-2921
BIC		-2459	-2753	-2772	-2799
Pseudo R-sq (Level 2)		—	0.23	0.37	0.63
AR(1), ρ		0.99	0.87	0.87	0.86
		(0.02)	(0.03)	(0.03)	(0.03)
Error Variance		1.48	0.04	0.04	0.04
		(0.45)	(0.01)	(0.01)	(0.01)

N=1926, n=121

Turning to Table 4.2B, the variance components and goodness-of-fit statistics are as consistent as they are for log total CO_2 emissions. As with log total CO_2 emissions log per capita CO_2 emissions have very little within-country variance, as expected by the ICC. A strong pattern of decreasing unexplained variation can be seen in the initial status variance component. The unconditional growth model has a variance of 0.90, Model 2 has a variance of 0.69, explaining 23 percent of the initial variance. Model 3 explains 37 percent of the variance while Model 4 explains 63 percent. Model 4 explains markedly more of the variance in initial status and the AIC and BIC model selection criteria both indicate the full model as the best fit.

Some preliminary conclusions can be drawn from the aggregate total and per capita CO_2 models presented above. First, ICT variables do seem to be an important part in explaining the variation in CO_2 both over time and between countries. In particular, it is apparent that fixed-line telephones play a significant role in the carbon footprints of nations. A not inconsiderable amount of the differences between nations may be directly attributable to their development of extensive fixed telecommunication networks. This will be explored more thoroughly in the discussion chapter but it is clear that some component of the effect of GDP per capita on emissions is explained by how wide spread fixed telecommunications are.

4.5 CO_2 Source Categories

Analyses of CO_2 emissions infrequently model the factors contributing to segmented source categories; instead they tend to focus on aggregate measures like total and per capita (see Jorgenson and Clark 2012 for a discussion of the common dependent variables). The next four sections will present the results from models for CO_2 emissions from electricity, buildings, manufacturing, and transportation. This has been done to better understand the role that ICT development plays in emissions as there may be a different pattern of effects for different source categories. Additionally, many of the investigations of CO_2 emissions focus on the beneficial effects of ICTs in different economic sectors (Webb 2008 for example). Segmenting helps determine if there is any validity to this. Keep in mind that the following source categories are disaggregated from the total CO_2 emissions dependent variable. The correlation coefficients with log total CO_2 emissions are as follows: log CO_2 emissions from electricity (r =0.98), log CO_2 emissions from buildings (r =0.89), log CO_2 emissions from manufacturing (r =0.96), log CO_2 emissions from transportation (r =0.95).

4.5.1 Global CO_2 Emissions from Electricity

Results for a multilevel growth model with AR(1) errors for CO_2 emissions from electricity are presented in Table 4.3A and Table 4.3B. The ICC for CO_2 emissions from electricity is 0.98 indicating that 98 percent of the variation in total CO_2 emissions from electricity is between countries and only about 2 percent of the variation is over time within a country. The results from the unconditional growth model show that there is still a significant effect of time. On average, a country's logged CO_2 emissions from electricity increase 0.02 units every year. The unadjusted cluster mean log total CO_2 emissions from electricity are 2.36.

Table 4.3A: Global Log CO_2 Emissions from Electricity 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.01*	-0.01	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		1.20***	1.20***	1.20***
		(0.19)	(0.19)	(0.18)
GDP per Capita (ln)		0.45***	0.46***	0.42***
		(0.05)	(0.05)	(0.05)
Urbanization		0.02*	0.02*	0.01*
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.04	0.04	0.04
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.06***
				(0.02)
Mobile Telephones per100 (ln)				-0.00
				(0.01)
Leapfrogging (ln)			-0.02	
			(0.01)	
Internet Users per100 (ln)				-0.01
				(0.01)
Level-2				
Initial Status	2.36***	2.34***	2.46***	2.71***
	(0.16)	(0.25)	(0.22)	(0.21)
Less-Developed Country		0.71*	0.53	0.27
		(0.30)	(0.30)	(0.25)
Mean Population (ln)		1.02***	1.02***	0.98***
		(0.07)	(0.06)	(0.06)
Mean GDP per capita (ln)		0.86***	0.75*	0.35**
		(0.12)	(0.11)	(0.12)
Mean Urbanization		0.01	0.01	0.00
		(0.01)	(0.01)	(0.01)
Mean Trade (ln)		0.65***	0.79***	0.45**
		(0.20)	(0.18)	(0.17)
Mean Service Economy		-0.01	-0.02*	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per100 (ln)				0.67***
				(0.09)
Mean Mobile Telephones per100 (ln)				-0.22
				(0.17)
Mean Leapfrogging Ratio (ln)			-0.85***	
			(0.15)	
Mean Internet Users per100 (ln)				0.14
				(0.22)

*** $p<0.001$, ** $p<0.01$ * $p<0.05$; N=1926, n=121; ln = natural logarithm

At first glance the results for Model 2 look very similar to the aggregate model. This is to be expected, as electricity production is the largest source of CO_2 emissions examined individually. The effect of time is reversed in Models 2 and 4. A 0.01 unit ($p<0.05$) decrease in log CO_2 emissions from electricity every year is predicted. The effect of time is not significant in Model 3. The effects of population, GDP per capita and urbanization over time do not change significantly from Model 2 to Model 4 at level-1. In Model 2 a 1 percent increase in log population is predicted to increase log CO_2 emissions from electricity by 1.20 percent ($p<0.001$). A 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from electricity by 0.45 percent ($p<0.001$). A 1 percent increase in urbanization is predicted to increase log CO_2 emissions from electricity by 0.02 units ($p<0.05$). The only ICT variable that has a significant effect at level-1 is fixed telephones. A 1 percent increase in the number of fixed line telephone subscription is predicted to increase log CO_2 emissions from electricity by 0.06 percent ($p<0.001$).

At level-2, the differences between the full model and the control model and Models 2 and 3 are starker. In the Model 2 a less-developed country is predicted to have, on average, 0.71 units ($p<0.05$) higher log CO_2 emissions from electricity than a developed country; however, in Model 3 and 4 the effect of development status is not even significant. A country with 1 percent higher than average log population is predicted to have 1.02 percent ($p<0.001$) higher log CO_2 emissions from electricity in Model 2 and 0.98 percent ($p<0.001$) in Model 4. The effect of log GDP per capita is reduced more dramatically. A country with 1 percent higher above average log GDP per capita is predicted to have 0.86 percent ($p<0.001$) higher CO_2 emissions from electricity in the Model 2 and 0.33 percent ($p<0.01$) in Model 4. Urbanization loses its significant effect at level-2 while log trade gains a significant effect. The effect of trade diminishes across models. A 1 percent increase above average level of trade increases CO_2 emissions from electricity by 0.65 percent ($p<0.001$) in Model 2 and 0.45 percent ($p<0.05$) in Model 4. Service economy does not have a significant effect in Model 2 but does have a significant effect in Model 4. A country with

1 percent above average level of service economy is predicted to have 0.03 percent ($p<0.001$) lower log CO_2 emissions from electricity.

Most interestingly, in Model 3 the effect of adding the leapfrogging ratio dramatically increased the size of effect for mean log trade. In Model 3 a country with a 1 percent above average level of log trade is predicted to have 0.79 percent ($p<0.001$) higher log CO_2 emissions from electricity. The effect of the leapfrogging variable is also significant. A country with a leapfrogging ratio that is 1 percent higher than average is predicted to have 0.85 percent ($p<0.001$) higher log CO_2 emissions from electricity.

Table 4.3B: Global Log CO_2 Emissions from Electricity 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	3.21	0.84	0.69	0.52
		(0.42)	(0.12)	(0.10)	(0.07)
	In rate of change	-0.00	-0.01	-0.01	-0.01
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	18	20	24
Deviance		-2482	-2778	-2810	-2846
AIC		-2468	-2742	-2770	-2798
BIC		-2430	-2642	-2659	-2664
Pseudo R-sq (Level 2)		—	0.74	0.79	0.84
AR(1), ρ		0.80	0.75	0.75	0.73
		(0.04)	(0.04)	(0.04)	(0.03)
Error Variance		0.02	0.02	0.02	0.02
		(0.00)	(0.00)	(0.00)	(0.00)

N=1926, n=121

Again, the only ICT development indicator at level-2 to impact CO_2 emissions from electricity is fixed-line telephones. For every1 percent above average level of log fixed telephones, a country is predicted to have 0.67 percent ($p<0.001$) higher log CO_2 emissions from electricity. While no other ICT development indicators appear to impact CO_2 emissions from electricity it is easy to understand the strong effect that fixed line telephones have on electricity demand. When the infrastructure for electricity (copper and steel wire) is being developed it has always made sense to piggyback telecommunications onto the same system. Essentially where telephones go electricity follows, or vice versa (Looney 1996).

Examining the variance components and model fit statistics found in Table 4.3B, the strength of the full model is revealed. The Model 4 explains about 84 percent of the unexplained variance in initial status from the unconditional growth model. As expected from the ICC, there is virtually no change in the within-country variance and rate of change. Both the AIC and BIC model fit statistics also prefer the Model 4.

4.5.2 Global CO_2 Emissions from Buildings

Results for a multilevel growth model with AR(1) errors for CO_2 emissions from buildings are presented in Table 4.4A and Table 4.4B. The ICC for total CO_2 emissions is 0.99, indicating that 99 percent of the variation in total CO_2 emissions is between countries and only about 1 percent of the variation is within countries over time. The results from the unconditional growth model show that there is still a significant effect of time. On average, a country's logged CO_2 emissions from buildings increase 0.01 ($p<0.001$) units every year. The unadjusted cluster mean log CO_2 emissions from buildings are 1.49 ($p<0.001$).

The control and full models of CO_2 emissions from buildings provide the first divergent pattern from the aggregate emissions models. In Model 2 only log population and log GDP per capita have a significant effect at both level-1 and 2. Every 1 percent increase in log population is predicted to increase log CO_2 emissions from buildings by 0.74 percent ($p<0.001$). A country with 1 percent above average log population is predicted to increase log CO_2 emissions from buildings by 0.85 percent ($p<0.001$). Every 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from buildings by 0.22 percent ($p<0.001$). A country with 1 percent above average GDP per capita is predicted to increase log CO_2 emissions from buildings

Table 4.4A: Global Log CO_2 Emissions from Buildings 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01***	-0.01**	-0.01*	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		0.74***	0.68***	0.70***
		(0.17)	(0.17)	(0.18)
GDP per Capita (ln)		0.22***	0.22***	0.20***
		(0.05)	(0.05)	(0.05)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.02	0.02	0.02
		(0.02)	(0.02)	(0.02)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.03
				(0.02)
Mobile Telephones per100 (ln)				-0.01
				(0.01)
Leapfrogging (ln)			0.01	
			(0.01)	
Internet Users per100 (ln)				0.03*
				(0.01)
Level-2				
Initial Status	1.49***	1.82***	1.89***	2.12***
	(0.14)	(0.21)	(0.20)	(0.19)
Less-Developed Country		0.00	0.10	-0.35
		(0.26)	(0.24)	(0.23)
Mean Population (ln)		0.85***	0.85***	0.83***
		(0.06)	(0.06)	(0.05)
Mean GDP per capita (ln)		0.43***	0.34***	0.13
		(0.10)	(0.10)	(0.11)
Mean Urbanization		0.00	0.01	0.00
		(0.01)	(0.00)	(0.00)
Mean Trade (ln)		0.16	0.28	0.11
		(0.17)	(0.16)	(0.15)
Mean Service Economy		-0.00	-0.00	-0.01
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per100 (ln)				0.57***
				(0.08)
Mean Mobile Telephones per100 (ln)				-0.24
				(0.15)
Mean Leapfrogging Ratio (ln)			-0.66***	
			(0.13)	
Mean Internet Users per100 (ln)				0.14
				(0.19)

*** $p<0.001$, **$p<0.01$ *$p<0.05$; N=1926, n=121; ln = natural logarithm by 0.43 percent ($p<0.001$). As noted above, the effect for time in the control model is now negative.

The effects of the control variables remain relatively stable across Models 3 and 4. The leapfrogging ratio does not have a significant effect at level-1. Most interestingly, the only ICT development indicator to have a significant impact on log CO_2 emissions from buildings over time is log Internet users. A 1 percent increase in log Internet users is predicted to increase log CO_2 emissions from buildings by 0.03 percent ($p<0.05$). While it is a small effect it is not surprising as the Internet has for the most part been an indoor activity requiring a modem and physical hook up. Even wireless Internet systems require a router to be directly connected. It is not until very recently that true anywhere Internet through 3G and 4G services became available. Still, it is interesting that log fixed telephones do not have a significant effect.

Moving on to level-2 the effect of the less-developed country dummy is no longer significant. Both log population and log GDP have significant effects at level 2 in Models 2 and 3. Surprisingly, the effect of GDP per capita on CO_2 emissions from buildings is no longer significant in Model 4. Instead, it appears that ICTs account for a large amount of log CO_2 emissions from buildings. For every 1 percent increase above average log fixed telephones, CO_2 emissions from buildings are predicted to increase by 0.57 percent ($p<0.001$). A country with 1 percent higher than average leapfrogging ratio is predicted to have 0.66 percent ($p<0.001$) lower log CO_2 emissions from buildings. There appears to be no level-2 effect of mean log Internet use on log CO_2 emissions from buildings.

Clearly, ICTs impact the way the built infrastructure is used. Countries experiencing above average leapfrogging have lower predicted emissions from buildings while countries with higher than average fixed telephone subscriptions and increasing Internet use have higher emissions. This relationship may be related to the differences between developed and less-developed nations, as developed countries tend to have higher Internet use and lower leapfrogging while less-developed countries have increasing fixed telephone use and higher levels of leapfrogging. The results from Chapters 5 and 6 should shed some more light on this complexity.

Table 4.4B: Global Log CO_2 Emissions from Buildings 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.26	0.57	0.51	0.44
		(0.29)	(0.08)	(0.07)	(0.06)
	In rate of change	-0.00	-0.01	-0.00	-0.01
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	18	20	24
Deviance		-2462	-2661	-2685	-2716
AIC		-2448	-2626	-2645	-2668
BIC		-2410	-2526	-2533	-2535
Pseudo R-sq (Level 2)		—	0.75	0.77	0.81
AR(1), ρ		0.79	0.77	0.77	0.77
		(0.04)	(0.03)	(0.03)	(0.03)
Error Variance		0.03	0.02	0.02	0.02
		(0.00)	(0.00)	(0.00)	(0.00)

N=1926, *n*=121

Reviewing the variance components and model fit statistics in Table 4.4B another clear pattern of increasing explained variance is apparent. Model 4 explains 6 percent of the unexplained variance over Model 2. Again, there is almost no explained variance at level-1. Not surprisingly, the full model is also selected by the AIC and BIC.

4.5.3 Global CO_2 Emissions from Manufacturing

Results for a multilevel growth model with AR(1) errors for CO_2 emissions from manufacturing are presented in Table 4.5A and Table 4.5B. The ICC for total CO_2 emissions is 0.99, indicating that 99 percent of the variation in total CO_2 emissions is between countries and only about 1 percent of the variation is over time within a country. The results from the unconditional growth model show that there is still a significant effect of time. On average, a

Table 4.5A: Global Log CO_2 Emissions from Manufacturing 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01**	-0.03***	-0.03***	-0.04***
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		1.42***	1.39***	1.45***
		(0.18)	(0.18)	(0.18)
GDP per Capita (ln)		0.65***	0.65***	0.59***
		(0.05)	(0.05)	(0.05)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.04	-0.04	-0.04
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.05**
				(0.02)
Mobile Telephones per100 (ln)				0.02
				(0.01)
Leapfrogging (ln)			-0.00	
			(0.01)	
Internet Users per100 (ln)				-0.02
				(0.01)
Level-2				
Initial Status	2.00***	2.19***	2.28***	2.47***
	(0.15)	(0.19)	(0.19)	(0.16)
Less-Developed Country		0.48*	0.36	0.24
		(0.23)	(0.20)	(0.19)
Mean Population (ln)		0.95***	0.95***	0.91***
		(0.05)	(0.05)	(0.04)
Mean GDP per capita (ln)		0.75***	0.68***	0.38***
		(0.09)	(0.08)	(0.09)
Mean Urbanization		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Mean Trade (ln)		0.33*	0.43***	0.15
		(0.15)	(0.15)	(0.13)
Mean Service Economy		-0.01*	-0.02***	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per100 (ln)				0.44***
				(0.14)
Mean Mobile Telephones per100 (ln)				-0.23
				(0.13)
Mean Leapfrogging Ratio (ln)			-0.59***	
			(0.11)	
Mean Internet Users per100 (ln)				0.30
				(0.16)

*** $p<0.001$, ** $p<0.01$ * $p<0.05$; N=1926, n=121; ln = natural logarithm

country's logged CO_2 emissions increase 0.01 units every year (p<0.01). The unadjusted cluster mean for log CO_2 emissions from manufacturing is 2.00 (p<0.001).

Model 2 for log CO_2 emissions from manufacturing illustrates the importance of including the segmented emissions outcome variables. Again, once controls are added to the model, the effect of time is negative. Log CO_2 emissions from manufacturing are predicted to decrease by 0.03 units every year ($p<0.001$). At level 1 only log population and log GDP per capita have significant effects. A 1 percent increase in log population is predicted to increase log CO_2 emissions from manufacturing by 1.42 percent ($p<0.001$) and a 1 percent increase in GDP per capita is predicted to increase log CO_2 emissions from manufacturing by 0.65 percent ($p<0.001$). Log population and log GDP per capita are also significant predictors at level 2. A country with 1 percent above average population is predicted to have 0.95 percent ($p<0.001$) higher log CO_2 emissions from manufacturing and a 1 percent above average in log GDP per capita is predicted to increase CO_2 emissions from manufacturing by 0.75 percent ($p<0.001$). Less-developed countries are predicted to have 0.48 units ($p<0.001$) more log CO_2 emissions from manufacturing than developed countries. As expected, a country with 1 percent above average log trade is predicted to have 0.33 percent ($p<0.05$) higher log CO_2 emissions from manufacturing, and not surprisingly a country with 1 percent above average level of service economy is predicted to have 0.01 fewer units ($p<0.05$) of log CO_2 emissions from manufacturing.

Adding the effect of the leapfrogging ratio in Model 3 has no significant effect on the level-1 coefficients. The effect of the log leapfrogging ratio over time is not significant. At level-2 the introduction of mean log leapfrogging variable increases the effects of mean log trade and mean service economy while reducing the effect of mean log GDP per capita. Less-developed country status is no longer a significant as well. The effect of the mean log leapfrogging ratio is significant. A country with 1 percent higher than average log leapfrogging ratio is predicted to have 0.59 percent ($p<0.001$) fewer log CO_2 emissions from manufacturing.

