UC Santa Cruz
UC Santa Cruz Electronic Theses and Dissertations

Title
Essays on the Economics of Environmental Issues: The Environmental Kuznets Curve to Optimal Energy Portfolios

Permalink
https://escholarship.org/uc/item/8hm921td

Author
Meininger, Aaron G.

Publication Date
2012

Peer reviewed|Thesis/dissertation

eScholarship.org Powered by the California Digital Library
University of California

UNIVERSITY OF CALIFORNIA
SANTA CRUZ

ESSAYS ON THE ECONOMICS OF ENVIRONMENTAL ISSUES: THE ENVIRONMENTAL KUZNETS CURVE TO OPTIMAL ENERGY PORTFOLIOS

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

DOCTOR OF PHILOSOPHY

in

INTERNATIONAL ECONOMICS

by

Aaron Gregory Meininger

June 2012

The Dissertation of Aaron Gregory Meininger
is approved:

Professor David Kaun, Chair

Professor Thomas Wu

Professor Carlos Dobkin

Tyrus Miller
Vice Provost and Dean of Graduate Studies

Copyright © by
Aaron Gregory Meininger
2012

Table of Contents

List of Figures

List of Tables

Abstract

Essays on the Economics of Environmental Issues:
The Environmental Kuznets Curve to Optimal Energy Portfolios

by

Aaron Gregory Meininger

In the first paper I delve into the current rift between the dissidents and supporters of the "Ecological Kuznets Curve." First, by recreating a 2006 study done by Bagliani, Bravo, and Dalmazzone, using a cross-sectional analysis, there does not appear to be strong evidence of an EKC when using the Ecological Footprint as the independent variable. Then, continuing from the Bagliani et. al. analysis, a panel data set is formed and using panel estimation techniques, the evidence is resubmitted. I find that under the panel estimation there is no common EKC realization for a majority of the countries when comparing Ecological Footprint to Per Capita GDP.

The second paper looks into the relationship between the diffusion of renewable energy production and the political economy. More specifically, I look at how the different political parties in power effect the penetration of renewable energy into the existing market. There are two novel aspects to the paper: the first being the use of U.S. data to test the analytical model proposed by Johnson and Jacobsson (Johnson and Jacobsson (2002)), and second, in order to test the hypothesis put forth by the analytical model, I will map this analytical model into an empirically testable equation. As far as the author's knowledge goes, this is the first such analysis. The results show that having a Democratic majority in the Senate will increase both the level and the growth rate of renewable energy. There is also some weaker evidence of a feedback loop between the increasing number of supporting agencies and the spread of renewable energy use.

The third paper explores two questions, 'Is the current energy portfolio in California efficient from a cost-risk point of view?' and, 'What changes are needed to the energy portfolio in order for California to meet its proposed Renewable Portfolio Standards (RPS) requirements?' After assessing the validity of the Mean-Variance Portfolio (MVP) technique when using illiquid assets, following papers such as Janson (Jansen et al. (2006)) and Awerbuch (Awerbuch et al. (2008)), I test plant-level data to find correlations between costs (returns), and also any correlations in the error terms due to unobserved shocks. I find that there are significant correlations between both of these factors. Following Krey (Krey and Zweifel (2006)), I use a Seemingly Unrelated Regression Estimation (SURE) methodology to control for these unobserved shocks which gives a less biased estimate of the true cost risks involved in the energy portfolio. Using the results from the SURE methodology, a cost-risk nexus is constructed and efficient frontiers of energy portfolios are then created. In answering the proposed questions, the results show that relative to the actual energy portfolio used by California, the state could reduce both its portfolio risk and lower its expected portfolio costs by decreasing the use of fossil fuels in its energy production mix, with special attention being paid to coal and natural gas, and by increasing the levels of energy production from renewable resources focusing on geothermal, solar, and wind. With respect to the ability to meet the RPS set in place by California's legislature, a substantial increase in geothermal and wind generated power is needed in order to realize either the 20 or 33 percent thresholds set by the renewable portfolio standards for 2020.

Dedication:

To my Parents, and all who helped me begin my journey.

Acknowledgments

I would like to thank my co-chairs David Kaun and Thomas Wu, without whose invaluable research, guidance, and encouragement this work would not have been possible. I would also like to thank K.C. Fung, for guiding me and chairing my qualifying examination committee, and Philip McCallman for all of his time, effort and guidance. My gratitude also goes to Carlos Dobkin, Joshua Aizenman and Alan Spearot, who have contributed in various ways throughout the development of these chapters. Finally, I would like to express my appreciation to UCSC Ph.D. students and faculty and the participants of the UCSC department seminars. All errors and omissions are mine.

Chapter 1

Introduction and Overview

This chapter outlines the main findings and contributions of the dissertation. In the first part of the dissertation, I revisit the debate on the Environmental Kuznets Curve. While the usual dependent variables in the literature are components of air pollution, I propose a more complete measure of environmental degradation by introducing a country's environmental footprint as the dependent variable of interest. This change incorporates both production and consumption based environmental degradation, whereas in the past, only production-based degradation was accounted for. Then, as well as executing a cross-sectional analysis which is common in the literature, I introduce support for the use of panel estimation in order to achieve less biased estimates of the impact of economic growth on the environment. My results show that due to technology and scale effects, in some countries there does appear to be a threshold at (and beyond) which GDP growth will then lead to less environmental degradation. A more interesting result below is that not all countries exhibit this pattern of increasing environmental degradation with an inflection point around some threshold: so that one cannot conclude that economic growth invariably does damage to the environment.

