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MEASURING EFFECTS OF CLIMATE CHANGE AND ENERGY EFFICIENCY REGULATIONS IN U.S. HOUSEHOLDS

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DISSERTATION

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Doctor of Philoshophy
Economics

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DEDICATION

To Shobha and Sushant, without their love and patience this would not have been possible.

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ABSTRACT

The first chapter explains the human causes of climate change and its costs, which is estimated to be about 3.6% of GDP by the end of 21st century (NRDC, 2008). The second chapter investigates how projected July temperatures will increase the demand for electricity in the U.S. by 0.8%, while projected January temperatures will decrease the demand for natural gas and heating oil by 1% and 2.3%, respectively. This chapter further examines effects of the energy-efficiency building codes: IECC 2003 and IECC 2006 in the U.S. in reducing the energy consumption in the U.S. households. This study finds that these state-level building codes are effective in reducing energy demand. Adoption of these codes reduces the electricity demand by 1.8%, natural gas by 1.3% and heating oil by 2.8%. A total of about 7.54 MMT per year emission reduction of CO_2 is

possible from the residential sector by applying such energy-efficiency building codes. This chapter further estimates an average of 1,342 kWh/Month of electricity consumption, 3,429 CFt/Month of natural gas consumption and 277 Gallon/Year of heating oil consumption per household. It also indentifies the existence of state heterogeneity that affects household level energy demand, and finds that assumption of independence of error term is violated.

Chapter 3 estimates the implicit prices of climate in dollar by analyzing the hedonic rent and wage models for homeowners and apartment renters. The estimated results show that January temperature is a disamenity for which both homeowners and renters are being compensated (negative marginal willingness to pay) through U.S. by \$16 and \$25 at the 2004 price level per month, respectively. It also finds that the January temperature is productive, whereas the July temperatures and annual precipitation are amenities and less productive. This study suggests that households would be willing to pay for higher temperature and increased precipitation; the estimated threshold point for July temperature is 75^{o}F and for annual precipitation is 50 inches. It further reports that homeowners pay more than renters for climate amenities in the Northeast and West with reference to the Midwest; where as in the South, these values do not differ much, suggesting that firms have incentive to invest in those regions. This chapter also identifies that both the housing and labor markets are segmented across the regions in the U.S.

Chapter 4 uses meta-analysis to explore the environmental Kuznets curve (EKC) relationship for CO_2 and several other environmental quality measures. Results indicate the presence of an EKC-type relationship for CO_2 and other environmental quality measures in relative terms. However, the predicted value of income turning point for CO_2

is both extremely large in relative terms (about 10 times the world GDP per capita at the 2007 price level) and far outside the range of the data. Therefore, this study cannot accept the existence of the EKC relationship for the CO_2.

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Chapter 1: Introduction

1. 1. Climate Change and Its Effects

The Earth's surface temperature has already increased since 19th century (IPCC, 2007). The National Research Council (NRC, 2001) reported that it has risen between 0.7º F and 1.4º F (0.4º C and 0.8º C) since the middle of the 19th century. Scientific studies of global climate change have reported that during the 20th century, the average U.S. temperature rose by almost 1° F (0.6° C) per decade and precipitation has increased nationally by 5%–10% (NRDC, 2008). If no major intervention is made to reduce greenhouse gas emissions, it is believed that average temperatures in the U.S. will rise by about 5–9° F (3–5° C) over the next 100 years, more than the projected global increase (see Fourth Assessment Report, IPCC, 2007).[1]

This change in temperature will affect household production choices, the amenity values of various locations, and the productivity of firms. Households' production choices change energy consumption patterns and the amount of energy consumed (Mansur et al., 2008; Nordhaus, 1991). Household's decision about location choices due

[1] IPCC Fourth Assessment Report is a synthesis report based on contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. This report discusses and presents on climate change rsulted by the applications of Atmosphere-Ocean General Circulation Models (AOGCMs), Earth System Models of Intermediate Complexity (EMICs) and the Simple Climate Models (SCMs). All models project increase in global mean surface air temperature (SAT) continuing over the 21st century, driven mainly by increases in anthropogenic greenhouse gas concentrations. Available at http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf, last accessed 2/20/2009.

to climate variations provide the amenity values of climate (Blomquist et al., 1988). This information will help consumers make decisions about climate adaptations, while producers can use this information to make cost-effective investment decisions. Further, information on climate change effects can help update public-sector policy guidelines to design a climate change abatement strategy and mitigation measures.

Although scientists have not ruled out the possible contributions of natural forces for global warming, they have found evidence that climate change is largely the result of human activities, mainly the burning of fossil fuels and deforestation (IPCC, 2007; NRDC, 2008). The burning of fossil fuels releases a huge amount of greenhouse gases (including CO_2), which affect atmospheric concentrations of these gases and lead to increases in Earth's surface temperature. Researchers and policymakers are concerned about the impact of those greenhouse gas emissions on the climate and their associated costs in the economic values of our properties and our lives today and the future. Since the climate change effects will have huge impact in terms of costs and lives, we then have to ask, "what are the best or most efficient options to respond to these changes: adaptation and/or mitigation?" Studies on the impact of climate change (e.g., NRDC, 2008) reported that the costs of doing nothing can be even higher than investing in mitigation. Areas in which the global warming will impose significant costs on the U.S. are: 1) hurricane damage, 2) losses in real estate, 3) energy costs, and 4) water costs (NRDC, 2008). These costs are about 1.8% of U.S. gross domestic product (GDP), or almost $1.9 trillion annually (in 2010 price level) by 2100, and the costs could go even higher, up to 3.6% of GDP (NRDC, 2008). These effects are drawn based on macroeconomic analysis and simulation. As impacts can differ from region to region and from individual to individual, an analysis of the impact of climate change at the individual level is essential to provide guidelines for formulating an appropriate policy to curb or to adapt to climate change.

The purpose of this dissertation is to examine the effect of global warming on energy consumption in U.S. households and the effects of energy-efficiency policies in reducing household emissions of CO_2. Residential energy consumption accounts for 39% of total energy consumption and contributes 21% (EIA, 2008) of CO_2 emissions into the atmosphere, so this analysis measures the energy costs of global climate change for U.S. households. Further, this dissertation estimates monetary values for climate in the U.S. Climate change will affect climate characteristics that vary across the U.S., and it produces both amenities and disamenities that will significantly affect housing prices and wage differentials. The public sector can use such information in drafting policy guidelines and designing a climate change abatement strategy. This dissertation also analyzes whether a decoupling relationship between CO_2 emissions and per-capita income exists by conducting a meta-analysis on the environmental Kuznets curve (EKC) studies. It analyzes the existence of EKC relationship for CO_2 and predicts income turning point or GDP per capita necessary to reduce atmospheric emissions of CO_2 to control global warming.

1.2. Hypotheses

The purpose of this study is to examine the effects of climate change in American households in general. Specifically, it estimates: i) the effects of climate change and energy-efficiency building codes on energy demand, ii) effects of climate change in property values, wage rates, and estimates the marginal willingness to pay for this these changes revealed by American households and iii) it analyzes the environmental Kuznets curve to examine whether a decoupling relationship exists between CO_2 emissions and GDP per capita. Such a decoupling relationship is required for public policy to curb global warming caused by the emissions of the anthropogenic greenhouse gas CO_2.

First, this analysis will define the effects of climate change and energy-efficiency policy measures on residential energy consumption. One of the important impacts of climate change is its effect on energy use. Energy is used for heating and cooling, along with cooking, at the household level. We use, in general, three types of energy: electricity, natural gas, and heating oil to meet our daily energy needs; however, the climate change will alter the consumption patterns of these types of energy. Further, the U.S. government has implemented energy-conservation policies to reduce anthropogenic emissions of greenhouse gases (e.g., CO_2) to curb the effect of climate change by introducing energy-efficiency building codes in the U.S. To estimate effects of climate change and the energy-efficiency policy measures in energy consumption at the household level in U.S., it is hypothesized that climate change will increase consumption of electricity and reduce the consumption of natural gas and heating oil; and adoption of energy-efficient building codes will reduce energy consumption for the same level of utility (Hypotheis-1). For this analysis, it is assumed that consumers prefer comfort in their homes' interior temperature, for which they maintain heating and cooling temperatures of their choice.

It is assumed that the effects of climate are embedded into housing prices and wage compensation. The primary empirical question of this study is whether climate characteristics that vary across the U.S. are in fact amenities that significantly affect housing prices and wage differentials. If so, what is the amenity value of the climate of the U.S. in general and the compensating differential for climate amenities in housing and labor markets in the U.S. in particular? To have this analysis, the hypothesis developed is January temperature is disamenity and July temperature is an amenity (Hypotheis-2). Households choose to work and live in preferred climate locations so that they will maximize their net benefits. This will bring an inter-urban equilibrium that will affect both housing markets and wage markets. An increase in climate amenities increases the utility of households, and they would therefore be willing to accept lower wages. With climate as a disamenity, households would reject lower wages and seek higher wages as compensation. This measure will give the monetary value of climate change based on the consumers' climate preferences.

The third hypothesis (Hypotheis-3) of this study is the existence of an inverted U-shaped relationship between per-capita emissions of CO_2 and the environmental quality indicators and GDP per capita. This relationship is called the environmental Kuznets curve (EKC). Evidence of an EKC relationship would show a threshold of economic development in which the relationship between some environmental degradation measures and income per capita reverses; this threshold or decoupling between economic growth and environmental degradation is referred to as the income turning point (ITP). The existence of an EKC relationship for CO_2 provides public policy information to have a required level of an economic growth to curb global warming.

1.3. Research Methods and Empirical Tools

The goal of the following chapters is to examine the hypotheses presented in the section 1.2. Several methods are borrowed from microeconomics, environmental economics (particularly tools of non-market valuation), and econometric tools to address the above mentioned research hypotheses. Each of the chapters addresses a different scale of observations, from state-level energy-efficiency policy to household-level observations on the types of energy uses and expenditures, income, housing property values, neighborhood characteristics, etc. Given the climate change and policy applications that form the basis of the hypotheses investigated here, it is necessary to cover the data across the U.S. from different sources.

This dissertation adds values to the existing literature in several ways. While addressing the Hypothesis-1, chapter 2 presents a study of how climate change and energy-efficiency building codes affect residential energy demand in the U.S. This study uses a large household-level data set obtained from American Community Survey (ACS) 2007 and the state level data obtained from different sources. The policy data, state-level data were retrieved from National Action Plan for Energy Efficiency, Energy Information Administration (EPA), Department of Energy (DOE) on Building Codes for Energy Efficiency Fact Sheet -2007 (DOE, 2007). January and July temperatures are used as proxies for the winter climate and summer climate, respectively. Few other studies have examined how climate change affects energy demand, and no published study has examined the effects of energy-efficient building codes or climate change on the demand for the three types of energy used by American households: electricity, natural gas, and heating oil. This chapter uses a hierarchical econometric model to analyze the state heterogeneity that affects residential energy consumption.

Chapter 3, which addresses the Hypotheis-2, provides an analysis of the effects of climate change on property values and households' wage rate. This chapter examines whether households in the U. S. would pay or get compensation for better/worse climate as an amenity or a disamenity through housing markets and labor markets. It estimates the implicit values of climate using hedonic price and wage methods. This analysis uses data published by the American Housing Survey (AHS) (2005) national micro data samples from the entire U.S. and by National Oceanic and Atmospheric Administration (NOAA) for climate variables. An assumption of the model used in chapter 3 is that people can move freely across the U.S. if housing prices rise too much or if wage rates in an area are too low, given the climate amenity available in any particular location. Given the heterogeneous preferences of homeowners and apartment renters, two separate analyses for homeowners and apartment renters are performed while estimating the implicit values of climate in the United States.

This study uses January (winter) and July (summer) temperatures and annual precipitation (wetness) as proxies of climate variables to examine the implicit prices of climate in the U.S. Chapter 3 further analyzes the productivity of climate, which will provide information on the effects of climate change in firms and labor productivity rates. The empirical analysis in this study allowed cross-equation correlation by using the SUR estimation method to capture the unobserved characteristics of individuals that influence their decisions of where to work and where to live, measurement error, and simultaneity between housing prices and wages.

Chapter 4 addresses the Hypothesis -3, which analyzes the relationship between CO_2 emissions and other indicators of environmental quality and GDP per capita. This is a meta-analysis of 103 empirical environmental Kuznets curve (EKC) studies (1992 to 2009) to explore this relationship. A meta-analysis is a statistical tool that synthesizes a large collection of analysis results to integrate the findings, which requires collecting findings on a specific topic from existing studies, using structured guidelines.

This study corrected for the methodological issues of meta-analysis to get robust estimates. While analyzing the EKC-type relationship and income turning points (ITPs), this analysis used cluster analysis to account for heterogeneity across studies. It also controlled for publication bias in analysis. To suggest whether there exists an EKC relationship for the high profile case of CO_2, a specific analysis is presented. This analysis provides policy makers information on the EKC relationship and the required GDP per capita to curb the emission of CO_2.

Although, individual chapters will provide specific conclusions about their results, chapter 5 is dedicated to a more general set of conclusions and attempts to address the broader hypotheses set for this research. This chapter also contains empirical questions raised by this research for future work.

Chapter 2: The Effects of Energy-Efficiency Building Codes and Climate Change on U.S. Residential Energy Demand

2.1. Introduction

Residential and commercial buildings together use more energy and consequently emit more CO_2 than either the industrial or transportation sectors in the U.S. (EIA, 2008). As the climate change and energy security are major concerns for our continued economic growth, improving energy efficiency in the household level is important to reduce both the consumption of energy and the emissions of CO_2 from the residential sector. The application of energy-efficiency standards at the household level suggests a reduction in the amount of energy required for the same (or a greater) level of utility that a household can get. It is a well-accepted scientific finding that the concentrations of CO_2 and other greenhouse gases in the atmosphere affect the Earth's climate (IPCC, 2001). Therefore, the application of energy-efficiency measures can be sought as one of the policy measures to mitigate the climate change effects. Energy efficiency has become a policy tool to address both the climate change and the energy security issues in most of the developed countries and European Union (Egenhofer et al., 2006).

Although the estimated per-capita energy consumption in the U.S. is decreasing, the demand for energy is growing due to our modern living style coupled with population growth (EIA, 2010). Consequently, the U.S. has been emitting greenhouse gases at an increasing rate. In 2008, Americans emitted about 5,802 MMT[2] of CO_2, and about 21% (about 1,221 MMT) of that was from residential energy consumption alone (EIA, 2008).

The amount and rate of future climate change depend on the level of greenhouse gases being emitted today (NRDC, 2008). To respond to the burgeoning effect of emissions of CO_2 into the atmosphere, energy-efficiency policy can be instrumental in reducing the emissions to limit future warming and to help adapt to the inescapable changes produced by our present actions. Energy efficiency, which is underutilized currently, could save a tremendous amount of energy in the U.S., given the growing demand, preserving energy for future needs (DOE & EPA, 2006).

Although energy efficiency is applicable to all consumption sectors, this study focuses on the residential sector. The residential sector's energy consumption alone accounts for about 39% of total energy consumption (about 37 quads[3] per year) (EIA, 2008) and is growing because of our life style and the population growth. To meet ever-increasing residential energy demands and to curb climate change, measures to improve the energy efficiency of buildings would be appropriate in public policy. The objective of this chapter is to estimate the effects of energy-efficiency building codes and climate change on residential energy demand in the U.S., using household-level data. This chapter also estimates the possible amount of reductions in emissions of CO_2 through implementing an energy-efficiency policy. No extant study has precisely quantified or analyzed such policy implications at the micro level. The energy consumption in this analysis means consumption of electricity, natural gas, and heating oil by U.S. households.

[2] Million Metric Tons
[3] 1 quad = 10^{15} BTU. BTU: British Thermal Unit.

The energy crisis of 1970s, coupled with growing environmental concerns, was the most important contributing factor for the development and application of energy-efficiency building code as one of the energy saving policy measures in the U.S. The BACP (2009) reported that through the proper adoption of such a code, in combination with appliance standards, a building could save between 30% and 40% of its energy demands compared with a building without efficiency codes. Further, Laitner (2009) reported that if such energy efficiency measure is applied properly, U.S. could save approximately 40 to 50 billion of oil equivalent from now to the year 2030, about 2.5 times the off-shore drilling in U.S. coastal waters. This predicted value is derived from a theoretical assumption based on expert judgment and engineering studies rather by a micro level ex-post analysis. What exact amount would be saved and what level of effect energy-efficiency building codes would produce in energy savings are not estimated.

Further, energy consumption is climate-sensitive. Depending on the types of climatic behavior, households use energy for heating and cooling for their comfort in addition to the energy used for cooking and lighting. Global climate change will affect both the energy used in heating and in cooling. Several papers (e.g., Mansur et al., 2008; Nordhaus, 1991) reported that global climate change would negatively affect the welfare of the U.S. households. However, none of these energy demand studies has analyzed the effect of such an energy-efficiency policy while controlling for climate change at the household level. A household-level analysis to estimate the exact amount of savings is essential for further improvements in such efficiency codes and to design policy incentives for the successful implementation of these energy-efficiency policy measures and to increase the number of households that would adopt this policy.

This study makes three specific contributions to the literature. First, instead of just estimating the residential energy demand, this study analyzes and quantifies the effect of a specific energy-efficiency policy tool: a residential energy building code. This study estimates the amount of reduction in emissions of CO_2 from energy use in the residential sector that such a building code would produce. Since the energy consumption is climate-sensitive, this study also analyzes the effect of climate change on the residential energy demand for three different types of energy–electricity, natural gas and heating oil. Second, this research endogenizes the policy by using an instrumental variables estimation strategy to get unbiased estimates. Treating energy-efficiency policy measure endogeneously means, it is responsive to factors such as economic, political, etc. Thirdly, it applies a hierarchical model to relax the state heterogeneity and to see state's effects on energy demand. As policy measures are applied at the state level, their effect should be analyzed at the state level to avoid bias in estimation. The findings of this study should be of broad interest for energy and climate policymakers because national residential building codes are the core energy-efficiency policies in the Waxman-Markey Climate Bill, which the House passed on June 26, 2009.[4] Further, households make decisions on investing in energy-efficiency measures by adhering to building codes.

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[4] The House of Representatives passed the American Clean Energy and Security Act on June 26, 2009. This Act was sponsored by Rep. Henry A. Waxman, Chairman of the House Energy and Commerce Committee, and Rep. Edward J. Markey, Chairman of the House Select Committee on Energy Independence and Global Warming. The Act has several provisions, one of which mandates new energy-saving standards for buildings, appliances, and industry, which is relevant to this study. Available at <http://energycommerce.house.gov/index.php?option=com_content&view=article&id=1697:house-passes-historic-waxman-markey-clean-energy-bill&catid=155:statements&Itemid=55, last accessed 2/25/2010.

2.2. Residential Energy Consumption and the Potential for Saving

Annual residential energy consumption in the U.S. accounts for one-third of all the energy used in the country and two-thirds of the total electricity demand (DOE & EPA, 2006). The U.S. Energy Information Administration's *Annual Energy Outlook 2010* (EIA, 2010) reported that out of total residential energy consumption, space heating accounts for 32%, water heating and space cooling consume 12% each and account for 56% in total, and these uses are directly related to climate change. The IPCC (2007) reported with persuasive evidence that anthropogenic factors are mainly responsible for increasing the emissions of greenhouse gases (GHGs), especially CO_2, into the atmosphere. It further reported that the current concentration level of CO_2 is 430 parts per million (ppm); and this is increasing at the rate of 2.3 ppm per year, which is creating a threat of increasing the mean global temperature by 4^o C by the end of this century. The U.S. consumes more energy than any other country in the world, and the U.S. is number one CO_2 emitter. It emits about 5,801 MMT from the energy sector alone and 1,221 MMT (21%) solely from residential energy consumption–a huge amount of contribution (EIA, 2008). Therefore, any policy to reduce residential energy consumption is crucial for both reducing energy expenditures and reducing CO_2 emissions.

The U.S. Census Bureau Population Division (2008) reported that there were about 128 million U.S. housing units in 2007 and 121 million in 2003. Until 2002, the number was 119 million, which shows strong demand for new construction. This figure shows that only about 7 million housing units could have adopted such codes since 2003 to date, even if all states had endorsed and made it mandatory to adopt the building-efficiency codes, while more than 121 million residential homes presumably are still without such energy-efficiency codes. Huge numbers of residential housing units do not adhere to energy-efficiency building codes, while on the other hand, a growing number of newly constructing housing units offer a tremendous opportunity for energy saving in the residential sector within the U.S.

Under the economic framework, application of energy efficiency fundamentally involves investment decisions that trade off higher initial capital costs and uncertain lower future energy operating costs. Therefore, it can be envisioned that if a meaningful savings from reduced energy consumption through adherence to the energy-efficient building codes could be proved, this proof could induce potentially about 121 million homeowners to adopt these standards. As a result, a huge reduction could be made in the demand for and consumption of energy. Further, the application of such energy-efficiency codes in existing and new construction of residential housing units would help significantly in reducing the amount of emissions of CO_2 from burning fossil fuels. Accurate estimates of these savings and reductions would encourage both households who are spending more of their income on energy, on the one hand, and the government, on the other hand, to lower the growth in energy demands (DOE & EPA, 2006).

2.3. Energy Used in Homes by Types of Energy

U.S. residential energy consumption is dominated mainly by natural gas and electricity. The consumption of natural gas, one of the most admired fuels for residential heating, is about 4.8 trillion cubic feet (TCf) (EIA, 2009). According to the American

Gas Association (AGA), about 51% of heated homes in the U.S. (or about 65. 7 million households) used natural gas heating in 2007. Electricity consumption for residential purposes is second to that for natural gas, which accounts for about 41% of total homes (52.8 million households) (EIA, 2010). During 2007, total residential electricity consumption was 1,393 billion kilowatt hours, which accounted for 37% of total electricity consumption in 2007. The consumption of residential electricity is increasing every year and the EIA (2010) reported that annual electricity demand increased on average by 1.1% per year from 2000 to 2007, and this growth was projected to increase by 1% per year until 2030.

About 8.5 million American households (6.6% of 129 million households), mostly in the Northeastern states, use heating oil for heating their homes during the winter, while less than 2% of American homes use some other type of fuel for heating (EIA, 2010). As compared with electricity and heating oil, natural gas heating systems are increasingly being used in new construction within the residential sector by high proportions. According to the U.S. Census Bureau (2007), 62% of single-family homes completed in 2007 used natural gas heating, followed by 34% that used electric heat, and 2% that used heating oil. Compared with electricity, natural gas is the conventional energy source at the lowest cost available for residential use, which is one of the reasons for its increasing use in the U.S. (DOE & EPA, 2006).

2.4. Building Energy Codes: Energy-Efficiency Policy

The fuel shortage in the 1970s played a critical role in developing and adopting the energy-efficiency building codes for buildings now used by local and state governments in the United States (Gerrard, 2007). Initially, a Model Energy Code (MEC) was developed by the Council of American Building Officials (Howard and Prindle, 1991) in 1983, with an objective of reducing residential energy consumption through applying building insulators. However, the demand for energy efficiency was greatly realized as a mandatory policy measure only in 1992 by the enactment of the Federal Energy Policy and Conservation Act (EPCA) of 1992,[5] which required all states to review and adopt the MEC and submit to the Secretary of Energy a progress report of their status. In accordance with the EPCA 1992, the MEC was revised and updated several times, but in 1998, the MEC was renamed the International Energy Conservation Code (IECC) and is considered the successor to the MEC. Since then, the IECC has become the most-applied building energy-efficiency code for residential structures in the U.S. Although the Energy Policy Act of 2005 specified the most current model energy codes (IECC 2004, ASHRAE 90.1[6]), energy codes can vary greatly from state to state, and even from edition to edition (BCAP[7], 2009). This study considers the most recent energy-efficiency building codes (IECC 2003 through IECC 2006) as policy measures to

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[5] Section 101/304 of the 1992 Energy Policy Act directly addressed energy efficiency in buildings and energy codes. Available at http://bcap-ocean.org/sites/default/files/EPAct%201992%20Section%20101.pdf., last accessed 4/10/2010.

[6] ASHRAE 90.1 was developed under the auspices of the American Society of Heating, Refrigerating, and Air Conditioning Engineers. (DOE, 2010).

[7] Building Codes Assistance Project.

analyze their effects on residential energy savings in the U.S. Both the IECC 2003 and the IECC 2006 represented the next stage in the evolution of model energy codes in the U.S. (BCAP, 2009). It has been argued that the energy-conservation requirements in these codes were designed to reduce the operating costs for residential energy through lower energy bills. So far (at the time of this study), 34 states have adopted energy codes for residential construction (DOE, 2007).

Producing cost-effective energy savings and combating greenhouse-gas pollution are major concerns for researchers and policymakers. *The National Action Plan for Energy Efficiency Report 2006* argued that the benefits from adopting building energy codes are cost-effective and also emphasized the energy savings from the residential sector as a strategic option at the time when the issues of global warming and the energy crisis are increasing (DOE, 2006). Adopting the building codes mainly would mean efficiency improvements in 1) insulation in walls, floors, and ceilings; 2) doors and windows; and 3) heating, ventilating, and cooling systems and equipment (DOE, 2010). The U.S. Department of Energy (DOE) stated that there would be a large savings in energy consumption if all states adopted and fully implemented the energy-efficiency measures that it supported, including ASHRAE Standard 90.1 and energy-efficiency codes for commercial buildings (DOE & EIA, 2006). The DOE's analysis showed that a total savings of about 16 trillion BTU of energy during the first year and almost 800 trillion BTUs cumulatively over the 10 years following the adoption of these codes. Further, it has been argued that although the adoption of the efficiency policy measures would add to a front-end cost of a home, the actual cost of living in an energy-efficient home would be less in the long run as a result.

It is necessary to have accurate estimates of the effects of energy-efficiency building codes on energy consumption, the economy, and the environment to assess their overall effectiveness and to provide the information needed to make prudent improvements. To date, there have been only limited data on energy and demand savings achieved through mandatory energy-code policies at the aggregate level. Where data exist, they tend to be ex-ante projections of a policy, not ex-post estimates of achieved savings at the micro level. To estimate the resource value of the mandatory energy-efficiency codes at the micro level, their effects on saving in energy use, the reduction in greenhouse gas emissions, and energy expenditures at the household level are essential pieces of information (DOE & EPA, 2006).

2.5. Empirical Studies of the Effects of Energy-Efficiency Building Codes

A significant number of research studies on residential energy demand have been conducted over the past four decades, following the energy crisis of 1970s. The majority of these studies have analyzed an economic framework of energy demand and a broader framework of the global warming issue as a consequence of the emission of greenhouse gases. Although offering a large number of econometric analyses for residential energy demand, the majority of studies (e.g., Asadoorian et al., 2006; Franco & Sanstad, 2008; Mansur et al., 2008; Nordhaus, 1991; Reiss & White, 2005; Rosenthal et al., 1995) estimated the demand for electricity without analyzing the effects of the introduction of energy-efficiency building codes as a policy measure. Recently, a few studies (e.g., Arimura et al., 2009; Aroonruengsawat et al., 2009; Herter et. al, 2006) have analyzed the effects of energy codes for buildings; however, these studies have mainly focused on electricity rather than covering all possible types of energy, including natural gas and heating oil, in demand analysis. The higher price of electricity as compared with other sources of energy and the growing interest in the issues of the emissions of CO_2 and other greenhouse gases into the atmosphere has engendered the focus on electricity demand analysis. In the United States, the electric power industry alone is responsible for emitting approximately 48% (about 2,363MMT) of CO_2 emissions, and the price of electricity per BTU is about 2.5 times higher than the price of natural gas and about 5 times higher than the cost of heating oil (EIA, 2007).