Adding the ICT development indicators to Model 4 does not dramatically change the picture at level-1 because of the centering strategy. The effect of time slightly increases from -0.03 to -0.04 ($p<0.001$). Population has a slightly larger effect, while GDP per capita has a smaller effect. The effect of fixed telephones is again significant at level-1. A 1 percent increase in log fixed telephones is predicted to increase CO2 emissions from manufacturing by 0.05 percent ($p<0.01$).

Table 4.5B: Global Log CO_2 Emissions from Manufacturing, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.55	0.47	0.40	0.30
		(0.33)	(0.07)	(0.06)	(0.04)
	In rate of change	-0.01	-0.01	-0.01	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	18	20	24
Deviance		-2433	-2856	-2881	-2928
AIC		-2419	-2820	-2841	-2880
BIC		-2380	-2720	-2730	-2746
Pseudo R-sq (Level 2)		—	0.82	0.84	0.88
AR(1), ρ		0.82	0.79	0.79	0.76
		(0.03)	(0.03)	(0.03)	(0.03)
Error Variance		0.03	0.02	0.02	0.02
		(0.01)	(0.00)	(0.00)	(0.00)

N=1926, n=121

There is a completely different story at level 2. Less-developed countries do not have significantly higher log CO_2 emissions from manufacturing. Population has an effect similar to that found in the control model, but GDP per capita's effect is almost cut in half. A country with 1 percent increase above average level of log population is predicted to have 0.91 percent ($p<0.001$) higher log CO_2 emissions from manufacturing and a 1 percent increase in log GDP per capita above average is expected to increase CO_2 emissions from manufacturing by 0.37 percent

($p<0.001$). Service economy has a slightly more powerful effect in Model 4 with a 1 percent increase above average predicted to decrease log CO_2 emissions from manufacturing by 0.03percent ($p<0.001$). Trade no longer has a significant effect on CO_2 emissions from manufacturing.

Not surprisingly, given the strength of its effects in the aggregate models, a 1 percent increase in fixed telephone lines is predicted to increase CO_2 emissions from manufacturing by 0.60 percent ($p<0.001$). The effect of fixed telephone development is to consistently increase CO_2 emissions.

The variance components and model fit statistics from Table 4.5B show the strength of the full model. While neither the within country or rate of change variance components have any large changes, there is a clear progression in the initial status variance components. In initial status variance the full model explains 38 percent more of the unexplained variance from the control model. The AIC and BIC model fit statistics also prefer the full model.

4.5.4 CO_2 Emissions from Transportation

Results for a multilevel growth model with AR(1) errors for log CO_2 emissions from transportation are presented in Table 4.6A and Table 4.6B. The ICC for total CO_2 emissions is 0.99, indicating that 99 percent of the variation in total CO_2 emissions is between countries and only about 1 percent of the variation is over time within a country. The results from the unconditional growth model show that there is still a significant effect of time. On average, a country's logged CO_2 emissions from transportation increase 0.02 units every year ($p<0.001$). The unadjusted cluster mean for log CO_2 emissions from transportation is 2.00 ($p<0.001$).

None of the models for log CO_2 emissions from transportation have a significant effect of time. This may be an artifact of logging or it may be due to transportation being a smaller portion of the total emissions picture. However, it may be the case that the controls account for most of the variation over time.

Table 4.6A: Global Log CO_2 Emissions from Transportation 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.00	-0.00	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		0.65***	0.64***	0.67***
		(0.12)	(0.13)	(0.12)
GDP per Capita (ln)		0.52***	0.52***	0.50***
		(0.04)	(0.04)	(0.04)
Urbanization		0.02***	0.02***	0.02***
		(0.00)	(0.00)	(0.00)
Trade (ln)		-0.01	-0.01	-0.01
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per100 (ln)				0.04**
				(0.01)
Mobile Telephones per100 (ln)				-0.00
				(0.01)
Leapfrogging (ln)			0.00	
			(0.00)	
Internet Users per100 (ln)				0.01
				(0.01)
Level-2				
Initial Status	1.99***	2.28***	2.33***	2.47***
	(0.13)	(0.12)	(0.12)	(0.11)
Less-Developed Country		0.17	0.10	-0.02
		(0.15)	(0.14)	(0.13)
Mean Population (ln)		0.84***	0.83***	0.82***
		(0.03)	(0.03)	(0.03)
Mean GDP per capita (ln)		0.61***	0.57***	0.37***
		(0.06)	(0.06)	(0.06)
Mean Urbanization		0.01	0.01*	0.00
		(0.00)	(0.00)	(0.00)
Mean Trade (ln)		0.06	0.11	-0.07
		(0.01)	(0.09)	(0.09)
Mean Service Economy		-0.01	-0.01	-0.01***
		(0.00)	(0.00)	(0.00)
Mean Fixed Telephones per100 (ln)				0.32***
				(0.05)
Mean Mobile Telephones per100 (ln)				0.09
				(0.09)
Mean Leapfrogging Ratio (ln)			-0.31***	
			(0.08)	
Mean Internet Users per100 (ln)				-0.07
				(0.11)

*** $p<0.001$, ** $p<0.01$ * $p<0.05$; N=1926, n=121; ln = natural logarithm

In Model 2, three level-1 controls have significant effects (log population, log GDP per capita and urbanization). A 1 percent increase in log population is predicted to increase log CO_2 emissions from transportation by 0.65 percent (p<0.001), a 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from transportation by 0.52 percent (p<0.001), and a 1 percent increase in urbanization is predicted to increase log CO_2 emissions from transportation by 0.02 units (p<0.001). At level-2, mean population and GDP per capita are the only controls that have a significant effect. A country with1 percent above average log population is predicted to have 0.84 percent (p<0.001) higher log CO_2 emissions from transportation and a country with 1 percent above average log GDP per capita is predicted to have 0.61 percent (p<0.001) higher log CO_2 emissions from transportation. The initial status for a country with average levels of control variables is 2.28 (p<0.001) log CO_2 emissions from transportation. Less-developed country status is not significant in Model-2.

Adding in the log leapfrogging ratio in Model 3 does not change the effects of the control variables. Log leapfrogging ratio does not have a significant effect at level 1. However, adding it to the model changes the significance of urbanization. A country with 1 percent more urbanization is predicted to have 0.01 units (p<0.05) higher log CO_2 emissions from transportation. At level-2 the effect of mean log leapfrogging is significant. A country with a 1 percent higher than average log-leapfrogging ratio is predicted to have 0.31 percent (p<0.001) fewer log CO_2 emissions from transportation.

In Model 4 the effect of the controls at level-1 are relatively similar to Model 2. The only ICT development indicator that has a significant effect is log fixed telephones per 100 people. A 1 percent increase in log fixed telephones per 100 people is predicted to increase log CO_2 emissions from transportation by 0.04 percent (p<0.01). At level-2 there are some notable differences from the control model. Mean log population and mean log GDP per capita both have a significant effect in Model 4. While mean log population has a relatively stable effect (0.84 to 0.82, P<0.001), mean log GDP per capita has about 30 percent of the effect over the control model (0.61 to 0.37, $p<0.001$). This has been a consistent trend over the six outcome models. Also different from the control model is that the effect of mean service economy is now significant. A country with 1 percent above average service economy is predicted to have 0.01 units ($p<0.001$) lower CO_2 emissions from transportation The only ICT variable that has an effect is mean fixed telephone lines per 100 people. A 1 percent increase above average of fixed telephones per 100 people is predicted to raise emissions by 0.32 percent ($p<0.001$).

Table 4.6B: Global Log CO_2 Emissions from Transportation, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	0.02	0.15	0.12	0.11
		(0.09)	(0.05)	(0.06)	(0.03)
	In rate of change	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	18	20	24
Deviance		-3745	-4252	-4267	-4309
AIC		-3731	-4216	-4227	-4261
BIC		-3692	-4116	-4116	-4127
Pseudo R-sq (Level 2)		—	0.93	0.94	0.95
AR(1), ρ		0.99	0.95	0.95	0.94
		(0.00)	(0.04)	(0.04)	(0.04)
Error Variance		2.08	0.05	0.05	0.04
		(0.27)	(0.05)	(0.05)	(0.02)

N=1926, n=121

Turning to the variance components and model fit statistics in Table 4.6, we find some interesting results. Each model explains about 1 percent more variance than the model before it, meaning that Model-4 explains 2 percent more variance than Model 2 with just the controls. The AIC and BIC both favor using the Model 4. These variance issues are probably the result of the limited variation over time found in the outcome. Most of the variation in CO_2 emissions from transportation is between countries rather than within countries over time.

Table 4.7: Optimistic (Opt.) and Pessimistic (Pess.) hypotheses and the Results from the Analyses of Total and Per Capita (Per.) CO_2 Emissions, and CO_2 Emissions from Electricity (Elec.), Buildings (Bldg.), Manufacturing (Mfg.), and Transportation (Tran.) for the Global Model

Independent Variables	*Opt.*	*Pess.*	*Total*	*Per.*	*Elec.*	*Bldg.*	*Mfg.*	*Tran.*
Level-1								
Annual Rate of Change	−	+	−	−	−	−	−	−
Population (ln)	+	+	+	N/A	+	+	+	+
GDP per Capita (ln)	−	+	+	+	+	+	+	+
Urbanization	−	+	+	+	+	NS	NS	+
Trade (ln)	−	+	NS	NS	NS	NS	NS	NS
Service Economy	−	−	NS	NS	NS	NS	NS	NS
Fixed Telephones per100 (ln)	−	+	+	+	+	NS	+	+
Mobile Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Leapfrogging (ln)	−	+	NS	NS	NS	NS	NS	NS
Internet Users per100 (ln)	−	+	NS	NS	NS	+	NS	NS
Level-2								
Less-Developed Country	+	+/−	+	+	+	NS	+	NS
Mean Population (ln)	+	+	+	N/A	+	+	+	+
Mean GDP per capita (ln)	−	+	+	+	+	+	+	+
Mean Urbanization	−	+	NS	NS	NS	NS	NS	+
Mean Trade (ln)	−	+	+	+	+	NS	+	+
Mean Service Economy	−	−	−	−	−	NS	−	−
Mean Fixed Telephones per100 (ln)	−	+	+	+	+	+	+	+
Mean Mobile Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Mean Leapfrogging Ratio (ln)	−	+	−	−	−	−	−	−
Mean Internet Users per100 (ln)	−	+	NS	NS	NS	NS	NS	NS

+ = significant positive coefficient; − = significant negative coefficient; NS = not significant

4.6 Discussion

The analyses of the full global sample revealed a recurring pattern of effects. Table 4.7 presents a summary of the results from the above analyses. In general the optimistic perspective predicts a decrease in CO_2 emissions, (represented by −) and the pessimistic perspective predicts an increase in CO_2 emissions (represented by +). Any results variable that did not produce a significant result is list as NS or not significant. The inclusion of some measure of the information society is important for better understanding the dynamics of CO_2 emissions at the global level. It is clear that the selection of variables is important for determining results. While fixed telephones consistently predicted increases in emissions, countries with large ratios of mobile telephones to fixed telephones had fewer emissions. Internet users had marginal effects in the segmented source models for emissions from buildings but did not affect the aggregate total and per capita CO_2 emissions.

The effect of affluence on environmental degradation is well understood and those effects are clearly demonstrated by the models presented in this chapter; however, these findings suggest that between countries, about half of the variation in CO_2 emissions due to affluence as measured by GDP per capita can be explained by some combination of ICT variables. The most powerful effect is from the number of fixed telephones per 100 people. One implication is that a more connected country will have higher emissions regardless of affluence. The null hypothesis should be rejected in favor of the pessimistic global hypothesis. Countries with higher average fixed telephones will have higher CO_2 emissions.

For the model of total CO_2 emissions, fixed telephones had a positive effect; however, the effect of the leapfrogging ratio was negative. While the development of mobile phones in and of themselves does not have an effect on emissions, countries with more mobile telephones than fixed telephones have lower emissions, all things being equal. Even countries that have high levels of mobile phone penetration may not necessarily have correspondingly low levels of population, affluence and fixed telephone penetration. In fact, countries that have relatively high mobile penetration are also likely to have high fixed line penetration. More so, in developing countries that have experienced rapid spread of mobile telecommunication, the demand for fixed lines is often increased rather than decreased. Differences in mobile and fixed penetration are also complicated because these technologies are integrated with each other. Even so, the null hypothesis should be rejected in favor of the optimistic leapfrogging hypothesis. Because mobile telephones in and of themselves do not have a predicted relationship with CO_2 emissions their development over fixed telephones does not accelerate emissions. More clarity should come after looking at the developed and less-developed models in the next two chapters.

In all cases where the ICT development indicators had a significant result the effect is an increase of CO2 emissions. There are no justifications for any of the optimistic source hypotheses for electricity, buildings, manufacturing and transportation. In fact, the general conclusion is that ICT development will increase emissions across all source sectors, most being affected by fixed telephones with buildings being affected by the Internet. The null hypothesis should be rejected in favor of the pessimistic source research hypothesis.

The differentiated source models for electricity buildings, manufacturing and transportation follow many of the patterns of the two aggregate models but offer some finer-grained insight into how ICTs impact CO_2 emissions. One notable difference is that Internet users per 100 people has a positive and significant impact on emissions from buildings over time. Not apparent in the aggregate model, the effect of the Internet here lends support for the pessimistic perspective. The more Internet users a country has, the more CO_2 emissions they are likely to have from buildings. The increase in emissions from buildings over time also makes sense. The need for indoor space to house IT service workers, secure servers, computer labs, and the recent trend of cloud computing all place demands for increased square footage.

Moving to emissions from transportation, the findings show more support for the pessimistic hypothesis. One of the most championed ICT emissions reduction strategies is to replace a face-to-face interaction with digitally interfaced interaction, the argument being that people who can talk with someone over the Internet or over the phone will be less likely to drive for a meeting. Alternatively, people who need goods or services will not need to drive to a store or office because they can obtain those goods or services electronically. This evidence contradicts those assumptions. The only significant effect is from fixed telephone lines and it predicts higher emissions over time. Studies on the impact of ICTs on social networks have found that they supplement face-to-face interaction without decreasing it or increasing it (Wellman et al. 2001). For future research into the social drivers of environmental impacts, ICTs should play a larger part of that discussion than they have in the past; however the development of the Internet, the technology most associated with the information age, has a negligible effect on aggregate CO_2 emissions.

4.7 Conclusion

The global models presented in this chapter shows the importance of looking at the impact of ICT development on CO_2 emissions and provides the first impressions of what the relationship may be for future ICT development. However, the effects predicted by optimistic perspectives are often hinged on the development status of a country. So now this research thus turns to an analysis of the same data for samples of developed countries and less-developed countries separately, to see if the findings between ICTs and CO_2 emissions found at the global level are replicated or vary between these two sets of countries.

CHAPTER 5

INFORMATION AND COMMUNICATION TECHNOLOGY DEVELOPMENT AND CARBON DIOXIDE EMISSIONS IN DEVELOPED COUNTRIES

The crossroads of optimistic and pessimistic perspectives is located in the modern promise of the developed world. If ICT development is a pathway to a reduced CO_2 emissions economy the evidence of its decline should appear in this sample of nations, as ecological modernizationist scholars would predict (Mol 2008). However, if ICT development is not a fulcrum for a reduced CO_2 emissions economy, these analyses will provide a better understanding of their degrading effect.

To better understand the effect of ICT development on CO_2 emissions a sample of developed countries was generated. This sample consists of countries that are in the top 25 percent of countries based on GDP per capita. Because of the repeated cross-sectional structure of the data, each country needs to be in the top 25 percent for at least 50 percent of the times observed, this cut of was selected to allow for the mobility of countries and is essentially their median development status over the time-frame of the study. GDP per capita is often used as a proxy for development status and world-system position (Roberts and Grimes 2002). It is frequently recognized that using any univariate delimiter to designate a country's development status or world-system position is an analytic convenience. Given that, the purpose of these analyses is to investigate the role ICT development plays in CO_2 emissions, this is an acceptable convenience.

Developed countries represent the highest potential of modernity. As a result, the trajectory of environmental degradation in developed countries is central to the argument of both optimistic ecological modernists and pessimistic scholars of the political economy school (Mol 2001; Schnaiberg 1980). For optimists, countries within the top tier of development are exemplars of a historicist trajectory that all countries will proceed through given enough time. The "Environmental Kuznets's Curve" hypothesis predicts the lowest levels of environmental degradation will occur within the most highly advanced countries (Grossman and Krueger 1995). Similarly, Ecological Modernization Theory highlights the role that environmental governance in developed countries plays in reducing degradation (Mol 2001). Both perspectives depend on the development of ICTs to facilitate the transition to a new economy and enhance the effectiveness of environmental governance (Mol 2008).

For pessimists, the development of new technologies is nearly irrelevant, as degradation, particularly on a global scale, is not sourced from the technology but rather from the underlying social structure, the treadmill of production (Schnaiberg 1980; Roberts and Grimes 2002). If there is any historicist trajectory it is that developed nations want to maintain their economic status. ICTs simply offer more avenues of remote surveillance and control over core nation interests in the periphery and semi-periphery (Drori 2006). Within core nations there are likely to be some changes that reflect the unequal exchange of environmental costs. Even so, because of new opportunities afforded through the development of ICTs, developed nations may have increased in their CO_2 emissions associated with some or all of the ICT development indicators.

5.1 The Multilevel Model for Growth

Analyses of the relationship between ICT development and CO_2 emissions in developed countries are broken into six parts. The first two analyses investigate the relationship between ICT development-using log total CO_2 emissions and log CO_2 emissions per capita. These aggregate outcome variables provide a broad view of the relationship between ICT development and CO_2 emissions and inform the broad optimistic and pessimistic research hypotheses. They also inform the environmental leapfroging hypothesis.

The final four analyses disaggregate log total CO_2 emissions into four source category outcome variables: log CO_2 emissions from electricity, log CO_2 emissions from buildings, log CO_2 emissions from manufacturing and log CO_2 emissions from transportation. Disaggregating CO_2 emissions in this fashion informs the more specific optimistic predictions relating to the potentially diverse impact of ICT development on CO_2 emissions in different economic sectors.

All six analyses provide information on the role that world-system position system plays in CO_2 emissions. At the top of the hierarchy, these countries are the beneficiaries of the global economic system and can therefore afford to expend more energy—predominantly in the form of fossil fuels—and have more of their population utilize the latest technological developments. This also means that developed countries are more likely to be further along the transition from one technology to another. Developed countries are actually losing fixed line telephone subscriptions while they are approaching full mobile telephone penetration.

As was done in Chapter 4, four models will be presented for each dependent variable. Model 1 is the unconditional growth model; it reports the annual rate of change and initial status of emissions for a developed country without any controls. Model 2 is the control model and includes log population, log GDP per capita, urbanization, log trade, and service economy at level-1 and mean log population, mean log GDP per capita, mean urbanization, mean log trade, and mean service economy at level-2. Keep in mind that all level-1 variables are group-mean centered, eliminating any cross-level interaction and allowing both levels to be presented at the same time. Model 3 is the leapfrogging model, which includes all of the control variables from Model 2 as well as log leapfrogging at level-1, and mean log leapfrogging at level-2. Model 4 is the full model incorporating three measures of ICT development at each level. At level-1 the log of fixed telephones per 100, mobile telephones per 100 and Internet users per 100 are included.