The second part of the dissertation focuses on the political arena in the United States, and the relationship between the diffusion of renewable energy production and the political economy. More specifically, I look at how the different political parties in power effect the penetration of renewable energy into the existing market. I use a very detailed data set gathered from many years of house and senate hearings, and the bills that have passed as their result, with other data coming from the Energy Information Administration and the U.S. Census. The novel introduction in this data set is that it maps the introduction of supporting government agencies and firms over time. Using key conditions for technology diffusion; institutional change, market formation, technology specific advocacy coalitions, and the entry of firms and other organizations, I construct a testable hypothesis to determine the different effects that these factors have in promoting the diffusion of renewable energy. The results show that geography as well as population parameters are important determinates in the spread of renewable energy. Looking further into the diffusion process, I also find that, in accordance with the theory, a Democratic majority in the Senate is indeed associated with higher levels and growth rates of renewable energy. With respect to the feedback loop described in the model, the results show some evidence of this phenomenon as well.

The third part of the dissertation uses financial portfolio theory and looks into the efficient mix of energy producing assets from a cost-benefit perspective. This section explores two questions, 'Is the current energy portfolio in California efficient from a cost-risk point of view?' and, 'What changes are needed to the energy portfolio in order for California to be able to meet its proposed Renewable Portfolio Standards (RPS) requirements, and at what cost?' Using highly disaggregated plant-level data, I test to find correlations between costs (returns) and also any correlations in the error terms due to unobserved shocks. I find that there is significant correlations between both of these factors. I use a Seemingly Unrelated Regression Estimation (SURE) methodology to control for these unobserved shocks which returns a less biased estimate of the true cost risks involved in the energy portfolio. Using the results from the SURE methodology, a cost-risk nexus is constructed and efficient frontiers of energy portfolios are then created. The results show that relative to the actual energy portfolio used in California, the state could reduce its portfolio risk and lower its expected portfolio costs by both decreasing the use of fossil fuels in its energy production mix, with special attention being paid to coal and natural gas, by increasing the levels of energy production from renewable resources focusing on geothermal, solar, and wind. With respect to the ability to meet the RPS set in place by California's legislature, a substantial increase in geothermal and wind generated power is needed in order to realize either the 20 or 33 percent thresholds set by the renewable portfolio standards for 2020.

Chapter 2

The Panel Is In on the Environmental Kuznets Curve

2.1 Introduction

The Kuznets Curve (EKC), introduced by Simon Kuznets in 1954, is the "inverted U" shape graph flowing from the hypothesis that economic inequality increases while a country is developing, and then after some critical average is obtained, the inequality begins to decrease.

The interpretation of the Kuznets Curve is the story of an economy's transition from one that is primarily agrarian to one that is urban and industrial. The time series literature is replete with studies that show growth rates in income from agriculture being far slower than those of income earned in a city, (Deininger and Squire (1996)). This difference in growth rates is the initial source of the inequality, and thus the initial rise in the Kuznets Curve. Further studies have shown that this inequality increases as rural workers tend to receive the same wages, while there are many different pay scales found in city employment, (Rynes and Milkovich (1988)). Then, as a country becomes more affluent, government social policy is a reason to explain the decline in the inequality, as a government may start to conduct wealth transfers through welfare, retirement, and health care.

The pattern is said to be applicable to the environment as well as to income inequality. Here the argument is that in a developing country little weight is given to environmental concerns, leading to the rise of environmental pollution. After attaining a certain standard of living from the industrial production, and when environmental polluting is at its threshold level, the focus of the government changes from individual needs to broader social consensus. The social interest in turn gives a greater weight to a clean environment, thus reversing the trend back toward less environmental pollution. Intuitively, this explanation makes a good connection with the neo-classical beliefs brought forth in the original Kuznets Curve argument. Whether or not the adapted argument is correct has become even more important with the increase in globalization.

The contemporary trade policy discussions have centered around the reduction of tariffs and duties toward a more "Globalized" free trade system. Many academic articles find a strong correlation between trade liberalization and growth of per capita GDP, (Antweiler et al. (1998), Edwards (1997), Dollar and Kraay (2004), Dollar and Kraay (2003)). These results influence policy makers to suggest that complete trade liberalization is the best method to achieve higher growth in per capita GDP and higher levels of welfare, where welfare is based on per capita GDP. The cornerstone of almost all of their arguments is the Environmental Kuznets Curve (EKC). Since trade liberalization has a strong correlation with growth in per capita GDP, and the Environmental Kuznets Curve Hypothesis states that at some level of per capita GDP the government will start to reduce its' detrimental effects on the environment, it then follows that trade liberalization helps the environment.

This paper is constructed to show that the results of the Environmental Kuznets Curve are not as they are presented in many papers. Using a panel data set I will show that once country specific variation is controlled for, there is no EKC effect. If this is the case, policy makers and other academics will have to come up with a better way to measure the effects of trade liberalization on the environment, and on the overall quality of life, or welfare, of the affected populations.

Section 2 explores the theoretical underpinnings of the cross-sectional model used by Bagliani, as well as theoretical reasons why the use of panel data may be more appropriate in order to retrieve unbiased parameter results. Section 3 reviews the cross-sectional models used in Bagliani, (Bagliani and Dalmazzone (2008)), and panel models including, the different specifications, and their relevant functions. Section 3 concludes with my chosen model specification, and some support for its use. Section 4 first describes some of the variables and data being used, then analysis of the results follows. Section 5 starts as a discussion of the conclusions rendered from the test results, and ends with some interesting caveats, as well as, my own thoughts on the future of the EKC and its effects on policy formation.