Gillingham et al. (2006) reported, in their review, an annual savings of about four quads of energy from energy-efficiency policies and programs, but they excluded the effect of energy codes for buildings. Literature on the effects of energy codes for buildings, for example, Arimura et al. (2009), has estimated savings in terms of electricity expenditures and reported about 1.1% of electricity savings at a weighted average cost to utilities during 2006, while analyzing the effect of utility demand-side management (DSM) programs and energy codes for buildings using aggregate data at the state level. Aroonruengsawat et al. (2009) reported a savings in per-capita residential electricity consumption ranging from 3–5% in the year 2006 from the IECC 2003 and IECC 2006 by using panel data for 48 U.S. states from 1970 to 2006. However, their study analyzed the impact of regulations on aggregate demand, not demand at the household level. An aggregate estimation is important only for a supply-side determination or for a macro-level policy determination rather than for household decisions or for policy adoption.

Not all estimated results from empirical analyses are consistent with the *Annual Energy Review Report of 2007*, which claimed a savings of 1.8% of total electricity demand in 2007 from the adoption of energy-efficiency codes (EIA, 2008). Further, there are variations between the states. For example, California has saved about 1.2%, while Vermont saved 2.5%, and Florida saved about 4% in electricity and about 6% in natural gas (Jacobsen & Kotchen, 2009).

Besides the United Stated, other countries, both OECD and non-OECD countries, have adopted energy efficiency as one of the main energy policies since the first oil crisis in the 1970s. The IEA (2005) reported that for 11 different OECD countries as a whole, including Japan and Australia, these countries have reduced their demand for energy by 1.6% per year on average through the application of energy-efficiency codes. Except for a few developed countries, developing countries are only able to think seriously of energy efficiency in the industrial sector. For example, China, the second-largest CO_2 emitter in the world, has been implementing energy-efficiency codes, but only in the industrial sector (Yanjia, 2006).

Although the importance of energy-efficiency policies has been realized in the U.S., no attempts have been made to analyze its ex-post effects at the household level. Ex-post empirical study at the household level would provide information needed for the successful implementation of energy-efficiency policy measures and, at the same time, to make necessary improvements in policy measures. This study provides an important analysis of the effects of energy efficiency that depends on both the economic efficiency of the market conditions that the consumer faces (e.g., energy prices) and the economic behavior of the individual decision maker (e.g., cost-minimization or utility maximization) with given climate change effects. Besides the effect of energy-efficiency policy measures, this study also focuses on the particular aspects of the effect of climate change on energy demand at the household level by analyzing the direct impact of changes in average mean temperatures (in January and July) on the household demand for electricity, natural gas, and heating oil.

2.6. The Theoretical Model

The primary empirical question of this study is whether energy-efficiency building codes and climate characteristics that vary across the United States have in fact a significant effect on energy consumption at the household level. Assuming weakly separable household preferences, the utility over all goods can be expressed as $U = U(Q_k, X)$. The consumer's utility, U, maximization problem is given as

$$\max U = U(Q_k, X) \qquad s.t. \quad m = p_k * Q_k + X \qquad 2.1$$

in which Q_k is the quantity of energy goods and p_k is corresponding energy price, while k represents the type of energy: Electricity, Natural gas and Heating Oil. Further, X is the vector of all nonenergy goods (numeraire goods with unit price); excluding durables and m is household income. The solution to the utility maximization problem gives the consumer's choice of fuel Q_k as a function of price and income. This type of demand function implicitly assumes that the consumer can purchase the desired quantity at a constant price, p_k. In real life, consumers' characteristics also affect the choice and quantity demanded. As the objective of this study is to analyze and to estimate the effect of the energy-efficiency policy and climate change effects on residential energy demand, controlling for these variables and building-characteristic variables is required in this demand function. After the inclusion of the consumer's characteristics—ζ, energy efficiency policy variable—Ψ, and climate variable—T, a general demand function typically takes the form

$$Q_k\ (p_k, m,\ \Psi, T, \zeta)\ . \qquad 2.2$$

For simplicity in analysis, the linear-in-price and linear-in-income demand functions have been used. In interpreting equation 2.2, it is important to note that it corresponds conceptually to the conventional demand function $Q_k\ (p_k, m,\ \Psi, T, \zeta)$ of classical consumer theory. That is, it specifies the amount of energy that the household would consume *if* it faced income level m, a constant price p_k for each unit or type of energy, Ψ policy variable, and T temperature variable. In this analysis, the policy variable is not directly observable. It is endogenously determined. It is assumed to be a function of other state-level variables that affect the demand for energy-efficiency regulation, which is given as

$$\Psi = \Psi\ (F, S, D, C) \qquad 2.3$$

in which F is federal policy on energy, S the state's revenue, D is population density, and C is a dummy for a coal mine in the state.

2.7. Data Sources

Data for this study were obtained from the American Community Survey (ACS), 2007, a source of national micro data. The surveyed data conducted by the U.S. Census Bureau covered sampling from the whole country of the U.S. The data used for this study were from a single-year survey Public Use Micro Data Sample (PUMS) 2007 (U.S. Census Bureau, 2008). According to the U.S. Census Bureau, the 2007 PUMS was designed to sample one percent of the housing units in the United States, including the District of Columbia and Puerto Rico. The PUMS 2007data contained 1,137,886 housing unit records and provided detailed information on economic, social, demographic, and housing characteristics, including housing unit structural information, unit built (year), state, regions, etc. The ACS data offered information about energy used for heating and total expenditures based on energy types, which are important pieces of data for the analysis of energy policy. This data were rich in micro-level information, and such richness is appropriate for an empirical analysis of energy-efficiency policy measures and climate change's effects on residential energy demand in U.S. households.

The primary interests in the empirical estimates within this study are measures of effects of energy-efficiency policy, climate effects, and the effect of state heterogeneity on energy consumption at the household level. State-level residential building energy-efficiency codes as policy measures were obtained from the Building Codes Assistance Project (BCAP, 2009; DOE, 2007). These codes considered for this analysis were the International Energy Conservation Code (IECC), IECC 2003, and IECC 2006, which were available at the time of ACS 2007. The information on energy codes was matched by state to get buildings with these codes. Another interesting estimate in this analysis is a measure of the effect of climate change, which has a major impact on the energy use of most residential buildings. To analyze the effect of winter and summer climate temperature variables for January and July were obtained from the National Climatic Data Center/NOAA (2006). These climate variables were average state level temperature. Independent variables were controlled to analyze the effect that these variables have on energy demand.

Price information for the various energy types was obtained from *Residential Sector Energy Price Estimates by Source 2006*, U.S. Department of Energy, Energy Information Administration (EIA) (EIA, 2007). The prices were measured per Million BTU and were used for all types of energy analyzed to get consistency in the analysis of the data.

2.8. Empirical Approach

Most empirical work applied in econometric energy demand analysis has focused on individual-level effect analysis. The effect of energy policy that is formulated at the state level mostly has been overlooked. The data used in this analysis were comprised of both household-level variables and state-level energy-efficiency policy variables. Therefore, the data for this analysis have two types of information: 1) the household level, and 2) the state level. To analyze the effects of the state-level policy variables and other state-level information, a measure of effects of state is essential, and for this, a two-level analysis is required. The two-level analyses will provide state influence on energy demand or savings due to the policy implementation, for which one of the research questions would be, “Why do states differ?”

In multilevel analysis, models capture the layered structure of multilevel data and determine how these layers interact and affect a dependent variable of interest (Steenbergen & Jones, 2002). Hox (2002) stated that the population with a hierarchical structure would have a multilevel problem and that the observations are nested within groups. Steenbergen and Jones (2002) and Hox (2002) stated that, in general, a multilevel data structure will have clustering: one level of the data (the lower level) is a subset of another level (the higher level of) data. Ignoring such clustering at the higher level violates the assumption that the errors are independent (Steenbergen & Jones, 2002). Because energy consumption observed at the household level is nested in the state-level variables, including energy efficiency and price variables, and given that those variables are observed at the state level, it is necessary to apply a multilevel model to capture the state-level interdependence.

Although econometric analysis observes variables at the different levels, the application of a multilevel estimation approach is not always recommended, and it is not free from criticism. The best way to decide where to use multilevel or single-level estimation methods can be justified by the statistical test of cross-level interaction (Hox, 2002). The intra-class correlation gives a measure of the degree of dependence of the individual household. For example, households from the same state will behave almost alike for any consumption (e.g., energy) decision, as they share same context: the same state. Therefore, they are likely to experience the same terms of policy, price, etc. If individual households share the common state’s situation, they are likely to be more similar. Intra-state correlation is important because it changes the error variance in regression analysis. To test the intra-state correlation involves first testing with an intercept model at two levels. Hox (2002) stated that the intercept-only model is used as a null-model that serves as a benchmark model to test the intra-class correlation. Following Hox (2002), the intercept model is given as

$$Y_{ij} = \beta_{0j} + e_{ij} \ . \qquad 2.4$$

The intercept without any explanatory variables decomposes into

$$\beta_{0j} = \gamma_{00} + u_{0j} \ . \qquad 2.5$$

The single equation intercept model by substituting equation 2 into 1 would be

$$Y_{ij} = \gamma_{00} + u_{0j} + e_{ij} \qquad 2.6$$

where Y_{ij} is the level-1 (household level) dependent variable, and for a level-1 unit *i* (=1, . . ., N*j*) nested in level-2 (state level) unit *j* (=1,. .., J). Further, e_{ij} is a level-*i* disturbance term. The full intercept does not explain any variance in Y_{ij} ; however, it only decomposes the variance into two independent components: σ_e^2 , variance at the household level or lowest level of the error term e_{ij} , and σ_{uo}^2 , variance at the highest level–state level of the error term u_{0j} .

From equation 2.6, we can derive the intra-state correlation ρ , which is given as

$$\rho = \frac{\sigma_{uo}^2}{\sigma_{uo}^2 + \sigma_e^2} \ . \qquad 2.7$$

The intra-state correlation explains the amount of variance explained by the grouping structure (Hox, 2002). If estimated covariance parameters σ_e^2 and σ_{uo}^2 are significant (as per testing with Z-statistics), then the application of the OLS is biased, and the assumption of independent residuals is invalid (Steenbergen & Jones, 2002).

In multilevel estimation, an alternative way to allow for group effects is to include dummy variables for groups in a traditional (ordinary least squares) regression model, which is called *fixed effects* model. Steenbergen and Jones (2002) stated that in a fixed effects model, the effects of group-level predictors are confounded with the effects of the group dummies. In other words, it is not possible to separate out effects due to observed and unobserved group characteristics. To overcome such problems and avoid bias in estimations, Hox and Kreft (1994) argued that analysis of multilevel models must include *random effects* because a multilevel model assumes a hierarchically controlled population with random sampling of both levels. Steenbergen and Jones (2002) further stated that dummy variables are only indicators of subgroup differences, and the application of dummies cannot explain why the regression regimes for the subgroups would be different. If variance at the highest level, the state level of the error term, is statistically significant, then the *random effect* model is the best choice (Gujrati, 2004).

To estimate the effect of energy-efficiency building codes and the climate on energy demand, an econometric model can be written by starting with the level-1 model, extending the equations 2.4 and 2.5. To incorporate the hierarchical difference variables, that is, household level and state level, this study has parameterized the demand function at two levels: household level (level-1) and state level (level-2), following Hox (2002). The level-1 model is given as

$$Y_{ij} = \beta_{0j} + \beta_{1j} \ X_{ij} + \varepsilon_{ij} \qquad 2.8$$

in which Y_{ij} is the dependent variable (energy demand at the household level) at the level-1. For level-1, unit *i* (=1, . . ., N_j) nested in level-2 unit *j* (=1,. .., J). Further, X_{ij} is a vector of level-1 predictor, and ε_{ij} is disturbance term at the level-1. β represents a vector of regression parameters with *j*-subscripts, which are not fixed and which vary across the level-2. To make econometric modeling simple, assume that the state-level variation, the variation of the level-1 intercept parameter in 2.8, is random and a function of level-2 predictors and is given as

$$\beta_{0j} = \gamma_{00} + \gamma_{01} Z_{ij} + u_{0j} \qquad 2.9$$

Here γ_{00} denotes the intercept, γ_{01} is the vector of effect of the state level (level-2) parameters, Z_{ij} denotes a vector of level-2 predictors, and u_{0j} is the state level (level-2) disturbance. The econometric single equation model is derived by substituting (2.9) into (2.8):

$$Y_{ij} = \gamma_{00} + \gamma_{01} Z_{ij} + \beta_{1j} X_{ij} + u_{0j} + \varepsilon_{ij} \qquad 2.10$$

2.9. Variable Definitions

The dependent variable, energy demand, is of three types: demand for electricity, demand for natural gas, and demand for heating oil. These three dependent variables are obtained by dividing each type of household-level energy expenditure by its corresponding exogenously given price per million BTU (MBTU). As there are three demand equations for the three energy types, there are three dependent variables. For household-level electricity demand analysis, the dependent variable is the natural log of electricity demand (LELECQ). For natural gas demand, it is the natural log of natural gas demand (LGASQ), and for the heating oil demand, the natural log of heating oil demand (LHOILQ). Variable definitions and descriptive statistics are given in Table 2.1.

As the magnitude of energy consumption by or savings for each household depends on many factors, a wide range of controlled variables are considered. The most commonly controlled variables are: unit structural variables, demographic information, prices, energy-efficiency policy measures, and climate. These are controlled for purposes of analysis. Under the unit characteristics, variables controlled are number of rooms (ROOMS), unit types: whether the house is a single unit (SINGUNIT), whether the single unit is attached (SINGATTACHED), and whether the housing unit is an apartment (UNITAPRT). Other remaining unit types those are not covered under above categories are considered as other unit types (OTHERUNIT). Similarly, the demographic variables are: household size (HHSIZE), the natural log of annual household income (LINCOME), whether the household head is female (HHFEMALE), whether the householder is only English-speaking American (AMERICANHH), whether the householder is Spanish speaking (HISPANICHH), whether the householder speaks Indo-European language other than Spanish (EUROPEANHH), and whether the householder speaks Asian or a Pacific Island language (ASIANHH). Other language speaking household not covered under above four different categories is left as residual household type, “OTHERHH”.

Energy price variables are controlled to measure the effects of price on energy demand and to estimate own as well as cross price elasticities. Price variables controlled for are: natural log of price of electricity per MBTU (LELEPRICE), natural log of price of natural gas per MBTU (LNGPRICE), and natural log of price of heating oil per MBTU

(LOILPRICE). As there is a sizable difference in the number of homeowners and apartment renters, and their preferences will affect the energy amount of the energy demand, this study has controlled for homeowner (HOMEOWNER) whether the householder is the owner of the house.

Energy demand also depends on the types of heating energy. In the U.S., there are mainly three types of heating energy: electricity, natural gas, and heating oil. However, there are other types of heating fuel, although these are used only at an insignificant level. This study only controlled for those three main types of heating energy–whether the household used electricity as heating fuel (HFUELELC), whether the household used natural gas as the heating fuel (HFUELLNG), and whether it used heating oil as the heating fuel (HFUELOIL).

One of the study objectives of this analysis was to measure the effect of climate change. Both extreme climates—hot weather and cold weather—require more energy for cooling and heating, respectively. Both January temperature (JANTEM) and July temperature (JULYTEM) measured in degrees Fahrenheit (^{o}F) were considered as the proxy of cold and warm climate, respectively. The inclusion of climate characteristics representing both warm and cold weather could be used to estimate the effects of climate change on residential energy demand in the U.S., measures in an empirical analysis of interest in this study.

To estimate the effect of energy-efficiency building codes—one of the main objectives of this analysis, this study has controlled for housing units with energy-efficiency codes (EFFICIENTHH). Buildings with energy-efficiency codes as the state policy would consume less energy for the same level of output, but what is the amount that an individual household could save with this policy measure is not estimated at the consumer level. Thus controlling for EFFICIENTHH would provide this quantity. All variables definitions and the descriptive statistics are given in Table 2.1. For estimation, the policy variables, price of specific energy use and climate variables have been entered at the state level (level-2), while the rest are at the household level (level-1).

2.10. Empirical Results

This study first analyzed the assumption of independence observations, which is why multilevel modeling is recommended when intra-class correlation exists. For this, a single-equation intercept model (equation 2.6) was regressed for each energy types: electricity demand, natural gas demand, and heating oil demand. The corresponding state-level and household-level variances and intra-class correlations were estimated. The state level variance, σ_{uo}^2 , and household level variance, σ_e^2 , both are significant at the 1% level for all three types of energy: electricity, natural gas, and heating oil. Further, calculated intra-state correlations (ρ) for all three energy types are 16.52, 15.45, and 18.27, respectively. The significant values of variances, as well as models, show that the assumption of independence of error terms is violated, and the application of OLS regression is inefficient (Steenbergen & Jones, 2002). A multilevel model overcomes these limitations and produces more accurate estimates of regression coefficients and standard errors (Raudenbush & Byrk, 2002). A hierarchical estimation method is thus recommended. The rationale for using the multilevel analysis is to allow the existence of (estimating separately) the variance between households within the state, and the variance between states. Results of multilevel estimations (two-level multilevel models) are presented in Table 2.2.

2.10.1. State Heterogeneity

This study performed three econometric models separately, using the econometric estimation model given in equation 2.10 for electricity, natural gas, and heating oil demand analysis. The results of multilevel estimation showed that both random and fixed effects are highly significant. This study analyzed the amount of dependence of or intra-state correlation after running the full model. Results of estimates of state residual variance and household residual variances are presented in Table 2.2. Variance of state-level residuals for electricity demand is estimated to be 0.057, which is highly significant. Similar results were obtained for natural gas and heating oil. Both models estimated that the state-level variances are 0.015 and 0.045, respectively, for natural gas and heating oil and are highly significant. These significant variances estimates suggest that states have influence upon household-level energy demand in the U. S. and that there is a presence of state heterogeneity in the U.S. The significant values of variances explain how state affects on the energy demand in the U.S. households, and the assumption of independence of error terms is violated.

2.10.2. Effects of Building and Household Characteristics

While analyzing the residential demand for electricity, this analysis controlled for housing unit characteristics. This study found a highly significant effect of the number of rooms on electricity demand. If the number of rooms (ROOMS) is increased by one unit, the electricity demand will be increased by 5.9%. This value is less than for the British households, as reported by Baker et al. (1989), as their study reported about 13% increase in electricity demand by a unit increase in room number. Similar effects were observed for natural gas and heating oil demand. This study found that demand for natural gas increases by 4% and about 5.8% for heating oil by every increase in the number of rooms by one unit.

Likewise, results of controlling for building types found similar effects. Given that residential buildings included single-family detached and attached homes, apartments, and mobile homes in the U.S., this study has controlled for types of building single unit (SINGUNIT), single unit attached (SINGATTACHED), and apartment (UNITAPRT) controlled against other unit types (OTHERUNIT). This study found that all house type variables all were significant at the 1% level. Results indicated that if the house type is SINGUNIT all else constant the demand for electricity, natural gas, and the heating oil increased by 23.7%, 16.1%, and 10.3%, respectively. These figures are smaller if building units are single but attached and apartment types. Ewing and Rong (2008) also found similar results: attached house units required less energy compared with detached ones. Results showed that if buildings are SINGATTACHED, their effects on demand for electricity, natural gas, and heating oil increased respectively by 4.9%, 8.8%, and 9.4%.

Similarly, if the housing units were apartments, the increase in demand for electricity, natural gas, and heating oil was 5.8%, 18.7%, and 8.6%, respectively. This study indicated that coefficients of single detached house are greater (about 19 %) than the attached single housing units.

This study has controlled for household size (HHSIZE) to look at the effects of family size on energy demand. Results of this study indicated a highly significant effect of household size on energy demand. This study showed that an increase in family size by one unit increased the consumption of electricity by 8.9% and natural gas by 3.6%. Interestingly, this study found a highly significant negative effect of HHSIZE on heating oil demand. It showed about a 4% decrease in heating oil demand per unit increase in family size. This finding helps to make an argument that higher family size will share heating energy that results in a decrease in per-capita heating oil as the heating energy demand. Another argument can be made that such families could switch from heating oil to another type of energy for heating when family size increased. This should be explored further in future research.

The U.S. Census Bureau (2008) has reported that there are not an equal percentage of homeowners (69%) versus apartment renters (31%), so the acceptance of this difference will be important for some policy questions for energy supply decisions. To look for any distinct behavior for energy demand, this study has controlled for the homeowner (HOMEOWNER) dummy variable. Results showed that the HOMEOWNER variable had significant effects on energy demand. If a householder is a homeowner, then the demand for electricity increases by 6.8%. The effects on natural gas and heating oil are comparatively higher than on electricity. The demand of natural gas and heating oil increases by 12.4% and 12.8%, respectively.

To test the gender effect, this study has controlled for the female householder (HHFEMALE) categorical variable and found positive and highly significant effects on all types of energy demand. It showed that demand for electricity, natural gas, and heating oil will increase respectively by 3.6%, 5.4%, and 4.6%, suggesting that female householders will consume more energy compared with male householders.

This study controlled for four different types of household ethnic background based on their language origin: English-speaking household (AMERICANHH), Spanish speaking household (HISPANICHH), European-language-speaking household (EUROPEANHH), and Asian or Pacific Islander household (ASIANHH) against OTHERHH type while analyzing the effects of household types based on language origin background. The AMERICANHH categorical variable has a positive and significant effect on electricity demand, whereas it has a negative and highly significant effect on natural gas demand, and no effects on demand for heating oil against the base category, OTHERHH. Results of this study suggest that American households demand more electricity and their presence contributes to an increase the electricity demand by 3.0%; contrarily, their presence reduces demand for natural gas by 10.7%.

A similar result was found that Hispanic households consume less energy compared to the category, OTHERHH. The effects of the HISPANICHH categorical variable are negative and highly significant on all types of energy–electricity, natural gas, and heating oil. The corresponding significant values are 4%, 9.2%, and 8.2%, respectively. However, this study showed that the effect of European household (EUROPEANHH) is negative and highly significant only for natural gas. Results of controlling for ASIANHH show all negative and highly significant values, which is a similar result to that of Hispanic households. The significant values are 9.4%, 12.7%, and 14.4%, respectively for electricity, natural gas, and heating oil. Negative effects of both types of households suggest that these types of households consume less energy than American households. Comparing these two types of households, Asian households consume less energy of any kind compared with the energy consumption of Hispanic households.

2.10.3. Effects of Economic Variables on Energy Demand

This study has controlled for the natural log of annual household income (LINCOME) and energy price variables those are transferred into natural log to analyze the effects of economic variables on energy demand. In all three models, the effect of LINCOME is highly significant and contributes to an increase in the demand for energy with an increase in annual household income. Results of this study showed that a 1.0% increase in income will increase by 0.02% the electricity demand. Although effects of LINCOME on demand for natural gas and heating oil are positive, the estimated values are quite small. The income elasticities of demand of all these three types of energy are less than one, revealing that the demands for these energy types are income-inelastic or sticky goods. Several studies (for example, Ewing & Rong, 2008; Lam, 1998; Lee & Singh, 1994) on electricity dedicated for household electricity demand analysis reported mixed results of the effects of income. Ewing and Rong (2008) reported that the effect on demand of income is positive and significant only for high-income households in the U.S. (income greater than U.S. $75,000).

Energy demand is also price-sensitive. To measure price effects on energy demand, all prices have been converted to natural log values to get a more direct measure of price elasticities. Price variables controlled for are the natural log of the price electricity per MBTU (LELEPRICE), the natural log of the price of natural gas per MBTU (LNGPRICE), and the natural log of the price of heating oil per MBTU (LOILPRICE). All of these covariates were used in all three models: electricity, natural gas, and heating oil. This was done to get both own-price and cross-price elasticities of demand. Results showed that the LELEPRICE had a negative effect on electricity demand. Elasticity value is negative and highly significant– 1% increase in the price of electricity would reduce consumption by 0.49%. Given that the price-elasticity demand is less than one, electricity is an inelastic commodity. Bohi and Zimmerman (1984) reported residential electricity price elasticities were -0.2 in the short run and -0.7 in the long run. Maddala et al. (1997) estimated a quite low value; the mean value of price elasticity was -0.16 from 49 states of the U.S.

Electric utilities reported price elasticiteis of demand for electricity within a range of -0.15 to -0.35 (EPRI, 1989), which is lower than that which was estimated by this study. The estimated value is within the range of -0.9 to -1.0 estimated for OECD countries by Verbruggen and Couder (2003). These findings suggest that only way to reduce energy consumption would be through the application of energy-efficiency measures rather that changing the price or implementing higher taxes on energy consumption.

While analyzing the substitutability of electricity, cross-price elasticities were examined by controlling for LNGPRICE and LOILPRICE in the electricity demand model. Results of this study did not indicate any significant effect of either price variables in electricity demand, suggesting no substitutability of electricity by natural gas or heating oil. The insignificant result could be due to the use of electricity for lighting and other electrical appliances rather than only for heating and cooling purposes. Due to the lack of detailed information in the data, this study did not analyze the substitutability of electricity by natural gas and heating oil for space-heating use.

Results of natural gas demand analysis showed that its own price elasticity is negative and highly significant, which was estimated at -0.67. Bohi and Zimmerman (1984) found lower elasticity values that ranged from -0.2 for the short run and -0.3 for the long run. These values are less than one, suggesting that natural gas is also inelastic in price. The analysis of substitutability for natural gas, it was found that only the cross-price elasticity of electricity is positive and highly significant, with a value of 0.13. This shows that electricity is a weekly substitute good for natural gas.

The demand estimation for heating oil showed that the price effect on demand is negative and highly significant. The estimated value of own-price elasticity was -2.52, which is greater than one. This higher value (greater than one) suggests that heating oil is an elastic good. This information is useful to oil suppliers to control the price rise, as higher prices would reduce their revenue. Further, this study found the cross-price elasticity (electricity price effect) on heating oil is positive and highly significant—a value of 0.65—suggesting that if the price of electricity were to increase by 1%, households would substitute electricity by heating oil by 0.65%. This finding is important for both electricity suppliers and heating-oil suppliers.