At level-2, the log of mean fixed telephones per 100, mean mobile telephones per 100 and mean Internet users per 100 are included. Since leapfrogging is a ratio of mobile telephones per 100 to fixed telephones per 100 it is not included in Model 4.

5.2 Log Total CO_2 Emissions.

The first set of analyses presented in Tables 5.1A and 5.1B investigate the relationship of ICT development on log total CO_2 emissions in developed countries. Model 1 is the unconditional growth model, which reports the predicted annual rate of change, and the initial status of log total CO_2 emissions for a developed nation without controls. In Model 1, a developed country is predicted to increase its log total CO_2 emissions by 0.01 ($p<0.05$) every year between 1990 and 2009. Developed countries have, on average, 11.67 units ($p<0.001$) of log total CO_2 emissions.

Model 2 introduces five control variables at both level-1 and level-2; log population, log GDP per capita, urbanization, log trade, and service economy. Including controls changes the direction of the annual rate of change. A developed country is now predicted to decrease its log total CO2 emissions by -0.02 units ($p<0.001$) every year. A 1 percent increase in log population is predicted to increase log total CO_2 emissions by 1.03 percent ($p<0.001$) within a developed country. A 1 percent increase in log GDP per capita is predicted to increase log total CO_2 emissions by 0.72 percent ($p<0.001$), within countries. Urbanization, log trade, and service economy do not have a significant effect on log total CO_2 emissions within countries. This is likely due to the already high level of urbanization, trade, and service economy existing in developed countries prior to 1990.

At level-2 the initial status for a country with average levels of log population, log GDP per capita, urbanization, log trade and service economy is 12.11 ($p<0.001$) log total CO2 emissions. For every 1 percent above average population in the developed world log total CO2 emissions are predicted to be 0.99 percent ($p<0.001$) higher on average. Mean log GDP per capita does not have a significant effect on log total CO2 emissions in the control model. For every 1

Table 5.1A: Developed Country Log Total CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01*	-0.02***	-0.02**	-0.02***
	(0.00)	(0.00)	(0.01)	(0.01)
Population (ln)		1.03***	1.12***	1.06***
		(0.17)	(0.17)	(0.16)
GDP per Capita (ln)		0.72***	0.77***	0.61***
		(0.10)	(0.10)	(0.10)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.04	-0.03	-0.05
		(0.05)	(0.05)	(0.05)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.08
				(0.06)
Mobile Telephones per 100 (ln)				0.02
				(0.01)
Leapfrogging (ln)			-0.05	
			(0.04)	
Internet Users per 100 (ln)				-0.00
				(0.01)
Level-2				
Initial Status	11.67***	12.11***	12.08***	12.12***
	(0.29)	(0.08)	(0.09)	(0.08)
Mean Population (ln)		0.99***	1.00***	1.03***
		(0.06)	(0.05)	(0.04)
Mean GDP per capita (ln)		0.30	0.22	0.41*
		(0.19)	(0.19)	(0.19)
Mean Urbanization		0.01*	0.01*	0.01*
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		-0.12	0.21	0.18
		(0.13)	(0.13)	(0.11)
Mean Service Economy		-0.03***	-0.03***	-0.02***
		(0.01)	(0.29)	(0.01)
Mean Fixed Telephones per 100 (ln)				-1.32**
				(0.42)
Mean Mobile Telephones per 100 (ln)				-0.52*
				(0.22)
Mean Leapfrogging Ratio (ln)			0.30	
			(0.29)	
Mean Internet Users per 100 (ln)				0.68***
				(0.16)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=461, n=26; ln = natural logarithm

percent above average urbanization in the developed world log total CO2 emissions are predicted to be 0.01 units (p<0.05) higher on average. For every 1 percent above average service economy in the developed world log total CO2 emission are predicted to be 0.03 units (p<0.001) lower on average. Mean trade does not have a significant effect on log total CO2 emissions.

There are slight differences between Model 2 and Model 3 where leapfrogging is added. The effect of log population is slightly more intense at level-1 and 2 (1.12 and 1.00), log GDP per capita is slightly more intense at level-1 (0.77), and the initial status is slightly lower (12.08). Besides these differences, adding the leapfrogging ratio does not significantly change this model. In fact, the leapfrogging ratio does not significantly impact log total CO_2 emissions at either level-1 or level-2. This falls in line with the optimistic leapfrogging hypothesis as developed countries do not leapfrog over dirty technologies but instead adopt them as they are developed. However, this is not conclusive evidence that leapfrogging has beneficial environmental impacts. The analyses of less developed countries in chapter six are the second piece of that puzzle.

Finally, in Model 4 we see the impact of ICT development on CO_2 emissions. There is no significant effect of ICT development—log fixed telephones per 100, log mobile telephones per 100, and Internet users per 100—on log total CO_2 emissions for developed countries at level-1. Control variables remain relatively stable at level-1. Log population has slightly smaller effect (1.06) while log GDP per capita has a noticeable smaller effect (0.61). It is not unexpected that there will no significant effects as there is little variation (1 percent) at level-1 to begin with.

That said, the results from Model 4 at level-2 are more insightful. There are small differences between the control model and the full model for initial status (12.12), mean log population (1.03), and mean service economy (-0.02). After the addition of the ICT development variables, mean log GDP per capita becomes significant. For every 1 percent above average log GDP per capita in developed countries, log total CO_2 emissions are predicted to be 0.44 percent (p<0.05) higher on average. This further highlights the relationship between ICT development and economic development discussed in Chapter 4. For every 1 percent above average log fixed telephones per 100 in developed countries, log total CO_2 emissions are predicted to be 1.32 percent ($p<0.01$) lower. For every 1 percent above average log mobile telephones per 100 in developed countries log total CO_2 emissions are predicted to be 0.53 percent ($p<0.05$) lower. Both fixed and mobile telephones are predicted to have dampening effect on log total CO_2 emissions. Fixed telephones may have a negative impact because they have been in decline all across developed nations. A nation with more fixed line telephones may also have slower economic development and less demand for energy; however, the same cannot be said for mobile phones. Everywhere in the developed and developing world mobile communication has been spreading. As discussed earlier, the energy investment of mobile phones is less than for fixed lines and the expansion of new electrical grids is not necessarily associated with mobile communications towers as it is with telephone lines. This is partial evidence in support of the optimistic hypothesis. New technologies may not be as energy demanding as the technologies they replace.

Table 5.1B: Developed Country Log Total CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.46	0.13	0.15	0.12
		(0.63)	(0.05)	(0.06)	(0.05)
	In rate of change	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-1039	-1188	-1190	-1210
AIC		-1025	-1154	-1153	-1164
BIC		-996	-1083	-1074	-1069
Pseudo R-sq (Level 2)		—	0.94	0.93	0.95
AR(1), ρ		0.74	0.55	0.55	0.48
		(0.08)	(0.06)	(0.06)	(0.06)
Error Variance		0.01	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)

N=461, n=26

On the other hand, Model 4 presents a very different image of the relationship between Internet use and CO_2 emissions. For every 1 percent above average log Internet users per 100 people in developed countries, log total CO_2 emissions are expected to be 0.68 percent ($p<0.001$) higher on average. The impact of the Internet, it seems, does not support the optimistic hypothesis. The development of the Internet over this period had a significant impact on the way that businesses were run (Castelles 2000). The reduction in fixed telephone lines in the developed world has more to do with the prevalence of business websites, online shopping, and voice over Internet protocol services. While the switch to mobile telephones has reduced emissions to some degree as more people access the Internet through mobile devices, the demand for data services increases, and the number of people with access to a panoply of industrial services grows.

Turning to the variance components in Table 5.1B, the relative strength of each model can be assessed. As with the global models, there are almost no differences in the within-country variances between models. Similarly there are no changes in the rate of change variances. Both variances indicate there was little change over time for these countries. This conforms to the ICC of .99 calculated earlier. However, in average differences between countries, the initial status variance indicates that our control model explains about 94% of differences between countries. The addition of all three ICT development indicators explains an additional 1 percent of the variation. The addition of the leapfrogging ratio does not add any explanatory value to the developed world model.

5.3 Log Per Capita CO_2 Emissions

The second set of analyses reported in Tables 5.2A and 5.2B examines the impact of ICT development on log per capita CO_2 emissions in developed countries. Model 1 is the unconditional growth models for log per capita CO_2 emissions. The annual rate of change for developed countries is not significantly different from zero. On average, each developed country has 2.32 ($p<0.001$) log CO_2 emissions. Even more so than with log total CO_2 emissions, log per

Table 5.2A: Developed Country Log Per Capita CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.00	-0.02***	-0.01**	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)
GDP per Capita (ln)		0.71***	0.73***	0.59***
		(0.09)	(0.09)	(0.09)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.04	-0.03	-0.05
		(0.05)	(0.05)	(0.05)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.08
				(0.06)
Mobile Telephones per 100 (ln)				0.02
				(0.01)
Leapfrogging (ln)			-0.05	
			(0.04)	
Internet Users per 100 (ln)				-0.00
				(0.01)
Level-2				
Initial Status	2.32***	2.46***	2.42***	2.47***
	(0.10)	(0.08)	(0.08)	(0.08)
Mean GDP per capita (ln)		0.29	0.22	0.42*
		(0.19)	(0.10)	(0.19)
Mean Urbanization		0.01*	0.01*	0.01*
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		-0.10	-0.19	-0.21*
		(0.10)	(0.11)	(0.09)
Mean Service Economy		-0.03***	-0.03***	-0.02*
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				-1.28**
				(0.41)
Mean Mobile Telephones per 100 (ln)				-0.53*
				(0.23)
Mean Leapfrogging Ratio (ln)			0.28	
			(0.28)	
Mean Internet Users per 100 (ln)				0.67***
				(0.21)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=461, n=26; ln = natural logarithm

capita CO_2 emissions have very little change within countries over the period examined. The real differences are in average level of development between countries.

Model 2 introduces four controls at both level-1 (log GDP per capita, urbanization, log trade and service economy) and level-2 (mean log GDP per capita, mean urbanization, mean log trade, and mean service economy). With the addition of controls, the annual rate of change is now significant and negative. A developed country is predicted to decrease its log per capita CO_2 emissions by -0.02 units ($p<0.001$) every year; however, for every 1 percent increase in log GDP per capita, log per capita CO_2 emissions are expected to increase 0.71 percent ($p<0.001$). None of the other controls have a significant impact on log per capita CO_2 emissions at level-1.

At level-2, the results are quite different. Developed countries with average levels of log GDP per capita, urbanization, log trade, and service economy are predicted to have an initial status of 2.46 ($p<0.001$) log per capita CO_2 emissions. A developed country with 1 percent above average level of urbanization is predicted to have 0.01 ($p<0.05$) units higher log per capita CO_2 emissions. A developed country with a service economy that is 1 percent larger is predicted to have 0.03 units ($p<0.001$) lower log per capita CO_2 emissions. Mean log GDP per capita and mean log trade are not significant in Model 2.

Model 3 introduces the leapfrogging ratio between mobile telephones and fixed line telephones. At level-1 there are few differences. The annual rate of change reduces to -0.01 and the effect log GDP per capita is slightly larger (0.73). At level-2 there are more interesting consequences. The initial status is slightly lower at 2.42 units log per capita CO_2 emissions. The inclusion of the leapfrogging variable did not change the effects of mean urbanization or mean service economy. Additionally, the effect of the leapfrogging ratio itself was not significant. One last note, the effect of mean trade increased slightly, but remained insignificant.

There are even more differences after the inclusion of the three ICT development indicators in Model 4. A developed country with average levels of log GDP per capita, urbanization, log trade, service economy, log fixed telephones per 100 people, log mobile telephones per 100 people, and log Internet users per 100 people is predicted to have an initial status of 2.47 units ($p<0.001$) log per capita CO_2 emissions. With the addition of the ICT development indicators, the effect of mean log GDP per capita becomes significant. A developed country with log GDP per capita 1 percent above the mean is predicted to have 0.42 percent ($p<0.05$) higher log per capita CO_2 emissions. The effect of mean urbanization is constant across Models 2, 3, and 4. Interestingly, the effect of mean trade is now significant. A developed country with 1 percent higher than average log trade is predicted to have 0.21 percent ($p<0.01$) lower log per capita CO_2 emissions. The effect of mean service economy is slightly lower in Model 4 (-0.02).

Table 5.2B: Developed Country Log Per Capita CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	0.28	0.12	0.13	0.12
		(0.08)	(0.04)	(0.05)	(0.04)
	In rate of change	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	15	17	21
Deviance		-1103	-1188	-1190	-1210
AIC		-1089	-1158	-1156	-1168
BIC		-1060	-1096	-1086	-1081
Pseudo R-sq (Level 2)		—	0.57	0.54	0.57
AR(1), ρ		0.72	0.55	0.55	0.48
		(0.07)	(0.06)	(0.06)	(0.06)
Error Variance		0.01	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)

N=461, *n*=26

All three ICT development indicators have a significant effect on log per capita CO_2 emissions. For every 1 percent log fixed telephones per 100 people above the mean a developed country is predicted to have 1.28 percent ($p<0.01$) lower log per capita CO_2 emissions. For every

1 percent log mobile telephones per 100 people above the mean a developed country is predicted to have 0.53 percent ($p<0.05$) lower log per capita CO_2 emissions. As with log total CO_2 emissions, a country with above average fixed telephones per 100 people does not represent the declining trend of fixed telephone lines in developed countries as a whole. It is also likely indicative of stagnant economic growth, given the close interaction between GDP per capita and ICT development. The same cannot be said for mobile telephone subscriptions. The Internet has a clear positive relationship with total and per capita CO_2 emissions. For every 1 percent increase in log Internet users per 100 above the mean log per capita CO_2 emissions are predicted to be 0.67 percent ($p<0.001$) higher.

Turning briefly to Table 5.2B, trends similar to those found in the log total CO_2 emissions models can be found in the log per capita models. There is no evidence of a change at level-1. All of the change is at level-2. The inclusion of control variables in Model 2 explains 57 percent of the variation between countries. Model 3 offers less explanatory value, again questioning the utility of the leapfrogging ratio for developed countries. Model 4 explains the same level of variation as Model 3, 57 percent. Adding the three ICT development indicators did not appreciably increase the explanatory power of the model. However, both the log total CO_2 emissions and log per capita CO_2 emissions models are limited by the sample size at level-2. This should not eliminate the utility of these analyses, as this sample closely mirrors the actual population of developed countries. Additionally, the transformation of variables using the natural logarithm to meet the regression assumption of normality removes some of the natural variability that might otherwise be present.

5.4 Source Specific Outcomes

The next four sets of analyses disaggregate the total CO_2 emissions for a given country into four source categories: CO_2 emissions form electricity, CO_2 emissions, from buildings, CO_2 emissions from manufacturing, and CO_2 emissions from transportation. It is often assumed that the negative effects of ICT development on CO_2 are not uniform (Webb 2008). While the effect of ICT development on total CO_2 emissions has already been examined, the disaggregated outcomes will inform each of the four source specific optimistic hypotheses.

5.5 Log CO_2 Emissions from Electricity

First are the analyses of ICT development on log CO_2 emissions from electricity. The results for these analyses can be found in Tables 5.3A and 5.3B. Model 1 is the unconditional growth model of log CO_2 emissions from electricity. On average, a developed country will increase their log CO_2 emissions from electricity by 0.02 units ($p<0.001$) every year. On average, a developed country is predicted to have and initial status of 3.75 units ($p<0.001$) of log CO_2 emissions from electricity.

Model 2 adds five control variables: log population, log GDP per capita, urbanization, log trade, and service economy. As with the log total CO_2 emissions, models adding controls reverse the sign for the annual rate of change. The log CO_2 emissions from electricity are expected to decrease every year by 0.01 units ($p<0.05$), in developed countries holding all else constant. Every 1 percent increase in log population is predicted to increase log CO_2 emissions from electricity by 1.08 percent ($p<0.001$). Every 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from electricity by 0.69 ($p<0.001$) percent. Urbanization, log trade, and service economy do not have a significant effect on log CO_2 emissions from electricity at level-1. At level-2, the initial status of CO_2 emissions increases to 4.22 ($p<0.001$) units of log CO_2 emissions (over 3.75) for a country with average levels of the control variables. A developed country with 1 percent higher than average log population is predicted to have 0.94 percent higher log CO_2 emissions from electricity. Notably, mean log GDP per capita does not have a significant effect in the control model, which is inconsistent with the log total CO_2 emissions model. Also, mean log trade does not have significant effect but that is consistent with total CO_2 emissions model. A country with 1 percent higher than average urbanization is predicted to have 0.01 units ($p<0.05$) higher log CO_2 emissions from electricity. A country with a 1 percent larger

Table 5.3A: Developed Country Log CO_2 Emissions from Electricity 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.01*	-0.01	-0.02*
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		1.08***	1.15***	1.14***
		(0.23)	(0.23)	(0.22)
GDP per Capita (ln)		0.69***	0.73***	0.59***
		(0.14)	(0.14)	(0.14)
Urbanization		0.02	0.02	0.02
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.03	0.04	0.03
		(0.07)	(0.07)	(0.07)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.16
				(0.09)
Mobile Telephones per 100 (ln)				0.02
				(0.02)
Leapfrogging (ln)			-0.04	
			(0.06)	
Internet Users per 100 (ln)				0.00
				(0.01)
Level-2				
Initial Status	3.75***	4.22***	4.19***	4.22***
	(0.29)	(0.12)	(0.13)	(0.21)
Mean Population (ln)		0.94***	0.97***	1.04***
		(0.10)	(0.10)	(0.10)
Mean GDP per capita (ln)		0.27	0.04	0.28
		(0.32)	(0.32)	(0.35)
Mean Urbanization		0.02	0.02*	0.02*
		(0.01)	(0.01)	(0.01)
Mean Trade (ln)		-0.04	-0.18	-0.13
		(0.23)	(0.22)	(0.20)
To Mean Service Economy		-0.03*	-0.03*	-0.01
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				-1.86*
				(0.09)
Mean Mobile Telephones per 100 (ln)				-0.36
				(0.40)
Mean Leapfrogging Ratio (ln)			0.67	
			(0.48)	
Mean Internet Users per 100 (ln)				0.74*
				(0.38)

*** p<0.001, **p<0.01, *p<0.05; *N*=461, *n*=26; ln = natural logarithm than average service economy is predicted to have 0.03 units (p<0.05) lower log CO_2 emissions from electricity.