2.2 Theoretical Underpinnings

2.2.1 Cross-sectional Model

The Environmental Kuznets Curve was first explored by Grossman (Grossman and Krueger (1991)) in a paper dealing with North American trade. Since then the literature has explored the different components of the Kuznets curve hypothesis in order to better understand the relationship between economic growth and environmental quality. Continuing on that thread, the current literature has identified three distinct structural forces:

- a scale effect, where a bigger scale of economic activity implies the extraction of more natural resources and the creation of more residuals;
- a composition effect, referring to the structural changes in the economy that lead, as income rises, to an increase in the share of less polluting activities (demand for greener products, environmental protection); and
- a technology effect, which is the change in resource and emission intensity in production due to technological modernization, (Bagliani and Dalmazzone (2008)).

2.2.1.1 Production-based vs. Consumption-based Approach

Given these three relationships, an identity generally referred to as "Environmental Pressure" is created for each country.

$$EP = \sum_{j=1}^{n} Y \left(\frac{Y_j}{Y}\right)\left(\frac{E_j}{Y_j}\right) = \sum_{j=1}^{n} Y * C_j * T_j \tag{2.1}$$

- Where Y is GDP, Y_j is sectoral GDP,
- E_j is the environmental pressure due to sector j,
- C_j is the share of GDP in sector j over total GDP, and
- T_j is the sectors environmental pressure intensity.

This general expression is preferred because it allows for an analysis of not only end-of-pipe environmental effects, but also other impacts, such as resource depletion and deforestation, (Grossman and Krueger (1994)).

This type of decomposition is production-based as it relates to the environmental damage accumulated due to domestic production activities in each nation. Another possibility is to allot to each country the environmental pressure (at home and abroad) required to produce the goods and services consumed by its population, the consumption based approach.

Both approaches, production and consumption, use the same environmental data, but their respective accounting principles are much different. The production method assigns the environmental impact to the country according to the geographical location of the sources. The consumption approach assigns environmental impact on the basis of consumer responsibility, which is more relevant when thinking of the environment in concert with conservation efforts.

Rothman (Rothman (1998)) expressed the importance of looking at the EKC from a consumption-based viewpoint. Ekins (Ekins (1997)) points out that when there is an increase in income, a shift toward a greener structure of the economy is not necessarily due to a change in consumption patterns. A perceived increase in demand for environmental quality may not lead to a shift to greener practices, but instead, may lead to a movement of the polluting industries off-shore. The displacement of environmental pressure from one country to another, Ekins' pollution-haven hypothesis, is supported by the empirical findings of Suri, (Suri and Chapman (1998)). In another paper by Aldy (Aldy (2005)), finds that emissions-intensive trade appears to play an important role in shaping the income-emissions relationship. Others, including Nahman (Nahman and Antrobus (2005)), argue that focusing on a country's consumption structure allows the analysis to go beyond the international displacement of environmental costs.

2.2.2 Panel Model

The main advantages of Panel Analysis are:

- individual heterogeneity; [1]

[1] Cross-section work at the international level assumes that many country level unobservables are uncorrelated with the explanatory variables. Thus, the use of panel estimation techniques relaxes this assumption, and allows the idiosyncratic differences to have an effect on the exogenous

- panel data can produce more reliable parameter estimates by eliminating bias originating from collinearity between the variables;
- panel data is better suited to study adjustment processes. In cross-sectional work, distributions that look very stable hide a multitude of changes;
- panel estimation can eliminate the chance of bias resulting from aggregation; and
- panel data are better able to identify and measure effects that are simply not detectable in pure cross-section or pure time series data, (Baltagi (2001)).

Some of the more prevalent drawbacks of Panel Estimation are:

- design and data collection problems;
- distortions of measurement errors;
- selectivity problems including non-response and attrition; and
- short time series dimension to the panel estimation.

In the inspiring influential work "Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence," (Rodrguez and Rodrik (1999)), Rodrik et. al. suggest that the international cross sectional analysis done in the past

variable. Without this, the results from looking at international cross section data are merely reflections of the specific differences among countries; this causes problems when two countries are being compared with each other. Unless the individual characteristics are explored, the comparison analysis is biased by these individual characteristics. In this paper, it is my goal to understand how income relates to a country's ecological footprint, not how a country's idiosyncratic differences affect their ecological footprint comparatively.

was confounded by extraneous phenomena, and thus provides the main motivation for the movements of the supposed "exogenous" variables. When various measures were taken to correct this bias problem, almost all explanatory value was stripped from the regression results. This is a significant problem with cross sectional analysis given in the Bagliani paper, since they do nothing to correct for the apparent bias in the estimation process.

2.3 Data Analysis

The Ecological Footprint is a measure of humanity's demand on the biosphere in terms of the area of biologically productive land and sea required to provide the resources we use and to absorb our waste. In 2003, the global Ecological Footprint was 14.1 billion global hectares, or 2.2 global hectares per person (a global hectare is a hectare with world-average ability to produce resources and absorb wastes).[2] The total supply of productive area, or bio-capacity, in 2003 was 11.2 billion global hectares, or 1.8 global hectares per person, (Loh et al. (2004)). The footprint of a country includes all the cropland, grazing land, forest, and fishing grounds required to produce the food, fibre, and timber it consumes, to absorb the wastes emitted in generating the energy it uses, and to provide space for its infrastructure.

In the first cross-sectional regression we see that in 1996 a rise in per capita GDP of 1000 dollars would increase the per capita ecological footprint by

[2] The hectare is the modern metric unit used for measure of land area. It is equal to 10,000 square meters (the area of a square 100 meters on each side).

.684 hectares or 6840 square meters. Table A.1 shows that at the higher per capita incomes, the same $1K change would result is a reduction of the per capita ecological footprint by .0000205 hectares or 0.205 square meters, a $10K change at these same high levels of GDP would decrease the per capita ecological footprint by 2.05 square meters. These are the effects predicted by the Environmental Kuznets Curve.

When we turn to the question of the trade affecting the environment, nearly all of the literature relating the environment to trade focus on three measures of air pollution ; sulfur dioxide, carbon emissions, and suspended particulate matter less than 10 microns in diameter.