2.10.4. Heating Fuel Types and Effects on Demand

This study has analyzed the effect of heating fuel on energy demand. For this, it has controlled for three types of heating fuels: heating by electricity (HFUELEL), heating by natural gas (HFUELLNG), and heating by using heating oil (HFUELOIL), which are most commonly used in space heating in residential buildings the U.S. All three controlled covariates showed positive effects on energy demand. This study showed that demand for electricity would increases by 0.23 times if houses were heated by electricity. A similar result has been obtained for natural gas. It is found that if households used natural gas for heating, it would have a positive and highly significant effect on demand for natural gas, and this demand increases by 0.94 times. Likewise, the effect of covariate HFUELOIL has positive and highly significant effects on the demand for heating oil. Controlling for HFUELOIL increased the demand for heating oil by 0.35 times. Comparing this with the amount of effects of other categorical variables, the effect of HFUELEL on electricity demand and the effect of HFUELLNG on natural gas demand, indicated that households use more electric items, along with the electricity that is used for heating. This information is useful for natural-gas suppliers. An increase in efficiency in natural gas utilities could encourage households to use more gas compared with electricity. However, such differences between electricity and heating oil are not much compared to their differences with natural gas.

2.10.5. Effects of Climate on Energy Demand

Effects of climate change are one of the major interests of this study. Global climate change is making the U.S. and the world's climate significantly warmer; consequently, an impact on residential energy use is expected. Impacts are in terms of derived demand for heating and cooling. While analyzing the effect of global warming on residential energy demand, two main contrasting effects have been considered: the heating effect, which is the decrease in the use of energy for heating purposes, and the cooling effect, which is the increase in energy demand for cooling (Cian et al., 2007). To analyze these two opposing effects, this study has controlled for both July (JULYTEM) and January (JANTEM) temperatures as proxies for winter and summer temperatures, respectively. Controlling for these climate variables will enable estimates to be made for the effects on cooling and heating demand for energy. Results of the electricity demand model show that the effect of the JULYTEM is weakly significant on electricity demand. Results showed that increase in 1^{o} F (Fahrenheit) of July temperature would cause an increase of 0.8% in electricity demand. This positive effect is due to the cooling effect, that is, that electricity is used for cooling homes during the summer. Mansur et al. (2008) reported a similar kind of result. Their study showed that about a 5% increase in electricity demand for a corresponding 1^{o} C increase in July temperatures.

The effect of JANTEM was found negative and significant. These results showed that a $1^{o}F$ change in January temperatures would result in decrease of -0.5% in electricity demand. The negative effect on January temperature is due to less amount of heating required if temperature rises. The difference between the cooling effect and the heating effect shows that global warming will increase consumption in electricity more during the summer than during the winter and that in total, there would be an overall increase in residential electricity consumption.

Likewise, the effect of global warming was tested for the demand for natural gas. This study found that July temperatures do not have any significant effect on natural gas demand, whereas January temperatures have a negative and significant effect. This suggests that natural gas is used for heating and that when temperatures rise, its demand falls. Results suggested that a 1^{o} F increase in January temperatures would decrease natural gas demand by 1%. This result is little less than what Mansur et al. (2008) had reported. Their study showed that there would be a decrease in the demand for natural gas by about 4% due to a 1^{o} C rise in temperature. An analysis of the effects of July and January temperatures on heating oil demand showed that only January temperature has any effect on heating oil demand. Results showed that a 1^{o} F increase in January temperatures would reduce heating demand by 2.3%, which is about 1.8% less than estimated by Mansur et al. (2008). While summarizing the effect of potential global warming, only residential electricity demand would be increased, whereas demand for the other two major energy commodities—natural gas and heating oil—would be reduced.

2.10.6. Effects of Energy Efficiency Building Codes on Energy Demand

One of the major interests of this chapter was to estimate the effect of energy-efficiency policy measures on the demand of residences for energy. The findings of this research could offer an important guideline for policymakers and households to make decisions about investing for energy efficiency. To investigate the effect of energy-efficiency building codes, policy variables have been endogenized. If policy is endogenous, then the estimated effects of policy will give biased results if policy is treated as exogenous (Copeland, 2005). A logit estimation approach was applied with instrumental variables. The instruments were state-level revenue per capita, ruling political party in the state and a coal-mining state dummy. This study controlled for buildings with energy-efficiency building codes (IECC 2003; IECC 2006), using EFFICIENTHH, a categorical variable that could explain its effect on energy demand. Results of this empirical model showed that the effects of EFFICIENTHH were negative and highly significant on estimates for all types of energy demand. The results of the electricity demand model showed that buildings with such efficiency codes would reduce electricity demand by 1.8% at the household level. This estimate is exactly the same as what the *Annual Energy Review* (EIA 2009) reported at the aggregate level. According to the EIA (2009), a total reduction in electricity demand of 1.8%, with corresponding savings, was achieved during the year 2007. At the aggregated level, Arimura et al. (2009) estimated savings on electricity expenditure of about 1.1% at a weighted average cost to utilities during 2006. However, this value is a nationwide average, and actual results varied from state to state. For example, the California Energy Commission (CEC

2008) reported a savings of 1.2% of residential electricity consumption, whereas Vermont reported a 2.5% savings during 2008 (Efficiency Vermont, 2008).

A similar effect of EFFICIENTHH has been reported on natural gas demand. The effect is negative and highly significant. Results showed that the adoption of such energy-efficiency codes would reduce demand for natural gas by 1.3%. Likewise, the adoption of this policy measure had a negative effect on the demand for heating oil. Controlling for EFFICIENTHH in heating oil demand resulted in a highly significant negative effect, with a marginal result of -0.028. This suggests that households with such energy-efficiency codes would reduce their demand for heating oil by 2.8%.

There are about 120 million homes that have not been affected by the adoption of such policy measures, indicating a huge potential for savings through the implementation of such policy measures. If such policy measures could be effectively applied in these huge numbers of homes, a large amount of savings on energy consumption could be made, with corresponding reductions in the emissions of the global warming gas CO_2. This study found a potential reduction in the consumption of energy per year (see Table 2. 3). It reported that 0.99 MBTU of electricity per year, 0.55 MBTU of natural gas, and about 1.08 MBTU of heating oil per year could be saved, which is a remarkably important piece of information for policymakers. Further, this study found that about 7.54 MMT per year of CO_2 emissions (see Table 2.3) into the atmosphere could be eliminated if energy-efficiency building codes were adopted by all households in the U.S.

Questions arise as to why such policy measures have not already been adopted. To respond to such questions, economists have presented several arguments (see Gillingham, 2009): hidden costs of implementation and higher initial costs of investment for energy saving and future energy prices are the main concerns for the residential sectors. Few studies, for example, Sutherland (1991) and Soest and Bulte (2001), have argued that consumers are indecisive about investments for energy efficiency because of the associated cost of investment and the option of waiting to invest later. This study has clearly given encouraging information to homeowners that the adoption of energy-efficiency building codes could save about 2.0% of overall household energy consumption per month. However, a benefit-cost analysis of energy-efficiency building codes and households' marginal willingness to pay are important research questions to explore further to make a firm recommendation for the adoption of the energy-efficiency codes and public and private investments in them.

Finally, this study estimated the average residential demand for electricity, natural gas, and heating oil (see Table 2.4). The estimated national average values are 1,342 kWh per month for electricity, 3,429 CFt[8] per month for natural gas and 277 gallons per year for heating oil. This study found that New York State has the lowest per-capita consumption of electricity (867 kWh per month), while and the highest per-capita consumption occurred in Kentucky (1,698 kWh per month) (see Figure 2.1). Similarly, it found Hawaii to consume least for natural gas (1,036 CFt per month) and Utah to consume the most (6,883 CFt per month) (see Figure 2.2). Likewise, this research found Louisiana to consume the least amount of heating oil per capita (123 gallon per year) and New Hampshire the most (632 gallon per year) (see Figure 2.3). This study estimated total residential energy consumption for all states in the U.S. It found that total energy consumption per year ranged from a low of 80 MBTU (in Hawaii) to a high of 177

[8] Cubic Feet

MBTU (in Utah) (see Table 2.5 and Figure 2.4). However, there is a wide variation of types of energy uses. While analyzing the substitution of one type of energy consumption for another, it found that out of the given total energy consumption, natural gas and heating oil were found to be substitutes for electricity (see Figure 2.5.).

2.11. Conclusions

This chapter has proposed open empirical questions of whether energy-efficiency building codes and climate characteristics were important determinants of residential energy demand. Further, another question addressed in this analysis was what would be the most appropriate selection of econometric estimation measures to get efficient and reliable results. First, to get efficient results, an analysis of assumption of independence of observations was analyzed for each type of energy. Until this analysis, it was not known that this assumption was violated in previous estimates. This violation was corrected by applying a multilevel modeling, estimated using intra-class correlations. This study found the existence of state-level heterogeneity across the states of the U.S. These variations have been considered while estimating the various energy demands. Using a large data set obtained from American Community Survey 2007, controlling for state-level variations was possible.

A considerable finding of this study was the significant effect of household-related structural variables. For example, an attached single-family home will save substantially more energy compared to the detached unit of the same kind, keeping all other variables constant. While estimating the effects of economic variables: income and price of energy, this study found that all energy types are inelastic; however, demand for energy increases with income. Similarly, this study also reported that own price elasticities are negative, and findings support the economic theories. Important information on energy substitutability was found between natural gas and electricity, as well as between heating oil and electricity. If the price of electricity increases, the demand for both natural gas and heating oil increases.

The important finding of this study is that an increase global temperature increases the consumption of electricity. However, for natural gas and heating oil, the demand for these two types of energy will be lowered, revealing that global warming will reduce the consumption of both of these types of energy.

Finally, the main interest of this study was to estimate the effect of energy-efficiency building codes (IECC 2003 and IECC 2006). This study found that the energy-efficiency codes would reduce the demand for energy. These findings offer an important road map for policymakers and households to make decisions on investments for energy efficiency. This finding provides information for homeowners, energy suppliers, and producers of efficient technologies for a given climate change scenario and increasing demand for electricity. We need to emphasize the importance of adopting energy efficiency as a policy measure that provides solutions that address issues of climate change, energy security and rising energy costs.

To encourage households to adopt such policies, a benefit-cost analysis should be conducted, based on ex-post data. Further, an analysis of the willingness to pay for such policy measures would substantiate the willingness to adopt the energy-efficiency building codes, regardless of their high initial cost of the related investment. Government should provide incentives to households for a successful implementation of such energy efficiency policy.

Table 2.1. Variable Definitions and Descriptive Statistics

Variables	Definitions	Mean	Std Dev
	Dependent		
LELECQ	Natural log of Electricity consumption	1.499	0.543
LGASQ	Natural log of Natural Gas consumption	1.165	0.994
LHOILQ	Natural log of Heating Oil consumption	0.622	1.327
	Independent		
ROOMS	Numbers of rooms in house	5.833	1.796
SINGUNIT	If house is Single Unit, Binary	0.703	0.457
SINGATTACHED	If house is Single Unit Attached, Binary	0.055	0.228
UNITAPRT	If house is Apartment Unit, Binary	0.029	0.167
OTHERUNIT	Other remaining unit types not covered in other categories	0.216	0.189
HHSIZE	Number of persons in house	2.504	1.414
HOMEOWNER	If householder owns home, Binary	0.775	0.418
LINCOME	Natural log of annual household income	10.701	1.327
HHFEMALE	If householder is Female, Binary	0.110	0.312
AMERICANHH	If householder is English-speaking household, Binary	0.824	0.381
HISPANICHH	If householder is Spanish speaking household, Binary	0.096	0.294
EUROPEANHH	If householder is European-language-speaking household , Binary	0.044	0.206
ASIANHH	If householder is Asian or Pacific Islander language speaking household, Binary	0.028	0.165
OTHERHH	Other residual household types not covered in any category	0.012	0.124
LNGPRICE	Natural log of natural gas price per million Btu	2.645	0.190
LOILPRICE	Natural log of heating oil price per million Btu	2.886	0.045
LELEPRICE	Natural log of price of electricity per million Btu	3.426	0.262
HFUELLNG	If house heating fuel if Natural Gas, Binary	0.493	0.500
HFUELELC	If house heating fuel is Electricity, Binary	0.318	0.466
HFUELOIL	If house heating fuel if Heating Oil, Binary	0.079	0.269
JULYTEM	July Temperature in °F	77.054	4.267
JANTEM	January Temperature in °F	42.060	9.253
EFFICIENTHH	Housing unit with energy efficiency codes	0.093	0.252

Notes:
1. Number of observations = 1,137,886

2. Data sources:
i. ACS Public Use Microdata Sample (PUMS) 2007 1-Year U.S. Census Bureau. Available at http://factfinder.census.gov/home/en/acs_pums_2007_1yr.html.
ii. Building Codes for energy Efficiency. U.S. Department of Energy 2007. Available at http://www.epa.gov/rdee/documents/buildingcodesfactsheet.pdf.
iii. U.S. Climate at a Glance 2007. Available at http://climvis.ncdc.noaa.gov/cgi-bin/state-map-display.pl.
iv. Residential Sector Energy Price Estimates by Source, 2007. Energy Information Administration, U.S. Department of Energy. Available at http://www.eia.doe.gov/emeu/states/sep_sum/html/sum_pr_res.html.

Table 2.2. Results of Multilevel Models

Variables	Electricity Demand Model	Natural Gas Demand Model	Heating Oil Demand Model
Fixed Parameters			
Intercept	1.894**	2.435*	8.726***
	(0.939)	(1.405)	(2.438)
ROOMS	0.059***	0.040***	0.058***
	(0.0002)	(0.0005)	(0.002)
SINGUNIT	0.237***	0.161***	0.103***
	(0.0009)	(0.002)	(0.009)
SINGATTACHED	0.049***	0.088***	0.094***
	(0.002)	(0.004)	(0.015)
UNITAPRT	0.052***	0.187***	0.086***
	(0.002)	(0.005)	(0.018)
HHSIZE	0.089***	0.036***	-0.041***
	(0.0003)	(0.0005)	(0.002)
HOMEOWNER	0.068***	0.124***	0.128***
	(0.001)	(0.002)	(0.009)
LINCOME	0.022***	0.002***	0.008***
	(0.0003)	(0.0006)	(0.002)
HHFEMALE	0.036***	0.054***	0.043***
	(0.001)	(0.002)	(0.008)
AMERICANHH	0.033***	-0.107***	-0.009
	(0.004)	(0.008)	(0.027)
HISPANICHH	-0.0405***	-0.092***	-0.082***
	(0.005)	(0.008)	(0.029)
EUROPEANHH	-0.005	-0.075***	-0.025
	(0.005)	(0.009)	(0.029)
ASIANHH	-0.094***	-0.127***	-0.144***
	(0.005)	(0.009)	(0.033)
LELEPRICE	-0.495***	0.138**	0.652***
	(0.047)	(0.071)	(0.124)
LNGPRICE	-0.038	-0.674***	0.255
	(0.076)	(0.109)	(0.190)
LOILPRICE	-0.168	-0.423	-2.525***
	(0.302)	(0.451)	(0.782)
HFUELLNG	-	0.944***	-
		(0.002)	
HFUELELC	0.237***	-	-
	(0.0009)		

Variables	Electricity Demand Model	Natural Gas Demand Model	Heating Oil Demand Model
	Fixed Parameters		
HFUELOIL	-	-	0.353***
			(0.006)
JULYTEM	0.008*	0.011	-0.008
	(0.004)	(0.007)	(0.012)
JANTEM	-0.005**	-0.010***	-0.023***
	(0.002)	(0.003)	(0.006)
EFFICIENTHH	-0.018***	-0.013***	-0.028**
	(0.001)	(0.003)	(0.012)
	Random Parameters		
Level -2: Between States	0.0057***	0.0150***	0.0446***
	(0.0011)	(0.0029)	(0.0090)
Level-1: Between Households	0.1752***	0.5611***	0.9355***
	(0.0002)	(0.0007)	(0.0032)
Intra-States Correlation in %	3.2	2.6	4.5
n	1,128,876	1,059,772	164,258

Notes:
1. Standard errors are given in parentheses.
2. ***, **, and * represent values that are significant at the1%, 5%, and 10% levels, respectively.

Table 2.3. Reduction of CO_2 Emission in Million Tons per Year due to Energy-Efficiency Building Codes in U.S. Households

Energy Types	Saving in Energy Consumption in Million Btu per year per Household	No. of Households in Million	Total Reduction of CO_2 Emission in Million Tons per year per Household
Electricity	0.99	52.80	4.94
Natural Gas	0.55	65.70	1.92
Heating Oil	1.08	8.50	0.68
			Total Saving = 7.54 MMT

Table 2.4. Predicted Residential Energy Demand per Household in U.S. at the 95% C.I. Level

Energy Type	Predicted Value in Natural log of Million Btu	Estimated Value at Household level
Electricity	1.522***	1,342 kWh/Month
	(0.027)	
Natural Gas	1.258***	3,429 CFt/Month
	(0.040)	
Heating Oil	3.654***	277 Gallon/Year
	(0.068)	

Notes:
1. Standard errors are given in parentheses.
2. ***, **, and * represent values that are significant at the 1%, 5%, and 10% levels, respectively.

Table 2.5. Prediction of Energy Demand per Household per Year by States in Million BTUs

State	Electricity	Natural Gas	Heating Oil
Alabama	68.834	29.145	20.071
Alaska	38.140	70.319	52.899
Arizona	62.959	35.189	20.435
Arkansas	63.208	40.355	20.282
California	46.050	56.278	23.191
Colorado	52.029	71.981	34.471
Connecticut	40.054	35.076	61.868
Delaware	53.841	35.784	41.676
Dist. of Columbia	49.574	42.165	29.089
Florida	65.946	18.544	21.106
Georgia	67.960	33.717	22.853
Hawaii	43.222	12.782	24.520
Idaho	65.574	48.302	29.965
Illinois	58.531	70.069	25.276
Indiana	60.567	51.921	26.934
Iowa	53.912	59.523	36.789
Kansas	63.555	58.727	24.861
Kentucky	69.550	38.495	23.002
Louisiana	68.173	36.030	17.164
Maine	37.699	30.750	81.904
Maryland	59.994	38.440	33.829
Massachusetts	38.484	40.223	68.054
Michigan	49.301	62.645	39.051
Minnesota	54.305	58.773	44.935
Mississippi	64.097	35.548	18.540
Missouri	66.569	44.543	25.065
Montana	55.563	51.634	37.290
Nebraska	65.796	57.645	26.661
Nevada	48.503	52.156	29.171
New Hampshire	39.813	34.235	87.941
New Jersey	46.998	54.084	37.566
New Mexico	52.522	53.819	27.235
New York	35.524	46.039	63.366
North car	63.163	29.748	29.515
North Dakota	61.877	48.908	37.621
Ohio	55.852	53.644	35.070
Oklahoma	65.752	50.900	21.843
Oregon	60.873	36.118	32.478
Pennsylvania	50.865	40.161	46.604

State	Electricity	Natural Gas	Heating Oil
Rhode Island	40.517	40.061	54.191
South Carolina	67.891	28.791	24.351
South Dakota	61.828	51.312	33.592
Tennessee	68.996	35.893	22.102
Texas	57.630	42.096	20.519
Utah	63.727	84.915	28.884
Vermont	40.243	33.132	61.615
Virginia	64.899	34.597	32.845
Washington	63.275	33.497	19.061
West Virginia	67.856	40.060	27.101
Wisconsin	48.808	53.414	45.607
Wyoming	55.834	60.588	34.374

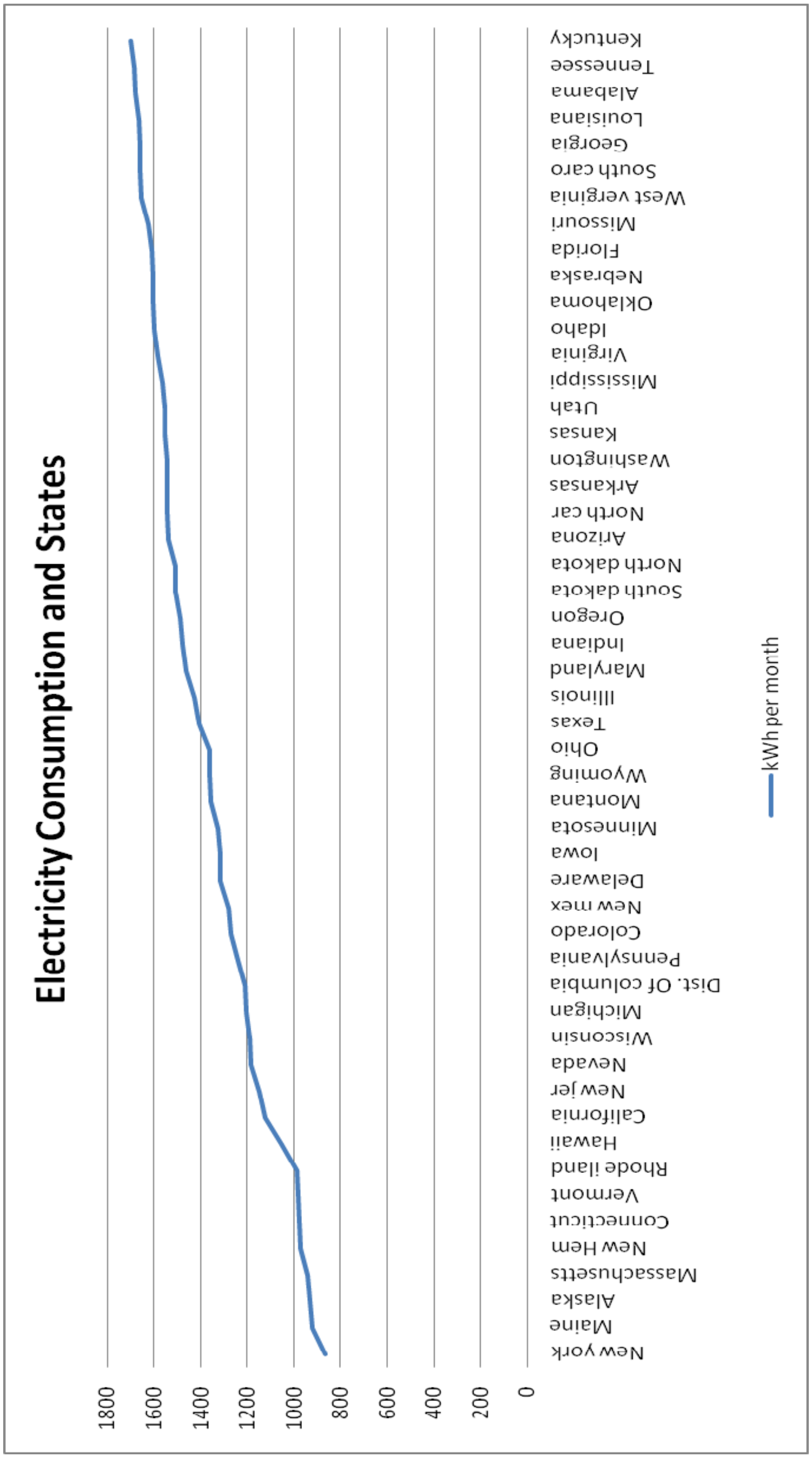

Figure 2.1. Monthly Household Electricity Consumption in kWh in the U.S. by States in an Increasing Order

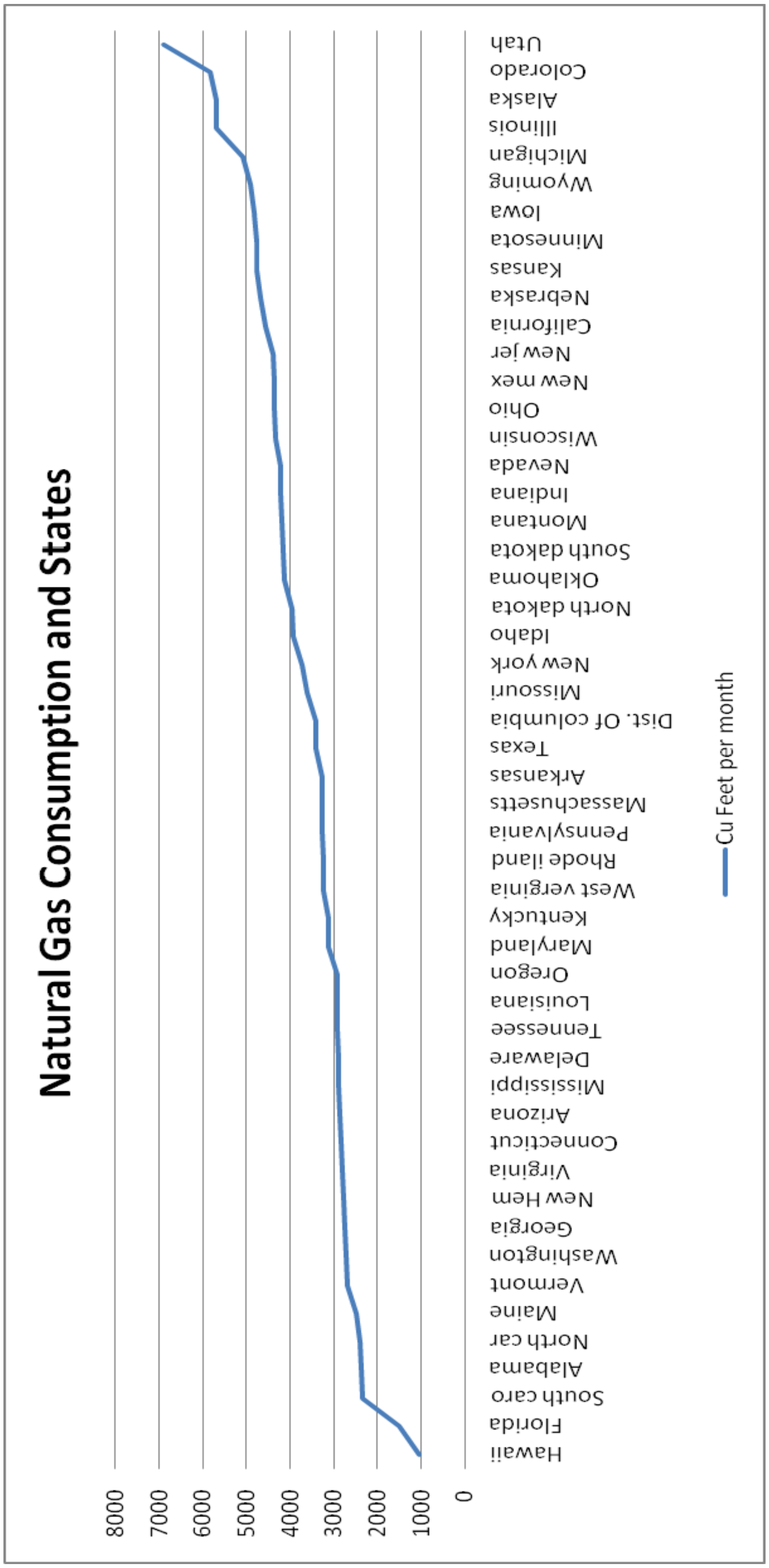

Figure 2.2. Monthly Household Natural Gas Consumption in CFt in the U.S. by States in an Increasing Order