There are small changes between Model 2 and Model 3, with leapfrogging added. level-1 effects remain stable save for the effect of time, which is no longer significant. At level-2, there are small changes in initial status and log mean population. Urbanization is now significant. Countries with 1 percent higher than average urbanization is predicted to have 0.02 units (p<0.001) higher log CO_2 emissions from electricity. The addition of the leapfrogging ratio does not have a significant effect on log CO_2 emissions from electricity in developed countries.

Table 5.3B: Developed Country Log CO_2 Emissions from Electricity 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.21	0.30	0.32	0.27
		(0.62)	(0.10)	(0.11)	(0.10)
	In rate of change	-0.01	-0.00	-0.00	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-785	-874	-876	-890
AIC		-771	-840	-838	-844
BIC		-743	-770	-760	-749
Pseudo R-sq (Level 2)		—	0.86	0.86	0.88
AR(1), ρ		0.71	0.61	0.62	0.54
		(0.07)	(0.07)	(0.07)	(0.06)
Error Variance		0.01	0.01	0.01	0.01
		(0.00)	(0.00)	(0.00)	(0.00)

N=461, n=26

Model 4 provides some interesting insights. There are still no significant effects at level-1 and at level-2 mean service economy is no longer significant in Model 4, suggesting a possible interaction between ICT development and the service economy. Log mean GDP per capita is still not significant, suggesting that CO_2 emissions from electricity do not significantly change if a country is above or below average GDP per capita in the developed world; however, a country with 1 percent above average log fixed telephones per 100 people is predicted to have 1.86 percent (p<0.05) lower log CO_2 emissions from electricity. Interestingly, log mobile telephones per 100 people does not have a significant effect on log CO_2 emissions from electricity. This differs from the log total CO_2 emissions model, suggesting that the development of mobile telephones in the developed world has not significantly reduced electricity consumption. The declining trend in fixed telephone lines across developed countries means that countries that are not replacing fixed lines with mobile lines have fewer emissions from electricity. The Internet, however, is increasing in penetration across the developed world, and a country with 1 percent above average log Internet users per 100 people is predicted to have 0.74 percent (p<0.05) higher CO_2 emissions.

Turning briefly to Table 5.3B, using the model fit and variance components the relative strength of each model can be determined. Model 2 explains about 86 percent of the variance over the unconditional growth model. Model 4 explains an additional 2 percent of the variance over Model 2. As with all of the models, they are less stable because of the small sample size at level-2.

5.6 Log CO_2 Emissions from Buildings

Tables 5.4A and 5.4B present the results from the analyses of log CO_2 emissions from buildings. These analyses reveal an entirely different emissions relationship. Model 1 is the unconditional growth model of log CO_2 emissions from buildings. There is no significant effect of time on log emissions from buildings. Average country in the developed world is predicted to have 2.63 units (p<0.001) of log emissions from buildings. In Model 2 at level-1 there is still no significant effect of time on log CO_2 emissions from buildings. A 1 percent increase in population is predicted to increase log CO_2 emissions from buildings by 0.51 percent (p<0.05). A 1 percent increase in log trade is predicted to reduce log CO_2 emissions from buildings by 0.19 percent (p<0.001), presumably from a reduction in building use due to reduced manufacturing.

Table 5.4A: Developed Country Log CO_2 Emissions from Buildings 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.00	-0.01	-0.01	-0.02**
	(0.00)	(0.00)	(0.01)	(0.01)
Population (ln)		0.51*	0.49*	0.41
		(0.24)	(0.24)	(0.22)
GDP per Capita (ln)		0.12	0.10	-0.07
		(0.13)	(0.13)	(0.13)
Urbanization		0.01	0.01	0.00
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.19***	-0.19***	-0.18**
		(0.06)	(0.06)	(0.06)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.02
				(0.08)
Mobile Telephones per 100 (ln)				0.03
				(0.02)
Leapfrogging (ln)			-0.00	
			(0.05)	
Internet Users per 100 (ln)				0.03
				(0.02)
Level-2				
Initial Status	2.62***	2.91***	2.93***	3.05***
	(0.34)	(0.21)	(0.20)	(0.13)
Mean Population (ln)		1.17***	1.08***	1.08***
		(0.11)	(0.10)	(0.12)
Mean GDP per capita (ln)		0.14	0.46	0.56
		(0.35)	(0.32)	(0.38)
Mean Urbanization		-0.02*	-0.02**	-0.02**
		(0.01)	(0.01)	(0.01)
Mean Trade (ln)		0.11	0.23	0.20
		(0.25)	(0.22)	(0.21)
Mean Service Economy		0.01	0.00	0.02
		(0.01)	(0.01)	(0.02)
Mean Fixed Telephones per 100 (ln)				-0.46
				(0.82)
Mean Mobile Telephones per 100 (ln)				-1.05*
				(0.44)
Mean Leapfrogging Ratio (ln)			-1.38**	
			(0.48)	
Mean Internet Users per 100 (ln)				0.45
				(0.42)

*** $p<0.001$, **$p<0.01$, *$p<0.05$; N=461, n=26; ln = natural logarithm

Log GDP per capita, urbanization, and service economy do not have a significant effect at level-1.

At level-2, a country with average log population, log GDP per capita, urbanization, log trade, and service economy is predicted to have 2.91 units ($p<0.001$) of log CO_2 emissions from buildings. A country with 1 percent higher than average log population is predicted to have 1.17 percent ($p<0.001$) higher log CO_2 emissions from buildings. A country with 1 percent above average urbanization is predicted to have 0.02 fewer units ($p<0.05$) of log CO_2 emissions from buildings. Mean log-GDP per capita, mean log trade, and mean service economy do not have a significant effect at level-2. It is notable that log trade has a significant effect within countries over time (level-1) but does not have a significant effect between countries (level-2).

Table 5.4B: Developed Country Log CO_2 Emissions from Buildings 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.97	0.33	0.24	0.33
		(0.29)	(0.18)	(0.11)	(0.12)
	In rate of change	-0.00	-0.00	-0.00	-0.01
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-946	-1023	-1030	-1044
AIC		-932	-989	-992	-998
BIC		-903	-919	-914	-903
Pseudo R-sq (Level 2)		—	0.89	0.92	0.89
AR(1), ρ		0.85	0.93	0.92	0.74
		(0.09)	(0.21)	(0.15)	(0.07)
Error Variance		0.02	0.03	0.03	0.01
		(0.01)	(0.10)	(0.05)	(0.00)

N=461, n=26

At level-1 in Model 3, there are only small differences from Model 2. Leapfrogging does not have a significant effect at level-1. At level-2 Model 3 does not differ dramatically from

Model 2. However, at level-2 the leapfrogging ratio does have a significant effect. A country with 1 percent higher than average log leapfrogging ratio is predicted to have 1.38 percent (p<0.01) fewer log CO_2 emissions from buildings. While this measure does not represent any actual technological leapfrogging, as developed countries all had relatively high levels of fixed line telephones, it does demonstrate the relationship between fixed line communication and CO_2 emissions from buildings. The more mobile telephones in use compared to fixed telephones the less demand there is for building space.

This relationship can be seen in Model 4 as well. There are minute changes in Model 4 compared to Models 2 and 3. Only log mobile telephones per 100 is significant from the set of ICT development indicators. A country with 1 percent above average level of log mobile telephones per 100 people is predicted to have 1.05 percent (p<0.05) fewer log CO_2 emissions from buildings. This is driven by mobile telephones as both fixed telephones and Internet users are not significant drivers of CO_2 emissions from buildings in developed countries. Briefly touching on the variance components in Table 5.4B, the strength of the leapfrogging ratio in explaining CO_2 emissions from buildings can be seen. Both Model 2 and Model 1 explain about 89 percent of the variance in CO_2 emissions from buildings, while Model 3 explains about 92 percent of the variance.

5.7 Log CO_2 Emissions from Manufacturing

Tables 5.5A and 5.5B present the results for the analyses of log CO_2 emissions from manufacturing. The results are interesting when compared with results from emissions from buildings. The unconditional growth model for log CO_2 emissions from manufacturing predicts no significant change over time. An average developed country is predicted to have 3.15 units (p<0.001) of log CO_2 emissions from manufacturing. In Model 2 the direction and significance changes for the annual rate of change. Every year a developed country is predicted have 0.03 units (p<0.001) lower log CO_2 emissions from manufacturing, holding all else constant. A 1 percent increase in log population is predicted to increase log CO_2 emissions from manufacturing

Table 5.5A: Developed Country Log CO_2 Emissions from Manufacturing 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.00	-0.03***	-0.04***	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)
Population (ln)		1.56***	1.66***	1.69***
		(0.27)	(0.27)	(0.26)
GDP per Capita (ln)		0.95***	0.97***	0.83***
		(0.14)	(0.15)	(0.15)
Urbanization		-0.01	-0.00	-0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.24***	0.24***	0.25***
		(0.06)	(0.07)	(0.07)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.11
				(0.09)
Mobile Telephones per 100 (ln)				0.01
				(0.02)
Leapfrogging (ln)			-0.00	
			(0.06)	
Internet Users per 100 (ln)				0.02
				(0.02)
Level-2				
Initial Status	3.15***	3.68***	3.69***	3.74***
	(0.29)	(0.09)	(0.10)	(0.10)
Mean Population (ln)		0.91***	0.96***	1.04***
		(0.14)	(0.07)	(0.04)
Mean GDP per capita (ln)		0.29	0.16	0.48***
		(0.22)	(0.21)	(0.15)
Mean Urbanization		0.01*	0.02**	0.01***
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		-0.12	-0.16	0.02
		(0.16)	(0.15)	(0.09)
Mean Service Economy		-0.04***	-0.04***	-0.02**
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				-2.43***
				(0.33)
Mean Mobile Telephones per 100 (ln)				-0.90***
				(0.18)
Mean Leapfrogging Ratio (ln)			0.82*	
			(0.34)	
Mean Internet Users per 100 (ln)				1.24***
				(0.17)

*** p<0.001, **p<0.01, *p<0.05; *N*=461, *n*=26; ln = natural logarithm by 1.56 percent (p<0.001). A 1 percent increase in GDP per capita is predicted to increase CO_2 emissions from manufacturing by 0.95 percent (p<0.001). Urbanization and service economy do not have a significant effect at level-1. Trade has a significant effect on emissions from manufacturing but unlike the negative relationship with emissions from buildings a 1 percent increase in log trade is predicted to increase log CO_2 emissions from manufacturing by 0.24 percent (p<0.001).

Table 5.5B: Developed Country Log CO_2 Emissions from Manufacturing, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	1.53	0.08	0.08	0.08
		(4.50)	(0.09)	(0.07)	(0.05)
	In rate of change	-0.01	-0.00	-0.00	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-801	-954	-959	-993
AIC		-787	-920	-921	-947
BIC		-758	-850	-843	-852
Pseudo R-sq (Level 2)		—	0.95	0.95	0.95
AR(1), ρ		0.99	0.95	0.94	0.93
		(0.04)	(0.07)	(0.06)	(0.02)
Error Variance		0.58	0.06	0.05	0.04
		(4.46)	(0.07)	(0.06)	(0.01)

N=461, n=26

A country with average log population, log GDP per capita, urbanization, log trade, and service economy is predicted to have 3.68 units of log CO_2 emissions from manufacturing. At level-2 a country with 1 percent higher than average population is predicted to have 0.91 percent (p<0.001) higher log CO_2 emissions from manufacturing. Log mean GDP per capita does not have a significant effect in the control model. A country with 1 percent higher urbanization is predicted to have 0.01 units (p<0.05) more log CO_2 emissions from manufacturing. Log mean trade does not have a significant effect at level-2. A country with a service economy that is 1 percent larger than average is predicted to have 0.04 units (p<0.001) lower log CO_2 emissions from manufacturing.

At level-1, adding in the leapfrogging ratio produces no substantive changes to the model. Leapfrogging is also not significant at level-1. Again at level-2, introducing the mean leapfrogging ratio does not substantively change the effects of the control variables; however, mean leapfrogging is significant at level-2. A country with 1 percent higher than average log leapfrogging ratio is predicted to have 0.82 percent (p<0.05) more log CO_2 emissions from manufacturing. This is the opposite of emissions from buildings. For manufacturing, the more mobile telephones there are per fixed telephones, the higher the emissions from manufacturing.

This is further complicated in Model 4 with the addition of the ICT development variables. The effects in Model 4 at level-1 and level-2 remain stable, except the level-2 effect of log mean GDP per capita at is now significant. A country with 1 percent larger than average log GDP per capita is predicted to have 0.48 percent (p<0.001) higher log CO_2 emissions from manufacturing. The effect of fixed telephones on manufacturing is dramatically elastic. A country with 1 percent above average level of log fixed telephones per 100 people is predicted to have 2.43 percent (p<0.001) lower log CO_2 emissions from manufacturing. As noted in Figure 1.2, the use of fixed telephones in the developed world is in decline. Manufacturing across the developed world is also in decline (Bureau of Labor Statistics 2013). When compared with the global analyses that show a positive relationship, it is clear there is a strong association between fixed telecommunications and the carbon intensity of manufacturing. A decline in both helps explains the strong elastic coefficient across countries; however, a country with 1 percent above average log mobile telephones per 100 is predicted to have 0.90 percent (p<0.001) lower log CO_2 emissions from manufacturing. Mobile telephone growth is not in decline. The association between manufacturing and mobile telephones is inelastic by itself but, as noted above, countries with a higher ratio of mobile to fixed telephones are likely to have higher CO_2 emissions from manufacturing.

This appears inconsistent with the analysis but can be explained by taking into account the last ICT development variable, Internet use. A developed country with 1 percent higher than average log Internet users per 100 people is predicted to have 1.24 percent (p<0.001) higher log CO_2 emissions from manufacturing. The Internet is a driver of new economic activity and provides an avenue for developed world manufacturing to expand. Turning briefly to the variance components and model fit statistics, it is clear that about 95 percent of the variation is explained in the control model. Adding ICT development variables explains a negligible amount of the remaining variance; however, the AIC and BIC selection criteria favor the more complex Model 4.

5.8 Log CO_2 Emissions from Transportation

Transportation is the last source specific emissions outcome that will be analyzed. Transportation is also a key fulcrum on which the ICT carbon reduction strategy sits. Because ICTs offer a direct alternative to travel, it is argued that the more available ICTs are, the less demand for travel there will be and consequently the lower CO_2 emissions will be. Model 1 is the unconditional growth model. Each year log CO_2 emissions from transportation are expected to increase by 0.02 units (p<0.001). An average developed country is predicted to have 3.32 units (p<0.001) of log CO_2 emissions from transportation.

Model 2 adds in population, GDP per capita, urbanization, trade, and service economy. After controlling for these factors there is no longer a significant annual rate of change; however, a country with average log population, log GDP per capita, urbanization, log trade, and service economy is predicted to have 3.65 units (p<0.001) of log CO_2 emissions from transportation, an increase over the unconditional growth model. A 1 percent increase of log population is predicted to increase log CO_2 emissions from transportation by 0.81 percent (p<0.001). A 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from transportation by

Table 5.6A: Developed Country Log CO_2 Emissions from Transportation 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.00	-0.00	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		0.81***	0.85***	0.84***
		(0.16)	(0.16)	(0.15)
GDP per Capita (ln)		0.67***	0.70***	0.61***
		(0.08)	(0.08)	(0.08)
Urbanization		0.00	0.00	0.00
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.11***	-0.10**	-0.11**
		(0.03)	(0.03)	(0.03)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.11*
				(0.01)
Mobile Telephones per 100 (ln)				0.01
				(0.01)
Leapfrogging (ln)			0.05	
			(0.03)	
Internet Users per 100 (ln)				0.01
				(0.01)
Level-2				
Initial Status	3.32***	3.65***	3.63***	3.70***
	(0.29)	(0.07)	(0.08)	(0.11)
Mean Population (ln)		0.87***	0.86***	0.89***
		(0.06)	(0.06)	(0.06)
Mean GDP per capita (ln)		0.32	0.32	0.36
		(0.18)	(0.19)	(0.20)
Mean Urbanization		0.00	0.00	0.00
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		-0.32*	-0.33*	-0.31**
		(0.13)	(0.13)	(0.11)
Mean Service Economy		-0.01	-0.01	-0.01
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				-0.60
				(0.43)
Mean Mobile Telephones per 100 (ln)				-0.52*
				(0.23)
Mean Leapfrogging Ratio (ln)			-0.05	
			(0.28)	
Mean Internet Users per 100 (ln)				0.65**
				(0.22)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=461, n=26; ln = natural logarithm

0.67 percent (p<0.001). A 1 percent increase in log trade is predicted to reduce log CO_2 emissions by 0.11 percent (p<0.001). It must be kept in mind that country-level emissions reports do not include emissions from international air and sea transport, which are the main sources of CO_2 emissions from transportation.

Table 5.6B: Developed Country Log CO_2 Emissions from Transportation, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Level-2	In initial status	2.17 (0.60)	0.02 (0.05)	0.03 (0.07)	0.01 (0.17)
	In rate of change	-0.01 (0.01)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
Model Fit Statistics					
Degrees of Freedom		6	17	19	23
Deviance		-987	-1525	-1528	-1543
AIC		-975	-1491	-1490	-1497
BIC		-951	-1421	-1411	-1402
Pseudo R-sq (Level 2)		—	0.99	0.99	0.99
AR(1), ρ		—	0.99 (0.00)	0.99 (0.00)	0.99 (0.03)
Error Variance		—	0.09 (0.02)	0.09 (0.02)	0.07 (0.17)

N=461, n=26

Adding the leapfrogging ratio into Model 3 does not significantly alter the coefficients of the control variables at level-1 or level-2 over Model 2. The log leapfrogging ratio is not significant at either level-1 or level-2. Finally, adding the three ICT development variables into Model 4 does not impact the effects of the controls, once again. At level-1 fixed telephones is the only ICT development variable to have a significant effect on CO_2 emissions from transportation. A 1 percent increase in log fixed telephones per 100 people is predicted to increase log CO_2 emissions from transportation 0.11 percent (p<0.001). Mobile telephones and Internet do not have a significant effect at level-1. This result reverses when comparing the impact if ICTs on transportation emissions between countries. A country with 1 percent higher than average log mobile telephones per 100 people is predicted to have 0.31 percent ($p<0.01$) fewer log CO_2 emissions from transportation. Conversely, a country with 1 percent higher than average log Internet users per 100 people is predicted to have 0.65 percent ($p<0.01$) more log CO_2 emissions from transportation. Oddly, fixed telephones has no significant impact on transportation emissions between countries yet impacts emissions over time, while mobile telephones and the Internet have no impact over time yet impacts between country comparisons.

Turning briefly to the variance components and model fit statistics of the log CO_2 emissions from transportation model the addition of ICT variables adds little to the control models explanatory power. 99 percent of the variation on CO_2 emissions from transportation is explained by the control variables. As with all models of developed nations, these limitations are from the sample size.