Sulfur dioxide, or SO2, belongs to the family of sulfur oxide gases (SOx). These gases dissolve easily in water. Sulfur is prevalent in all raw materials, including crude oil, coal, and ore that contains common metals like aluminum, copper, zinc, lead, and iron. SOx gases are formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil, or metals are extracted from ore. SO2 dissolves in water vapor to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment, (EPA (1975)).

Carbon monoxide, or CO, is a colorless, odorless gas that is formed when carbon in fuel is not burned completely. It is a component of motor vehicle exhaust, which contributes about 56 percent of all CO emissions nationwide. Other non-road engines and vehicles (such as construction equipment and boats) contribute about 22 percent of all CO emissions nationwide. Higher levels of CO generally occur in areas with heavy traffic congestion. In cities, 85 to 95 percent of all CO emissions may come from motor vehicle exhaust. Other sources of CO emissions include industrial processes (such as metals processing and chemical manufacturing), residential wood burning, and natural sources such as forest fires. Wood stoves, gas stoves, cigarette smoke, and non-vented gas and kerosene space heaters are sources of CO indoors. The highest levels of CO in the outside air typically occur during the colder months of the year when inversion conditions are more frequent. The air pollution becomes trapped near the ground beneath a layer of warm air, (EPA (n.d.)).

"Particulate matter," also known as particle pollution, or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects, (Board et al. (2004)).

One of the Ecological Footprint advantages over these other standard measures of pollution is the ability to reflect a more realistic picture of the total harm being done to the environment. People consume resources and ecological services from all over the world, so their footprint is the sum of these areas, wherever they may be on the planet. The other measures may be incorrectly counting some transboundary pollution and attributing it to the local factors of production. The three standards are also not counting certain types of pollution at all, since as indicated they are all measures of air pollution.

The data for all of the cross-sectional results for the ecological footprint come from the World Wildlife Fund's "Living Planet Report," (Loh et al. (2004), Loh et al. (2002), Loh and for Nature (2000), Loh et al. (1998)). The data is reported in global hectares per person. The GDP per capita data comes from the "CIA World Factbook," (Agency (1996), Agency and States (1999), Agency (2001), Agency-CIA (2003)).

The data used for the panel regressions is the Ecological Footprint data for 1996(1997), 1999, 2001, and 2003, derived from the World Wildlife Fund's "Living Planet Report" 1998, 2000, 2002, and 2004, respectively.[3] This data is reported in global hectares per person. All of the GDP data are from the "CIA World Factbook" for the years used in the respective LPR data.

[3] the WWF's LPR for 1999 used the 1996 data, there was no LPR in 2001 or 2003, (Loh and for Nature (1999)).

2.4 Model

2.4.1 Cross-sectional

The models used in the cross-sectional analysis are of the traditional linear, quadratic, and cubic forms.

$$EF = \beta_0 + \beta_1 GDP + \epsilon. \tag{2.2}$$

$$EF = \beta_0 + \beta_1 GDP + \beta_2 GDP^2 + \epsilon. \tag{2.3}$$

$$EF = \beta_0 + \beta_1 GDP + \beta_2 GDP^2 + \beta_3 GDP^3 + \epsilon. \tag{2.4}$$

In regard to the linear specification, if the relationship between GDP and the ecological footprint is increasing linearly, this would mean that any increase in GDP would lead to more environmental degradation. In terms of the decomposed effects, this would imply that the scale effect is the dominant driving factor.

With the quadratic specification we should observe the EKC. If, in fact, the quadratic term is negative, and the vertex is at a level of income within the data range, this depicts the EKC. In this case, there must be some forces at work that are slowing and then reversing the scale effect. These forces may include:

- physical constraints to consumption by individuals,
- declining natural resource intensity of individual consumption with an increase in the size of the service sector relative to the industrial sector,

- a tendency to give environmental protection priority in wealthier countries via market mechanisms (greener product demand) and greater environmental regulation (technology effect), and
- on the supply side, the availability of the resources necessary for the development of cleaner technologies (technology effect).

If the quadratic has a positive sign this would imply that at high levels of GDP there is a positive feedback between income and the Ecological Footprint. This could be a result of some "over-lapping" factors including the following:

- higher incomes may cause changes in individual consumption bundles towards goods and services with a heavier impact on the environment,
- pollution control technologies may have decreasing returns,
- economic growth may bring about environmentally unfriendly technological change, both in the sense of increased extractive capacity and of resource-intensive products, and
- technological change that saves resources may cause a rebound effect due to behavioral responses where the increase in efficiency is overcompensated by a rise in demand for the same polluting or even more polluting consumption bundles, (Binswanger (2001)).

A cubic function with a positive cubic coefficient provides a model where high levels of income are eventually associated with a positive level of environmental destruction. The common assumption in the literature is that of an "N" shaped curve, which shows that after an EKC phase, the environmental degradation continues. This can be due to the same factors, changes in consumption patterns, decreasing returns to pollution control technologies, environmentally unfriendly technological change, and the rebound effect, that can explain the re-emergence of a positive relationship between GDP and the environmental impact described in the case of the quadratic specification.

2.4.2 Panel

When considering panel data, there are many methods of regression estimation used. These include constant coefficients models, fixed effects models, and random effects models. Among these models are dynamic panel, robust, and covariance structure models.