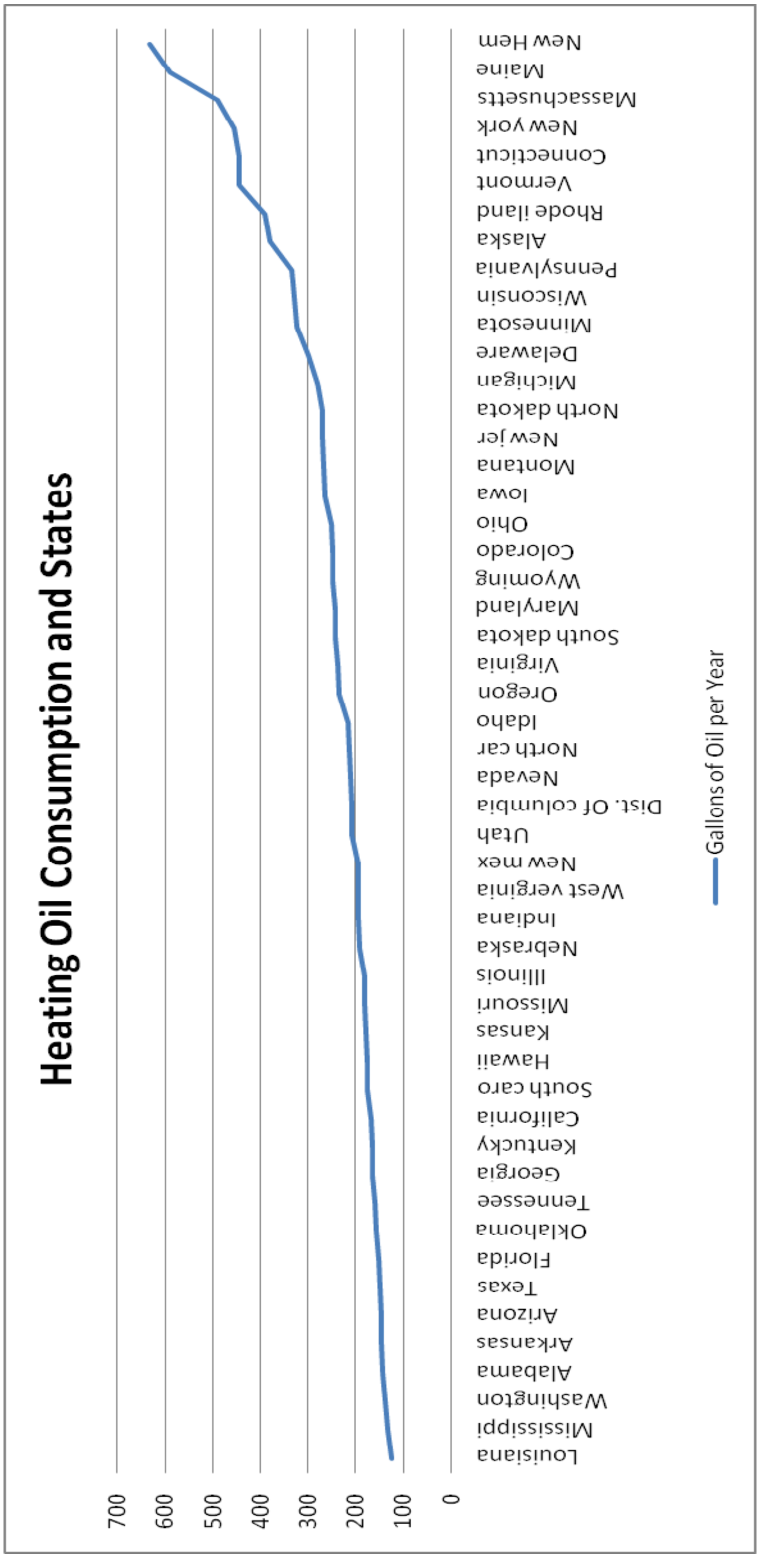

Figure 2.3. Yearly Household Heating Oil Consumption in Gallons in the U.S. by States in an Increasing Order

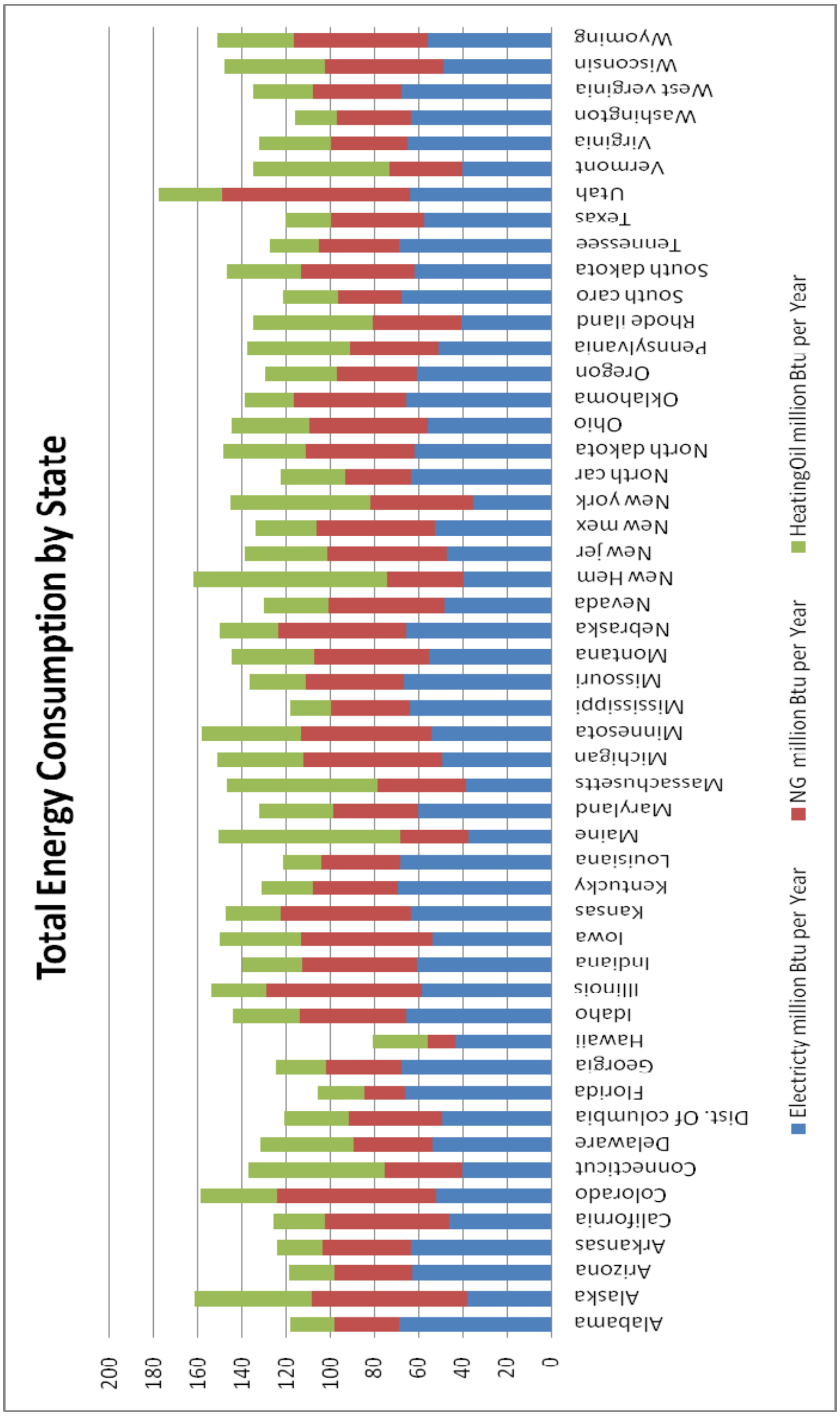

Figure 2.4. Yearly Household Total Energy Consumption in Million BTUs in the U.S. by States

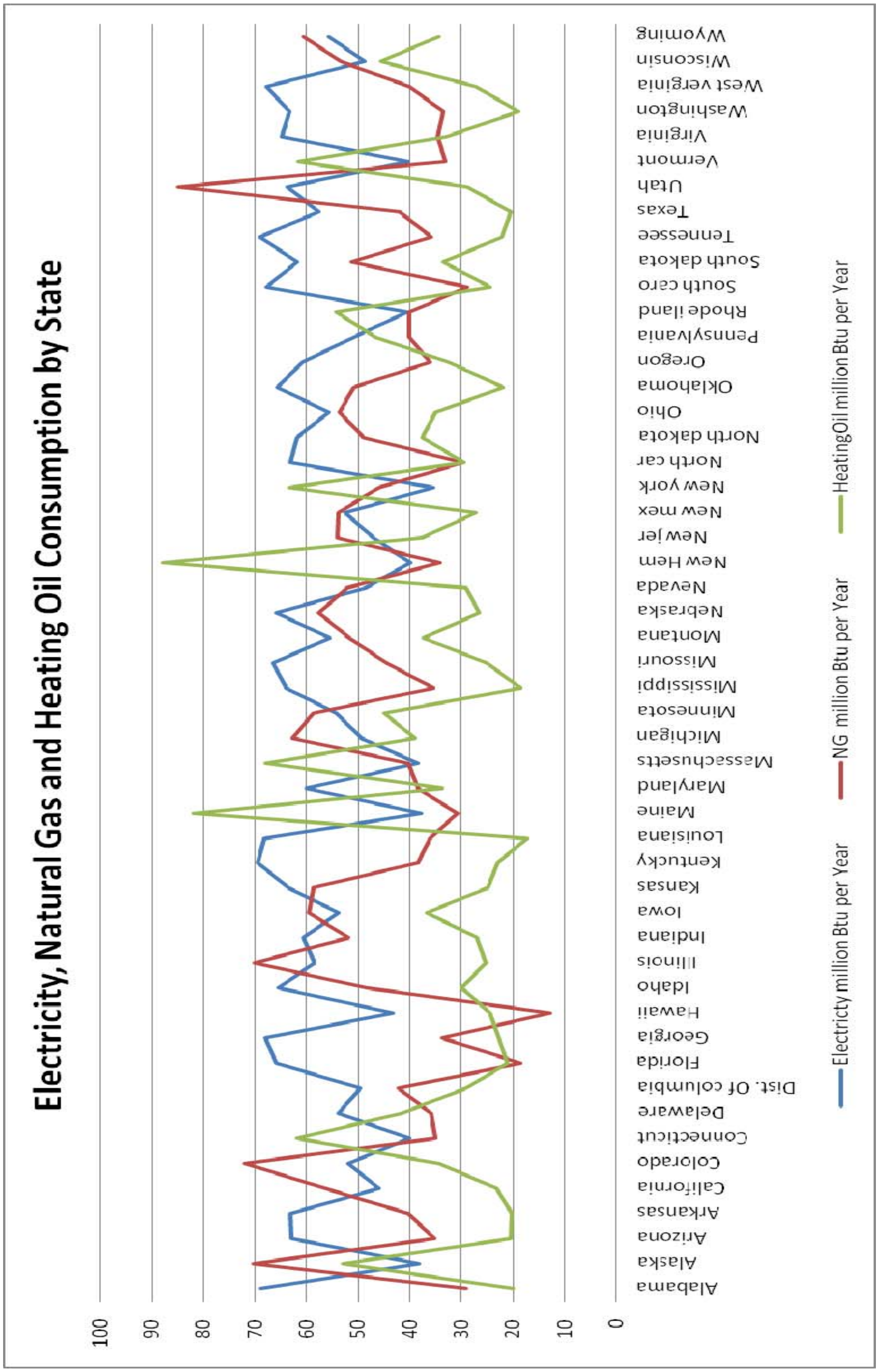

Figure 2.5. Yearly Household Consumption of Electricity, Natural Gas, and Heating Oil in Million BTUs in the U.S. by States

Chapter 3: Valuing U.S. Climate Amenities for Homeowners and Renters Using a Hedonic Pricing Framework

3.1. Introduction

Climate provides both an amenity and a disamenity that affects households' location choices. Cities with good climates (amenity) attract workers for jobs, which increases the demand for housing and lowers the demand for labor. As a consequence, housing values increase and wage rates decreases with amenity and vice versa. Climate further influences the level of expenditure on food, clothing, health, heating and cooling of housing units, recreation activities, etc. This factor of climate-related expenses persuades an individual to choose a location with the preferred climate, one that maximizes the individual's utility, subject to budget constraint.

An individual's utility-maximizing choice of location will have a direct effect on firms' investment decisions in the real-estate market, recreational market, and other commodity markets. Besides this, climate also affects firms directly; however, its effects are different from households. A firm may experience higher cooling costs due to higher temperature during summer and a lower during the winter or it may experience higher heating cost due to lower temperature in winter. Thus, there are several ways in which climate affects both consumers' utility and producers' welfare. Hence, estimating the effect of climate change has an economic meaning, and determining the amenity values of U.S. climate in various locations could provide information required to design adaptation policies for climate change that could help to reduce the damage arose by the global warming.

The primary empirical question of this study is whether climate characteristics that vary across the United States are in fact amenities that significantly affect housing prices and wage differentials. An estimate of the compensating differential provides an implicit dollar value for even a small change in climate, as reflected in January and July temperatures. This study estimates the marginal effects of climate on housing prices and wages and measures marginal willingness to pay for the climate as an amenity in the United States.

A number of previous studies have estimated the implicit price of climate using a hedonic approach (e.g., Blomquist et al., 1988; Roback, 1982). These studies did not investigate the effects of winter and summer temperatures on housing price or rent and wage rate explicitly that give a marginal willingness to pay for climate change. Their studies assumed that homeowners and apartment renters had homogeneous preferences for climate, which is another fundamental issue. According to the U.S. Department of Housing (2001), homeowners and apartment renters behave differently and are not homogeneous in their housing expenditures (HUD, 2001). If climate preferences are heterogeneous, the estimated amenity values of climate under this assumption are inefficient. This study explicitly tests whether renters and homeowners have the same preferences for climate amenities and estimates the amenity values for both types of households.

If the dependent variables are correlated to each error term, this creates a serious problem in the accuracy of the estimates. Allowing the cross-equation correlation in estimation provides an opportunity to capture the unobserved characteristics of individuals that influence the decision of where to work and where to live, as well as capturing the measurement error and the simultaneity between housing prices and wages. One of the objectives of this study is to provide consistent and efficient estimates that overcome the omission bias problem.

This study contributes in the literature in three main respects. First, as noted earlier, global climate change is already occurring, and the mean U.S. temperature is increasing at an average decade rate of almost 1° F (0.6° C) (IPCC, 2001). Therefore, it is required that a detailed analysis of the variable of temperature with more observations be conducted. Further, data for this study provide micro-level information on housing characteristics, including detailed information on unit structure and neighborhood, wage, and demographic characteristics. Second, as the preferences of homeowners and apartment renters are not homogeneous regarding amenity and expenditure choices, it estimates the amenity values of climate for both types of households separately. As there is a sizable difference in the number of homeowners and apartment renters and as their respective preferences will affect housing prices and wage rates, a separate analysis for homeowners and apartment renters is required to predict the amenity values efficiently. Third, this study addresses the cross-equation correlation problem for an accurate and efficient estimate.

3.2. Existing Literature

Literature on the hedonic method begins with Ridker and Henning's (1967) study on the effect of local amenities on land prices. However, Hoch and Drake (1974) were among the first to estimate preferences for various climates. They estimated wage differentials of the U.S. climate for different occupations and showed that climate variables are significantly correlated with wages. Their study reported that wages are lowered for a higher mean summer temperatures. With his seminal paper on what he termed *hedonic prices*, Rosen (1974) provided a theoretical model that postulated that the product prices of characteristics associated with each good are reflected implicitly. He proposed that hedonic prices are formulated by a spatial equilibrium in which the entire set of implicit prices guides both consumer and producer location decisions.

Roback (1982) added a more detailed analysis of hedonic theory to Rosen's (1974) work and applied the hedonic method to estimate the effects of climate on both housing prices and wages. Both Rosen (1974) and Roback (1982) argued that the implicit price of an attribute represented marginal benefits to consumers and marginal costs to the firm. Hence both sides of the market have to be considered to get the marginal value changes in amenities. The underlying idea behind the hedonic estimation approach is that individuals will freely select from differentiated localities that maximize benefits from locations that collateralize into property prices and wages. As compared with other methodologies, the hedonic approach compares areas where it is assumed that all possible cost-minimizing adaptations to climatic differences have already been made.

Since Rosen (1974) and Roback (1982), more frequent applications of the hedonic approach to estimate the amenity values of locations have been made. However, studies of the effect of amenities on property values and wage rates in tandem are very few. Blomquest et al. (1988) estimated amenity values in U.S. cities, adapting the Roback (1982) approach. Their analysis allowed both intracity and intercity variation of climate amenity in U.S. cities, which is an extension of the Roback estimation approach. Their study used household expenditures in place of housing prices and six different climate variables except temperature. Results were mixed in signs and coefficients.

Maddison and Bingo (2003) estimated amenity values of Italian climates and suggested that Italians preferred drier climates during the winter and lower temperatures during the summer. They included the quadratic form of climate variables to see the positive and negative effects of these controls. Similarly, Rehdanz and Maddison (2004) used the hedonic approach to measure the amenity value of climate in Germany and found that while climate amenities strongly affect housing prices, there is less of an impact of climate on the wage rate. They used two separate hedonic wage rates and house price regressions for their estimation. Rehdanz (2006) conducted a similar study to estimate the climate-change effect on housing prices and wages in Great Britain by using a single hedonic model. This study suggested, as in Germany and Italy, that British households prefer higher January temperatures and decreased precipitation during January.

Although applications of the hedonic models are increasing, criticism of this approach (see Maddison, 2001) has included questioning of the assumptions about the free cost of mobility; free mobility is not always possible. Maddison (2001) argued that approach other than hedonic approaches are required to estimate the effect of the climate amenity on property prices, as mobility is not always free due to cultural ties or language barriers. He further argued that due to weak complementarity and weak substitutability, there exists either a commodity bundle or a price vector at which the marginal utility of any additional environmental amenity becomes zero. The alternative approach to estimating the implicit price of the climate amenity is to observe the consumption of marketed goods (Maddison, 1998, p. 2). This approach uses differences in consumption between different countries to explain the effect of climate. Kahn and Cragg (1996) suggested a discrete choice model as another approach to estimate the demand for climate amenity. The idea behind the use of the discrete choice model is that migrants will make their location choices to reveal their willingness to make a tradeoff of private consumption for local amenities. This approach uses income-amenity tradeoffs that are implicit in the discrete choice of location by migrants.

Although there remain few other approaches to estimate the implicit price of an amenity, the hedonic estimation approach is widely used for the estimation of the implicit price of the amenity (Bartik, 1988; Ekeland et al., 2004; Hand et al., 2008; Hoch & Darke, 1974; Maddison & Bingo 2003; Mueller 2005, Nordhaus, 1996; Roback, 1982). The strength of the hedonic approach compared with other methods is that it compares areas where the cost-minimizing adaptations to climatic differences have already occurred, so in those areas, there is no further incentive for firms or households to relocate. However, a hedonic analysis generally overlooks a problem of market segmentation. Hedonic estimation methods suffer from a market segmentation problem if the mobility between locations is constrained; then the hedonic estimations encounter unstable pricing and wage functions across these locations. This problem can be overcome either by running separate models for each location, as suggested by Straszheim (1974) or by controlling for regions using region dummies, as done by Rehdanz (2006).

One issue with the hedonic estimation model is not having proper functional forms for hedonic price and wage functions. The hedonic literature has suggested that different sets of functional forms can be applied in any empirical analysis. For example, Rehdanz (2006) found the linear model to be the most consistent. However, Maddison and Bingo (2003) reported using the semi-log model, while Blomquist et al. (1988) applied the Box-Cox transformation. Therefore, there is no single functional form applicable to all data sets; rather, appropriate functional form depends on the types of dependent and explanatory variables to be used in the estimation. Rosen (1974), Goodman (1978), and Halvorsen and Pollakowski (1981) recommended applying the goodness-of-fit criteria to define the best functional form to get the most accurate estimate of hedonic models.

Another issue with the hedonic method is the selection of appropriate variables. Owing to the risk of excluding important variables that affect the estimation of hedonic models, there is always a tendency to include more and more variables in any analysis, as these additional variables may explain the hedonic estimations. But the inclusion of unnecessary variables may result in an increased variance or lead to a multicollinearity problem or both (Freeman, 1993; Gilley & Pace, 1990; Reichert & Moore, 1986). Therefore, the selection of variables that could explain the relationships between the dependent and the explanatory variables must be checked for the colinearity problem in hedonic estimation methods.

Most of the hedonic studies for climate amenities are not consistent with other studies in terms of their use of climate variables, and this inconsistency has affected the results. For example, Maddison and Bingo (2003) used the average of January and July temperatures, precipitation, and sky clarity to estimate the amenity value of climate for Italy, whereas Rehdanz and Maddison (2004) applied average January and July temperatures and precipitation, but did not include sky clarity for their study of Germany. Kahn and Cragg (1996) controlled for average annual temperature, precipitation, sunshine, and humidity, along with average January and July temperatures, but they did not use January and July average precipitation data. Blomquist et al. (1988) only used heating and cooling degree-days rather than mean January and July temperatures. Therefore, there is a wide variation in the climate variables used in hedonic estimation methods, making it difficult to compare the results of the various studies.

A similar problem of inconsistency between various sources occurs when controlling for the structural characteristics of houses. For example, Blomquist et al. (1988), Kahn and Cragg (1996), and Maddison and Bingo (2003) have controlled for house unit structural attributes that have a direct effect on the unit price, such as the number of bedrooms, the number of bathrooms, the age of the unit, etc., whereas Rehdanz (2006) did not include data for these measures.

Although there have been numerous studies on the effect of climate on property values and wage rates, there is still a lack of consensus on the signs and the magnitude of the effects of climate on welfare and the use of different variables and estimation techniques. This study will address this issue of prior inconsistencies in study methodology by considering housing prices, climate variations, and wage differentials for both homeowners and apartment renters separately in the United States.

3.3. Theory of Hedonic Wages and Housing Prices

The primary empirical question of this paper is whether climate characteristics that vary across the United States are amenities that significantly affect housing prices and wage differentials. A number of empirical studies have shown that the climate characteristics unambiguously affect housing and labor markets (Hoch & Darke 1974; Rehdanz, 2006; Rehdanz & Maddison, 2004; Roback, 1982).

The main theoretical question to analyze is whether climate variation across the U.S. generates compensating differentials. In other words, if individuals value climate as an amenity, is the individual willing to pay for this amenity, and is that willingness to pay observable in housing prices and in labor markets? Applied first by Rosen (1974), the idea of compensating differentials in the housing market and the labor market is that when individuals engage in these markets, they are purchasing a bundle of characteristics tied to a heterogeneous good in the market. The heterogeneous good that can be of relevance to the climate is where an individual lives and works. An individual living in Albuquerque, New Mexico may enjoy moderate winter temperatures, may be able to gain easy access to outdoor recreation, and may experience lower expenses for electricity or natural gas for home heating. In contrast, an individual living in Boston, MA, although that is a big and vibrant city, may experience more frigid winter temperatures and fewer outdoor activities, and that individual may have to spend a significant amount of money on winter heating bills.

Climate also affects human health and medical costs, which vary from place to places. In addition, the labor market opportunities are different in different parts of the country. These differences characterize the bundle of amenities, concerning which people have preferences. These differing bundles of amenities and individual preferences may lead to compensating differentials (Rosen, 1974).

Roback (1982) undertook a comprehensive study of the effect of climate variation on wages and property values following the hedonic approach pioneered by Rosen (1974). Her seminal analysis pointed out the existence of wage compensations and housing price differentials due to the climate amenities. To capture compensating differentials and housing prices affected by climate, this study proposes a similar type of analysis. Consumers compete implicitly for climatic goods in two markets: the housing market and the labor market. Consumers are willing to pay higher property prices for a house in a preferred location, and they may accept lower wage rates if they can secure work in their preferred location (Rehdanz, 2006). This study has applied two hedonic models: hedonic prices and hedonic wages. This study has tested different modeling approaches to find the most consistent and reliable results.

Following Roback (1982), a model to quantify the value of the change in climate can be derived in the following way. The consumer's utility, U ,maximization problem can be given as:

$$\max U = U(X, H, C) \qquad s.t. \quad m = X + pH \qquad 3.1$$

in which the choice variable X is a composite numerical good, H is house unit purchase at price p , and C is the value of the climate amenity. The climate amenity is implicit and determined by individuals' choices for housing location. The consumer's maximization problem is that the consumer will choose X and H for a given level of

C against the budget constraint. The interior solution of the utility-maximization problem would give the Marshallian demand as

$$X^* = X(p, m, C) \tag{3.2}$$

$$H^* = H(p, m, C)\ . \tag{3.3}$$

The indirect utility function V is obtained by substituting the values of X^* and H^* from 3.2 and 3.3 in the utility function in equation 3.1.

$$V = V(p, m, C) \tag{3.4}$$

Assuming free and costless mobility, a spatial equilibrium will occur when there is no utility difference between locations. Then the equation 3.4 can be represented for k locations [where k = 1, 2, . . . , K].

$$V_k = V(p, m, C) = V_0 \quad \forall k. \tag{3.5}$$

Characteristics of the good vary spatially. Differentiating the indirect utility function in equation 3.5 and setting $dV_0 = 0$ gives

$$dV_0 = \frac{\partial V}{\partial p} dp + \frac{\partial V}{\partial m} dm + \frac{\partial V}{\partial C} d\,C$$

$$\frac{V_C}{V_m} = -\frac{V_p}{V_m}\frac{dp}{dC} - \frac{dm}{dC} \tag{3.6}$$

in which V_C, V_m and V_p represent the partial differential of the indirect utility function with respect to climate, income, and price, respectively. The marginal rate of substitution between the climate amenity and goods consumption (equivalent to the marginal effect of a change in income) gives an implicit price of climate amenity. Land or housing unit supply is not unlimited, and consequently, not everyone can have the most amenable place to live at the same time. Most people have to make a tradeoff. Roback (1982) and Hand et al. (2008) assumed that the limited supply of land would be a sufficient condition to generate a market tradeoff. For a given spatial heterogeneity of climate, the price of property (land or housing) varies. Thus, given climate-driven price variations, an individual will have the same level of indirect utility from any given choice of location:

$$V(p_1, m, C_1) = V(p_2, m, C_2) = ... = V(p_K, m, C_K) \qquad 3.7$$

Market wages in each location are determined by the interaction of the demand and the supply of workers. As the indirect utility across all locations is equal, the production cost across all locations also remains equal. As noted by Roback (1982) and Hand et al. (2008), the market for the composite good is perfectly competitive, and it can be assumed that the unit cost of production for any location can be given as

$$\Psi(p, w, C_k) = 1 \qquad \forall k \qquad 3.8$$

Equation 3.5 can be written as

$$V_0 = V(p, w, C_k) \qquad \forall k \qquad 3.9$$

in which *w* represents the market wage rate. Following Hand (2008), to find the marginal effect of climate on wages and housing unit prices requires totally differentiating equations 3.8 and 3.9 and setting $dV_0 = d\Psi = 0$. Solving yields:

$$\frac{dw}{dC} = \frac{V_C \Psi_p - V_p \Psi_C}{\Theta} \qquad 3.10$$

$$\frac{dp}{dC} = \frac{V_w \Psi_C - V_C \Psi_w}{\Theta} \qquad 3.11$$

in which $\Theta = -V_w \Psi_p + V_p \Psi_w < 0$, and the subscript indicates the partial derivatives.