5.9 Discussion

The developed world's emissions profile is vastly different from entire world and the developing world. Table 5.7 presents the complete results of the hypotheses tested in this chapter. For analytical completeness, all results are included but the focus of this discussion will be on the results related to the ICT development indicators. Telecommunications (fixed telephones and mobile telephones) have an overall negative relationship with CO_2 emissions when comparing across countries. In particular, fixed telephones have a consistently strong negative relationship with CO_2 emissions differences between countries, save CO_2 emissions from buildings and transportation. Not only is the relationship strong, it appears to be quite elastic in relation to emissions. As noted above the direction and strength of fixed telephones per 100 people should be taken in context as developing countries began to decline in the number of fixed lines in about the year 2000 and over that whole period had rather stable levels of fixed line communications. In other words, countries above average level of fixed telephones in the developed world were on the wrong side of the ICT development norm and therefore had lagging economies.

Table 5.7: Optimistic (Opt.) and Pessimistic (Pess.) hypotheses and the Results from the Analyses of Total and Per Capita (Per.) CO_2 Emissions, and CO_2 Emissions from Electricity (Elec.), Buildings (Bldg.), Manufacturing (Mfg.), and Transportation (Tran.) for Developed Countries

Independent Variables	*Opt.*	*Pess.*	*Total*	*Per.*	*Elec.*	*Bldg.*	*Mfg.*	*Tran.*
Level-1								
Annual Rate of Change	−	+	−	−	−	−	−	−
Population (ln)	+	+	+	N/A	+	+	+	+
GDP per Capita (ln)	−	+	+	+	+	NS	+	+
Urbanization	−	+	NS	NS	NS	NS	NS	NS
Trade (ln)	−	+	NS	NS	NS	−	+	−
Service Economy	−	−	NS	NS	NS	NS	NS	NS
Fixed Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	+
Mobile Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Leapfrogging (ln)	−	+	NS	NS	NS	NS	NS	NS
Internet Users per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Level-2								
Mean Population (ln)	+	+	+	N/A	+	+	+	+
Mean GDP per capita (ln)	−	+	+	+	NS	NS	+	NS
Mean Urbanization	−	+	+	+	+	−	+	NS
Mean Trade (ln)	−	+	NS	−	NS	NS	NS	−
Mean Service Economy	−	−	−	−	NS	NS	−	NS
Mean Fixed Telephones per100 (ln)	−	+	−	−	−	NS	−	NS
Mean Mobile Telephones per100 (ln)	−	+	−	−	NS	−	−	−
Mean Leapfrogging Ratio (ln)	−	+	NS	NS	NS	−	+	NS
Mean Internet Users per100 (ln)	−	+	+	+	+	NS	+	−

+ = significant positive coefficient; − = significant negative coefficient; NS = not significant

Another interpretation can also be offered. Those countries with higher numbers of fixed telephones became more service driven economies at the same time becoming more dependent on foreign imports. This makes sense, given the very strong coefficient (2.43) for fixed telephones on emissions from manufacturing. With either explanation it is clear that fixed telephones play a central role in the overall energy demand structure of an economy. The pessimistic view does not seem to be supported. At least within the developing world, there is evidence that increases to fixed telephone lines can reduce CO_2 emissions when comparing across developed nations. However, as noted above this may simply be evidence of emissions transfer. The optimistic perspective's argument of national environmental tipping points is tentatively supported for fixed telephones; however, the world-system model of unequal ecological exchange weakens this optimistic evidence. Placed in context with the world as a whole and the developing world specifically, these reductions may simply be transfers made possible through telecommunication.

Mobile telephones also have a consistent negative effect on CO_2 emissions across countries, save for emissions from electricity. There is no ambiguity in the trajectory of mobile telephone growth. It is has increased year after year across the developed world. This makes the interpretation more straightforward. Mobile telephones do have some role in the reduction of CO_2 emissions. There is good reason to be optimistic and reject a pessimistic appraisal of mobile telephones impact on CO_2 emissions; however, the reduction gains are predominately inelastic with CO_2 emissions, except for an elastic relationship (1.05) with CO_2 emissions from buildings. It should be noted that mobile telephones do not have a significant effect on CO_2 emissions from electricity, the largest specific source category. Even with an optimistic appraisal of CO_2 emissions from mobile telephones in the developed world, it should still be noted that mobile telephones are susceptible to the same pessimistic world-systems critique that fixed telephones are, namely the transfer of emissions to other countries.

Because of the interchangeability of fixed and mobile telephony, the impact of their ratio to one another should also be taken into consideration before any final determination about their positive or negative role in CO_2 emissions. For the most part the number of mobile phones per fixed telephone does not have a significant effect on emissions. This in and of itself tells us something about the separate rates of adoption. The effects of mobile or fixed telephones are not dependent on any assumption that there is more of one than the other. In other words, they can be treated somewhat interchangeably. This holds for total and per capita emissions; however, when the effect of the difference in adoption rates is applied to specific source categories, two interesting results are produced. On the one hand, when a country has higher than average number of mobile telephones to fixed telephones, that country is predicted to have lower CO_2 emissions from buildings. This significant, elastic effect supports the optimistic contention that mobile telephones can contribute to emissions reductions in certain scenarios -- in this case, by reducing the emissions from buildings.

On the other hand, when a country has more than an average number of mobile telephones per fixed telephones, that country is predicted to have higher CO_2 emissions from the manufacturing sector. This is counter not only to the optimistic contention but also the results from mobile telephones and fixed telephones, which are both strongly negative in relation to emissions from manufacturing. As noted above, both fixed telephones and manufacturing have been in decline across the developed world (Bureau of Labor Statistics 2013). This leaves the predicted increase in emissions largely on the shoulders of mobile telephones. Even so, this information does not fit the pattern previously established. This may be a case where the distance between mobile telephone adoption and fixed telephone cancellation is significant itself, regardless of relationship between the constituent variables.

The Internet in the developing world is the outlier of the ICT development indicator set. Internet use per 100 people has a strong positive effect on total and per capita CO_2 emissions and on every source category except for buildings. While significant Internet use is mostly inelastic in relation to CO_2 emissions, in the case of CO_2 emissions from manufacturing, Internet use is elastic with CO_2 emissions. Internet use provides evidence that supports an ecologically pessimistic perspective about new technologies. While the mobile phone was on the rise over the same time it offered relatively few new opportunities for private interests. The Internet connected the industrialized world like never before and opened markets that would have been closed if it were not for the Internet. All of the optimistic economic predictions about the Internet were somewhat confirmed, if belatedly (Castelles 2000).

In turn, the optimistic predictions of reduced carbon intensity made by some seem to have fallen short (Romm, Rosenfeld and Harmann 1999). The Internet is not a low speed setting on the treadmill of production. Rather, in the developing world it is yet another link in a chain of technologies that facilitate profit accumulation at the expense of additional energy reserves (Gould, Pellow and Scnaiberg 2008). The Internet does not appear to have altered the intensity of energy demand. If anything, it seems to have added additional demands. The optimistic ecological modernist governmental and industry reports predict some generic savings due to the spread of the Internet that does not present itself here (Romm, Rosenfeld and Harmann 1999; Webb 2008). However, it does seem that telecommunications in general and mobile telephones in particular may have some effect on slowing CO_2 emissions. This would partially support the idea that at least some ICTs do help structure society in a less carbon intensive way.

5.10 Conclusion

Optimism and pessimism seem to be left to fight it out in the developing world. The evidence from developed countries supports taking a more nuanced view of the relationship between ICT development and CO2 emissions. A nuanced view should take into consideration these findings in the following ways. First, not all ICTs behave the same way. Mobile telephone development and the spread of Internet use have differing effects on emissions. While there may be an emerging academic emphasis on convergence—the replacement of two or more existing technologies with one technology—this should not conflate the real differences between technologies and their underlying infrastructures (van Dijk 2006: 46). Second, the surrounding context must be considered to fully understand the impact of a technology. For example, the impact of fixed telephones on manufacturing seems dramatic without taking into consideration the decline of both fixed telephones and manufacturing in the developing world. Finally, while nuance may be important for evaluating the direct impact of ICT development on CO_2 emissions, population and economic growth cause the majority of CO_2 emissions. Without changes in these factors the optimistic case for secondary or broader systemic effects of ICT development on CO_2 emissions are difficult to make.

CHAPTER 6

INFORMATION AND COMMUNICATION TECHNOLOGIES AND CARBON DIOXIDE EMISSIONS IN LESS-DEVELOPED COUNTRIES

The terms *developing country* and *less-developed country* are used to indicate not only a *likely* trajectory of industrialization, technological advance and standard of living increase but also a *desired* trajectory. Most prominent economists predict that developing countries will inevitably follow the economic growth trajectory that the current developed countries have (Spence 2011), meaning that the CO_2 emissions profile of the developed world is likely to be imitated, more or less, across the developing world. ICT development is one of the strategic technologies used to encourage economic growth (Drori 2006). The potential risk of advancing economic growth in a country through CO_2 intensive technologies makes the investigation of the effect ICTs has on CO_2 emissions in the less-developed world vital.

As with the definition of the developed world, the less-developed world is defined by GDP per capita. Less-developed countries are those countries that fall below the top 25 percent of GDP per capita. This metric is used strictly as a statistical convenience and it is recognized that there are many factors that contribute to the structural position of a country. In the developed world this convenience may be more appropriate as those countries are relatively homogeneous. This is not the case for less-developed countries. Because the sample of countries is three times as large, there are vast differences in size, economic growth, and position within the global hierarchy. This classification scheme collapses the traditional world-systems positions of periphery and semi-periphery into the same group (Wallenstein 1979). In particular Brazil, Russia, India, and China (commonly called the BRIC countries) are outliers on several indicators and represent the complexity of defining the structural position of a country. However, for the purposes of these analyses it is important to have a common metric to compare countries.

In the context of the less-developed world, optimists see the potential for ICTs to change underlying economic structures and therefore potentially "leapfrog" unnecessary and dirty stages of economic development. If environmental leapfrogging is occurring, the transition from fixed line to mobile telecommunication is an ideal case for which to study this relationship. However, optimists are not dependent on this line of thinking; in fact increased CO_2 emissions are not necessarily a problem for optimists who use the logic of the Environmental Kuznet's Curve. The more a country develops, the more demands will be put on policy makers and businesses to reign in degrading practices. This assumption is underwritten by a transition from an industrial economy to a service or non-industrial economy, typically associated with the development of ICTs.

On the other hand, less-developed countries are not "catching up" with developed nations. The economic gap between the developed world and the less-developed world has widened even as both groups have increased economic development (Roberts and Grimes 2002). While developed nations have higher average CO_2 emissions, the single largest CO_2 emitter, China, still lags behind in measures of GDP per capita. The structural arrangement of nations allows developed countries to exchange ecologically undesirable activities, such as industrial production and resource extraction with still developing economies (Rice 2007). Both internal development and external exchange of ecological degradation make it very unlikely that less-developed countries will transition to a low CO_2 intensity economic structure. In fact, the development of ICTs may accelerate the industrial trajectory of some less-developed countries, providing the same opportunity structure for unequal ecological exchange afforded to developed countries. In addition, these opportunities provide a structure through which developed nations can better control their interests remotely.

The examination of CO_2 emissions in the less-developed world should provide additional evidence as to whether optimistic or pessimistic perspectives better approximate the environmental consequences of ICT development from 1990 to 2009. As is already clear from the developed country analyses in Chapter 5, the relationship between ICT development and CO_2 emissions may be a complex and nuanced one. However, the global model in Chapter 4 provided a more straightforward analysis and less-developed countries are more like the rest of the world than developed countries.

6.1 The Multilevel Model for Growth

The analyses of the relationship between ICT development and CO_2 emissions in developing countries follows those used previously. The first two analyses investigate the relationship between ICT development using log total CO_2 emissions and log per capita CO_2 emissions. These aggregate outcome variables provide a broad view of the relationship between ICT development and CO_2 emissions and inform the broad optimistic and pessimistic research hypotheses. They also inform the Environmental Leapfrog Hypothesis by illustrating the relationship of economic development status on these phenomena.

The final four analyses disaggregate log total CO_2 emissions into the four source category outcome variables: log CO_2 emissions from electricity, log CO_2 emissions from buildings, log CO_2 emissions from manufacturing and log CO_2 emissions from transportation. Disaggregating CO_2 emissions in this fashion informs the more specific optimistic predictions relating to the potentially diverse impact of ICT development on CO_2 emissions in different economic sectors.

All six analyses provide information on the role that world-system position plays in CO_2 emissions. At the bottom of the global hierarchy, poor countries cannot afford to expend excess energy. While some countries (Brazil, Russia, India and China, in particular) have high emissions profiles, they still have high levels of economic disparity and low standards of living for a large number of their populations. Developing countries are also workhouses for developed nations, providing a majority of global manufacturing and resource extracting industry operations. This exchange does not necessarily benefit the economic development of the host country, though it can. Developing countries have increasing rates of all three ICT development indicators. While the developing world is where mobile telephone leapfrogging is expected to have the strongest impact, it must also be noted that fixed telephones are still on the rise in developing countries. Developing countries also have growing but limited access to Internet services.

As previously noted in Chapter 3, four models will be presented for each dependent variable. Model 1 is the unconditional growth model; it reports the annual rate of change and initial status of emissions for a developed country without any controls. Model 2 is the control model and includes log population, log GDP per capita, urbanization, log trade, and service economy at level-1 and mean log population, mean log GDP per capita, mean urbanization, mean log trade, and mean service economy at level-2. Keep in mind that all level-1 variables are group-mean centered, eliminating any cross-level interaction and allowing both levels to be presented at the same time. Model 3 is the leapfrogging model, which includes all of the control variables from Model 2 as well as log leapfrogging at level-1, and mean log leapfrogging at level-2. Model 4 is the full model incorporating three measures of ICT development at each level. At level-1 the log of fixed telephones per 100, mobile telephones per 100 and Internet users per 100 are included. At level-2 the log of mean fixed telephones per 100, mean mobile telephones per 100 and mean Internet users per 100 are included. Since leapfrogging is a ratio of mobile telephones per 100 to fixed telephones per 100 it is not included in Model 4.

6.2 Log Total CO_2 Emissions.

The results for the less-developed country log total CO_2 emissions multilevel model for growth can be found in Table 6.1A and 6.1B. The models for log total CO_2 emissions for less-developed countries are similar to the global models of log total CO_2 emissions with a few notable differences. Model 1, the unconditional growth model, predicts that log CO_2 emissions

Table 6.1A: Less-Developed Country Log Total CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.03***	-0.02***	-0.02***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.01)
Population (ln)		1.88***	1.83***	1.85***
		(0.23)	(0.23)	(0.23)
GDP per Capita (ln)		0.77***	0.77***	0.76***
		(0.06)	(0.06)	(0.06)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.00	-0.00	-0.01
		(0.03)	(0.03)	(0.03)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.04
				(0.02)
Mobile Telephones per 100 (ln)				0.00
				(0.01)
Leapfrogging (ln)			-0.01	
			(0.01)	
Internet Users per 100 (ln)				-0.02
				(0.02)
Level-2				
Initial Status	9.68***	10.36***	10.35***	10.33***
	(0.20)	(0.10)	(0.09)	(0.09)
Mean Population (ln)		1.20***	1.20***	1.14***
		(0.07)	(0.06)	(0.05)
Mean GDP per capita (ln)		0.92***	0.82***	0.49***
		(0.12)	(0.09)	(0.10)
Mean Urbanization		0.01	0.01	0.00
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		0.95***	1.07***	0.53**
		(0.23)	(0.19)	(0.18)
Mean Service Economy		-0.01	-0.01*	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				0.64***
				(0.07)
Mean Mobile Telephones per 100 (ln)				-0.19
				(0.14)
Mean Leapfrogging Ratio (ln)			-0.82***	
			(0.13)	
Mean Internet Users per 100 (ln)				0.13
				(0.19)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=1465, n=95; ln = natural logarithm

for less-developed countries will increase by 0.03 ($p<0.001$) units every year. The unadjusted log average total CO_2 emissions for developing countries are 9.69 ($p<0.001$).

In the control model, Model 2, the effect of time is now reversed. A 0.02 ($p<0.001$) unit decrease each year in log total CO_2 emissions is now predicted. As with the global and developed country analyses, log population and log GDP per capita explain the positive effect over time; however, unlike the global models, log population and log GDP per capita are the only significant factors over time. Urbanization does not seem to have a significant effect over time for less-developed countries. Within countries, a 1 percent increase in log population is predicted to increase log total CO_2 emissions by 1.88 percent ($p<0.001$) and a 1 percent increase in log GDP per capita is expected to increase log total CO_2 emissions by 0.77 percent ($p<0.001$). Both the leapfrogging model and the ICT model do not produce significant results over time and have only minor variations in the effect of log population and log GDP per capita.

There is a different picture at level-2. In the control model, a country with average levels of population, GDP per capita, urbanization, trade, and service economy is predicted to have log total CO_2 emissions of 10.36 ($p<0.001$). Between countries, a country with 1 percent above average level of log population is predicted to have 1.2 percent ($p<0.001$) higher log total CO_2 emissions. A country with 1 percent above average log GDP per capita is predicted to have 0.92 percent ($p<0.001$) higher log total CO_2 emissions. Unlike level-1, trade has a significant effect on differences in total CO_2 emissions between countries. A less-developed country with 1 percent above average level of log trade is predicted to have 0.95 percent ($p<0.001$) higher log total CO_2 emissions.

Adding the effect of telecommunications leapfrogging adds some additional effects in the controls. The effect of mean log population remains constant (1.20, $p<0.001$) while the effect of mean log GDP is decreased (0.82%, $p<0.001$). The effect of trade is intensified. Less-developed countries with 1 percent above average level of log trade are predicted to have 1.07 percent ($p<0.001$) higher log total CO_2 emissions. Additionally, the effect of the service economy is now significant. A country with 1 percent above average service economy is predicted to have log total CO_2 emissions that are 0.01 ($p<0.05$) units lower. The effect of leapfrogging on CO_2 emissions is significant. Countries with 1 percent above average leapfrogging ratio are predicted to have log total CO_2 emissions that are 0.85 percent ($p<0.001$) lower. Countries with low fixed telephone development and higher mobile telephone development have higher leapfrogging ratios and lower CO_2 emissions.

Table 6.1B: Less-developed Country Log Total CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	3.33	0.66	0.53	0.34
		(0.81)	(0.11)	(0.09)	(0.06)
	In rate of change	-0.02	-0.01	-0.01	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-1564	-1923	-1958	-1998
AIC		-1550	-1889	-1920	-1952
BIC		-1513	-1799	-1819	-1830
Pseudo R-sq (Level 2)		—	0.80	0.84	0.90
AR(1), ρ		0.98	0.87	0.87	0.86
		(0.05)	(0.04)	(0.04)	(0.04)
Error Variance		0.28	0.05	0.04	0.04
		(0.65)	(0.01)	(0.01)	(0.01)

N=1465, n=95

This relationship can be seen in the ICT model. A country with 1 percent higher than average log fixed telephones per 100 people is predicted to have 0.64 percent ($p<0.001$) higher log total CO_2 emissions. Mean log mobile telephones per 100 people and mean log Internet users per 100 people did not have a significant effect on log total CO_2 emissions. This indicates that the effect of the leapfrogging ratio is due to a lack of a developed fixed telephone infrastructure, rather than an increase in the development of mobile telephone infrastructure.