2.4.2.1 Fixed-Effects Models

Another type of panel model can have constant slopes, but intercepts that differ according to the cross- sectional country. Although there are no significant temporal effects, there are significant differences among countries in this type of model. While the intercept is country specific and differs from country to country, the intercept may or may not differ over time. Because (i-1) dummy variables are used to designate the particular country, this same model is referred to as the Least Squares Dummy Variable model, where;

$$EF_{it} = \alpha_1 + \alpha_2 Country_1 + \alpha_2 Country_2 + ... + \beta_2 GDP_{2it} + \beta_3 GDP^2_{3it} + \beta_4 GDP^3_{4it} + \epsilon_{it}. \tag{2.5}$$

Another type of fixed effects model has constant slopes, but intercepts that do differ over time. In this case, the model has no significant country differences, but because of some time-lagged effects, might be affected by autocorrelation. The residuals of this type of model may have autocorrelation, and is given by;

$$EF_{it} = \alpha_1 + \lambda_2 Year_1 + \lambda_3 Year_2 + ... + \beta_1 GDP_{it} + \beta_2 GDP^2_{it} + \beta_3 GDP^3_{it} + \epsilon_{it}. \tag{2.6}$$

Another fixed effects panel model is where the slope coefficients are constant, but the intercept varies over time and country, where;

$$\begin{aligned} EF_{it} = \alpha_0 + \alpha_1 Country_1 + \alpha_2 Country_2 + ... \\ + \lambda_0 + \lambda_1 Year_1 + \lambda_2 Year_2 + ... \\ + \beta_1 GDP_{1t} + \beta_2 GDP^2_{2t} + \beta_3 GDP^3_{3t} + \epsilon_{it}. \end{aligned} \tag{2.7}$$

Yet another type of fixed effects model has both differential intercepts and slopes. This model has intercepts and slopes that both vary according to the country. To formulate this model, we would include country and time dummies, and their interactions with the time-varying covariates. It would be represented as in Equation 2.5, but would include cross-products in the exogenous side of the regression.

There is also a fixed effects panel model in which both intercepts and slopes might vary according to country and time. This model specifies (i-1) country dummies, (t-1) time dummies, the variables under consideration and their interaction. If all of these are statistically significant, there is no reason to pool the data.

These fixed effects models have several drawbacks. They often have too many cross-sectional units of observations requiring too many dummy variables for their specification. Too many dummy variables can take away degrees of freedom needed for the statistical tests. Also, a model with many variables may be plagued with multicollinearity, which increases the standard errors and thus reduces the statistical power needed to test parameters. Although the model residuals are assumed to be normally distributed and homogeneous, there could easily be country-specific heteroskedasticity or autocorrelation over time that would further bias the estimation. The one big advantage of the fixed effects model is that the error terms may be correlated with the individual effects.

2.4.2.2 Robust Panel Models

There are a number of problems that plague panel data models. Highly significant outliers bias regression slopes, and heteroskedasticity problems arise from group differences. The use of a White heteroskedasticity estimator with ordinary least squares estimation in fixed effects models can yield standard errors robust to unequal variance along the predicted regression line, (Greene (2001)). Another method of eliminating heteroskedasticity is by using the group means. If there is also autocorrelation in the models, one can obtain a weight-adjusted combination of the White and Newey-West estimator to handle both the heteroskedasticity and the autocorrelation.

Since the data contains many different countries, and we do not want the idiosyncratic differences to bias the results, a fixed effects test will be conducted. The type of fixed effects model used will include country specific dummies, this will allow us to look at a more pure relationship between per capita GDP and per capita global hectare usage.[4] Two types of random effects models are also tested, the random effects model, as described above, and the MLE specification. All of the above models will be run under the robust specification in order to control for possible multicollinearity. Finally, the pooled results are run if per chance there is not enough variation in the preferred model to produce statistically significant results.

There are many advantages to using pooled data, including generalizability: We want our conclusion to apply to many cases and over many time periods. Pooling provides the variation needed to answer questions we couldn't answer with time-series or cross-sectional data alone, and pooling can help us with the measurement

[4] All models (located in the index) are still tested because of some interesting results.

error and omitted variables problems that arise if using time-series or cross-sectional data alone. Pooled data analysis relies on the assumption that the relationship between the dependent and the independent variable does not vary cross-sectionally or through time. There are two conditions to consider before relying upon pooled analysis:

- the relationship between the dependent variable and the independent variable is exactly the same for all countries and time periods, and
- the process affecting the error term is also the same for all countries and time periods.

Since one of the problems thought to affect the cross-sectional results is that the relationships between the dependent variables and the independent variables are not the same for all countries, pooling the data is not a reliable method for obtaining unbiased estimates.

2.5 Estimation Results

2.5.1 Cross-Sectional

The first cross-sectional regression uses the 1996 data from the above sources. As indicated in Table A.1, all coefficients are statistically significant. The regression confirms the EKC hypothesis for all forms of GDP per capita, although the supposed "N" shape in the cubit formation is extremely weak. The results indicate that for every $1K increase in per capita income there is a .684 increase in the Ecological Footprint per capita (EFPC). That is 6840 more square meters being used by each person. In the higher levels of GDP we see that there is a negative usage effect of .205 square meters EFPC. In the highest levels of GDP, the EFPC usage again turns positive but is very close to zero.

The second cross-sectional regression uses 1999 data. In Table A.3, the coefficients are all statistically significant. The regression shows evidence of the EKC hypothesis, although weaker than in the 1996 cross-sectional results. Again, the case for the "N" shape is still extremely weak. A $1K change in GDP in 1999, results in a .541 rise in EFPC, or 5410 square meters. For the mid level GDP we again see the negative usage of EFPC hypothesized by the EKC, now close to .173 square meters. In the high GDP levels we again see the return of a positive, albeit very small, increase in EFPC.

The next cross-sectional regression uses data from 2001. Again, as can be seen in Table A.5, all coefficients are statistically significant. This regression again provides strong support for the EKC Hypothesis, with the same "N" results as the earlier regressions. The results for a $1K shift in the low, medium, and high levels of GDP are now; 5280, -.163, and almost zero square meters, respectively. An interesting note is that the amount of negative usage of EFPC, or the EKC change, gets smaller with each successive regression, until it is finally statistically insignificant in the last cross-section test.