3.4. The Empirical Framework

To estimate the left-hand-side values in equations 3.10 and 3.11, one must know the variable that affects the wage rate or the income of individuals. The conventional framework to estimate hedonic wages specifies that an individual will have preferences over job characteristics, as well as over location attributes. The same climate amenity factors affect both the hedonic wage and the hedonic price. Following Mincer (1974), the hedonic wage equation for econometric analysis would be

$$W_{ik} = \alpha_0 + \beta' Y_i + \rho' C_k + \mu_i \qquad 3.12$$

in which W_{ik} , Y_i , and C_k are, respectively, the monthly wage of individual *i*, a vector of human capital characteristics, and climate characteristics. The inclusion of climate characteristics is of interest in this study. Similarly, the hedonic econometric model for housing price is given as

$$P_{ik} = \delta_0 + \varphi' Z_i + \varsigma' N_k + \phi' C_k + \upsilon_i \qquad 3.13$$

in which P_{ik} and Z_i respectively, are the hedonic price of the housing unit and the structural characteristics of the housing unit. N_k is the vector of neighbor characteristics. The house unit rent is used as the price variable in this empirical analysis.

Both econometric models include a common bundle of climate characteristics. As Hoehn et al. (1987), Blomquist et al. (1998), and Hand et al. (2008) pointed out, the common bundle should be in both econometric models to get the effect of climate amenity, both on housing prices and wage rates.

3.5. Hypotheses

The primary empirical question of this study is whether climate characteristics that vary across the United States are in fact amenities that significantly affect housing prices and wage differentials. If so, what is the amenity value of the United States climate in general and the compensating differential for climate amenities in the U.S. housing market and labor market in the U.S.?

Prior to estimating the compensating differentials, it is appropriate to test whether house owners and apartment renters have the same climate preferences. If not, they will hold significantly different amenity values for climate.

Hypothesis 1: *House owners and apartment renters have different climate preferences.*

The sample has information on whether a housing unit is owner-occupied, as well as information on renters. Homeowners and renters differ in several important ways. Campbell and Cocco (2007) stated that the wealth effect on the housing price for renters is negative and that this is different from the effect of wealth for homeowners, which affects housing consumption behavior for both renters and owners. Owning a house may have been induced by long-term preferences for locations, local amenities, neighborhood, community service, etc., whereas these preferences may not be reflected much in the price of rent. On the other hand, renting is typically a relatively short-term behavior, one for which consumers always have an incentive to move for better opportunities. It is hypothesized that the difference between short-term and long-term decision-making behavior on investment will affect both the housing market and the labor market equilibriums and will result in different amenity values for climate embedded in the housing prices for owners and renters.

Hypothesis 2*: January temperature will have the opposite effects of July temperature on rents and wages.*

The second hypothesis is based on the assumption of free and costless movement of households from one U.S. city or town to another, based on individuals' preferred climate. Households choose to work and live in their preferred climate locations so that they will maximize their net benefits. This will bring an inter-urban equilibrium that will affect both housing markets and wage markets.

An increase in climate amenities increases the utility of households, making them more willing to accept lower wages. With climate as a disamenity, households will reject lower wages and seek higher wages as compensation. This variation can be observed if January and July temperatures are different in terms of amenities. For the housing market, unit costs increase with an increase in an amenity and decrease with an increase in a disamenity. Therefore, our interest is to test the effect of January and July temperatures in both markets.

Hypothesis 3*: Climate has amenity and/or disamenity values for U.S. households.*

Different preferences for climate as an amenity and a disamenity are implicit in wages and in house rents. Households will be willing to pay higher housing costs and accept lower wage rates for a preferred climate and will seek compensation for a poor climate. The difference between the rent differential and wage differential provide information on amenity values or the disamenity of climate for U.S. households. If the difference is positive, it is an amenity to U.S. households; otherwise it a disamenity. The differences in housing rents and wage rates are possible if the marginal value of climate amenity affects both housing markets and wage markets. The effects of climate on the production of goods can result in different wage rates, as well as in differences in house rents.

3.6. Data Sources

Data for this study were obtained from the American Housing Survey (AHS) (2005) national micro-data samples from the entire U.S. The AHS survey data include housing price, rent, structural information about the housing unit, and the year in which the housing unit was built. Neighborhood characteristics include information on: environmental amenities (e.g., waterfront, open space, etc.), crime, distance from the nearest school, regions, climate zones, and degree-day, etc. The data also identify metropolitan areas over 100,000 in population (SMSA) and whether a unit is located within the central city of an SMSA.

For estimating wages, the AHS micro survey data provide detailed demographic information on each household, including wage income, age, sex, race, ethnicity, education level, nationality, etc.

Climate data selected for this study are average January temperature, average July temperature, and average annual precipitation. The January and July temperatures are considered to represent cold and warm climates, respectively. As the AHS data do not have county-level geographical information, this study used state-level information for climate data. The climate variables are significantly different only for relatively large areas in the U.S., so the average state-level temperature data can provide sufficient variations for the purposes of this analysis. The data on temperatures and precipitation used in this study were obtained from the National Climatic Data Center's NOAA (2004).

3.7. Dependent Variables

This study has two dependent variables: housing price (or rent) and wages. For the variable of housing price or rent, the AHS data provided two types of information: monthly apartment rent, which is transferred into natural log (LnARENT) and current value of dwelling unit of the owner-occupant. As we have separate hedonic models for homeowners and apartment renters, we needed to convert the value of the dwelling into a monthly rent for owner-occupied units. Monthly rents for owner-occupied units were calculated as the income that they were earning on that property as an investment and assumed to be equal to what they could earn if it were being rented. The monthly rents for owner-occupied units were imputed by multiplying the value of unit by an annual discount rate of 7.5%. This discount rate was chosen because it was used in other studies, for example, Costa and Khan (2003) and Hand et al. (2008) used 7.5%. However, Hoehn et al. (1987) and Blomquist et al. (1988) used 7.85%, but this discrepancy was not significant.

The second dependent variable, monthly wage, was created by dividing annual household income by 12. The sample used in the wage equation was restricted to wage-earning homeowners and apartment renters. Variables for monthly wages were transferred into the natural log (LnWAGE), which were created for wage models (see Table 3.1).

3.8. Independent Variables

This study considered two climate variables that affected both unit price or rent and household wage-income: average January (JAN. TEMP) and average July (JULY TEMP) temperatures, measured in degree Fahrenheit (^{o}F). January and July temperatures are the proxy of cold and warmth, respectively. In addition, the empirical analysis also considered average annual precipitation, as global warming will affect both the amount and location of precipitation in various locations throughout the U.S.

Other amenity-specific variables used in the hedonic pricing model included proximity to open space (OPENSPACE), water body (WATBODY), train station (TSTATION), and public parking (PUBPRKG), as well as urban status (URBAN), city status (CENCITY) against rural area (RURAL) and neighborhood crime status as reported by households (CRIMEAREA). Other amenity variables dealing with the quality of residential location were community recreation services (CMRECREATION) and distance from home to the nearest elementary school (ELESCHOOL).

The categorical structural variables considered for the housing-price equation were those that determined unit price or apartment rents. These variables were whether the unit was single (SIGUNIT), attached (UNITTACHED), an apartment (APPARTMENT), or a condominium (CONDO), and unit types not covered or residual unit types (UNITOTHER). Other variables included the natural log of the square footage

(LUNITSQFT), the number of bedrooms (BEDRMS), the number of bathrooms (BATHS), the housing unit's age (UNITAGE), and the natural log of lot size in square feet (LLOTSIZE).

The independent variables for the wage equation included possession of an associate's or bachelor's degree (DEGREE), and the possession of a graduate degree (GRAD), potential experience and its square term (EXPERIENCE and EXPERSQ), whether the household head was female (HHFEMALE), interaction of female and experience (FMEXP), marital status (MARRIED), ethnicity/race indicators (NATIVE, AFRI.AMERICAN, ASIAN, HISPANIC), and other ethnicity/race of households are with majority of white American and other undefined are kept as residual, (OTHERRACE). This study also analyzed the effect of noncitizen status (NONCITIZEN) for against the U.S. citizen on wage rate.

To look at the possibility of market segmentation for both housing markets and wage markets at the regional level, both hedonic models included regional dummies: Northeast (NE), South (SOUTH), and the West (WEST). All variable definitions and the descriptive statistics are given in Table 3.1.

3.9. Empirical Results

Estimated results of hedonic wage and rent models are presented in Table 3.2. Before discussing the results of hedonic models, this study first tested whether homeowners and apartment renters have any heterogeneous preferences for climate, which was one of the hypotheses of this research. This study performed a Chow test, applying separate hedonic models for homeowners and renters and testing whether the coefficients estimated for homeowners (β_i^{OH}) and the coefficients for apartment renters (β_i^{AR}) were not different statistically different for both the hedonic pricing and wage models. This analysis used an F-test to test whether coefficients from the two groups were equal: β_i^{OH} - β_i^{AR} = 0, and found $F_{42578}^{21} = 65.12$ for the hedonic pricing model and $F_{42570}^{25} = 54.43$ for the hedonic wage model. This analysis thus rejected the hypothesis of equal coefficients at the 1% level. This finding suggested that the coefficients of two groups are not the same. This result is consistent with Campbell and Cocco's (2005) argument about the existence of differences in wealth effects on housing prices for renters and for homeowners. As reported by the U.S. Census Bureau (2000), 69% of Americans own homes (houses, condominiums, or cooperatively owned apartments), while 31% rent apartments. This study's sample data set was closed to resemble this result: around 69% owned a house and 31% rented an apartment in the sample used for this study. Acceptance of this distinct behavior is indisputable for some policy questions of climate adaptation measures, and the accurate sample representation of homeowners versus rents will provide more reliable predictions of the amenity values of climate for these two groups.

Given this finding, any estimation that does not consider the differences between homeowners and renters would be biased and could not provide efficient estimates of the amenity values of climate. Thus the analysis for this study included running two separate hedonic models for homeowners (hereinafter called *owners*) and apartment renters (hereinafter called *renters*), which is a major departure from previous studies in the literature.

Furthermore, there could be a simultaneity problem between wages and housing rent: both may be affecting each other. However, to estimate the implicit price of the climate amenity via a simultaneous model may not be appropriate, as the effects of wages on housing rents and vice versa are embedded (Blomquist et al., 1998). Further, the estimation of these two equations with a single equation method may not have efficient results due to the possible presence of unobserved factors that affect the error terms. To minimize these effects on the error terms in both housing models and wage models, a seemingly unrelated regression (SUR) is applied, which takes account of intercorrelation of the error terms across estimating equations (Zellner, 1962). For this, an iterative generalized feasible least-square estimation (IFGLSE) method was applied. This estimation method provides smaller standard errors of parameters as compared with single-estimation methods.

For this study, a test of independence was performed, and the null hypothesis of no contemporaneous correlation was rejected at the 99% confidence level for all the models by a Breusch-Pagan test, thus justifying the use of an SUR model. Thus, the wage model (equation 3.12) and the housing pricing model (equation 3.13) were estimated for both homeowners and for renters using the ISUR estimation method.

3.10. Results of House Rent Models

The results of the SUR estimation are reported for owners and renters in Table 3.2. The estimated results show that housing prices are determined by several nonclimatic variables, as well as by climatic variables. Under the nonclimatic category, unit structure, neighborhood quality, and location or region-specific variables were controlled to see the effects of these variables on rents and wages.

Along with the climate amenity that affects housing rent, other neighborhood amenity and location-specific variables are also important in determining residential property prices and rents in U.S. This study has controlled for nine different unit-related structural variables that contribute in determining housing prices and rents. The structural dummy variables, single unit (SIGUNIT), single unit attached (SIGUNITATC), apartment types (APPARTMENT), and condominium (CONDO) were all positively significant at the 1% level against the base category, "UNITOTHER" for both homeowners and renters, as determined by the models described above. This result suggests that these characteristics positively contribute to the house values in the U.S. Likewise, the effect of continuous variables—unit size in square feet or the natural log of the square feet of unit (LUNITSQFT), number of bedrooms in the housing unit (BEDRMS), and the number of bathrooms (BATHS)—also significantly contribute to increases in housing prices for both groups. However, unit age (UNITAGE) is negatively significant, which lowers the housing price. The results showed that every additional year in the age of the unit would lower its value by 0.3% and 0.2% for homeowners and renters, respectively. Results showing the effects of structural variables on housing rents were consistent with other existing hedonic pricing studies, for example, Anselin and Gallo (2006), Day (2009), and Tse (2002). The size of lot (LLOTSIZE) increases housing values for homeowners, but reduces rents for renters. The negative contribution would be that the renters consider the large lot size requires extra costs for maintenance, increasing the net cost of the rental housing.

Under the nonclimatic amenity effect on housing price, this study has controlled for nine different important neighborhood variables that contribute to determining housing rents. Out of those nonclimatic amenity variables, this study controlled for natural amenities: water body (WATBODY) and open space (OPENSPACE); and this study found that these variables were positive and significant at the 1% level for homeowners, while for renters, only OPENSPACE was significant. This suggests that water body and open space were both positive determinants of housing rent and that both are natural amenities. This analysis showed that an open space accessible within 300 feet increases the rent by 0.04 to 0.06 points for homeowners and apartment renters, respectively. A similar analysis was done for built environment, including proximity to a train station (TSTATION) and public parking (PUBPARKG). The train station appeared as a disamenity only to homeowners, while public parking has a significant negative effect for homeowners as well as renters. Being close to public parking reduces the rent by 10% and 2% for house owners and renters, respectively. This result suggests that both homeowners and apartment renters prefer living in a peaceful and a less crowded area, which serves as an amenity and will have a significant affects on housing price. Similarly, neighborhood crime status as reported by households (CRIMEAREA) appeared as a disamenity that affects housing prices negatively and significantly for both house owners and apartment renters. The results show that CRIMEAREA reduces the rent values by 10% and 8% for homeowners and renters, respectively. This finding is consistent with the findings made by Berger et al. (2008) concerning Russian cities.

While analyzing the amenity values of urban (URBAN) and central city (CENCITY) locations against the rural areas, this study found that both urban-related variables URBAN and CENCITY were statistically significant at the 1% level for both types of householders and contribute to higher housing rents. Although urban and center-city locations increase housing prices, the effect is higher for renters than house owners. The urban effect is higher by about 0.03 points and center-city effect is about 0.11 points higher. This implies that renters are willing to pay higher rents in the center city and in urban areas than for rural areas, and the reasons could be time and travelling cost savings in those areas. However, living in an urban area or a central city is viewed as disamenity as wage rates are positive in those areas.

The primary objective of this study was to test the effect of climate on housing prices and wages, so this analysis controlled for two different seasonal climates: winter and summer temperatures (mean January and July temperatures) and annual precipitation to analyze the effect of global climate change. Although a great number of climate variables were available, temperatures and precipitation were the most widely discussed variables associated with climate change. Including too many climate-related variables would lead to a multicollinearity problem. Consequently, this study controlled for the minimum number of climate variables needed for a reliable analysis of the effect of climate. The results showed that increases in the January temperature (JAN. TEMP) positively and significantly affects housing rents in the U.S.: for a 1^{o} F increase in

January temperature, housing rents would increase by 2.7% for homeowners and 1.3% for renters. More specifically, the data showed that for a 1^{o} F increase in January temperatures, the average monthly rent would increase by $41 (in 2004 dollars) for homeowners and by $9 for renters. This study also controlled for the square January temperature (not shown). While the results for the square term were significant, the coefficients are almost zero for both groups, although the marginal effects of these climate variables were significant (standard errors are estimated using delta method) but not qualitatively or quantitatively different.

Similarly, it is found that the effect of increases in the July temperature (JULY TEMP) on housing rents is negative and significant at the 1% level for both homeowners and renters: the increase in temperature in an already warm climate reduces the amenity value of climate embedded in housing rents. For a 1^{o} F increased in July temperature, the average house rent for a homeowner would decrease by 4% or about $61, all else being equal,. Likewise, for apartment renters, the values decrease by 2.2% or about $16 per month. These findings are consistent with results found for European countries, for example, in Great Britain, in Italy, etc. (see Rehdanz, 2006).

The positive effect of increases in January temperatures on housing rents and the negative effect for increases in the July temperature reflects that the warmer January temperature is productive to the firms, while the warmer July temperature is unproductive for U.S. firms; however, the precise effect on the housing market can only be inferred based on how the labor market is affected by both January and July temperatures (Maddision, 2001, p. 5). Analyzing the housing rents via winter and summer temperatures, firms have incentives to relocate their investments from warmer to the colder-temperature regions according to the effects on house rents in different temperature regions until the market reaches equilibrium.

Besides temperature, this study controlled for annual rainfall, another climate variable, to test the effect on housing rents due to precipitation, as the Intergovernmental Panel on Climate Change (IPCC) (2001) third assessment report stated that rainfall patterns in terms of location and quantity will change as a result of global warming throughout the regions of the world. The likely effect in the Northern Hemisphere or over higher-altitude regions will be an increase in precipitation of 5–10%. Hence, this predicted effect on precipitation in the U.S. is very probable. The study results showed that additional annual rainfall affects housing rent negatively and significantly. However, results showed that the reduction in house rents due to an inch increase in annual rainfall would be less than 1%. For every additional inch of rainfall per year, the housing rent would fall by about $10 per month (for homeowners) and about $2 per month (for renters). This implies that housing rents are higher in drier climates than in wetter climates; but higher precipitation is less of a disamenity for renters than for homeowners. Maddison (2001) also measured a qualitatively consistent result for rainfall for British households; however, he reported that increases of 1 mm of rainfall would reduce the price of housing by about 15%. The higher effect on British housing values could be due to the fact that colder regions with greater rainfall would have more severe effects on boosting the disamenity value of greater precipitation.

The housing market in the U.S. is large, and it varies from region to region across the country. Studies in housing markets in the U.S. have indicated a regional heterogeneity and have suggested that considering the response of the various regions is important to avoid the issue of aggregation bias (Baffoe-Bonnie, 1998). Rehdanz (2006) suggested that including region dummies for different regions would correct the problem of regional market segmentation. This study used regional dummies to examine the effects of housing market segmentation at the regional level in the U.S. This study found that the regional dummies—Northeast, West, and South—were significant at the 1% level against the Midwest, suggesting that the housing markets in U.S. are segmented. Compared with the Midwest, housing rents are about 46% higher in the Northeast, 32% higher in the West, and 8.6% lower in the South. Likewise, for renters, the housing rents are 37% higher in the Northeast, 11% higher in the West, and 8.6% lower in the South.

However, temperature variation across the regions is wide, and the South is warmer than the Northeast. This study did not control for other variables related to regions, so this study controlled for region with a temperature interaction to check whether the regional segmentation was due to variables other than temperature. Interactions of the Northeast dummy and the West dummy with January temperatures were both positively significant, and the interaction of West with July temperatures was negatively significantly for house owners. For renters, this study found significant positive interactions only between the Northeast and January temperatures, as well as between the West and January temperatures. However, the coefficients were less than the coefficients of these regions without interaction. This finding suggests that regions have market segmentation and the effects of January and July temperatures are not high. Therefore, factors other than temperature are also contributing to the market segmentation for housing prices.

Given that this study found positive effects of regions (Northeast and West) on housing rents, the conclusion is that these regions have some positive externality that offer incentives to real-estate firms to invest more in those regions than in the South as compared with the Midwest. In summary, this study found strong evidence that the amenity values of climate are embedded in housing prices.

3.11. Climate Amenity and Wage Rates

As with the hedonic pricing models, the hedonic wage models were also separately estimated for homeowners and renters in this study (see Table 3.2). This study has controlled 12 different types of demographic variables, 2 city-related dummies, 3 regional dummy variables, and 3 climate variables. To examine the effect of education level, this study controlled two types of dummies: GRAD to represent graduate degree or a higher level of education and EDUC to represent undergraduate or associate-level education. The estimated results showed that the return from education was positive and significant at the 1% level, meaning that the return from education at the college level and university level as higher as compared with a high school education or an associate's degree. More specifically, for homeowners, the returns from the GRAD and EDUC against the high school education were about 0.49 and 0.35 times higher, respectively. Likewise, the results for renters were also highly significantly, and the effect of GRAD and EDUC were respectively 0.35 and 0.45 times higher compared with a high school education or an associate's degree.

In wage estimation, experience enters into a quadratic form based on experience and the square of experience. The results showed that the variable EXPERIENCE was positively significant, while EXPERSQ was negatively significant at the 1% level. These results indicated that wages increase, but at a decreasing rate, based on experience. There is a wider variation than in return to education.

Mincer (1974), in a seminal work, estimated that the return to education ranges 10% to 15%. A meta-analysis on returns to education examined by Pereira and Martins (2004) reported the return value of 9%, based on studies from Portugal. However, Graves et al. (1999) reported that if amenity variables were controlled in a wage model, then the estimated return to education and experience would be less. Their argument was that omitted amenity variables provided bias estimates of the return to education and experience. However, this argument depends on which effect—the productivity effect (positive effect on production) or the amenity effect (negative effect)—outweighs the wage in amenable areas.

Analyzing the effect of gender, this study found that the gender effect (being female) was negatively significant at the 1% level, suggesting that women get significantly lower wages and salaries than their male counterparts. The reduction of wage ranges from 38 to 59 percentage points, respectively, for homeowners and renters. The higher differential values for renters could be due to their short-term commitment in that location. However, the interaction of female and experience is positively significant at 1% for both groups, suggesting that women with experience reduce the gender wage gap.

This study found a similar result for married persons. If the person is married, the effect of being married on wages was positive and highly significant. Wages for people in married households increased by more than 50 percentage points compared with unmarried household for both homeowners and renters.

Similarly, this study analyzed the effects of race variables: the race of households. All ethnicity-related controlled variables: ASIAN, NATIVE, AFRI.AMERICAN, and HISPANIC were negatively significant for owner and renter models against the base category, OTHERRACE, except for NATIVE for the homeowner model. This implies that it remains true in the U.S. that wage rates for white Americans were higher than for members of other races. Similarly, this study controlled for non-U.S. citizens (NUSCITIZEN) against the U.S. citizen and found a negatively significant relationship at the 1% level for both homeowners and renters. This suggests that the non-U.S. citizens are being paid less than U.S. citizens, all else being constant. These results were consistent with the findings made by Hand et al. (2008) while analyzing the effects of regional amenity on wage determination in the U.S. South.

While analyzing how the amenity values of urban (URBAN) and central-city locations (CENCITY) were imbedded in wage rates against the rural area, this study found that both urban-related variables (URBAN and CENCITY) were statistically significant at the 1% level only for homeowners, while renters were indifferent to these amenities. This finding suggests that either urban and center-city locations are amenities for homeowners or that the urban and center-city locations were productive to the firms. As stated by Roback (1982), the city with fewer amenities will offer higher wages if it receives higher productivity from workers. Glaeser (1998) explained that with an accumulation of higher human capital for higher wages, cities provide higher rates of productivity.

As productivity and amenity operate in opposite directions; the empirical question is which effect dominates. If cities are productive, then firms can offer higher wages in those areas and vice versa. However, just considering the wage equation independently cannot provide complete information on the measure of amenities and productivity. Because higher wages may be a compensation for a locational or climate disamenity, then it also follows that a lower wage may be due to an amenity provided by location.

Measures for compensating differentials that take into consideration housing and wage models are required for exact information. Compared with the marginal effects of the URBAN and CENCITY from the hedonic pricing model and the wage model, this analysis found that the compensated wage differential was positive for both URBAN and CENCITY for both homeowners and rents. It can be inferred that center cities are an amenity for homeowners and renters in the U.S. A valuable finding of this analysis is that cities in the U.S. are productive.

To analyze the effect of global climate change on wages, this study again controlled for winter and summer temperatures and for annual precipitation. The effect of January temperatures on wages for homeowners and renters was positively significant at 1%, suggesting that the higher January temperature makes a positive contribution in determining the wages for both groups. A 1^{o} F increase in the January temperature would increase the average wages by 2.7% for homeowners and 1.2% for renters, or by $147 and $32 per month, respectively. This suggests that a colder winter climate is a disamenity for both homeowners and renters.

This study also controlled for the square term of the January temperature to test the optimal level of increase in January temperature that affects the average wage. The result for the square term showed a positive and significant effect on wages only for homeowners; however, the coefficients were almost zero, suggesting that the effect of an increased January temperature on wages is positive and nonlinear. It further suggested that the increase in January temperatures reduces the disamenity of cold winter temperatures at a decreasing rate, as the coefficient of square term of January temperature was less than the linear term. However, this finding was valid only for homeowners.

Similarly, the effect of an increase in the July temperature on wages was negatively significant at 1% for both homeowners and renters. An increase in 1^{o} F in July temperature decreased the average wage by 1.6% for homeowners and 1.8% for renters, respectively. These values are equivalent to \$84 and \$48 per month, respectively, for homeowners and renters. This study controlled the square term of July temperatures to check the rate of change of the effect on wages and found that initially, the effect increases with an increase in temperature, and finally it changes sign for any further increase in the July temperature as the sign of coefficient of the square term of the July temperature is significant and negative. However, this relationship is significant only for homeowners. This analysis involved looking at the marginal effect of the quadratic model and found that the marginal effects of these climate variables (January and July temperatures) were significant (standard errors are estimated using delta method) for both groups. This study showed that an increase in July temperature was an amenity; however, this was so at a decreasing rate. A similar result has been reported for British householders by Rehdanz (2006).

This study examined the effect of another climate variable: annual precipitation (PRECIPITATION). The effect PRECIPITATION was negative and highly significant for both homeowners and for rents. However, the coefficients were small; its effects are 0.7% and 0.4% for homeowner and renters, respectively ($38 and $11, respectively). Maddison (2001) conducted a similar analysis, but did not find any significant result for British households. This suggests that Americans would prefer additional precipitation, although this was not the case for the British, who live in a generally wetter (and colder) climate.

Although there are ongoing debates on the segmentation of the labor market, this study investigated interregional market segmentation on wages for both homeowners and renters. The wage market in the U.S. is large, and it varies from region to region in the country. Because of substantial mobility costs, neither employers nor workers can move effortlessly or without cost from one location to another location, with the result that wages can remain high in big cities, as compared to small towns or rural areas. This study controlled regional dummies to look at the effects of wage market segmentation at the regional level in the U.S. This study found that the regional dummy Northeast (NE) was positively significant at the 1% level against the Midwest (MW) for both homeowners and renters. The region West was positively significant at the 10% level, but only for homeowners. This result suggests that the wage markets in the U.S. are segmented geographically in two parts: 1) Midwest and South versus 2) Northeast and West. Wages are about 19% higher in the Northeast and about 5% higher in the West for homeowners; and wages are 16% higher for renters in the Northeast as compared with renters in the Midwest.

Regional-level market segmentation arises due to the effects of any of these variables: climate, population density, population growth rate, etc. This study controlled for the interaction of region with January and July temperatures to check whether the regional segmentation is due to factors other than winter and summer temperatures. It is found that only in the West were increases in the January temperature positively significant for homeowners. In the West and the South, increases in the July temperatures were positively significant, but only for renters. The interaction of the South with increases in January temperature was negative and significant for renters only. The mixed results suggest that factors other than temperature are causing the market segmentation for wages in the U.S. As this analysis found positive effects of regions (Northeast and West) on wages, this suggests that these regions have offered incentives to attract more laborers into those regions.