The introduction of the ICT development indicators also affects the strength of log GDP per capita and log trade on log total CO_2 emissions. Between countries, a country with 1 percent above average GDP per capita is predicted to have 0.49 percent ($p<0.001$) higher log total CO_2 emissions and a country with 1 percent above average level of log trade is predicted to have 0.53 percent ($p<0.01$) higher CO_2 emissions. Both effects are about half what they are in the control and leapfrogging models. The effect of service economy is slightly more intense in the ICT model (-0.03, $p<0.001$).

Turning to the variance components and model fit statistics in Table 6.1B, there is a steady decrease in unexplained variance between Models 1 and 4. Adding the effect of leapfrogging in Model 3 explains about 84 percent of the variation over the control models 80 percent and the ICT model 90 percent. The reductions in the effects of log GDP per capita and log trade and the increase in the effect of service economy are attributed to the increase in explained variance. At least some of the effects of log GDP and log trade are due to the development of fixed telephone lines in less-developed countries.

6.3 Log Per Capita CO_2 Emissions

The results for the less-developed country log per capita CO_2 emissions multilevel model for growth can be found inTtable 6.1A and 6.1B. Model 1 is the unconditional growth model for per capita CO_2 emissions. A less-developed country is predicted to increase its per capita CO_2 emissions every year by 0.02 units ($p<0.001$). The unadjusted log average per capita CO_2 emissions for less-developed countries are 0.32 ($p<0.05$) units.

Adding the control variables in Model 2 produces two significant effects at level-1. A 1 percent increase in log GDP per capita is predicted to increase log per capita CO_2 emissions by 0.74 percent ($p<0.001$). A 1 percent increase in urbanization is predicted to increase log per capita CO_2 emissions by 0.02 units ($p<0.001$). Urbanization seems to have an effect on per capita emissions over time but not on differences between countries. At level-2, the differences between countries are explained differently. First, the initial status for a country with average levels of log

Table 6.2A: Less-developed Country Log Per Capita CO_2 Emissions 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.01**	-0.01*	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)
GDP per Capita (ln)		0.74***	0.73***	0.72***
		(0.05)	(0.06)	(0.06)
Urbanization		0.02***	0.02***	0.02***
		(0.01)	(0.01)	(0.01)
Trade (ln)		-0.00	-0.00	-0.00
		(0.03)	(0.03)	(0.03)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.04
				(0.06)
Mobile Telephones per 100 (ln)				0.00
				(0.01)
Leapfrogging (ln)			-0.01	
			(0.01)	
Internet Users per 100 (ln)				-0.03
				(0.01)
Level-2				
Initial Status	0.32*	0.62***	0.62***	0.58***
	(0.15)	(0.10)	(0.08)	(0.08)
Mean GDP per capita (ln)		0.94***	0.83***	0.48***
		(0.12)	(0.10)	(0.10)
Mean Urbanization		0.00	0.00	0.00
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		0.50**	0.65***	0.25
		(0.19)	(0.16)	(0.15)
Mean Service Economy		-0.01	-0.02**	-0.03***
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				0.65***
				(0.08)
Mean Mobile Telephones per 100 (ln)				-0.19
				(0.15)
Mean Leapfrogging Ratio (ln)			-0.81***	
			(0.13)	
Mean Internet Users per 100 (ln)				0.13
				(0.20)

*** $p<0.001$, **$p<0.01$, *$p<0.05$; N=1465, n=95; ln = natural logarithm

GDP per capita, urbanization, log trade, and service economy is 0.62 ($p<0.001$) units of log per capita CO_2 emissions. Mean log GDP per capita is the strongest predictor of emissions in Model 2. A less-developed country with 1 percent higher than average log GDP per capita is predicted to have 0.94 percent ($p<0.001$) higher log per capita CO_2 emissions. At level-2 there is also a significant effect of log trade. A less-developed country with 1 percent above average level of log trade is predicted to have 0.5 percent ($p<0.01$) higher per capita CO_2 emissions. Mean urbanization and service economy are not significant in Model 2.

Adding log leapfrogging ratio and the logged ICT development indicators does not change the predictions in any significant way at level-1. The annual rate of change does fail to reach significance in Model 3 indicating that any changes in log per capita CO_2 emissions over time are due to the control variables. At level-2, the addition of the leapfrogging ratio does not change the predicted initial status. The effect of log GDP per capita is reduced. A less-developed country with a log GDP per capita 1 percent above average is now predicted to have 0.83 percent ($p<0.001$) higher log per capita CO_2 emissions. The effect of log trade is slightly higher. A less-developed country with 1 percent higher than average level of log trade is predicted to have 0.65 percent ($p<0.001$) higher log per capita CO_2 emissions. Service economy now has a significant effect. A less-developed country with a service economy that is 1 percent higher than average is predicted to have 0.02 ($p<0.01$) fewer units of log per capita CO_2 emissions. The addition of mean leapfrogging ratio is significant as well. A less-developed country with a ratio of mobile telephones to fixed telephones that is 1 percent higher than average is predicted to have 0.85 percent ($p<0.001$) fewer log per capita CO_2 emissions. Countries that demonstrate the greatest evidence for leapfrogging have fewer per capita CO_2 emissions.

The addition of the three ICT development indicators in Model-4 produces some interesting changes to the outcomes. First the initial status of a country with average levels of controls and average levels of the ICT development indicators is predicted to be slightly lower at 0.58 ($p<0.001$) units of per capita CO_2 emissions. Similarly, the effect of log GDP per capita is further reduced from Model 3. A less-developed country with 1 percent above average level of log GDP per capita is predicted to have 0.48 percent ($p<0.001$) higher log per capita CO_2 emissions. Log trade no longer has a significant effect and the effect of service economy is increased. A less-developed country with a service economy that is 1 percent larger than average is now predicted to have 0.03 ($p<0.001$) fewer units of log per capita CO_2 emissions. Of the three ICT development indicators only log fixed telephones per 100 people has a significant effect. A less-developed country with 1 percent higher than average log fixed telephones per 100 people is predicted to have 0.65 percent ($p<0.001$) higher log per capita CO_2 emissions. Log Internet users per 100 people and log mobile telephones per 100 people have no significant effect.

Table 6.2B: Less-developed Country Log Per Capita CO_2 Emissions 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	1.86	0.80	0.64	0.39
		(0.64)	(0.13)	(0.11)	(0.07)
	In rate of change	-0.01	-0.01	-0.01	-0.01
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	15	17	21
Deviance		-1646	-1905	-1937	-1979
AIC		-1632	-1875	-1903	-1937
BIC		-1895	-1796	-1813	-1826
Pseudo R-sq (Level 2)		—	0.57	0.66	0.79
AR(1), ρ		0.98	0.88	0.87	0.87
		(0.05)	(0.04)	(0.04)	(0.04)
Error Variance		0.26	0.05	0.04	0.04
		(0.59)	(0.02)	(0.01)	(0.01)

N=1465, n=95

With this additional information, it is possible to add further initial understanding to the effect of the leapfrogging ratio. Fixed telephony has an impact and mobile telephony does not, indicating that the ratio's negative relationship with per capita CO_2 emissions is due to the underdevelopment of fixed lines rather than the development of mobile telephones. This, in addition to the results from the total CO_2 emissions models, suggests that mobile telephones are not a driver of carbon dioxide emissions. This further reinforces the evidence from Chapters 4 and 5.

In table 6.2B the variance components and model fit statistics are presented. The control model explains only 57 percent of the variation in log per capita CO_2 emissions. The addition of leapfrogging explains 66 percent, an additional 11 percent. Model 4 is the best explanatory model explaining 79 percent of the variance, 23 percent more than the control model. The AIC and BIC model selection criteria also favor Model 4.

6.4 Log CO_2 Emissions from Electricity

Moving on from the aggregate models, the results of the four source category outcome analyses will now be examined. First is the analysis of CO_2 emissions from electricity. The models for log total CO_2 emissions for less-developed countries are similar to the disaggregated source emissions results, with a few notable differences. The results for the less-developed country log CO_2 emissions from electricity multilevel model for growth can be found in table 6.3A and 6.3B. Model 1, the unconditional growth model, predicts that log CO_2 emissions from electricity for less-developed countries will increase by 0.02 ($p<0.001$) units every year. The unadjusted log average of CO_2 emissions from electricity is 1.98 ($p<0.001$) units.

Model 2 is the control model. The annual rate of change reverses direction with the inclusion of the control variables, as a less-developed country is now predicted to decrease log CO_2 emissions from electricity by 0.01 ($p<0.05$) units each year. Log population and log GDP per capita have the only significant effects on log CO_2 emissions from electricity. A 1 percent increase in log population is predicted to increase log CO_2 emissions from electricity by 1.42 percent ($p<0.001$) in less-developed countries. A 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from electricity by 0.44 percent ($p<0.001$) in less-developed countries.

Table 6.3A: Less-developed Country Log CO_2 Emissions from Electricity 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.02***	-0.01*	-0.01	-0.02**
	(0.00)	(0.00)	(0.00)	(0.01)
Population (ln)		1.42***	1. 40***	1.43***
		(0.26)	(0.26)	(0.26)
GDP per Capita (ln)		0.44***	0.45***	0.42***
		(0.05)	(0.06)	(0.06)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.04	0.04	0.04
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.06**
				(0.09)
Mobile Telephones per 100 (ln)				-0.00
				(0.01)
Leapfrogging (ln)			-0.02	
			(0.01)	
Internet Users per 100 (ln)				0.01
				(0.01)
Level-2				
Initial Status	1.98***	2.49***	2.47***	2.53***
	(0.17)	(0.11)	(0.10)	(0.10)
Mean Population (ln)		1.11***	1.11***	1.03***
		(0.08)	(0.07)	(0.07)
Mean GDP per capita (ln)		0.81***	0.69***	0.37**
		(0.14)	(0.12)	(0.13)
Mean Urbanization		0.01	0.01	0.00
		(0.01)	(0.01)	(0.01)
Mean Trade (ln)		1.13***	1.29***	0.76***
		(0.27)	(0.23)	(0.23)
Mean Service Economy		-0.00	-0.01	-0.02*
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				0.67***
				(0.10)
Mean Mobile Telephones per 100 (ln)				-0.30
				(0.19)
Mean Leapfrogging Ratio (ln)			-0.89***	
			(0.15)	
Mean Internet Users per 100 (ln)				0.11
				(0.25)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=1465, n=95; ln = natural logarithm

The initial status for a less-developed country with average log population, log GDP per capita, urbanization, log trade and service economy is 2.49 ($p<0.001$) units of log CO_2 emissions from electricity. This is substantially higher than the unadjusted log average. At level-2 log mean population and log mean GDP per capita have significant effects in addition to a significant effect for log mean trade. A less-developed country with a log population that is 1 percent above average is predicted to have 1.11 percent ($p<0.001$) higher log CO_2 emissions from electricity. A less-developed country with log GDP per capita that is 1 percent higher than average is predicted to have 0.81 percent ($p<0.001$) higher log CO_2 emissions from electricity. A less-developed country with 1 percent more trade than average is predicted to have 1.13 ($p<0.001$) higher log CO_2 emissions from electricity.

Adding the leapfrogging ratio in Model 3 changes some of the effects. The effect of Log GDP per capita is reduced to 0.69 percent ($p<0.001$) while the effect of log trade is increased to 1.29 percent ($p<0.001$). The effect of log population is stable from Model 2. The effect of the leapfrogging ratio is statistically significant. A less-developed country with a log ratio of mobile telephones to fixed telephones that is 1 percent higher than average is predicted to have 0.89 percent ($p<0.001$) lower log CO_2 emissions from electricity. This is expected given the strong association of electricity development to the development of fixed telephone lines.

Adding the three ICT development indicators to the model further changes the effects of the control variables. There are minor changes in the effect of controls at level-1 but more importantly the effect of log fixed telephones per 100 people is now significant. A 1 percent increase log fixed telephones per 100 people is predicted to increase log CO_2 emissions from electricity by 0.06 percent ($p<0.01$). Log mobile phones per 100 people and log Internet users per 100 people do not have a significant effect at level-1.

At level-2 mean log population now has a slightly lower impact, 1.03 percent ($p<0.001$). The effect of log GDP per capita is further reduced in Model 4 to only 0.37 percent ($p<0.01$). Log trade changes too and is no longer elastic with log CO_2 emissions from electricity only generating a 0.76 percent ($p<0.001$) increase in log CO_2 emissions from electricity for a country with 1 percent higher than average log trade.

Table 6.3B: Less-developed Country Log CO_2 Emissions from Electricity 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.81	0.92	0.72	0.55
		(0.41)	(0.15)	(0.12)	(0.09)
	In rate of change	-0.00	-0.01	-0.01	-0.01
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-1750	-1965	-1997	-2022
AIC		-1736	-1931	-1959	-1976
BIC		-1699	-1841	-1859	-1854
Pseudo R-sq (Level 2)		—	0.67	0.74	0.80
AR(1), ρ		0.81	0.77	0.77	0.76
		(0.04)	(0.04)	(0.04)	(0.04)
Error Variance		0.03	0.02	0.02	0.02
		(0.01)	(0.00)	(0.00)	(0.00)

N=1465, n=95

Log Internet use per 100 people and log mobile telephones per 100 people are not predicted to have a significant effect on emissions from electricity differences between countries. Log fixed telephones per 100 people does have a significant effect. A less-developed country with 1 percent above average log fixed telephones per 100 people is predicted to have 0.67 percent ($p<0.001$) higher log CO_2 emissions from electricity. The strong relationship between fixed telephones and the development of electricity is illustrated here. There is a significant effect within countries over time and between countries. The implications for the pessimistic perspective are laid bare: more fixed lines, more power lines, and more CO_2 emissions.

Table 6.4A: Less-developed Country Log CO_2 Emissions from Buildings 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01***	-0.01	-0.01	-0.01
	(0.00)	(0.00)	(0.01)	(0.01)
Population (ln)		0.81***	0.74***	0.78***
		(0.23)	(0.23)	(0.23)
GDP per Capita (ln)		0.24***	0.25***	-0.24***
		(0.06)	(0.06)	(0.06)
Urbanization		0.00	0.00	0.00
		(0.01)	(0.01)	(0.00)
Trade (ln)		0.04	0.04	0.04
		(0.03)	(0.03)	(0.03)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.02
				(0.02)
Mobile Telephones per 100 (ln)				-0.02
				(0.01)
Leapfrogging (ln)			-0.01	
			(0.01)	
Internet Users per 100 (ln)				0.03
				(0.02)
Level-2				
Initial Status	1.18***	1.47***	1.45***	1.48***
	(0.13)	(0.09)	(0.08)	(0.13)
Mean Population (ln)		0.81***	0.82***	0.79***
		(0.07)	(0.10)	(0.05)
Mean GDP per capita (ln)		0.32**	0.23**	0.07
		(0.11)	(0.10)	(0.10)
Mean Urbanization		0.01*	0.01**	0.01
		(0.01)	(0.00)	(0.00)
Mean Trade (ln)		0.49*	0.61***	0.31
		(0.21)	(0.22)	(0.19)
Mean Service Economy		0.00	-0.01	-0.01
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				0.52***
				(0.08)
Mean Mobile Telephones per 100 (ln)				-0.20
				(0.15)
Mean Leapfrogging Ratio (ln)			-0.65***	
			(0.12)	
Mean Internet Users per 100 (ln)				-0.15
				(0.20)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=1465, n=95; ln = natural logarithm

6.5 Log CO_2 Emissions from Buildings

The results for the less-developed country log CO_2 emissions from buildings multilevel model for growth can be found in table 6.4A and 6.4B. Model 1, the unconditional growth model, predicts that log CO_2 emissions from buildings for less-developed countries will increase by 0.01 ($p<0.001$) units every year. The unadjusted log average of CO_2 emissions from buildings is 1.18 ($p<0.001$) units.

Model 2 introduces the control variables at level-1 and level-2. The introduction of control variables at level-1 changes the direction of the annual rate of change. A less-developed country is now predicted to decrease its log CO_2 emissions from buildings by 0.01 ($p<0.001$) units every year. The initial status for a less-developed country is now 1.47 ($p<0.001$) units of log CO_2 emissions from buildings for a country with average levels of log population, log GDP per capita, urbanization, log trade, and service economy. At level-1 log population and GDP per capita have the only significant effects across Models 2,3, and 4. The effects do not differ substantially from those in Model 2. A 1 percent increase in the log population of a less-developed country is predicted to increase log CO_2 emissions from buildings by 0.81 percent ($p<0.001$). A 1 percent increase in log GDP per capita in a less-developed country is predicted to increase log CO_2 emissions from buildings by 0.24 percent ($p<0.001$).

At level-2 every variable except for service economy impacts CO_2 emissions from buildings in less-developed countries. A less-developed country with 1 percent higher than average log population is predicted to have 0.81 percent ($p<0.001$) more log CO_2 emissions from buildings. A less-developed country with 1 percent larger log GDP per capita is predicted to have 0.32 percent ($p<0.01$) more log CO_2 emissions from buildings. A less-developed country with 1 percent more urbanization is predicted to have 0.01 ($p<0.05$) more units of log emissions. A less-developed country with 1 percent more log trade is predicted to have 0.49 percent ($p<0.05$) more CO_2 emissions from buildings. In Model 3 these four controls still have significant effects. The effect of log GDP decreases to 0.23 percent ($p<0.01$) while the effect of log trade increases to 0.61 percent ($p<0.001$) for a country with 1 percent above average of either.

Adding the effect of the log leapfrogging ratio seems to affect the strength of these coefficients. A less-developed country with 1 percent higher ratio of mobile telephones to fixed telephones is predicted to have 0.65 percent ($p<0.001$) lower log CO_2 emissions from buildings. This effect is not as large as the effect for emissions for CO_2 emissions from electricity, but is still large. This makes sense, as buildings are a large source of the demand for fixed telephone lines.