The last cross-sectional regression uses 2003 data. The results in Table

A.7 are the most interesting, with statistically significant results in favor of the EKC hypothesis, until the higher order GDP specification is added. Then, all but the scale effect are rendered insignificant. Here we still show an EKC like curve in the fitted representation, although when the higher order specification is added, all that can be deduced from either the graph or the table is that the scale effect was dominant, and that there is absolutely no evidence of an "N" shaped curve. Here the results for a $1K increase in per capita GDP on EFPC are 3120 square meters for the low level, -.456 square meters for the medium level which is not statistically significant, and zero square meters for the high level, which is also not significant at the statistical level used.

2.5.2 Log Normalized Cross-Sectional

The data has many points in the lower end of the GDP and EF range. The uneven distribution can result in a bias estimate. By taking the natural log of GDP, it allows for more precise estimates by systematically ranking answers (so that a repeated point is counted both times in the distribution). The first cross-sectional regression uses the 1996 data from the above sources. As indicated in Table A.2, the linear component is statistically significant. The regression confirms the beginning of the EKC hypothesis for the scale effect of GDP per capita. The environmental improvement coefficient reinforced the strength of the scale effect. The results indicate that for every $1K increase in per capita income there is a .440 increase in the Ecological Footprint per capita (EFPC). That is 4400 more square meters being used by each person. In the higher levels of GDP we see that there is a positive usage effect of 2200 square meters EFPC. In the highest levels of GDP, the EFPC usage does turns negative, which indicates that an EKC effect may exist but only at very high levels of GDP, but is very close to zero and not statistically significant.

The second cross-sectional regression uses 1999 data. In Table A.4, the coefficients are all statistically significant. The regression shows evidence of the EKC hypothesis. A \$1K change in GDP in 1999, results in a .404 rise in EFPC, or 4040 square meters. For the mid level GDP we again see the positive usage of EFPC reflecting the scale effect of the EKC, now close to 2020 square meters. In the high GDP levels we see the decrease in EFPC by 17950 meters.

The next cross-sectional regression uses data from 2001. Again, as can be seen in Table A.6, only the scale effect coefficient is statistically significant. The results for a \$1K shift in the low level of GDP is now; 4150.

The last cross-sectional regression uses data from 2003. The results in Table A.8 reinforce the earlier mentioned scale effect. There is no environmental improvement effect, or a re-emerging scale effect present in the log normalized data.

2.5.3 Panel

The first panel regression is the fixed effects model. Here we see in Table A.9 that the results are very interesting. When the country-specific factors are controlled for, we see that there is an initial negative relationship between growth in GDP per capita and environmental footprint EKC. Specifically, for a 1000 dollar increase in per capita GDP there is a negative usage of 395 square meters of Earth. When a higher level of GDP per capita is added to the regression we see that the negative usage at the lower level GDP is now 724 square meters. These results are coming from a technology effect not unlike the phenomenon described by Grossman,(Grossman and Krueger (1991)). The higher order GDP is shown to have a positive usage effect of .00000119 global hectares or .0119 square meters. Even as this result is not statistically significant, it does suggest evidence of an over-arching scale effect. When all three GDP orders are added to the regression, all coefficients fail to show statistical significance. What is of some interest is the fact that both of the lower orders of GDP show a negative usage sign while the highest level, although zero, has a positive sign. This reinforces the notion that there may be a significant scale effect happening here that is taking the statistical power out of the lower level orders of GDP per capita.

The second panel regression is of the random effects model. As can be seen in Table A.11, the only effect that is statistically significant is the scale effect. Thus, there is no evidence of behavior consistent with the EKC hypothesis. There is also a complete absence of an "N" shape at the higher orders of GDP per capita. The significant results here imply an increased usage of EFPC on the order of 1250 square meters. That the scale effect is still prevalent, even though the use of this specification is highly questionable, is itself interesting.

The next panel regression is still a random effects model, now using a maximum liklyhood estimator. Interpreting Table A.11, I find that under this specification even the scale effect breaks down at the higher order regression level. Here there is no support for the EKC hypothesis.

Finally, the last panel regression is the pooled model. Here in Table A.11 we see that pooling all of the cross-sections yields one large cross-sectional result. The results show strong support for the EKC hypothesis.

2.5.4 Log Normalized Panel

The first panel regression is the fixed effects model. Here we see in Table A.10 that the analysis is much like the raw data conclusion outlined above. The data show signs of the technology effect and provide more evidence of a very strong scale effect.

2.6 Discussion and Conclusions

The cross sectional results are all consistent with the EKC Hypothesis. As indicated in Figure A.9, there is a prominent scale effect at the first level. There seems to be some composition and technology effects at play as well.

Using the data described above and implementing a cross sectional analysis provides strong evidence of an EKC Effect. Further analysis reveals that the "threshold" level of GDP for the 1999 data used in Bagliani (Bagliani and Dalmazzone (2008)) is around \$30K, for 1996 and 2001, the levels were around \$27K, for 2003, the level was about \$40K. The results of the tables can give a good approximation of the strengths of the composition and technology effects. Table A.3 can be interpreted to shows that every one unit increase in GDP squared leads to a very small unit decrease of the EFPC in square meters per capita. Even in the significant specification we find that raising per capita GDP by as much as $1K would do little to improve the environmental footprint of a country.