In summary, this study found strong evidence that the amenity values of climate are embedded in wages. It further indentified that regional labor markets are segmented in the U.S. However, the exact dollar amount of the amenity values of the climate is only possible to determine by taking into consideration the compensating differentials of hedonic housing prices and hedonic wage models. This issue is discussed below.

3.12. Estimating the Implicit Price of Climate as an Amenity

After using both hedonic econometric models for estimates, the estimation of the implicit price of climate amenity is given as

$$P_C = \frac{dp}{dC} - \frac{dw}{dC} \qquad 3.14$$

Equation 3.14 gives the difference between the two partials—that of the hedonic housing price and the hedonic wage—estimated by two hedonic econometric models (equations 3.12 and 3.13). The hedonic pricing model provides the marginal effect of climate amenity on monthly housing rents, while the hedonic wage model provides the marginal effect of the climate amenity on the monthly wage rate. The difference gives the average individual monthly marginal willingness to pay (MWTP) for climate amenities. If the difference is positive, it is an amenity, whereas if it is negative, the difference is compensation for a climate disamenity. This measure therefore provides the implicit price of climate.

Once the implicit prices for climate amenities were derived, the analysis proceeded by calculating the standard error for the estimated values using the delta method. The analysis considered the variance-covariance of contemporaneous error terms by allowing for heterogeneity in error terms in the SUR regression estimation method. The calculated MWTPs are reported in Table 3.3.

The implicit price of January temperatures for homeowners was negative and significant at the 10% level. The negative sign reveals that the differentiated compensation for homeowners is U.S. \$16.48 at the 2004 price level per month per one unit of change in January temperature (annually \$198, rounded figure) for homeowners. This value is higher for renters. This study found that the mean value of compensation for renters is U.S. \$25.21 per month and \$300 (rounded figure) annually. This finding is reasonable, as renters are more mobile, and the job is the primary means to keep them for moving elsewhere (as they are not tied down by homeownership), suggesting that firms are offering higher wages to renters than homeowners to keep them in a designated area. However, there may be other factors that influence the renters in their location choices.

The results showed that an increase of 1° F in the January temperature in the U.S. positively and significantly affects the productivity of the firm $(\frac{\partial Houserent}{\partial Jantemperature} > 0)$; however, its effect on wages, although positive, is higher than the effect on the housing market that has created compensation to the house owner. This finding suggests that the income effect dominates the rent effect and that firms are offering higher wages for higher January temperatures in the U.S. As reported by Roback (1982) and Hoehn (1987), if climate is productive, then the marginal effect on the cost of production is positive. That results in a positive marginal effect on housing prices (the partial of the hedonic price equation will be positive). However, the sign of the marginal effect on wages (the partial of the hedonic housing equation may be indecisive, $(\frac{\partial Wage}{\partial Jantemperature} \lesseqgtr 0)$. This study has shown a positive marginal effect on wages, suggesting that the income effect dominates the amenity effects.

Looking at the interregional variations of these effects across the U.S., it showed that regions with lower January temperature, namely, the Midwest and the Northeast, are being compensated with higher wages than those that prevail in other regions, namely, the South and the West, that have higher January temperatures (see Table 3.3). To find the effect of an increase in the January temperature, a curve showing a relationship between marginal willingness to pay of compensation against January temperatures was plotted keeping all else constant, which showed that the marginal implicit price initially decreases (i.e., the compensation initially decreases with increase in January temperature), but after reaching about 50^{o} F, this trend changes in direction and starts to fall (as shown in Figure 3.1).

The marginal implicit price or MWTP value for the July temperature for homeowners is positive but insignificant, although the housing price and wage differentials were highly significant. While analyzing these values for different regions, the estimated value is significant only for the Midwest. This result suggests that homeowners are being paid lower wage rates in all regions other than the Midwest as compared with the renters. This study showed that in all regions except for the Midwest, the amenity effects dominate the income effect. The estimated WTP for a 1^{o} F increase in July temperature is U.S. \$32.25 at the 2004 price level for homeowners in the Midwest. One reason that the results were not significant in other regions could be that a firm's productivity in those areas is less and so this could inhibit the income effect.

However, the estimated MWTP for renters for an increase in the July temperature is positive and significant. The average value of the MWTP is U.S. \$32.46 per month (annual U.S. \$390; rounded figure). The positive implicit price of renters reveals that the higher July temperature is an amenity to renters in the U.S., and they are paying for it. This is true in the sense that renters are more likely to plan for the short term, and they choose their locations based on their climate preferences, or they will trade for climate with income. The study also shows that the increase in July temperature is unproductive, which increases the production cost of firms. This is because the marginal effect of higher July temperatures on wages is negative and significant at the 5% level:

$\frac{\partial Wage}{\partial Julytemperature} < 0$. This study showed that the negative contribution of a higher July temperature on production also contributes negatively to the housing rent: $(\frac{\partial Houserent}{\partial Julytemperature} < 0)$, which is significant at the 1% level. This unproductiveness affects the income of householders. Rehdanz and Maddison (2004) found similar results for German households; however, their values were higher than the estimated results obtained in this study. The relationship between MWTP and the July temperature showed, as given in Figure 3.2, that the marginal implicit price increases with increases in July temperatures until the July temperature reaches about 75^{o} F, above which it then changes its direction, that is, it decreases with further increases in the July temperature. As the January and July temperature for this analysis are available at the state level, the estimated MWTP values measure the climate amenity for averaged state level temperature. A micro level climate data measured at the county or at the city level would give more precise estimation. It is left for future improvements.

This study has provided Americans' preferences for climate and has revealed the dollar values of their preferences. Thus the findings of this study can be taken as a policy prescription to develop a climate-change adaptation policy in the U.S. for the given scenario of the climate change effects in the United States that have already begun. Over the course of the 20th century, U.S. average temperatures rose by almost 1.8° F (0.6°C) per decade, and climate science has indicated that the 21st century will be significantly warmer than the 20th century was due to the anthropogenic emissions of greenhouse gases into the atmosphere (IPCC, 2001).

A synthesis report on climate change (IPCC, 2007) stated that the projected global average surface warming by the end of the 21st century would be 1.8^o C (3.24^o F) for the B1 scenario (the best-case scenario, i.e., with improvements in technology and a reduction in the worldwide consumption of fossil fuels and in the emissions of CO_2 ppm[9] at the 600 level) and 4^o C (7.2^o F) for the A1F1 scenario (the worst-case scenario or with a continuation of fossil-fuel consumption and the continued emission of CO_2 ppm at the 1550 level). Both best-case and worst-case scenarios are climate-sensitive levels to the Earth. The climate-change prediction in the U.S. on average for the next 100 years was based on the "best scenario" and the "worst scenario" ranges from 5^o F to 9^o F, respectively (IPCC, 2007). From our study, the disamenity values of January temperatures will be lowered (the future average January temperature will be increased by 3^o F to 7^o F) and in contrast, the amenity values of July temperature will be reduced too. This suggests that the compensation for January temperature will be decreased, as well as suggesting that the positive MWTP for the July temperature will also be lowered. This study concludes that American households would be willing to pay for higher temperatures with a limited global warming result. These effects will have direct and indirect effects on the housing markets and the labor markets. However, exploring such implications is beyond the scope of the present study, so it must be left for future research. Further, to predict the effect of future climate change on the marginal effects on housing prices and wages, an analysis on households and firms' behavior for an ensuing future context is necessary to get a reliable prediction. Lucas (1976) argued that the

[9] Parts per million

prediction that is based on historic data for a particular given scenario may not predict a reliable effect for the future, which is an important caveat in this prediction for the future.

Scientists have also provided evidence that global warming will have effects on precipitation, both in its quantity and in its variability. The spatial variability of precipitation will mean a reduction of rainfall in the subtropics and an increase at higher latitudes. Precipitation in the U.S. West and South will decrease; these regions of the U.S. are already suffering from reduced rainfall. The Northeast will have more precipitation. Therefore, there will be an interconnected relationship between rising temperatures and precipitation patterns, although these effects will vary from place to place.

While analyzing the amenity values of precipitation for homeowners and renters, this study found that increased precipitation was an amenity for both groups. The marginal implicit price value for increased annual rainfall is U.S. $11.12 per month for each one inch increase in rainfall ($133 per year) for homeowners and U.S. $9 per month for renters ($108 per year). This suggests that American households prefer more rainfall and that rainfall is an amenity for them. In contrary, British households would prefer a drier climate, so increased precipitation is a disamenity for them (Rehdanz, 2006). Similar to the July temperature, this study also shows that the amenity values of rainfall will be reduced if the average annual rainfall rises to more than 50 inches (see Figure 3.3). While examining the effect of precipitation on productivity, this study found that an increase in rainfall would increases the production cost for firms. This is because the marginal effect of rainfall on wages is negative and highly significant, as shown in the equation: $\frac{\partial Wage}{\partial precipitation} < 0$. The study showed that the negative contribution of increased rainfall on production contributes negatively to the value of housing rent: $(\frac{\partial Houserent}{\partial precipitation} < 0)$,

which is significant at the 1% level for both homeowners and renters. This finding matches qualitatively with the preference of British households, as well as German households, as estimated by Maddison (2001) and Rehdanz (2006), respectively.

3.13. Conclusions

Given the severe threat of climate change on health, global ecology, and the economy, the number of studies that seek to measure the value of climate effects has been increasing. However, compared with the volume of studies on the effects of climate change, very few research studies have been published that estimate the implicit price of climate as an amenity. The valuation of an amenity or a disamenity of climate might provide information to housing and labor markets, as well as policy information to design a climate-change adaptation strategy. This study used a hedonic pricing approach to determine the implicit values of climate, a preference-driven approach concerning the preference for environmental goods by analyzing the market equilibrium for goods and services.

This study investigated the heterogeneity of the preferences of homeowners and apartment renters in the U.S. for climate as an amenity and offered separate hedonic models for prices and wages were carried out to see the effects of climate change on these two groups. This study has measured the extent to which U.S. households' preferences for climate amenities are capitalized into wages and house rents for both homeowners and renters. Estimated imbedded prices derived from hedonic pricing and wage models have shown that households are being compensated for low January temperatures. However, an individual hedonic pricing and wage model estimate that housing rents and wages are higher in January with higher temperature, but lower in July for higher temperatures. This suggests that the January temperature is productive, but is a consumer disamenity, whereas the higher July temperature is an amenity, while being less productive.

A similar result was also found for increased annual precipitation. Both types of householders (homeowners and renters) were willing to pay for higher precipitation; nevertheless, the dollar amount of the amenity value was small compared with the dollar value of the increases in July temperatures. Further, this study found that increases in precipitation would be as unproductive as the July temperatures in the U.S. In conclusion, with limited global warming, households would be willing to pay for that change.

The United States of America is a vast country with four very different regions. Markets for housing and labor are not homogeneous across those four regions. This study found both housing and labor markets to be segmented across those regions. The Northeast region had both housing rents and wages that were higher than those in the Midwest. This study suggested that the wage markets in the U.S. were segmented in two parts: 1) the Midwest and the South, in which low wages prevailed, and 2) the Northeast and the West, in which higher wages prevailed. Similar suggestions for housing rents were made. Housing rents were higher in the Northeast and the West, while being lower in the South and the Midwest. However, this heterogeneity is different in the values that it yielded for renters and homeowners. It is found that homeowners were paying more than renters for the amenity of living in the Northeast and the West, whereas for the South, this value was not much different, signaling a plus for the firms' investment in those regions.

This study found that besides the climate factors, other variables: neighborhood, city location, and building structure characteristics, were also the determinants of housing rents. The study also reported that wages were determined by city locations, race, and nationality, in addition to other demographic variables and education.

Table 3.1. Variable Definition and Descriptive Statistics

Variables	Description of Unit Structural Variables	Mean	Std. Dev
LnMRENT	Natural log of monthly rent of unit in $	6.692	1.131
SIGUNIT	If one-unit building, detached from any other building, Binary	0.643	0.478
SIGUNITATC	If one-unit building, attached to one or more buildings, Binary	0.056	0.230
APARTMENT	If building with two or more apartments, Binary	0.242	0.430
CONDO	If unit is condominium or cooperative, Binary	0.051	0.223
UNITOTHER	If unit types not covered or residual unit types, Binary	0.011	0.165
UNITAGE	Age of unit	40.280	25.286
BEDRMS	Number of bedrooms in unit	2.745	1.043
BATHS	Number of full bathrooms in unit	1.576	0.710
LLOTSIZE	Natural log of square footage of lot	7.346	4.537
LUNITSQFT	Natural log of square footage of unit	6.627	2.219
WATBODY	If natural water body is within 1/2 block, Binary	0.022	0.148
OPENSPACE	If any open spaces, such as parks, woods, farms or ranches within a 1/2 block, Binary	0.446	0.497
TSTATION	If railroad/airport/4-lane hwy within 1/2 block, Binary	0.130	0.336
PUBPRKG	If parking lots within 1/2 block of unit, Binary	0.234	0.423
CRIMEAREA	If neighborhood has crime as reported by households, Binary	0.149	0.356
CMRECREATION	If community recreational facilities available, Binary	0.321	0.467
ELESCHOOL	If neighborhood public Elementary school within 1 mile, Binary	0.162	0.368
	Description of Region and City Independent Variables		
CENCITY	If central city of MSA, Binary	0.293	0.455
URBAN	If city is inside MSA, but not in central city – urban, Binary	0.429	0.495
RURAL	If area other than central city and urban, Binary	0.278	0.216
NE	If census region is Northeast, Binary	0.194	0.395
SOUTH	If census region is South, Binary	0.356	0.479
WEST	If census region is West, Binary	0.214	0.410

	Description of Climate Independent Variables	Mean	Std. Dev
JAN.TEMP	Average January Temperature in ^{o}F	31.018	12.654
JULY TEMP	Average July Temperature in ^{o}F	74.459	4.882
PRECIPITATION	Average Annual Precipitation in inch	42.430	16.131
	Description of Wage Variables		
LnWAGE	Natural log of monthly wage of householder in $	6.509	1.348
EDUC	If householder has Associate degree or College degree, Binary	0.340	0.474
GRAD	If householder has Graduate degree or more, Binary	0.150	0.357
EXPERIENCE	Householder age - highs school graduate	22.498	3.228
EXPERSQ	Square of experience	516.591	143.208
MARRIED	If householder is married, Binary	0.514	0.500
HHFEMALE	If householder is female, Binary	0.441	0.497
FMEXP	Interaction of experience and female householder	1.385	1.562
AFRI.AMERICAN	If householder is African American, Binary	0.114	0.318
NATIV	If householder is Native American, Binary	0.007	0.085
ASIAN	If householder is Asian American, Binary	0.033	0.178
HISPANIC	If householder is Hispanic American, Binary	0.111	0.314
OTHERRACE	Household types not covered in any other ethnicity/race are with majority of white American, Binary	0.735	0.374
NUSCITIZEN	If household is not U.S. citizen, Binary	0.060	0.238

Notes:
1. Number of total observations: 42,620
2. House owners: 29,591
3. Renters: 13,029
4. Data sources:
i. American Housing Survey (AHS) (2005) national micro-data samples from the entire U.S. Available at http://www.huduser.org/portal/datasets/ahs/ahsdata05.html.
ii. NOAA. 2004. U.S. Climate at a Glance. Available at http://climvis.ncdc.noaa.gov/cgi-bin/state-map-display.pl.

Table 3.2. Estimated Hedonic Rents and Wage Models using SUR Estimation Method for Homeowners and Renters

	Homeowners		Renters	
Variables	Rent Model	Wage Model	Rent Model	Wage Model
INTERCEPT	6.521***	8.550***	6.820***	8.100***
	(0.270)	(0.307)	(0.269)	(0.574)
SIGUNIT	1.786***		0.403***	
	(0.025)		(0.036)	
SIGUNITATC	1.785***		0.472***	
	(0.038)		(0.041)	
APARTMENT	1.757***		0.304***	
	(0.049)		(0.078)	
CONDO	0.296***		0.127***	
	(0.042)		(0.028)	
UNITAGE	-0.003***		-0.002***	
	(0.0002)		(0.000)	
BEDRMS	0.146***		0.058***	
	(0.008)		(0.008)	
BATHS	0.323***		0.266***	
	(0.01)		(0.015)	
LLOTSIZE	0.017***		-0.014*	
	(0.004)		(0.007)	
LUNITSQFT	0.033***		0.012***	
	(0.003)		(0.002)	
WATBODY	0.204***		0.024	
	(0.038)		(0.047)	
OPENSPACE	0.062***		0.039***	
	(0.013)		(0.012)	
TSTATION	-0.063***		-0.023	
	(0.020)		(0.014)	
PUBPRKG	-0.103***		-0.021*	
	(0.018)		(0.012)	
CRIMEAREA	-0.102***		-0.087***	
	(0.018)		(0.014)	
CMRECREATION	0.092***		0.018	
	(0.012)		(0.012)	
ELESCHOOL	0.026		-0.017	
	(0.017)		(0.015)	

	Homeowners		Renters	
Variables	Rent Model	Wage Model	Rent Model	Wage Model
EDUC		0.233***		0.455***
		(0.024)		(0.036)
GRAD		0.493***		0.355***
		(0.021)		(0.054)
EXPERIENCE		0.030***		0.027***
		(0.002)		(0.003)
EXPERSQ		-0.001***		-0.0005***
		(0.000)		(0.0000)
HHFEMALE		-0.389***		-0.592***
		(0.064)		(0.063)
FMEXP		0.084***		0.108***
		(0.019)		(0.022)
MARIED		0.614***		0.583***
		(0.015)		(0.031)
ASIAN		-0.145***		-0.345***
		(0.042)		(0.068)
NATIV		-0.087		-0.198*
		(0.095)		(0.120)
AFRI.AMERICAN		-0.230***		-0.295***
		(0.026)		(0.036)
HISPANIC		-0.200**		-0.066*
		(0.027)		(0.040)
NUSCITIZEN		-0.174***		-0.198***
		(0.040)		(0.046)
URBAN	0.191***	0.165***	0.220***	0.041
	(0.015)	(0.016)	(0.020)	(0.043)
CENCITY	0.125***	0.099***	0.231***	-0.059
	(0.019)	(0.020)	(0.021)	(0.044)
NE	0.462***	0.199***	0.370***	0.163***
	(0.023)	(0.027)	(0.022)	(0.048)
SOUTH	-0.087***	-0.050	-0.087***	-0.061
	(0.031)	(0.035)	(0.028)	(0.065)
WEST	0.323***	0.050*	0.116***	0.071
	(0.026)	(0.030)	(0.027)	(0.060)

	Homeowners		Renters	
Variables	Rent Model	Wage Model	Rent Model	Wage Model
JAN. TEMP	0.027***	0.010***	0.0138***	0.012***
	(0.002)	(0.001)	(0.001)	(0.003)
JULY TEMP	-0.047***	-0.016***	-0.022***	-0.018**
	(0.004)	(0.004)	(0.003)	(0.008)
PRECIPITATION	-0.007***	-0.004***	-0.003***	-0.004**
	(0.001)	(0.001)	(0.001)	(0.002)
n	29591	29591	13029	13029
R^2	0.34	0.2	0.16	0.12

Notes:
1. Residual corr.: 0.12*** for owning house group and 0.20*** for apartment renting group, respectively.
2. Standard errors are in parentheses
3. *, **, and *** indicate that the estimated coefficients are significant, respectively, at 10%, 5%, and 1% levels.
4. All the dummy variables are measured by changing from 0 to 1.

Table 3.3. Marginal Willingness to Pay (MWTP) per month in U.S. $ (2004 Price Levels)

Homeowners

Variables	Unit	Across U.S.	Northeast	Midwest	South	West
January Temperature	^{o}F	-16.48*	-17.53	-25.02	-21.46	4.62
		(10.51)				
July Temperature	^{o}F	17.01	17.34	32.52	26.57	-20.89
		(24.56)				
Annual Precipitation	inch	11.12**	12.26	12.86	11.81	6.52
		(5.6)				

Renters

Variables	Unit	Across U.S.	Northeast	Midwest	South	West
January Temperature	^{o}F	-25.22***	-27.13	-21.16	-24.01	-28.37
		(9.26)				
July Temperature	^{o}F	32.46*	34.84	27.23	31.13	36.31
		(22.8)				
Annual Precipitation	inch	9.08*	9.8	7.63	8.58	10.3
		(6.7)				

Notes:

1. Standard errors were estimated using delta methods and are presented in parentheses.
2. *, **, and *** are significant at 10%, 5%, and 1% levels for one-tail test, respectively.

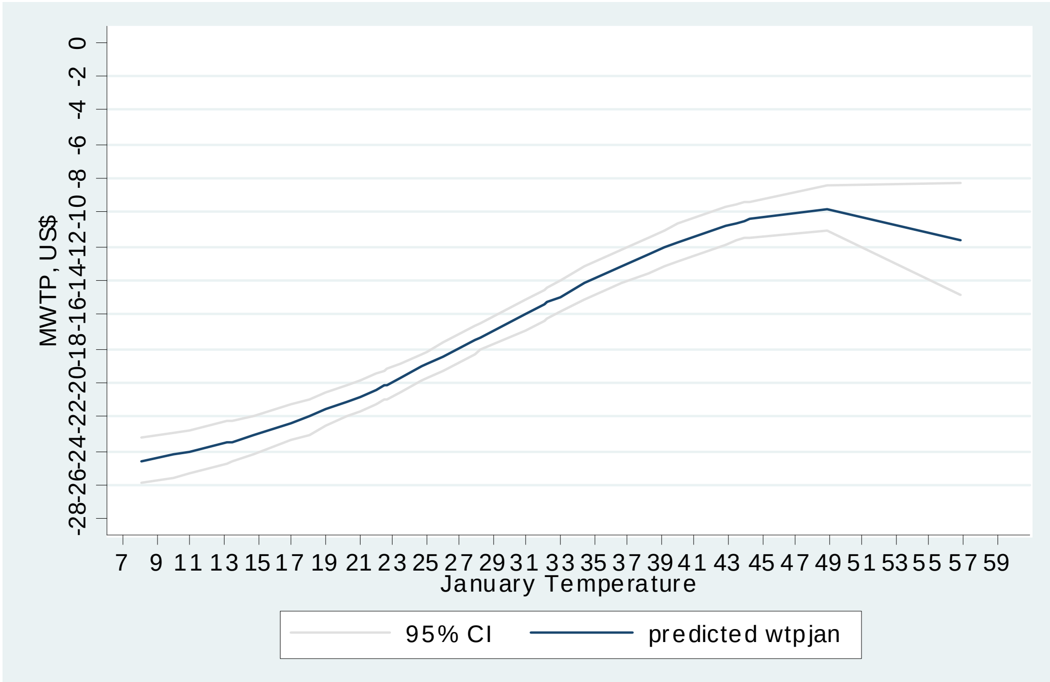

Figure 3.1. Relationship between Marginal Willingness to Pay (MWTP) and January Temperature in ^{o} F

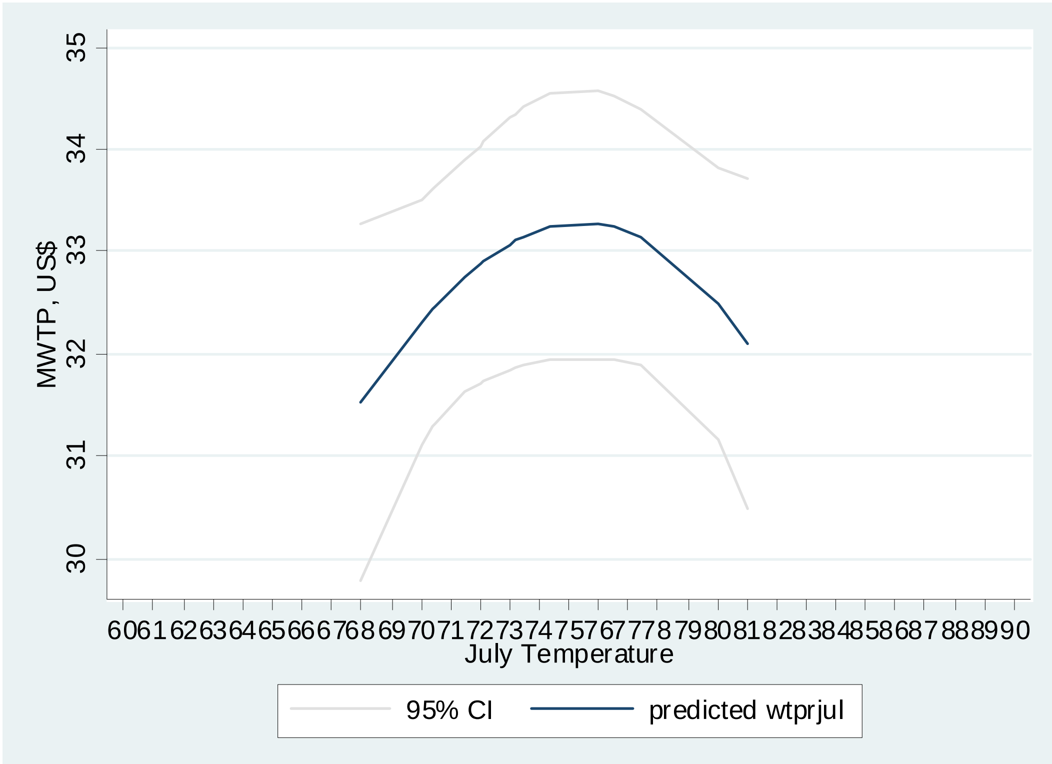

Figure 3.2. Relationship between MWTP and July Temperature in ^{o} F

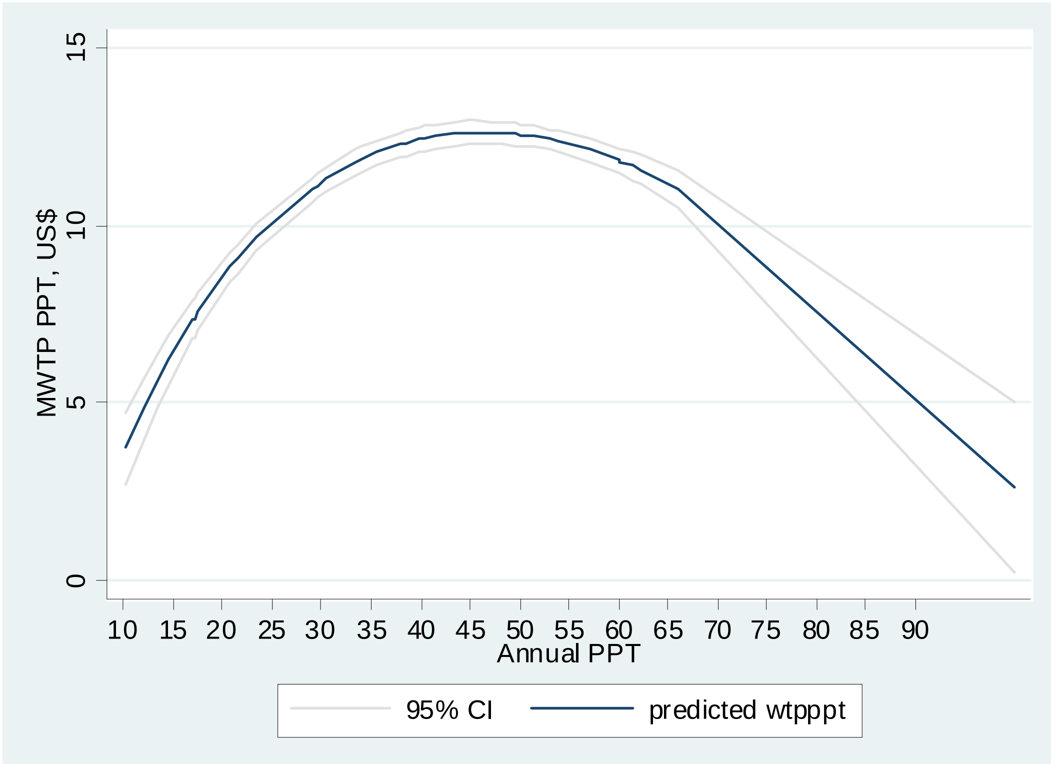

Figure 3.3. Relationship between MWTP and Annual PPT in Inches

Chapter 4: Further Investigation of Environmental Kuznets Curve Studies Using Meta-Analysis

4.1. Introduction

The environmental Kuznets curve (EKC) hypothesis, which echoes Kuznets' (1955) finding of the inverted U-shaped relationship between inequality and per-capita income, holds that environmental quality initially worsens and then improves with the increases in per-capita income (Pearce & Barbier, 2000). Evidence of an EKC relationship would show a threshold of economic development in which the relationship between some environmental degradation measure and income per-capita reverses; this threshold or decoupling between economic growth and environmental degradation is referred to as the income turning point (ITP). After Grossman and Krueger's (1991) early study on the existence of the EKC for select pollutants, empirical studies on the EKC for different pollution measures have continued to accumulate rapidly, with a mixed bag of results.