Table 6.4B: Less-developed Country Log CO_2 Emissions from Buildings 1990-2009, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
<u>Variance Components</u>					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	1.59	0.51	0.43	0.39
		(0.24)	(0.08)	(0.07)	(0.06)
	In rate of change	-0.00	-0.00	-0.00	-0.01
		(0.00)	(0.00)	(0.00)	(0.00)
<u>Model Fit Statistics</u>					
Degrees of Freedom		7	17	19	23
Deviance		-1664	-1805	-1830	-1850
AIC		-1650	-1771	-1792	-1804
BIC		-1612	-1681	-1692	-1683
Pseudo R-sq (Level 2)		—	0.68	0.73	0.75
AR(1), ρ		0.78	0.75	0.75	0.75
		(0.04)	(0.04)	(0.04)	(0.04)
Error Variance		0.03	0.03	0.03	0.03
		(0.01)	(0.00)	(0.05)	(0.00)

N=1465, n=95

Finally, in Model 4 there is a dramatic shift in the effects of the control variables at level-2. Mean log GDP, mean urbanization, and mean log trade are no longer significant predictors of log CO_2 emissions from buildings. The addition of the three ICT development indicators dampened their effect on the outcome, in particular the effect of log fixed telephone lines per 100 people. A less-developed country with 1 percent more fixed telephone lines per 100 people is predicted to have 0.52 percent ($p<0.001$) higher CO_2 emissions from buildings. The ICT development indicators do not affect the effect of log population. Turning to table 6.4B, the variance components and the model fit statistics, there are some interesting results. First, Model 2 explains about 68 percent of the variation at level-2 while the introduction of the leapfrogging ratio in Model 3 explains 73 percent (5 percent more) and the introduction of the ICT development indicators explains 75 percent (8 percent more). The AIC selection criteria generally favor the more complex model and here it selects for Model 4. The BIC is not as biased toward more independent variables and here it favors Model 3. This indicates the results for the leapfrogging ratio are important predictors for CO_2 emissions from buildings. Fixed line development is a significant driver of CO_2 emissions from buildings and may account for some of the effects of other common building CO_2 emissions drivers such as GDP, trade, and urbanization. This is further reinforced by the negative effect of the leapfrogging ratio. Less-developed countries with more mobile telephones to fixed telephones have lower emissions but when the average number of fixed telephones increases so do emissions from buildings.

6.6 Log CO_2 *Emissions from Manufacturing*

The results for the less-developed country log CO_2 emissions from manufacturing multilevel model for growth can be found in table 6.5A and 6.5B. Model 1, the unconditional growth model, predicts that log CO_2 emissions from manufacturing for less-developed countries will increase by 0.01 ($p<0.001$) units every year. The unadjusted log average of CO_2 emissions from manufacturing is 1.67 ($p<0.001$) units.

Model 2 introduces the control variables. At level-1 log population and log GDP per capita are the only controls that have significance. This trend continues across Models 3 and 4 at level-1 with only slight variation in the predicted effects. A 1 percent increase in log population is predicted to increase log CO_2 emissions from manufacturing by 1.42 percent ($p<0.001$). A 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from

Table 6.5A: Less-developed Country Log CO_2 Emissions from Manufacturing 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.01**	-0.03***	-0.03***	-0.04***
	(0.01)	(0.00)	(0.01)	(0.01)
Population (ln)		1.42***	1.37***	1.44***
		(0.24)	(0.24)	(0.24)
GDP per Capita (ln)		0.60***	0.60***	0.55***
		(0.05)	(0.06)	(0.06)
Urbanization		0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.02	0.02	0.01
		(0.02)	(0.02)	(0.02)
Service Economy		-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.06**
				(0.09)
Mobile Telephones per 100 (ln)				0.02
				(0.01)
Leapfrogging (ln)			-0.00	
			(0.01)	
Internet Users per 100 (ln)				0.01
				(0.01)
Level-2				
Initial Status	1.67***	2.21***	2.21***	2.29***
	(0.15)	(0.08)	(0.08)	(0.08)
Mean Population (ln)		1.00***	1.00***	0.95***
		(0.06)	(0.05)	(0.05)
Mean GDP per capita (ln)		0.71***	0.62***	0.40***
		(0.10)	(0.09)	(0.10)
Mean Urbanization		0.00	0.00	-0.00
		(0.01)	(0.01)	(0.00)
Mean Trade (ln)		0.62**	0.73***	0.34*
		(0.20)	(0.17)	(0.17)
Mean Service Economy		-0.00	-0.01	-0.02**
		(0.01)	(0.01)	(0.01)
Mean Fixed Telephones per 100 (ln)				0.45***
				(0.07)
Mean Mobile Telephones per 100 (ln)				-0.26
				(0.14)
Mean Leapfrogging Ratio (ln)			-0.62***	
			(0.12)	
Mean Internet Users per 100 (ln)				0.24
				(0.19)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=1465, n=95; ln = natural logarithm

manufacturing by 0.60 percent ($p<0.001$). Urbanization, log trade, and service economy do not have a significant effect at level-1 in Models 2, 3, and 4.

At level-2 the initial status for a less-developed country with average levels log population, log GDP per capita, urbanization, log trade, and log service economy is 2.01 ($p<0.001$) units of log CO_2 emissions from manufacturing. As with the log total CO_2 emissions model mean log population, mean log GDP per capita, and mean log trade are significant at level-2 across Models 2, 3, and 4. In Model 2 a less-developed country with 1 percent higher than average log population is predicted to have 1 percent ($p<0.001$) higher log CO_2 emissions from manufacturing, a less-developed country with 1 percent more than average log GDP per capita is predicted to have 0.71 percent ($p<0.001$) more log CO_2 emissions from electricity and a less-developed country with 1 percent more log trade is predicted to have 0.62 percent ($p<0.01$) more log CO_2 emissions from manufacturing.

In Model 3 the effects of mean log GDP per capita are slightly lower while the effects of mean log trade are slightly higher. The effect of the leapfrogging ratio is significant and negative as with the other models. A less-developed country with a log ratio of mobile telephones per 100 people to fixed telephones per 100 people that is 1 percent higher than average is predicted to have 0.62 percent ($p<0.001$) fewer log CO_2 emissions from manufacturing.

In Model 4 the addition of the ICT development indicators has an effect at both level-1 and level-2. At level-1 the control variables remain relatively constant in Model 4 from Models 2 and 3. In Model 4 the effect of log fixed telephones per 100 people is significant. A 1 percent increase in log fixed telephone lines per 100 people is predicted to increase log CO_2 emissions from manufacturing by 0.06 percent ($p<0.01$). At level-2 the control variables are notably affected by the introduction of the ICT development indicators. The effect of mean log population is reduced slightly to 0.95 ($p<0.001$), while the effect of mean log GDP is reduced to 0.40 ($p<0.001$) and the effect of mean log trade is reduced to 0.34 percent ($p<0.001$). In addition to the dampening of these effects the effect of service economy is now significant. A less-developed country with a service economy 1 percent larger than average is predicted to have 0.02 ($p<0.01$) fewer units of log CO_2 emissions from manufacturing. This is not unexpected as there is a theoretically assumed positive relationship between service economies and ICT development in addition to a negative relationship with manufacturing (Jorgenson 2003).

Table 6.5B: Less-developed Country Log CO_2 Emissions from Manufacturing, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	2.18	0.48	0.39	0.31
		(0.32)	(0.08)	(0.06)	(0.05)
	In rate of change	-0.01	-0.01	-0.01	-0.00
		(0.01)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		7	17	19	23
Deviance		-1701	-2000	-2025	-2057
AIC		-1687	-1966	-1987	-2011
BIC		-1650	-1876	-1886	-1889
Pseudo R-sq (Level 2)		—	0.78	0.82	0.86
AR(1), ρ		0.77	0.74	0.74	0.74
		(0.03)	(0.04)	(0.04)	(0.03)
Error Variance		0.03	0.02	0.02	0.02
		(0.00)	(0.00)	(0.00)	(0.00)

N=1465, n=95

As above, the only ICT development variable that has a significant effect is log fixed telephones per 100 people. A less-developed country with 1 percent more log fixed telephones per 100 people than average is predicted to have 0.45 percent ($p<0.001$) more log CO_2 emissions from manufacturing. This effect is not as strong as the effect of fixed telephones on emissions from electricity and buildings; however, it is significant at level-1 unlike Model 4 for CO_2 emissions from buildings.

Table 6.6A: Less-developed Country Log CO_2 Emissions from Transportation 1990-2009, Coefficients and (Standard Errors) for the Multilevel Model for Growth with AR(1) Error Correction

Fixed Coefficients	*1*	*2*	*3*	*4*
Level-1				
Annual Rate of Change	0.03***	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Population (ln)		0.55***	0.52**	0.58***
		(0.16)	(0.17)	(0.16)
GDP per Capita (ln)		0.51***	0.51***	0.50***
		(0.04)	(0.04)	(0.04)
Urbanization		0.02***	0.02***	0.02***
		(0.01)	(0.01)	(0.01)
Trade (ln)		0.00	0.00	0.00
		(0.02)	(0.02)	(0.02)
Service Economy		0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)
Fixed Telephones per 100 (ln)				0.03*
				(0.01)
Mobile Telephones per 100 (ln)				0.00
				(0.01)
Leapfrogging (ln)			0.00	
			(0.01)	
Internet Users per 100 (ln)				0.01
				(0.01)
Level-2				
Initial Status	1.62***	2.01***	2.01***	2.05***
	(0.13)	(0.06)	(0.05)	(0.11)
Mean Population (ln)		0.87***	0.86***	0.84***
		(0.04)	(0.03)	(0.03)
Mean GDP per capita (ln)		0.57***	0.52***	0.37***
		(0.06)	(0.06)	(0.06)
Mean Urbanization		0.01**	0.01**	0.00
		(0.00)	(0.01)	(0.00)
Mean Trade (ln)		0.39***	0.45***	0.18
		(0.12)	(0.11)	(0.11)
Mean Service Economy		-0.00	-0.01	-0.01*
		(0.00)	(0.00)	(0.00)
Mean Fixed Telephones per 100 (ln)				0.30***
				(0.05)
Mean Mobile Telephones per 100 (ln)				0.11
				(0.09)
Mean Leapfrogging Ratio (ln)			-0.32***	
			(0.07)	
Mean Internet Users per 100 (ln)				-0.16
				(0.12)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$; N=1465, n=95; ln = natural logarithm

6.7 Log CO_2 *Emissions from Transportation*

The results for the less-developed country log CO_2 emissions from transportation multilevel model for growth can be found in table 6.6A and 6.6B. Model 1, the unconditional growth model, predicts that log CO_2 emissions from transportation for less-developed countries will increase by 0.03 ($p<0.001$) units every year. The unadjusted log average of CO_2 emissions from transportation is 1.62 ($p<0.001$) units.

Model 2 introduces the control variables. At level-1 log population, log GDP per capita and urbanization are significant. A 1 percent increase in log population is predicted to increase log CO_2 emissions form transportation by 0.55 percent ($p<0.001$). A 1 percent increase in log GDP per capita is predicted to increase log CO_2 emissions from transportation by 0.51 percent ($p<0.001$). A 1 percent increase in urbanization is predicted to increase log CO_2 emissions from transportation by 0.02 ($p<0.001$) units. The significance of urbanization at level-1 sets emissions from transportation apart from the aggregate measures and the other source categories. This is notable because urbanization is not even significant at level-1 for CO_2 emissions from buildings. The effect of log population, log GDP per capita and urbanization remain significant and relatively constant across Models 3 and 4 at level-1.

In Model 2, a less-developed country with average levels of log population, log GDP per capita, urbanization, log trade and service economy is predicted to have 2.01 ($p<0.001$) units of log CO_2 emissions from transportation. At level-2 every control variable is significant except mean service economy. A less-developed country with 1 percent higher than average log population is predicted to have 0.87 percent ($p<0.001$) higher log CO_2 emissions from transportation. A less-developed country with 1 percent more than average log GDP per capita is predicted to have 0.57 percent ($p<0.001$) more log CO_2 emissions from transportation. A less-developed country with 1 percent more than average urbanization is predicted to have 0.01 ($p<0.01$) more units of log CO_2 emissions from transportation. A less-developed country with 1 percent more log trade than average is predicted to have 0.39 percent ($p<0.001$) more log CO_2 emissions from transportation.

The introduction of the log leapfrogging ratio does not change the effects of the control variables too noticeably; however, the effect of mean log trade does increase to 0.45 ($p<0.001$). The effect of log mean leapfrogging ratio on CO_2 emissions from transportation does have a significant effect. A less-developed country with a log ratio of mobile phones per 100 people to fixed telephones per 100 people that is 1 percent higher than average is predicted to have 0.32 percent ($p<0.001$) fewer log CO_2 emissions from transportation. The effect of the leapfrogging ratio on log CO_2 emissions from transportation is the lowest in the source specific outcomes. In the developed country model the effect of the leapfrogging ratio was not even significant. It seems that the leapfrogging ratio has the least impact on CO_2 emissions from transportation.

Table 6.6B: Less-developed Country Log CO_2 Emissions from Transportation, Variance Components and Model Fit Statistics for the Multilevel Model for Growth with AR(1) Error Correction

		1	*2*	*3*	*4*
Variance Components					
Level-1	Within-country	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Level-2	In initial status	1.55	0.16	0.13	0.11
		(0.23)	(0.03)	(0.03)	(0.02)
	In rate of change	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)
Model Fit Statistics					
Degrees of Freedom		6	17	19	23
Deviance		-1717	-2965	-2982	-3008
AIC		-1705	-2931	-2944	-2962
BIC		-1673	-2841	-2844	-2840
Pseudo R-sq (Level 2)		—	0.90	0.92	0.93
AR(1), ρ		—	0.90	0.90	0.89
			(0.04)	(0.04)	(0.04)
Error Variance		—	0.03	0.03	0.03
			(0.01)	(0.01)	(0.01)

N=1465, *n*=95

The addition of the ICT development indictors in Model 4 produces a significant effect in both the level-1 and level-2 models. At level-1, a 1 percent increase in log fixed telephones per 100 people is predicted to increase log CO_2 emissions from transportation by 0.03 percent ($p<0.05$). At level-2 the effects of the control variables are affected by the introduction of the ICT development indicators. Mean log population is slightly less but mean log GDP per capita is now noticeably lower (0.37, $p<0.001$) than in Model 2 and 3. Mean urbanization and mean log trade no longer reach significance and now service economy has a significant effect. Less-developed countries with a service economy 1 percent larger than average is predicted to have 0.01 ($p<0.05$) fewer units of log CO_2 emissions from transportation. As with all of the less-developed models the only ICT development indicator that has a significant effect is fixed telephone lines. A less-developed country with 1 percent more than average log fixed line telephones per 100 people is predicted to have 0.30 ($p<0.001$) more log CO_2 emissions from transportation.

6.8 Discussion

The effect of ICT development on CO_2 emissions in less-developed countries is more straightforward than for developed countries. The results of the above analyses are summarized and compared to the optimistic and pessimistic hypotheses in Table 6.7. There are two significant effects that run through both the aggregate and source specific models, the effect of the leapfrogging ratio and the effect of fixed telephones per 100 people. These two effects are interrelated and inform the acceptance of the pessimistic perspective over the optimistic views.

First, there is a very consistent positive effect of fixed telephones per 100 people. In less-developed countries from 1990 to 2009 there has been a slow and steady increase in the number of fixed telephones per 100 people. Without reservation, the effect of an increase in fixed telephones increases CO_2 emissions across all emissions sources with the strongest impact being in the electricity sector. This makes sense given the strong relationship between building point-to-point telephone lines and point-to-point electricity lines. The effects of mobile telephones per 100 people are not significant. Spreading wireless communications does not affect the point-to-point development necessary for electricity and therefore mobile telephones are not as impactful on the emissions trajectory of a country.

Table 6.7: Optimistic (Opt.) and Pessimistic (Pess.) hypotheses Compared the Results from the Analyses of Total and Per Capita (Per.) CO_2 Emissions and CO_2 Emissions from Electricity (Elec.), Buildings (Bldg.), Manufacturing (Mfg.), and Transportation (Tran.) in Less-developed Countries

Independent Variables	*Opt.*	*Pess.*	*Total*	*Per.*	*Elec.*	*Bldg.*	*Mfg.*	*Tran.*
Level-1								
Annual Rate of Change	−	+	−	−	−	NS	−	NS
Population (ln)	+	+	+	N/A	+	+	+	+
GDP per Capita (ln)	−	+	+	+	+	+	+	+
Urbanization	−	+	NS	+	NS	NS	NS	+
Trade (ln)	−	+	NS	NS	NS	NS	NS	NS
Service Economy	−	−	NS	NS	NS	NS	NS	NS
Fixed Telephones per100 (ln)	−	+	NS	NS	+	NS	+	+
Mobile Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Leapfrogging (ln)	−	+	NS	NS	NS	NS	NS	NS
Internet Users per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Level-2								
Mean Population (ln)	+	+	+	N/A	+	+	+	+
Mean GDP per capita (ln)	−	+	+	+	+	+	+	+
Mean Urbanization	−	+	NS	NS	NS	−	NS	+
Mean Trade (ln)	−	+	+	+	+	+	+	+
Mean Service Economy	−	−	−	−	−	NS	−	−
Mean Fixed Telephones per100 (ln)	−	+	+	+	+	+	+	+
Mean Mobile Telephones per100 (ln)	−	+	NS	NS	NS	NS	NS	NS
Mean Leapfrogging Ratio (ln)	−	+	−	−	−	−	−	−
Mean Internet Users per100 (ln)	−	+	NS	NS	NS	NS	NS	NS

+ = significant positive coefficient; − = significant negative coefficient; NS= not significant

Second, the significance of fixed telephone development on CO_2 emissions can be seen in the other significant ICT indicator, the leapfrogging ratio. The leapfrogging ratio has a consistent negative effect on CO_2 emissions across all source categories. Less-developed countries with a higher ratio of mobile telephones to fixed line telephones generally have two characteristics. First, they have little to no developed fixed telephone infrastructure. Second, they have a more developed mobile communications infrastructure. The least developed countries generally have the highest ratio as they likely have very few fixed telephone lines per 100 people. One extreme outlier is the Democratic Republic of the Congo; in 2007 they had a leapfrogging ratio of 1880 mobile telephones for every one fixed telephone. That year the Democratic republic of the Congo only had 0.006 active fixed telephone subscriptions per 100 people (or 6 per 100,000 people) compared to the 10.8 active mobile telephone subscriptions per 100 people. Ten percent mobile penetration is not a great number, yet it far exceeds the number of fixed telephone lines.

The relationship between mobile and fixed communication underlies another significant conclusion. Economic development is not just dependent on any type of inter- and intra-national communication but communication from fixed points to other fixed points. Mobile communication has no significant effect on CO_2 emissions in less-developed countries. One of the best explanatory variables for CO_2 emissions is GDP per capita as it captures both economic development and position in the world system (Roberts and Grimes 2002; York, Rosa, and Dietz 2003). The introduction of fixed telephones per 100 people affects the strength of the GDP per capita effect on CO_2 emissions across the all models. As noted in Chapter 4, there is a strong association between economic development and the development of fixed telephone infrastructures. Both the development of electricity and the increase in trade push the demand for fixed points of communication.

6.9 Conclusion

The evidence suggests that a pessimistic perspective based on the political economic perspectives of World Systems Theory and Treadmill of Production Theory provides a more realistic view of the role of ICT development in CO_2 emissions (Roberts and Grimes 2002; Schnaiberg 1980). With the analyses complete for all three models the broad implication for the investigation of CO_2 emissions are apparent. The variance in CO_2 emissions due to GDP is a placeholder for a more diverse array of the effects of affluence and technology on CO_2 emissions.