The panel results are much different than those of the cross sectional. In the fixed effects panel estimation there appears to be evidence in support of the Grossman and Krueger caveat mentioned below in their 1994 paper: that as a country's citizens become "richer" they engage in less environmentally wasteful practices. This result bodes well for the EKC explanation surrounding the wood burning stoves in Africa, (Bruce et al. (2000)). In the next two panel estimations, a random effects specification is used. In the random effects regressions the scale effect is the only effect that remains. Although interesting, the random effects specification does not make sense here, since it is assumed that some of the unobservables are driving the other variables. The pooled results are mirror images of the cross sectional results, with the critical level being around $32K.

Why are the two results so different? Many reasons have already been proposed concerning the differences between cross-sectional and panel results. I would argue the main difference lies in those idiosyncratic differences present within each country that were controlled for when employing the use of the panel estimation techniques. Again, the pooled results are interesting, but we must recall the proper conditions and assumptions in order to fully accept the pooled story, a requirement not met for this study.

2.6.1 Caveats and Queries for Future Research

Within the panel results there were a few interesting cases of instances where, although not statistically significant, there does appear to be a graphical representation of an EKC, Figure A.31. Other countries that show this same apparent EKC are Australia, Belarus, Belgium, Estonia, Finland, Greece, Italy, Korea Rep., Kuwait, Latvia, Malaysia, Phillippines, So. Africa Rep., and Thailand.

However, there are also results that hearken back to Grossman's argument (Grossman and Krueger (1991)) where it was said that:

> "...(the study) finds no evidence that economic growth...does unavoidable harm to the environment."

This can be interpreted as saying that growth in GDP does "not necessarily start to destroy the environment." Instead, as suggested in this paper a country may be involved in environmental protection as it is growing (in GDP), Figure A.32. Other countries that display this characteristic are Canada, China, France, Ireland, Khazakstan, Lithuania, Norway, Poland, Saudi Arabia, Slovenia, Sweden, Switzerland, and the United Kingdom.

The results of this paper clearly show that there is no proof of an EKC type relationship between per capita GDP and EFPC. As this is the case, the defense of trade liberalization improving environmental quality is broken. As far as trade liberalization improving one's quality of life, the results here shed some doubt on those findings. Since getting access to clean water and clean air is a necessity, even at the lowest qualities of life, the effect of trade liberalization on welfare has not been examined properly.

In some countries there appears to be an EKC like effect. In other countries it seems that there are no detrimental effects of raising per capita GDP. And yet in still other countries, there is ambiguity as to the effects of increased personal wealth on environmentally conscious behavior. In order to better understand the relationship between per capita GDP and EFPC, we first must understand the differences between these three sets of countries. Then, we can more accurately predict how a change in trade policy will effect the environment, and the welfare of a given country and population.

Chapter 3

Which Socio-Economic Factors are Most Supportive to Green Energy Penetration

3.1 Introduction

In the United States around election time there are many graphics shown on news sources depicting the country in two colors, red and blue. These colors correspond to the two main political parties, the republicans and the democrats, respectively. If one then compares this picture to a similar breakdown of states producing renewable energy, an eerie correlation becomes visually present; it looks as though the majority of blue or democratic states are producing the majority of renewable energy. Why might this be so?

When looking into the factors that effect the spread, or diffusion, of technology, there are a few that standout, one of the most intuitive is that of geography. Countries that share borders are more likely to trade with one another, and thus the diffusion of ideas between two is greater than say another country half-way around the world. Another important aspect of diffusion is the amount of resources devoted to that specific technology and its' related fields. A third compelling argument is that of political climate. In the literature on technology diffusion, it has been shown that a democratic regime is more conducive to the spread of ideas. In other words, a democratic government allows for further penetration of technology at a faster rate, (Comin and Hobijn (2005)). All of the states in the United States and under the same democratic government system, yet there remain large discrepancies between the make-up of each state's power production.

The purpose of this paper is to explore different political viewpoints under a democratic regime, and how to determine those differences' effect on the the diffusion of renewable energy. The paper uses an analytical model developed mainly by Johnson and Jacobsson (Johnson and Jacobsson (2002), Jacobsson and Bergek (2004)) to construct a testable form regression that will allow for careful analysis of the phenomenon. The novel aspects of this paper are the use of U.S. data gathered from many years of House and Senate hearings, and bills that have passed as a result, and it is one of the first to map this analytical model into an empirical model in which to test the proposed theory.

3.2 The Beginnings of an Analytical Framework.

[1] As of 2006, the two largest components of renewable energy are hydro power and the combustion of different types of biomass. In 2006, hydro power produced 2997.063 Billion Killawatt Hours (BKwh) of electricity, and biomass combustion accounted for 229.488 BKwh of electricity with the next highest renewable energy being wind, which generated 124.930 BKwh of electricity worldwide, (EIA (2008*b*), EIA (2008*a*)).

The figures in this chapters' appendix show the diffusion of wind energy in different regions of the globe, and the world overall.[2] With respect to wind energy in the US, Figure B.6 shows a length of time where there is little to no growth in production; then in 1989 we begin to see some signs of improvement in the diffusion of green energy technology. After this initial increase in production, it would seem as though the industry was again stymied, and growth leveled out for about another decade. The global stock of wind produced electricity grew quite rapidly during the period between 1990 through 2006, (Figure B.7). The bulk of the stock was installed starting around 1995, and has been growing since then. The data displays a pattern that is very similar to that of the "take off" period in the context of long term technology diffusion.[3]

Based on the rapid growth, it may seem as if renewable energy makes up a

[1] Much of this section is taken from the works of Jacobsson and Bergek (2004), Jacobsson and Lauber (2006), and Johnson and Jacobsson (2002)

[2] Figures: B.1, B.2, B.3, B.4, B.5, B.6, B.7

[3] Klepper (1997)

large portion of the world's total energy consumption. Unfortunately this is not true. Table B.1 shows the different energy sectors and their respective percentage of the world's energy generation. While the total amount of the world's electricity being generated by renewable sources has grown, they still only make up about 13 percent of the world's total energy generation. By far the greatest amount of electricity from renewable sources comes from hydroelectric power, which makes up around 10 percent of the world's total energy generation. By contrast, wind power makes up about .7 of a percent of the world's electricity, and that is a generous estimate, (EIA (2008*c*)). The growth of the renewable energy sector overall has infused hope among certain advocates, as some studies have called for wind power to make up ten percent of the world's electrical supply by the year 2020, (*EWEA, 1999. Forum for Energy and Development, Greenpeace, 1999. WindForce 10. A blueprint to achieve 10% of the worlds electricity from wind power by 2020.* (1999)). Currently, the issue is not about the technical potential of the renewable energy technologies, but rather how to use their potential to contribute to the restructuring of the entire energy sector.