Cavlovic et al. (2000) conducted the first meta-analysis into the EKC relationship, which synthesized findings of studies carried out during the 1990s. Their analysis used 155 observations from 77 studies, and considered 11 different environmental pollution measures, including carbon dioxide (CO_2) (the much-discussed global-warming gas) and sulfur dioxide (SO_2). Results included a predicted ITP value of $199,345 for CO_2 (at the 1992 US$ price level), which was more than 70.96 times above the median global per-capita income of $2,809 in 1992. As a follow-up, using data collected from 77 studies, Li et al. (2005) conducted a second EKC meta-analysis with588 observations. Notably, Li et al. (2005) focused on two types of greenhouse gases: anthropogenic activity-related (e.g., CO_2, CH_4) and chemically-active greenhouse gases (e.g., SO_2). They could not find statistically significant evidence to support the existence of an EKC relationship over any policy-relevant income range for those two types of greenhouse gases.

Within broader debates over sustainable development, and the need for decoupling economic growth and environment degradation, public interest in exploring the empirical evidence on the relationship continues (e.g., see Tierney, 2009). Further, arguments that the EKC supports notions that societies can simply grow their way out of pollution problems also persist (Beckerman, 1992; Tierney, 2009). However, the results of numerous empirical studies on economic growth measures (e.g., per capita income) and a wide variety of environmental pollution measures remain mixed and difficulty to interpret broadly.

As empirical EKC studies continue to accumulate, the objective of this study is to further investigate potential systematic variations across studies. The particular interests in this study were to indentify: (1) variations in the income and environmental degradation relationship; and (2) the magnitudes of predicted income turning points (ITPs) for different environmental pollution measures, especially for CO_2. To help minimize any misleading comparisons from meta-analysis (George, 2001), this study has disaggregated the environmental quality measures into 11 different variables, based on their physical and chemical properties. There are 878 observations, with a broad spectrum of controlled factors from 1992 to 2009.

The main environmental degradation measures considered for this analysis are: (1) CO_2; (2) SO_2; (3) nitrogen-based compounds; (4) chemically active gases, such C, CO, CFC, etc.; (5) other gas emissions, such as volatile organic compounds, methane, unburned energy, etc.; (6) particulate matter; (7) toxic metals and elements; (8) water-based pollution; (9) landscape; (10) municipal-related wastes; and (11) agr.waste–pollution measures that include, for example, wastes from processing of meat, agriculture products, etc.

Compared with prior meta-analysis studies, this study uses 878 observations from 103 studies, which is five times more than the observations used in the study by Cavlovic et al. (2000) and about one and a half times the number used by Li et al. (2005), and the present study has a much wider set of environmental pollution measures than that used in the most recent study (Li et al.).

For investigating the systematic patterns in variations of the relationship between income and environmental pollution, this study groups them into three primary categories: monotonically decreasing and inverted U–shape relationships (improving category, hereafter referred to as “IMPROVE”); monotonically increasing relationships (worsening category, hereafter referred to as “WORSEN”); and other (insignificant or undefined relationship or some other category, hereafter referred to as “OTHER”). A cluster multinomial logit (MNL) estimation method is employed to analyze the EKC relationship considering the “OTHER” as the base category. Further, a cluster OLS as well as cluster Tobit estimation methods with heteroskedasticity correction are applied to estimate the ITPs. In meta-analysis, there will be a variation in study outcomes, which is a common methodological issue in meta-analysis (Nelson and Kennedy, 2009), and the application of cluster estimation method can correct such heterogeneity at source. The application of the cluster estimation methods nest the observations created within studies to correct for the heterogeneity of sources, (Steenberg and Jones, 2002). Further, since publication bias is another potential issue in any meta-analysis (DeCoster, 2004), a dummy variable indicting whether a paper is published or not allows a test for such bias. A sensitivity analysis was conducted to test how the variation in income per capita affects the ITP prediction.

4.2. Literature on the EKC Hypothesis

After Grossman and Krueger's (1991) groundbreaking study (done in the context of pre-NAFTA [North American Free trade Agreement] debates) on the existence of EKC relationships for SO_2 emissions and several other pollution measures, empirical studies on EKC began to rapidly proliferate. These studies covered a wide variation of local pollutants, and geo-political scales and these studies emerged amid growing concerns over global ecological sustainability issues (see Stern, 2004). For example, it became common for empirical research to investigate the absence or presence of an EKC for global warming gases or greenhouse gases, for example, CO_2, amidst rising debates over the extent and implications of global climate change.

At very general level, studies devoted to localized pollutions (e.g., sulfur dioxide, suspended particles, fecal coli forms, etc.) have shown the existence of an EKC relationship (e.g., Grossman & Krueger, 1995; Panayotou, 2000; Pasten, 2006; Selden & Song, 1994). But often results are more mixed. Complex degradation measures like biodiversity risk may show no relationship with income (Mozumder and Berrens, 2007), and air pollutants that are transboundary or global in nature, notably CO_2, often do not follow the inverted-U shape trajectory with income in general (Dijkgraaf & Vollebergh, 2005; Nguyen & Azomahou, 2007; Stern 2004). For example, a few studies have reported N-shaped relationships (see Friedl and Getzner, 2003), while a very few have evidenced a decoupling trend with income for CO_2 (Galeotti et al., 2006). Stern and Common (2001) and Galeotti et al. (2006) reported that an inverted U-shape relationship with a reasonable turning point for CO_2 is valid only for a selected group of OECD countries. Empirical analyses from developing countries have shown either a monotonically increasing relationship between CO_2 and income per capita or have demonstrated an EKC relationship with an estimated ITP that is far beyond the observed GDP per capita range (Stern & Common, 2001). More specifically, Selden and Song (1994) reported that the ITPs for CO_2 increase with any increase in the share of developing countries in the database. Therefore, inferring an EKC relationship for CO_2 based on any select study appears far from the generalization.

Whiling analyzing the proponents' views (e.g., Beckerman, 1992; Grossman, 1993, and Panayotou, 2000) on the existence of EKC relationships, it was found that economic growth often derives demand for a structural transformation in production and consumption that includes: economies of scale, structures of economy, and efficiencies in technology that an economic growth finally exhibits in an EKC relationship (see He, 2007). However, critics (e.g., Carson et al., 1997; Deacon and Norman, 2006; Galeotti et al., 2006; Stern, 2004) in various studies on the other hand have pointed that the pollution-income relationship and the ITP values are sensitivity to time, country specific, data types, function form and the estimation methods; and there are no consistent results applicable uniformly to both developed and developing countries. They argued that findings from few developed countries analyses on the existence of the EKC relationship cannot be generalized. Hence, based on their arguments, there are no generalized EKC type relationships or ITP values that are consistently applicable to all countries and for a continuous timeframe. Further, Suri and Chapman (1998) argued a similar view on the role of trade on explaining the EKC relationship; the existence of such inverted-U pattern is the consequence of trade liberalization, as a result of which, polluting industries are displaced from developed nations to developing countries. Accordingly, they suggested that the EKC hypothesis is a temporary incident that can only be observed in a specific time period and for specific country samples.

4.3. Meta-Analysis and the EKC Relationship

Meta-analysis analyzes the results of empirical studies, which was formally defined by Glass (1976) as the analysis of analyses. It is a statistical analysis of a large collection of analysis results for the purpose of integrating the findings, which requires collecting findings on a specific topic from existing studies with structured guidelines and is most commonly structured in regression form. As such observations are individual study results, one or more specific outcome of choice is the dependent variable, and the explanatory variables are characteristics of individual studies (types of applications, research methods used, nature of the data, etc.). Rather than relying on individual studies or a descriptive literature review, meta-analysis can control for a wide variety of factors, and allow opportunities for improved statistical inference and arrives at a tangible conclusion that offers an opportunity for a policy decision (Hunt, 1997).

With an increasing quantitative research studies in social and natural sciences, both application and variety of meta-analyses are growing covering a wide number of social sciences and environmental issues. Nelson & Kennedy (2009) in the review of meta-analyses published over the last three decades reported an existence of more than 140 meta-analyses in economics, with at least one-third in the area of environmental and resource economics. Toward this end, Cavlovic et al. (2000) first implemented the meta-analysis technique to examine the systematic variation between economic growth and environmental degradation while analyzing the EKC relationship of different environmental pollution measures. Their analysis found that CO_2, SO_2, and hazardous waste exhibit the EKC relationships, but predicted high ITP value for CO_2 (US $199,345 at the 1992 price level). Li et al. (2005) conducted another meta-analysis, as a follow-up meta-analysis study, with a broader dataset and new modeling approaches; however, did not report an existence of EKC-type relationship for anthropogenic greenhouse gases. Findings of these two meta-analyses, conducted during the five year period, contradicted to each other on the existence of the EKC-type relationship for CO2 at the time when policy makers for a sustainable development are expecting such a relationship. However, ITP value for CO_2 reported by Cavlovic et al. (2000) was not within the range of the attainable economic growth.

Although the use of meta-analysis to integrate findings across a body of research has grown considerably in many fields, there are common methodological issues that could lead to misleading results if not properly addressed (George, 2001). Such concerns include: improper comparison of variables, heterogeneity in data due to variability in sources, and publication bias due to the selection only of published papers for analysis (see DeCoster, 2004). However, a proper coding method, application of appropriate statistical estimation methods to correct source heterogeneity, and the inclusion of both published and unpublished papers can overcome these issues and provide a valid conclusion (DeCoster, 2004; George, 2001 and Glass, 1976). This meta-analysis applies appropriate correcting measures that include systematic coding for environmental degradation measures based on their chemical and physical properties, employs a cluster-estimation technique to correct the possibility of heterogeneity arose from different study sources, and controls for published studies by introducing a publication dummy variable to correct for the publication bias in the analysis. The application of the cluster-estimation method will correct for heterogeneity of sources by nesting the observations created within studies (Steenbergen and Jones, 2002). Correcting for all these issues, results of this meta-analysis can make valid inferences as compared with those made in the previous meta-analyses of EKC.

4.4. Data and the Construction of Variables

The study has used 878 observations, which adds 290 new observations, an increase of 49% in the size of the data set, to the most recent EKC meta-analysis (Li et al., 2005). The data set was created from 103 EKC-related studies (obtained from online ources: EconLit and JSTOR), including journal articles (87.9%), working papers (9%), book chapters (1.8%), and dissertation chapters (1.3%)[10].

The dependent variable for the multinomial logit model, EKC-RELATION, has been divided into three different categories based on the pollution-income relations: (i) IMPROVE, (ii) WORSEN, and (iii) OTHER. Again, the IMPROVE category means that economic growth would eventually bring better environmental quality, and this is demonstrated by either monotonic decreasing or an inverted U-shape (EKC relationship) scenario. The WORSEN category refers to the situation in which economic growth aggravates the problems with environmental quality. Under this category, the relationships between economic growth and the environmental quality exhibit any of the following cases: a monotonic increasing relationship, a U-shaped relationship, or an N-shaped relationship. All of the remaining undefined or insignificant relationships are grouped into the OTHER category. This category represents any case in which no statistically significant income effects on the environmental quality can be deduced from a study. Analyzing the IMPROVE and WORSEN relationships against the OTHER category provides an explicable information on the environment–income relationship.

The natural log of the income reported turning point, LnITP, another dependent variable, was used to model the systematic variations in predicted income turning points (ITPs) across different studies for diverse environmental quality variables. There were a total of 644 observations with reported ITP values. All ITPs have been converted into

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[10] A complete bibliography of all 103 studies, along with the data used in this meta-analysis are available upon request from the author, and can also found at: http://www.bishwask.bravehost.com

U.S. dollars at the 2007 price level. The number of studies that have predicted the income turning points is reported in Table 4.1. The descriptive statistics of EKC-RELATIONSHIP and LnITP are given in Table 4.1. The data created show that the IMPROVE category has the highest percentage of observations (55.9 %), while the WORSEN category has the lowest percentage (9.9%), and the OTHER has 34.2 %. The mean of LnITP measures is 12.69 (see Table 4.1).

Controlled covariates are classified into methodological variables and measures of environmental pollution. To maintain consistency, this study has followed Li et al. (2005) to design these variables. The methodological variables refer to the controlled factors, which are used to analyze the income-environment relationship in a study. This study has constructed a total of 10 different variables to control for methodological factors and their description and summary are presented in Table 4.2. The variables created under this classification are: 1) the sample size used in an EKC study—the logarithm of the number of observations (LNOBS), 2) whether a study used GDP per capita as the income measurement (INCPC), 3) whether or not the income measurement is interacted with other variable(s) in the study analysis(s) (INTINC), 4) whether a study used data from a developed country (or developed countries) only (DPED), 5) whether or not the data in an EKC study covered more than one country or region (study covering multiple countries or region) (GLOBE), 6) the length of the time coverage in data—the logarithm of the duration of coverage (LNTIME), 7) whether or not a study controlled for trade-related policy (TRADE), 8) whether or not a study controlled for the effect of population density as an exogenous factor (POPDENS), 9) whether or not a study controlled for government/institutional factors (e.g., regimes types, level of political conflicts) or social development indices (INST), 10) whether or not a study utilized a panel data set (PANEL). To these ten methodological factors chosen in the research process, this study also added a research outcome measure: whether or not a study output was published in a scholarly, peer-reviewed journal (PUBLISHED).

As far as the environmental pollution measures are concerned, the initial set of 32 different indices of environment quality are grouped into 11 pollution categories based on their properties and effects. The proper coding of these pollution measures was based on their chemical and physical properties to avoid any possible improper comparison of variables in the analysis. There are a variety of possible categorizations, and the proper coding of these pollution measures based on their chemical and physical properties can help in avoiding, or at least minimizing any possible improper comparison of variables in the analysis. Some distinct pollutants have numerous observations (and thus are perhaps less controversial), while in other cases small numbers of observations either have to be lumped with similar measures, or left in a residual category. The chosen categories have at least 15 observations each, and include: 1) CO_2; 2) SO_2; 3) NO_X; 4) chemically active gases, such as C, CO, CFC, etc. (ACTIVEGAS); 5) a volatile organic compound (voc), CH_4, energy and other air-related pollution, etc. (VAIRGRUP); 6) suspended particulate matter, such as smoke and dust (SPARTICLE); 7) heavy toxic elements (HTOXIC); 8) water quality and pollution, including dissolved oxygen, biological oxygen demand, chemical oxygen demand, E. Coli, etc. (WATPOLN); 9) landscape degradation (LANDSCAPE); 10) municipal-related wastes (MUNWASTE); and 11) agricultural by-products (AGR. WASTE) resulted from the processing of an agricultural commodity into a consumable or industrial product, which include byproducts of meat processing, agriculture products, etc. The summary of environmental-quality degradation categories by their environment-income relationship is given in Table 4.3.

Briefly, the data on environmental measure indicators show that the air quality measures dominate the EKC studies (about 68.8%), among which CO_2 and SO_2 have been the two most popular measures of air quality, contributing 34.2% and 13.9% of total observations, respectively. Other air related pollutants– NO_X, SPARTICLE, ACTIVEGAS and VAIRGRUP represent 7.1%, 6%, 5.9% and 1.7%, respectively.

4.5. Modeling Approaches

This study implements a multinomial logit model (MNL) to analyze the systematic variations of the pollution-income relationship (EKC-RELATION) and applies both OLS and Tobit models to estimate income turning points (ITPs).

For the MNL modeling, the EKC-RELATION is the dependent variable, and OTHER is the base category, compared with the IMPROVE and WORSEN groups. The MNL model of the probability is given by the following equation:

$$\Pr(Y_i = j \mid M) = \frac{\exp(\beta'_j X_i)}{\sum_{K \in M} \exp(\beta'_K X_i)} \quad 4.1$$

where, Pr ($Y_i = j | M$) is the probability that the EKC relationship (Y_i) for *i* study falls under alternative *j* within *M* possible choices, which include IMPROVE, WORSEN and OTHER groups. X_i represents a vector of attributes and *K* stands for choices. β_j and β_K are vectors of interested parameters (Greene, 2003, p. 721).

To estimate ITPs of the environmental pollution measures, a general form of natural logarithm of the ITP estimation model is given as follows:

$$LnITP_i = P'_i\gamma + C'_i\theta + \varepsilon_i \qquad 4.2$$

in which P'_i is the vector that represents the vector of environmental pollution or degradation measures and C'_i is the vector of key characteristics (the ten methodological factors, and the publication outcome variable). γ and θ are the conformable vectors of estimable parameters, respectively, and ε is a random-error term, which follows a normal distribution with $N(0, \sigma^2)$.

In order to draw reliable statistical inferences for ITPs (since not all studies report them), it is important to select an appropriate model and obtain as broad of data coverage as possible. This analysis employs two estimation techniques: (i) OLS by utilizing observations of all reported ITPs; and (ii) Tobit model by imputing missing ITPs for observations without. For OLS, the usable sample size consists of 644 available observations from original data without missing ITP values. The reported predicted ITP values have two extremely high values of ITP ($25 million and $115 million at the 2007 price level) for the ACTIVEGAS indictor variable. However, in the OLS analysis, no exclusions were made for those extremely high ITP values.

As an alternative to OLS, a Tobit model was applied to include all observations that showed certain relationships, and thus the sample size was expanded to 727 observations. That is, a total of 83 observations were added into the analysis, of which 63 observations were with either an EKC-type or monotonic increasing relationships, while 20 were with monotonic decreasing relationships. Specifically, by setting an upper-censored value, this study allowed the sample to include the observations outside the data range—those demonstrating either a positive-income and environment relationship or a decreasing relationship while not reporting ITPs.

By letting Ln*ITP* $=y_i$ be the latent variable, the Tobit model can be written as the following equation:

$$\begin{cases} y_i = P_i'\gamma + C_i'\theta + \varepsilon_i & if \quad P_i'\gamma + C_i'\theta + \varepsilon_i < T \\ y_i = T & if \quad P_i'\gamma + C_i'\theta + \varepsilon_i \geq T \end{cases} \qquad 4.3$$

in which T is the right-censoring limit, and i stands for the number of observations. The dependent variable y_i is truncated at ln (ITP) =13.5, that is, ITP ≥ \$730,000. This income level was chosen after performing sensitivity analysis[11]–results were qualitatively similar when the right censoring were truncated for \$850,000 and \$1,000,000.

The predicted value of the logarithm of the ITP was calculated by using the following equation:

$$E[LnITP = y_i \,|(P_i{}'\gamma + C_i{}'\theta)] = \Phi(\frac{P_i{}'\gamma + C_i{}'\theta}{\sigma})\,(P_i{}'\gamma + C_i{}'\theta) + \sigma\phi(\frac{P_i{}'\gamma + C_i{}'\theta}{\sigma}) \qquad 4.4$$

[11] A sensitivity analysis was also performed by testing different censoring threshold values: (i) ln(ITP) = 9.24 (average world GDP per capita of \$10,497 in 2007); (ii) ln(ITP) =13.81(ITP>=\$1, 000,000) (arbitrarily taken as a currently unattainable GDP per capita threshold); and (iii) a lower censoring point to model (3), where lower ln (ITP) = 7.25 (\$1,410 the average world GDP per capita of 50 poor countries as listed by UN in 2007). Estimation results are qualitatively consistent across these alternative censoring thresholds.

where the P'_i, C'_i, γ and θ are as defined earlier. Notations ϕ and Φ are, respectively, the probability density function and cumulative distribution function for a normal distribution.

To capture heterogeneity and improve efficiency in estimations, this study implement cluster MNL for the EKC-relationship estimation, and cluster OLS and cluster Tobit for the ITPs estimation (Brusco et al., 2008).

4.6. Empirical Results

Estimation results of the cluster multinomial logit (MNL) model for investigating different EKC relationships are presented in Table 4.4. The estimated standard errors are adjusted for 103 clusters of number of papers and are robust standard errors, since the clustering provides robust standard error (Cameron and Trivedi, 2010). Compared with the base category of OTHER (that is, the studies that exhibited no environment-income relationships, or for which the relationship could not be defined), the results of this study indicated that using more observations would decrease the odds of finding an EKC-type relationship (IMPROVE). Results suggested that the probability of having IMPROVE relationship decreases by 2.7 percentage points if the number of observation increases by 1%. The results also suggested that the inclusion of the developed-country indicator variable (DPED) and using data that covers multiple countries or regions (GLOBE) would significantly increase the probability of achieving a better environment-income relationship by 16.8 and 18.4 percentage points, respectively. That is, results indicate that if an EKC study uses data from multiple regions or countries, and/ or the data is for developed countries, then it is more likely to find an EKC-type relationship.

Compared with the OTHER group, the results suggested that all air-pollution-related measures have significantly positive effects in predicting the EKC-type relationship.

More specifically, CO_2, SO_2, NO_X, other active gases (ACTIVEGAS), volatile organic compound and other air-related pollution compounds (VAIRGRUP), particle matter, smoke, air toxics (SPARTICLE) significantly increased the odds of finding IMPROVE category by at least 19% percentage points. The trans-boundary pollutants such as CO_2, SO_2, and NO_X are more likely to find IMPROVE relationship by 28.2%, 24.4% and 36.6%, respectively. For more localized pollutants, such as SPARTICLE, HTOXIC and AGR. WASTE the probability of finding the IMPROVE environment-income relationship would increase by 19.4% 27.0% and 18.8%, respectively.

Meanwhile, the cluster MNL results did not find statistically significant evidence of the EKC-type relationships for other environmental-degradation measures, such as landscape degradation (LANDSCAPE), and municipality-related wastes (MUNWASTE).

This study controlled for whether or not a study output was published in a journal (PUBLISHED) to test the effect of publication on the EKC prediction. The MNL results showed no significant effect of results being published in a peer-reviewed journal on the estimated EKC relationship, suggesting that there is no publication bias in the EKC literature on predicting the EKC relationship.

On the other hand, the inclusion of air pollution measures such as SO_2, NO_X, ACTIVEGAS, VAIRGRUP, SPARTICLE significantly decreased the odds of finding

WORSEN relationship; however, their values of marginal effects are quite low. Likewise, controlling for other pollution measures like, LANDSCAPE and AGR. WASTE also reduced the odds of finding of WORSEN relationship. While analyzing the effects of the methodological variables only TRADE and population density (POPDENS) would reduce the probability of finding the WORSEN relationship by 0.67% and 0.008%, respectively. While there is no consensus in the literature regarding the impact of trade activities on environment quality (e.g., Stern 2004), these meta-analysis results did not support any effect of trade factor (TRADE) in predicting the EKC relationship. However, it showed that the TRADE would contribute the probability of finding WORSEN environment-income relationship compared with the base category, OTHER. The results from this meta-analysis have indicated that the globalization could reduce the pollution in the home country (region).

In previous findings (e.g., Li et al., 2005), most of the data-related variables, research method factors, and modeling strategy-related variables have significant effects on the patterns of environment-income relationship. While the current meta-analysis has more observations and has correction for methodological issues of meta-analysis, this study has identified significant results for only a few methodological variables, such as number of observations (LNOBS), the development status (DPED) and data coverage from more than one country or region (GLOBE). For a given different estimation methods with more observations and application of correction for methodological issues of meat-analysis, it therefore has provided richer information critically on the existence or nonexistence of the EKC-type relationship for most of the important environmental-degradation measures.

Estimation results for ITPs using the cluster OLS and Tobit models are presented in Table 4.5. This analysis has included all the methodological variables as well as 10 categorical environmental degradation indicator variables in the models. In general, the cluster regressions appear to exhibit adequate goodness-of-fit; for the cluster OLS model, the R^2 is 0.55, and the Chi-square value from the cluster Tobit model is significant (at the 1% level). In both models, methodological variables– LNOBS, GLOBE and POPDENS significantly affected the variation in ITPs. Variables– logarithm of duration of coverage (LNTIME), a panel data set (PANEL) and income measurement interacts (INTINC) were significant only in cluster OLS, whereas per capita income (INCPC) was significnat only in the cluster Tobit model. This study found that the estimated coefficient for LNOBS was positive and significant at the 5% and 10% levels in the Tobit and OLS, respectively. Thus, results from both the OLS and the Tobit models have suggested that the more observations a study uses and the more countries and regions the data could cover, the higher ITP values would be. Further, inclusion of income interaction variable (INTINC) in the cluster OLS model also increased the ITP value (positive and significant at the 10% level).

On the other hand, longer time period (LNTIME) and using panel data set (PANEL) are both significant and negative at the 5% level in the cluster OLS, and therefore studies exhibiting these two features have found lower ITP values. Similarly, controlling for income per capita (INCPC) in cluster Tobit model also decreased the ITPs (significant and negative at the 10% level). In both the OLS and Tobit models, the data set used in the present analysis supported a strongly negative effect of the population density (POPDENS) on the ITP values (at the 5% level).

To test the effect of publication on ITP prediction, this study has controlled for study output published in a journal (PUBLISHED), and results of both estimations models showed no significant effect of published journal on the ITP prediction. This suggests that there is no publication bias in predicting the ITP.