The implications for structural human ecology are potentially profound and will be expounded upon in the subsequent discussion.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

Does a pessimistic or optimistic perspective best capture overall relationship between ICT development and CO2 emissions? As noted in Chapter 2, ICTs are often viewed through a hyperbolic lens as either utopia inducing panaceas or the broken seventh seal before Armageddon (Kling 1994). In contrast the findings of this dissertation reveal a complex relationship between the ICT development indicators and the various measures of CO_2 emissions examined. The analyses in this dissertation are conducted at the world system level and do not offer a fine-grained analysis of cases when ICTs may reduce (or increase) CO_2 emissions. This is also not a study of the potential for ICT to reduce or increase CO2 emissions—even though those inferences can be made. This study is a historical analysis of the effects of ICT development on CO_2 emissions from 1990 to 2009. In the end, the preponderance of evidence suggests that it is justifiable to view ICT development through a pessimistic lens. However, this does not mean that ICTs consistently increase CO_2 emissions. The effects of fixed telephones, mobile telephones, the leapfrogging ratio and the Internet all have their own logics.

7.1 Fixed Telephones

Fixed telephones have the strongest impact on CO_2 emissions of all of the ICT development indicators. The effect of fixed telephones is different for developed countries and less-developed countries. In developed countries fixed line telephones have a strong and elastic negative effect. A greater than proportional change in CO_2 emissions occurs when fixed telephones per 100 people is above the average. This was the strongest observed effect for any of the ICT development indicators. As discussed in Chapter 5 this strong effect must be explained in the context of two related factors: 1) the number of fixed telephones has been in slow decline since the year 2000, and 2) the manufacturing sector—a large contributor of CO_2 emissions—is in decline over the same period in developed countries. However, the best explanation for this effect is the close similarity of fixed telephone development for each developed country. Statistically, the standard deviation of average log fixed-telephones is very low (SD= 0.22) for developed countries; since the range of variation is very low a one percent unit change is likely to produce a larger effect. However, there are no outliers here. Reduction in fixed telephones is not reducing CO_2 emissions because there are no real differences between countries. This is illustrated in the lack of an effect over time in the aggregate model.

On the other hand, the effect of fixed telephones per 100 people is more straightforward for less-developed countries. There are effects for fixed telephones both over time (level-1) and between countries (level-2). As fixed telephone lines are developed year-after-year CO_2 emissions grow in less-developed countries. In addition, countries with higher than average fixed telephone development also have higher emissions. This is particularly true for emissions from electricity production. The total average effect in the global model also shows the direct effect of fixed telephone development over time on CO_2 emissions and recognizes that countries with higher than the global average of fixed telephones will have higher emissions—including all developed countries.

While on the surface the findings of the developed country analyses show support for an optimistic appraisal of fixed telephone technology modeling the effect for all three samples gives insight to the real relationship. Fixed telephones are often left out of the literature on the effect of ICTs on CO_2 emissions in favor of more contemporary technologies like mobile telephones and the Internet (Romm et al 1999, Kuhndt et al 2003, Erdman et al 2004, Erdman 2010). Yet, this research presents evidence that fixed-line telephones have the largest impact on CO_2 emissions. Countries that are investing in the development of fixed telephones are likely to increase their overall CO_2 emissions. While the effect of fixed telephones is strongest relative to emissions from the production of electricity, it is also significantly related to emissions from manufacturing and transportation. While the close tie of electricity development and fixed telephone lines is a good explanation for the strong effect of fixed telephones, it is not sufficient to explain its relationship with manufacturing and transportation (Looney 1998).

7.2 Mobile Telephones

While from the end-user perspective mobile telephones and fixed line telephones are an equivalent technology, that is not the case when their entire flow of energy is considered. Fixed telephones have large direct effects of CO_2 emissions across all models, but mobile telephones do not. In the global models there are no significant effects for mobile telephones. This also holds true for the less-developed country models. For most of the world mobile telephones have not had a significant impact on CO_2 emitting activities.

This is not true for the developed countries sample. As with fixed telephones, mobile telephones have a large negative effect on CO2 emissions between developed countries. However, mobile telephones in the developed world suffer from the same narrow standard deviation problem that fixed telephones do. There are really no outliers in the developed countries sample. Even after these statistical considerations it is still notable that telecommunications have such a strong negative relationship with CO2 emissions. There is some evidence that mobile telephones do not have the same relationship with electricity production that fixed telephones do. Mobile telephones do not have a significant effect on CO_2 emissions from electricity in developed countries. Overall, there is not enough evidence to suggest that mobile telephones are impacting CO_2 emissions on a global scale. This null statement is supportive of the optimistic perspective. Mobile telephones appear, at least for the time being, to be a carbon neutral technology. While not a force for CO_2 emissions reductions it is good to know that the spread of mobile telephones is at least not increasing emissions.

Mobile telephones represent a consumer product and use paradigm. While it is true that mobile telephones are issued by businesses to their employees, like e-mail addresses and company cars, for the most part mobile telephones are an individual use device. On the other hand the fixed line telephone is more closely associated with a CO_2 intensive infrastructure. Telephone lines and electricity lines are generally run together. Fixed telephones use tends to follow energy availability. Telephones are fixtures of the built environment. Where there are buildings there are fixed line telephones. While the general public consumer may be turning down fixed telephones in the developed world, businesses still rely on place-based telephones. That is why fixed telephones are still rising in less-developed countries and fixed telephones have not fallen off completely in developed countries. Part of industrializing is connecting products to markets and companies to one another.

7.3 Leapfrogging

Given the above conclusions, the effects of the leapfrogging ratio can be placed in context. A large ratio of mobile telephones to fixed telephones does have a significant negative relationship with CO2 emissions. In both the global and less-developed models the effect of leapfrogging is consistent. Fixed telephone development represents industrialization, modernization, economic growth, and access to electricity for most of the world. Mobile telephone development has essentially happened without the major advance of any of theses modernization goals. Fixed telephones took a century to get to the present situation; mobile phones took little more than a decade (see Figure 1.2 and 1.3). Essentially the leapfrogging ratio is a proxy for modernization. Where there is a high leapfrogging ratio there is low economic development. While the phenomena of telecommunication leapfrogging is certainly real, it is not clear that this is an example of environmental leapfrogging.

Environmental leapfrogging assumes that a new cleaner technology replaces an older dirty technology, the operant word being "replace" (Perkins 2003). While it can be argued that mobile telephones are not a significant driver of CO_2 emissions they are certainly not replacing fixed telephones, particularly in less-developed countries where fixed telephones are still developing. The development of mobile telephones is certainly beneficial to the well-being of people and the results of this dissertation cannot suggest that their development has not led to an increase in CO_2 emissions. However, as mobile telephones increasingly become the predominant way people connect with the Internet, this conclusion should be reexamined (Cisco Systems 2012b).

7.4 The Internet

The impact of Internet on CO_2 emissions is probably the most striking finding of this dissertation. For the global models and less-developed models the number of Internet users per 100 people had no significant effect on CO_2 emissions. However, for the developed country models Internet users has a significant positive effect on CO_2 emissions. The limited variability problem for mobile and fixed telephones is less of an issue for Internet users.

This finding is striking for several reasons. First, the Internet is the symbolic core of the information age. If any grand narrative can be made about how contemporary society is different from previous societies it is often centered on the rise of the Internet (Castelles 2000, van Dijk 2006, Tappscott and Williams 2010). Second, in the developed countries model the Internet is the only ICT indicator that has a positive effect on CO_2 emissions. Finally, there is not a global effect of Internet users. The development of the Internet is not a proxy for global structural change. In fact, the evidence from the developed country models suggests that the Internet facilitates the burning of more fossil fuels. The Internet is not a globally transformative technology in this context. The underlying structure of the global fossil fuel economy is not affected by the development of the Internet.

7.5 Source Sectors

The above findings represent the general conclusions about the effects of ICT development on CO_2 emissions for each indicator used. However the effects of the ICT development indicators are not uniform across the four source sectors examined (electricity, buildings, manufacturing, and transportation). This reveals one of the common concerns with conducting an analysis of the environmental effects of specific technologies, that of complexity (Rosa et al. 2010). There is truth in this concern. Approaching this problem by compartmentalizing the complexity of ICT development effects into more specialized analyses is helpful in this regard.

7.6 Implications for Ecological Modernization and Associated Perspectives

For the most part Ecological Modernization Theory and its associated optimistic perspectives do not provide an adequate explanation for the results. That is not to say there were no effects that fit an optimistic interpretation. In the developed world one could be led to the conclusion that telecommunications have a very strong negative effect on CO_2 emissions. An explanation has already been offered as to why there is the appearance of such a large negative effect (little variation). However, assuming these findings do represent real differences between nations the effect is only present in developed countries. In all other cases ICTs either have no effect or a positive effect on CO_2 emissions. These effects need to be discussed in the appropriate context of declining fixed telephones and manufacturing base.

In addition to the impact that dematerialization will have on other sectors of the economy it is hyperbolic to suggest that media dematerialization is anything of the sort. Moore's law attests to the increase of computing power every 18 months through miniaturization, and the utilization of new materials computers have slimmed, from once weighing tons to now weighing ounces. Lighter new computers and media devices are more prevalent than they have ever been. It is not uncommon to have a cell phone, a laptop, a tablet, and an e-reader as regular companions. Audio requires speakers; video, and text require screens. Those fundamental basics have yet to be overcome. It is true that ICTs have experienced a renaissance in dematerialization by becoming thinner, lighter and bigger all at the same time, but it is still unclear that physical ICTs will be an obsolete technology in the near future. There are certainly scientific advancements such as nano-technology and atomic computing that will push the limits of miniaturization to an extreme, which may make material requirements negligible (Kursweil 2004). Regretfully, AGW is on an accelerated time-table and the 15, 20, or 30 years these innovations may take to commoditize and replace existing technology may not be soon enough. Remember that cell phones took 40 years to become as ubiquitous as they are today.

7.7 Implications for World Systems Theory and Political Economy

The results from the global and less-developed country models conform to expectations from a political economy perspective. Specifically, the development of fixed telephones can be viewed as a key mechanism of both the treadmill of production and the maintenance of world system positions (Roberts and Grimes 2002; Gould, Pellow and Schaniberg 2008). As Grimes (1999) noted, telecommunications are a tool through which powerful developed countries can control expropriated resources in distant less-developed countries. Developed countries certainly exploit their position to use resources and transfer dirty industries to other countries as argued by Unequal Ecological Exchange Theory (Rice 2007; Jorgenson et al. 2009).

7.8 Implications for Structural Human Ecology

While the negative effects of ICT development can be modeled sufficiently well using Treadmill of Production Theory and its political economy antecedent, World Systems Theory, ICT development has not been strongly considered in the Structural Human Ecology literature. The organization of the structural human ecology of CO_2 emissions has been recently summarized in *Nature Climate Change* and while the effects of technology in general are discussed along with some particular technologies the effects of ICTs have not been specified (Rosa and Dietz 2012). This dissertation is a step in the right direction towards how to investigate the impact of specific technologies on global environmental problems such as AGW.

In fact, the impacts of specific technologies are not very well understood and are under-studied (Rosa et al. 2010). This dissertation begins to bridge that gap in the Structural Human Ecology literature. There are several implications for SHE that can be derived from the findings of this dissertation. First, specific technology indicators such as the ones analyzed here can produce models that account for a significant amount of unexplained variance. Second, the effects of certain ICT variables—fixed telephones per 100 people in particular—should be incorporated into a broader view of human ecology that not only considers population growth and size, affluence, organization and efficiency but also *communication and connectedness*. Finally, investigations of specific technologies should use additional procedures to account for the complexity of technological impacts. This dissertation uses the four additional source category dependent variables above the typical aggregate measures.

7.9 Limitations

One of the largest limiting factors in this study was the effect of time. Even with t coverage spanning 20 years the variance in the dependent variables due to time was almost negligible, as noted above this is partly due to the vast differences that exist between nations to begin with, and partially a function of the log transformations necessary to deal with skewed distributions. Either way, the level-1 results presented were of limited explanatory value.

This study was also limited by the use of unbalanced data. While the multilevel model for change can handle unbalanced data it would still be preferable to have the same years and cases for each country. This was and is prohibitive given the variables needed for an analysis of ICT development and CO_2 emissions. An extension of this limitation is the sample size for developed countries. While using such small samples is common practice in cross-national research; however, it is clear that there are problems with model fit with such small level-2 sample sizes.

Finally, the availability of detailed ICT data is one of the strongest limitations. The analyses here all operate under the assumption that having a subscription for either fixed telephone service or mobile communication and using the Internet captures the effects of ICT development. This is not an unfair assumption as access to ICT services is a prerequisite for any effect. However, these variables tell us nothing about ICT driven environmental governance, the use of ICTs for scientific study, environmental messaging or any other potentially beneficial or detrimental effects for that matter.

Beyond the black box of use there are ICT variables that would be useful in addition to the three utilized here, such as: broadband Internet subscriptions; secure Internet servers per 1 million people; the number of personal computers per household; foreign and domestic investment in ICTs; and the import, export and use of domestic ICT services. Data on these variables are available but are either over a shorter time frame or with excessive missing data. There are other ICT variables that are harder to track down, like the amount of data uploaded or downloaded over a year, or the degree of Internet commerce within and between a countries. These limitations in the data are also part of the ICT development phenomena; as ICTs develop quickly data collection is likely going to change quickly as well. But, the three key variables used here are a good beginning.

7.10 Future Research

There are many directions future research can take. Because the quantitative analyses used in this dissertation were selected to model change over time, and very little of the effect of ICTs on CO_2 emissions was due to such change future research will need to overcome this limitation. One way would be to conduct a longer-term study of fixed telephones. Data are available going all the back to the early 1970s. Over such a long span the effect of time should be more readily apparent. On the other hand, it may be useful to conduct investigations that ignore the effect of time in order to examine cross-sectionally variables that have short collection histories, such as Internet servers per capita, and broadband subscriptions per capita. Such a study could also investigate more dimensions of ICT development, including foreign and domestic investment in ICTs, import and export flows of ICT services and goods, and degree of Internet freedom.

This dissertation research can also be directly extended to the investigation of environmental outcomes other than CO_2 emissions. An examination of deforestation could examine the role that ICTs play in paper consumption specifically and wood consumption more broadly. An examination of the ecological footprints of countries could highlight the broad ways that ICTs affect resource use. ICTs also have some environmental outcomes that are specifically tied to their manufacture and disposal. Several powerful greenhouse gasses are used in the production of ICTs, including hexafluoroethane, nitrogen trifluoride, sulfur hexafluoride, and tetrafluoromethane (Grossman 2006). These gasses are small percentage of atmosphere; yet they absorb many times more heat than does CO_2.

In addition to these outcomes it might be useful to look at some secondary relationships that ICTs may have on other technologies and social structure. One celebrated effect is the reduced need for travel due to instant global communication. It would be interesting to see if ICTs do have an impact on travel variables such as flights taken or miles driven. The use of structural equation modeling to examine causal paths, particularly the effect of ICT development on CO_2 emissions through GDP per capita, would also be interesting. The possible avenues for future research are numerous.

7.11 Policy Implications and Concluding Remarks.

ICT development facilitates economic activity that is dependent on fossil fuels. The elimination of ICTs would not eliminate the demand for fossil fuels. Blocking funding for additional investment in ICT infrastructure does not directly attack the problem of increased CO2 emissions. Encouraging ICT development should not be perused as a mitigation strategy because it is neither a large source of emissions nor an effective avenue for reducing emissions. . Additionally, discouraging ICT development should not be perused in lieu of other mitigation strategies or social movement effort. The ICT industry needs to align itself more closely with the alternative energy sector, which it has already done to some degree. Pressure in this regard is warranted.

Manufacturing and design of products needs to be taken into consideration. While Google may be “greening” its data centers, it is also stepping up production of new Google gadgets such as the chrome book and chrome cast both made in China at a hefty carbon cost (Cook, and Van Horn 2011). The design of products should incorporate alternative energy sources. Solar mobile telephone chargers are becoming more common but could also be included as part of device design. The technology of energy capture through the piezoelectric effect could be used to power devices through their movement and human operation (Kalyanaraman and Babu 2010). As this sentence is being typed it could be powering the device receiving that information and creating printed words.

These above remediation attacks the problem from the inside out. The scope of the solution is immense and external. If there are no shifts in the structural pattern of accumulation and degradation any such remediation is meaningless (Gould, Pellow and Schnaiberg 2008; Foster, Clark and York 2010). Fossil fuels are a cheap and heavily subsidized energy source (York 2010). The most often proposed way to reduce CO2 emissions is to put a “price on carbon” by capping the amount of emissions that can be emitted and trading carbon allowances for industries that exceed their allotment (Environmental Defense Fund 2013). This should incentivize innovation of energy technology on a massive scale. Whatever the remediation, ICTs cannot in and of themselves stop CO_2 emissions and in most cases play the opposite role. Policy time and money spent on ICT development for this sole purpose is probably better spent elsewhere. As long as electricity is directly tied to fossil fuels, ICTs will have an impact on fossil fuel consumption and thus CO_2 emissions.

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ENDNOTES

1. When sitting on the graduate dean search committee the second round of interviews were conducted via Skype. Even though there was an on-site candidate for the position he used Skype from a location on campus for the interview. Reasoning that meeting in person would not be fair to the other candidates. This illustrates the intuitive understanding that something is lacking form ICT enabled replacements.
2. In other recent sociological studies (Jorgenson and Clark 2012) CO2 data was gathered from the World Resources Institute. To make this study more consistent and to keep the additional year of 2009, all data was gathered from the World Bank. However, a comparison of the two data sources shows virtually no difference (r =0.999).

VITA

Joseph Michael Simpson

Candidate for the Degree of

Doctor of Philosophy

Thesis: INFORMATION AND COMMUNICATION TECHNOLOGY DEVELOPMENT AND ANTHROPOGENIC GLOBAL WARMING: A CROSS-NATIONAL PANEL STUDY OF ICT DEVELOPMENT ON CARBON DIOXIDE EMISSIONS 1990-2009

Major Field: Sociology

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Sociology at Oklahoma State University, Stillwater, Oklahoma in December 2013.

Completed the requirements for the Master of Science in Sociology at Oklahoma State University, Stillwater, Oklahoma in May 2008.

Completed the requirements for the Bachelor of Science in Sociology at Cameron University, Lawton, Oklahoma in July 2005.

Experience:

08/2005- 05/2013: Oklahoma State University, Sociology Department
08/2013- present: Instructor Texas A&M-San Antonio

Publications:

Simpson, Joseph M. and Vicly L. Elias. 2011. "Choices and Chances: The Sociology Role-playing Game—The Sociological Imagination in Practice," *Teaching Sociology* 39(1): 42-56.