As far as the dummy variables of environmental degradation measures were concerned, the estimated coefficients on municipal waste (MUNWASTE) and AGR. WASTE were positive and significant at the 1% level in both cluster OLS and cluster Tobit models. As deforestation has intensified several problems such as climate change, loss of biodiversity and decline in agricultural productivities; it has raised concerns of policy makers for a sustainable harvesting of forest resource. The estimated effect of LANDSCAPE, a local level environmental degradation, was positive and significant at the 10% level in the cluster Tobit model. A similar result was also found for suspended particles (SPARTICLE), as one of the local air pollutants, on ITP in both estimation models.

For other pollutant categories, estimation results were found consistent across models and specifications. In both cluster OLS and cluster Tobit models CO_2, SO_2, NO_x, ACTIVEGAS, and VAIRGRUP exhibited significantly positive effects on ITPs, estimating relatively higher ITPs.

As noted above, predicting the ITP was also one of the objectives of this study. Considering the advantages of controlling for heteroskedasticity and data expansion (allowing more observations), the results from cluster Tobit model were of primary interest. The number of clusters (coverage of number of studies) remained only 87 for OLS, while in Tobit model, it increased to 97. This increase in number of clusters in the

Tobit model increased the validity of the predicted ITPs and the basis for inference. However, for completeness and comparison purposes, estimated ITP values from the cluster OLS model estimation, and reported ITP values from the original data are also presented in Table 4.6. On average, the predictions from cluster Tobit model were higher than those from OLS due to the inclusion of the monotonically increasing relationship (the WORSEN category). Further the predicted results from the cluster Tobit model appeared to closely match the sample means for most environmental degradation measures (Table 4.6). The exceptions were ACTIVEGAS and VAIRGRUP. The extremely high estimated ITP values for ACTIVEGAS were due to the reported two extreme ITP values of over $25 and $115 millions.

The results suggest that identifiable characteristics of environmental pollution or degradation measures systematically vary across the dispersion of estimated ITPs. For example, some local or regional pollutants (e.g., WATPOLN, MUNWASTE, SPARTICLE and LANDSCAPE) with immediate visible effects such as health risks, landslides, etc., exhibit lower ITPs. To note, the corresponding predicted ITPs for WATPOLN, MUNWASTE, SPARTICLE and LANDSCAPE are US $4,469, $32,337, $9,516 and $11,761, respectively. The estimated ITP for SO_2 is $17,978 from the cluster OLS model, and $21,137 from the cluster Tobit model. As these local environmental degradations could relatively be easier to internalize in a single economy, and it might be more likely the local policy makers would correct these externalities at the lowered ITPs values. However, except for water pollution, most of the these value estimates remained only within the range of average GDP per capita of the developed countries of OECD country members[12], whose average per capita GDP is $32,700 in 2007. Compared with the previous meta-analysis study by Cavlovic et al. (2000), the predicted ITP values of this study were generally higher except for CO_2, but within the quantitatively comparable range and consistent in magnitude. The characteristics of all environmental-pollution measures determined the dispersion of the ITPs. For example, some local or regional pollutants (e.g., WATPOLN, SPARTICLE, and LANDSCAPE) with immediate visible effects, such as health risks, landslides, etc., exhibited lower ITPs. It is important to note that the corresponding predicted ITPs for WATPOLN, SPARTICLE and LANDSCAPE were U.S. $3,855, $9,542, and $12,206, respectively. The estimated ITP for SO_2 appears to be $17,929 (OLS) and $21, 261 (Tobit). This value remains within the GDP per capita of the developed countries.

The estimated ITPs for the greenhouse gases examined in this study were noticeably higher due to the high cost of international or cross-regional co-operation efforts. For example, estimated ITPs for ACTIVEGAS and VAIRGRUP were $161,746 and $157,851, respectively. The predicted ITP for CO_2, a much discussed global warming gas, was $102,281 from the cluster Tobit model, and $91,487 from the cluster OLS model, at the 2007 price level.

While analyzing the predicted value of ITP for CO_2 by this meta-analysis against the predicted ITP values of earlier studies is concerned, the results showed a somewhat lower ratio between ITP and GDP per capita. Here, the ITP and GDP per capita ratio is 10 times at the 2007 US dollar price level) compared to the initial finding made by

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[12] Organization for Economic Cooperation [OECD]. 2008. *Stat Extracts*. Available at http://stats.oecd.org/index.aspx., last accessed May 22, 2010.

Cavlovic et al. (2000) with a ratio that was 70.96 times the median global per capita income at the 1992 US dollar price level . Yet, although the results of the cluster multinomial logit for EKC relationship find the possibility of decoupling between economic growth and CO_2 emission; the ITP models still estimate extremely high threshold values (in the \$91,487 to \$102,281 range), which are well outside of the range of the observed data, and seem essentially unattainable for any foreseeable future. For example, for our preferred cluster Tobit model, which relies on a larger set of observations, the predicted ITP of CO_2 is \$102, 281with standard deviations, \$69,722, which is above the median global average GDP per capita of \$10, 497 in 2007 (IMF, 2008).

To help place the estimated ITP values for CO_2 into context, these can be compared against the scenario analysis for CO_2 emissions, climate change and the GDP per capita provided by Intergovernmental Panel on Climate Change (IPCC, 2000). The results of integrated assessment models of the Special Report on Emissions Scenarios – SRES[13] from IPCC (2000) report a best case scenario (fast economic growth with application of environmental policy measures) that estimates an average GDP per capita of US \$73,800 at the 2007 price level and a CO_2 emissions level of 600 ppm [the emissions of CO_2 level is 385 ppm at 2007 (IPCC, 2000)], accompanied by a rise in global average temperature of 1.8^{o} C over the 93 years of time frame from 2007 or by the

[13] The Special Report on Emissions Scenarios (SRES): a Special Report of Working Group III of the Intergovernmental Panel on Climate Change report published a new set of scenarios in 2000 in the Third Assessment Report of IPCC-2000. The SRES provided future developments in the global environment and the production of greenhouse gases and aerosol emissions.

end of 21st century. Similarly, the worst case scenario (fast economic growth– without environmental policy measures and with no substitute to fossil fuel) estimates an average GDP per capita of US $116,599 at the 2007 price level and CO_2 emissions level of 1,550 ppm (almost 4 times greater than the CO_2 emissions level at 2007), accompanied by a rise in the global average temperature by 4^o C by the end of 21st century or after 93 years from 2007. As can be seen, the predicted ITPs ($91,487 to $102,281) for CO_2 from this meta-analysis don't show any evidence for a predicted "de-coupling" of economic growth and increase in CO_2 emissions until much higher income levels. It further highlights that any economic growth that reaches the range of the predicted ITPs to control the emissions of the CO_2 would appear be above the threshold point of irreversible damage due to the global warming effect [given as 1,550 ppm would increase global temperature by 4^oC (IPCC, 2000)]. Thus, if lowering emissions, responding to global climate change and the slowing rate of global warming, are of international importance, then it should be clear that the EKC literature to date offers no basis for predicting that this will happen simply as a result of continued economic growth.

However, results from chapter 2 have evidenced that the application of environmental policy, for example, energy-efficiency building codes can reduce CO2 emissions from U.S. households into the atmosphere. An effective implementation of such building codes can be made in other part of the world and the emissions of CO2 can be reduced globally where energy consumption is increasing. Therefore, a coordinated global effort would possibly lower the emissions of CO2 with attainable ITPs that could explain an EKC relationship.

4.7. Conclusions

With the continued accumulation of empirical studies on environment-income relationships, meta-analysis represents an important tool for investigating possible systematic patterns across studies. Following several prior investigations (Cavlovic et al., 2000; and Li et al., 2005), the current study represents the largest meta-analysis to-date to attempt to synthesize the empirical EKC literature. Specifically, this study constructs a richer dataset, with 878 observations from 103 existing studies (including all studies in the prior analyses, and covering a broad spectrum of controlled factors from 1992 to 2009). Further, the meta-analysis: (i) uses cluster estimation techniques to correct the possible heterogeneity generated from different study sources; (ii) controls for a variety of research method effects, such as possible publication bias via a publication dummy variable; and (iii) allows considerable dis-aggregation of environmental degradation measures by systematic coding based on chemical and physical properties. More specifically, eleven dummy variables of environment degradation measures were characterized, including 6 different categories of air pollutants – CO_2, SO_2, NO_X, ACTIVEGAS, VAIRGRUP and SPARTICLE.

Results indicate that data characteristics, methodological choices (of the research analyst) and environmental quality characteristics all have significant effects on finding an improved relationship (EKC-type) between environment degradation and per capita income. From, the multinomial logit modeling, similar factors also have a statistical impact on finding an insignificant EKC-type relationship, but the directions and magnitudes of these effects vary. As one prominent finding, holding other factors constant, the 6 different air pollution indicators (relative to the base category–OTHER) all have a significantly higher probability of finding an environment-income relationship that eventually improves (IMPROVE).

This meta-analysis finds that predicted ITPs vary significantly across the environmental degradation measures depending on their characteristics. In general, some local pollutants such as suspended particles, water pollution and deforestation exhibit lower ITPs than the pollutants with a regional or global nature, for example, most air quality-related or greenhouse gas pollutants. While an EKC-type relationship has been observed in a wide range of environmental quality measures, as these results indicate in many cases, the estimated ITPs are so large that they are far outside the observed range of current income per capita. As such, for environmental pollution or degradation measures with large-scale effects (e.g., global in some cases), then issues of regional or global carrying capacity (e.g., Arrow et al.,1995) are likely to become important threshold considerations far before any "decoupling" could be expected.

Certainly, the results of this meta-analysis on the existence of EKC-relationships for different pollutant and degradation measures show some mixed results, specifically with highly varying ITPs estimates for different measures. But, for the principal greenhouse gas, CO_2, results confirm the absence of any predictable decoupling of emission and at any attainable global average per capita income range (e.g., as might be predicted to happen within the next 50 years). This remains consistent with the earlier meta-analyses of Cavlovic et al. (2000) and Li et al. (2007).

Identifying economic development paths while controlling for CO_2 and other greenhouse gas emissions remain a long-term policy challenge. The results of this meta-analysis indicate that the EKC literature to date offers no basis for predicting that decreasing CO_2 emission levels will somehow sufficiently decrease simply as a result of continued economic growth. Rather, solving such environmental concerns will require coordinated international policy actions.

Table 4.1. Dependent Variable Definitions and Descriptive Statistics

Variables	Definitions	Mean	No. of Obs.
EKC-RELATIONSHIP (for use in Multinomial Logit Model)	IMPROVE means the environmental degradation eventually improves with increasing income. If relationship is IMPROVE then =1	.559	491
	WORSEN means environmental degradation deteriorates with increasing income, eventually. If relationship is WORSEN then = 2	.099	86
	OTHER refer to the case that the relationship is not identifiable or not statistically significant. If relationship is OTHER then = 3	.342	301
LnITP	Log of Predicted Income Turning Point (ITP), converted into 2007 price level.	12.69	644

Table 4.2. Definitions and Descriptive Statistics of Methodological Category Variables

Variables Category	Explanatory Variables on Methodological	Mean	Std. Dev.
LNOBS	Log of number of the observations used in EKC study	5.200	2.211
INCPC	Income per capita indicator variable equals to 1 if the EKC study has considered, otherwise 0.	.932	.250
INTINC	Income interaction indictor variable equals to 1 if the study has considered, otherwise 0.	.053	.225
DPED	Developed country indicator variable equals to 1 if the EKC study has considered, otherwise 0.	.370	.483
GLOBE	Multi-country pollution data indicator variable equals to 1 if the EKC study considered, otherwise 0.	.637	.480
LNTIME	Log of time duration of data (longitudinal data) indicator variable equals to 1 if the study has considered, otherwise 0.	2.648	1.318
TRADE	Trade related policy indicator variable equals to 1 if the EKC study has considered, otherwise 0.	.117	.321
POPDENS	Population density indicator variable equals to 1 if the EKC study has considered, otherwise 0.	.281	.449
INST	Types of government regimes and interventions, or social development indices variable indicator equals to 1 if the EKC study has considered, otherwise 0.	.238	.426
PANEL	Panel data indicator variable equals to 1 if the EKC study has used, otherwise 0.	.777	.415
PUBLISHED	Indicator variable equals to 1 if the observation is from a published journal article, otherwise 0.	.817	.386

Table 4.3. Summary of Environmental Pollution Measure Categories across Environment-Income Relationships

Category	Measures	EKC Relationship				Observations with Reported ITP
		IMPROVE	WORSEN	OTHER	TOTAL	
CO_2	Carbon dioxide	176	41	83	300	246
SO_2	Sulfur dioxide	71	3	48	122	86
NO_X	NO_2, nitrogen, nitrates, NH_3, NO_x, and nitrogen related compounds	52	4	6	62	56
ACTIVEGAS	Active gases like C, Sulfur, CFC, CO, O_3, etc.	36	1	15	52	29
VAIRGRUP	Volatile organic compound (voc), CH_4, and other air related pollution groups	12	0	3	15	12
SPARTICLE	Smoke, TSP, Particles, solid, SPM_tran, PM10, etc.	25	6	22	53	38
HTOXIC	Lead, Arsenic, Hazardous Waste, Cadmium, Mercury, Nickel, HWS, etc.	20	5	9	34	27
WATPOLN	BOD, COD, DO, Coli form and other water related pollution.	26	20	44	90	71
LANDSCAPE	Deforestation, loss of biodiversity, park degradation, etc.	24	0	29	53	40
MUNWASTE	Waste from house, rents, food, municipal waste, etc.	13	2	16	31	15
AGR. WASTE	Environmental degradation that includes agricultural by-products or wastes resulted from the processing of agricultural commodities, which include byproducts of meat processing, agriculture produces, etc.	36	4	26	66	24
Total		491	86	301	878	644

Notes: IMPROVE means that the environmental degradation eventually improves with increasing income; WORSEN means that environmental degradation deteriorates with increasing income, eventually; OTHER refers to the case that the relationship is not identifiable or not statistically significant.

Table 4.4. Estimates of Cluster Multinomial Logit Model for EKC Relationship (Compared to OTHER Group [all studies in the Insignificant and Other categories])

			Marginal Effects	
Variables	IMPROVE	WORSEN	IMPROVE	WORSEN #
INTERCEPT	-2.536**	-.740	------	------
	(1.100)	(2.076)		
LNOBS	-.119*	-.212**	-.027*	-. 001
	(.077)	(.088)	(.016)	(.001)
INCPC	1.010	. 915	.246	.003
	(.724)	(1.633)	(.174)	(.016)
INTINC	. 341	.569	. 074	.004
	(.417)	(1.074)	(.087)	(.016)
DPED	. 755**	.756	. 168**	.003
	(.375)	(.642)	(.080)	(.008)
GLOBE	. 784**	.166	. 184**	-.003
	(.341)	(.454)	(.080)	(.006)
LNTIME	. 077	-.159	. 017	-.002
	(.163)	(.209)	(.037)	(.002)
TRADE	-. 340	-34.852***	-.076	-. 674***
	(.461)	(.680)	(.112)	(.140)
POPDENS	-. 326	-1.077	-.076	-. 008*
	(.362)	(.538)	(.085)	(.005)
INST	. 095	-.094	.021	-. 001
	(.370)	(.593)	(.084)	(.006)
PANEL	. 202	.790	.047	.006
	(.475)	(.714)	(.112)	(.006)
CO_2	1.340***	.429	. 282***	-.005
	(.458)	(.571)	(.086)	(.006)
SO_2	1.277**	-.681	. 244***	-.011***
	(.462)	(.809)	(.069)	(.004)
NO_X	2.771***	1.238**	. 366***	-.007*
	(.750)	(1.098)	(.049)	(.004)
ACTIVEGAS	1.347**	-1.414	. 242***	-.012***
	(.610)	(1.476)	(.079)	(.003)
VAIRGRUP	1.899**	-34.009***	. 242***	-.021***
	(.806)	(.919)	(.079)	(.004)
SPARTICLE	1.003*	-.107	. 194**	-.006*
	(.483)	(.589)	(.075)	(.004)
HTOXIC	1.630	.852	. 270**	-.004
	(1.048)	(1.186)	(.102)	(.007)
AGR. WASTE	.964	-.513	.188	-.008**
	(.705)	(1.105)	(.109)	(.004)
LANDSCAPE	.579	-34.969***	. 122	-. 098***
	(.582)	(.825)	(.109)	(.019)

Variables	IMPROVE	WORSEN	Marginal Effects	
			IMPROVE	WORSEN#
MUNWASTE	.617	-.639	. 128	-.007
	(.557)	(2.304)	(.102)	(.011)
PUBLISHED	.673	-.705	. 161	-.019
	(.478)	(.528)	(.117)	(.014)
Pseudo R^2	0 .13		-	-
Log likelihood	-701.349***		-	-

Notes:
1. Number of Observations: 878
2. Number of Clusters: 103
3. Standard errors are in parentheses.
4. *, **, and *** indicate the estimated coefficients are significant at the .01, .05, and 0.01 levels, respectively.
5. # denotes that values of marginal effects and standard error terms are multiplied by 10^{-2}.

Table 4.5. Modeling Results for Income Turning Points (ITPs)

Variables	Cluster OLS Model	Cluster Tobit Model
INTERCEPT	8.52***	8.489***
	(.930)	(1.054)
LNOBS	.176*	.183 **
	(.105)	(.095)
INCPC	-.571	-1.102*
	(.544)	(.624)
INTINC	. 438*	. 562
	(.250)	(.524)
DPED	-. 065	-. 220
	(.271)	(.318)
GLOBE	. 702 **	. 748 **
	(.312)	(.347)
LNTIME	-. 188 **	-. 152
	(.085)	(.113)
TRADE	-. 067	.047
	(.254)	(.365)
POPDENS	-. 437 **	-.534 **
	(.202)	(.284)
INST	-.091	-.043
	(.171)	(.252)
PANEL	-.740**	-. 370
	(.320)	(.394)
CO_2	2.699 ***	3.078***
	(.509)	(.487)
SO_2	1.611***	1.860***
	(.516)	(.502)
NO_X	2.026 ***	2.109***
	(.555)	(.517)
ACTIVEGAS	2.645***	3.380***
	(.684)	(.751)
VAIRGRUP	3.093***	3.255***
	(.686)	(.763)
SPARTICLE	.990**	.855*
	(.505)	(.484)
HTOXIC	.942	1.554**
	(.612)	(.730)
AGR. WASTE	1.286***	3.274 ***
	(.478)	(.761)
LANDSCAPE	.325	1.016 *
	(.513)	(.630)

Variables	Cluster OLS	Cluster Tobit
MUNWASTE	2.609 **	2.708***
	(1.021)	(.906)
PUBLISHED	. 228	.230
	(.354)	(.407)
n	644	727
R^2	0.55	-
χ^2	-	184***
$\hat{\sigma}$	-	1.579***
		(.114)
No. of clusters	87	97

Notes:
1. Cluster Tobit model is censored with an upper threshold of US$ 730,000.
2. Standard errors are in parentheses.
3. *, **, and *** indicate the estimated coefficients are significant at the 0.10, 0.05 and 0.01 levels, respectively.

Table 4.6. Predicted Per Capita ITPs by Type of Pollutants

Variables	Predicted ITP from Cluster OLS (US $ 2007)	Predicted ITP from Cluster Tobit (US $ 2007)	Reported ITP by EKC Studies (US $ 2007)
CO_2	91,743***	102,281***	186,271
	(4,505)	(4,019)	
SO_2	17,978***	21,137***	44,341
	(982)	(1,177)	
NO_X	31,699***	30,427***	29,340
	(2,105)	(2,435)	
ACTIVEGAS	86,481***	161,746***	156,899[a]
	(4,549)	(8,833)	
VAIRGRUP	134,769***	157,851***	829,632
	(14,476)	(23,504)	
SPARTICLE	12,520***	9,516***	18,779
	(959)	(672)	
HTOXIC	20,800***	28,189***	24,884
	(1,360)	(1,736)	
WATPOLN	4,397***	4,469***	8,725
	(542)	(611)	
LANDSCAPE	7,061***	11,761***	7,275
	(669)	(876)	
MUNWASTE	27,159***	32,337***	29,188
	(2,303)	(2,287)	
AGR. WASTE	27,040***	164,470***	32,796
	(2,146)	(12,049)	

[a]Excludes two observations with ITPs of $115 million and $25.2 million.

Chapter 5: Conclusions

Conclusions about the research results of individual applications that have explored the links between various potential climate changes and their effects on individual households and relationship between emissions of CO_2 and per-capita GDP are provided in each of the preceding chapters. This chapter provides a broader perspective of these individual results with discussions on policy applications and recommendations for further research.

5.1. Summary of Dissertation

The research results presented in this dissertation have indicated that climate change does not impose effects uniformly on all households and states across the U.S. Out of three empirical analyses, two main analyses from chapter 2 and chapter 3 directly measured the effects of climate change on residential energy demand with energy-efficiency building codes, and these analyses also estimated the monetary values of climate amenity revealed by homeowners and apartment renters, respectively. These two analyses supported the hypotheses that global warming can affect the residential energy demand in U.S. households, as well as residential property values and wage rates. Chapter 4 analyzed the relationship between CO_2 emissions and other environmental quality indicators and the per-capita GDP. The chapter also estimated the income turning point (ITP) for CO_2 emissions into the atmosphere.

Chapter 2 proposed open empirical questions of whether climate characteristics and energy-efficiency building codes were important determinants of residential energy demand. This study has answered these questions and found significant results. With an application of multilevel econometric estimation, this analysis has given efficient and reliable results by correcting for the violation of the assumption of independence of observations. The chapter made an important finding in the increase in July mean temperatures increases the consumption of electricity, suggesting that global warming will increase the demand for electricity at the household level. Unlike the demand for electricity, the demand for natural gas and heating oil will actually be reduced by global climate change. An increase in the consumption on electricity would result in the release of more CO_2 into the atmosphere, as in the U.S., about 48.2% of electricity is produced by burning coal. This study estimated the effects of economic variables: income and prices. This study found that all types of energy are inelastic. Both natural gas and heating oil are substitutes for electricity. This study reported that if the price of electricity increased, then the demand for both natural gas and heating oil would also be increased by 0.13% and 0.65%, respectively.

This study found that both energy-efficiency codes (IECC 2003; IECC 2006) are significant to reduce the energy demands. These findings offer an important policy guideline for policymakers and households to make decisions on investments for energy efficiency. This finding provides information for homeowners, energy suppliers, and producers of efficient technologies for a given climate-change scenario and the corresponding increase in the demand for electricity.

This analysis has supported several policy recommendations. As electricity consumption would increase with global warming, its production by using fossil fuels would be counterproductive in any policy to combat global warming. Therefore, an alternative source for generating electricity or an alternative to fossil-fuel-fed electricity (e.g., renewable-energy resources: solar, wind, hydropower, etc.) would be an appropriate policy recommendation. However, the application of such renewal-energy resources would require a huge initial investment. At present, only about 9 million residential buildings from about 34 states have adopted energy-efficiency building codes. A policy measure is required to adopt energy efficiency to address issues of climate change, energy security, and rising energy costs by all states. A policy needs to be developed for existing buildings that encourages renovation to adopt these efficiency measures.

Chapter 3 estimated the effects of climate change on the property values and the wage rates of American households. It applied hedonic pricing methods to determine the implicit values of climate, a preference-driven approach. Preference for climate was estimated by analyzing the market equilibrium for goods and services to estimate the implicit price of the climate-amenity values. This chapter measured the extent to which U.S. households' preferences for climate amenities are capitalized in wage and house rents for both homeowners and renters. An individual's hedonic pricing and wage models estimated that housing rents and wages are higher for greater January temperatures and lower July temperatures.

Scientific studies on climate change have reported that the U.S. may experience a rise in its surface temperature during the 21st century of between 5^{o} F and 9^{o} F (3° C–5° C), this research predicted that marginal willingness to pay for this warming is positive for Americans—both homeowners and renters. However, this result varies across the regions of the U.S. Unlike the July temperature, January temperatures (or winter temperatures) are a disamenity. What this means is that Americans want compensation to live and work in a cold place. Global warming (the models suggest) will lower employee compensation because higher January temperatures increase the amenity values for Americans. A similar result is also found for increasing annual precipitation. Both householders—homeowners and renters—are willing to pay for higher precipitation; nevertheless, the dollar amount of this amenity value is small compared with the dollar value of the July temperature. This preference for warming temperatures has effects on both the housing market and the labor market, as hypothesized, which provides information to firms for their investment decisions. As July temperatures are unproductive compared with January temperatures (lower wages and property values in warm regions), these results suggest having appropriate policy measures to encourage investors in warmer climates. While summarizing the results from chapter 3, with limited global warming, households are willing to pay for that change. This research also found other variables other than climate factors—neighborhood, city location, and building structure characteristics—are also determinants of housing rents. For wages, city locations, race and nationality, demography, and education are also determinants, along with climate factors.

Chapter 4 analyzed whether a decoupling relationship exists for CO_2 emissions and GDP per capita through applying a meta-analysis tool. Meta-analysis is a statistical tool to synthesize the results of several studies. To get an efficient estimation, this meta-analysis corrected for common methodological issues of meta-analysis; by employing a cluster-estimation technique to correct for the possibility of heterogeneity generated from different study sources and a publication bias by controlling for a publication dummy in the analysis to get valid inferences.

Results of Chapter 4 supported an environmental Kuznets curve (EKC)-type relationship for global warming caused by the anthropogenic greenhouse gas CO_2. However, estimating the income turning point (ITP) is to too high (US $102, 281 at the 2007 price level) and is beyond the range of data. For the given current per-capita GDP or the future projected economic growth of U.S. or across the world, none of the country could reach the predicted income turning points, which confirm the absence of any predictable decoupling of emission and at any attainable global average per capita income range. This study also highlights the difficulty of achieving economic growth that reached the range of the predicted ITP to control for the projected emissions of CO_2 that would be above the threshold point of irreversible damage due to the global warming effect. Further research is needed on economic growth that would not increase CO_2 emissions, a long-term policy challenge that could explain the EKC relationship for CO_2.

5.2. Opportunities for Future Research

This research concludes with an analysis of the effectiveness of the energy-efficiency building codes to minimize residential energy demand and to reduce the emissions of CO_2 into the atmosphere–a mitigation strategy to curb the burgeoning problems from global warming. These findings reinforce the conclusion that energy-efficiency measures are a promising public policy option towards achieving the targeted minimization of energy demand and the reduction in emissions of global-warming gases. A proper implementation of an energy-efficiency policy could have two directly measureable beneficial impacts: reductions in the demand for energy and the emission of CO_2, a global warming gas. To encourage households to adopt such policies, a benefit-cost analysis based on ex-post data is recommended. Further, an analysis of the willingness to pay for such policy measures would substantiate the need to adopt such energy-efficiency building codes, regardless of their high initial cost of investment.

As climate related variables are measured at the state level, climate information measured at the county level would provide more precise estimated values for climate amenity, which is recommended for research.

Further, analysis of the relation between CO_2 emissions and GDP per capita shows a very high ITP, which is unattainable for any realistic current or projected scenario for economic growth. Future research is needed to explore the long-term policy challenges of economic growth that would limit the emissions of CO_2 that could explain the EKC relationship for CO_2.

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