As can be imagined, a transformation on such a large scale would require changes in many different facets deep within the energy sector. These changes would take time to enact and be realized throughout the sector, and would require political and policy support in the pioneering countries. Understanding the economic channels will help determine the optimal course of action to hasten the speed and ease of transition. Taking elements from many different articles, an outline for an analytical framework that accounts for some key features of the natal stages of the transformation process is formed.

Looking into the characteristics of the early phases of a transformation process, we find that the literature on industry life cycles has much to offer. This literature emphasizes a range of competing designs, (Van de Ven and Garud (1989)), small markets, (Bonaccorsi and Giuri (2000)), many entrants and high uncertainty in terms of technologies, markets, and regulations, as the main characteristics for the early phases of the transformation process, (Afuah and Utterback (1997), Klepper (1997)). For the approach taken in this paper, it is more important to understand the conditions under which the formative stage of development emerges within a specific area. Four key conditions are outlined as crucial elements for the early parts of the formative stage process. The four elements proposed by Jacobssen, (Jacobsson and Bergek (2004)) are;

- Institutional changes,
- Market formation,
- The formation of technology specific advocacy coalitions, and
- The entry of firms and other organizations.

According to Freeman, (Freeman and Louçã (2002)), institutional change is the foundation of the process. This includes, but is not limited to, changes in science, technology, and educational policies. As an example, if we are interested in creating a range of competing designs, a characteristic of the formative stage, prior investment in knowledge must take place. This may include a redirection of science and technology policy far in advance of any emergence of a market. Institutional alignment is also very important, as it pertains to affecting demand, market regulations, and tax policies. The specific nature of the institutional framework has effects over access to resources, the availability of markets, and the legitimacy of a new technology and its supporters, (Maskell (2001)). In work by Carlsson and Rotmans, (Carlsson and Jacobsson (1997) and Rotmans et al. (2001)), the institutional framework can then be seen as one of the mechanisms that may obstruct the emergence of a formative stage. Therefore, firms compete in the market for goods and services, and in gaining influence over the institutional framework, (Davies (1996)).

Second, institutional change is one of the many requirements in order to actually generate a market for a new technology. In the formative phase, market formation is seen mostly in exploring niche markets where the new technology is superior in some specific dimension. Levinthal, (Levinthal (1998)), shows that these markets may have very unusual selection criteria, and may or may not involve government subsidies. Ericsson, (Ericsson and Maitland (1989)), and more recently Porter, (Porter (1998)), show that a sort of protected market, or "nursery," for an emerging technology can allow the performance relative to the price of the technology to improve. It is also reasonable to assume that nursing markets could have a demonstration effect influencing the preferences of potential customers, as well as inducing other firms to enter, and the development of user-supplier networks.

The importance of these early niche markets for the learning process is paramount, (Kemp et al. (1998)).

This leads nicely into the third aspect, the formation of specific advocacy coalitions. The introduction of a constituency involves the formation, or entry, of organizations other than the firm. These could include universities and also non-commercial organizations such as Greenpeace. Unruh, (Unruh (2000)), highlights the existence of such organizations, and some of the roles they play. He writes that those actors within a growing technological system can recognize collective interests and needs that can be full filled by technical and professional organizations. These institutions create non-market forces through networking, which can lead to influence on expectations, confidence, and political forces to lobby on behalf of a technological system.

The central importance of the formation of constituencies is repeated often in the literature on networks within political science, (Rhodes (1997)). Sabatier ,(Sabatier (1998)) and Smith, (Smith (2000)) argue that advocacy coalitions compete with each other for policy influence. In order for a new technology to obtain a solid footing, certain technology specific coalitions need to be formed, and they need to engage in wider political debates to gain influence over institutional alignment. A part of this process is the building of support among broader coalitions to advance the perception that a particular technology, such as wind turbines, answers a wide and diverse range of policy concerns. Thus, the formation of these political networks, in so much as shaping the institutional regime, is an important part of the formation stage.

Lastly, and perhaps most directly to the transformation process is the entry of new firms. With each new entrant, new knowledge, capital, and other resources are incorporated into the fledgling industry. Entrants fill gaps in the supply and demand chains by exploiting new or very specific applications. A division of labor is to be expected, and thus the refinement of knowledge through specialization and accumulated experience, (Smith and Nicholson (1895)). Early entrants also raise the future returns of latter entrants through positive external economies, (Scitovsky (1954)). In addition to the build up of experience and specialized suppliers, the early entrants give strength to the political clout of a technology specific coalition, and provide opportunity into influencing the institutional set up. The early innovators also provide legitimacy for a new field which would improve access to markets and resources for later entrants, and they help to resolve uncertainties in the market and technical processes, (Carrol (1997)).

When investments into the new technology are such that a new system can emerge, the take-off part of the development cycle may occur, and the industries employing the technology will enjoy rapid growth and may also enter a phase which begins development in a self sustaining way, (Porter (1998)). As mentioned long ago in Myrdal, (Myrdal and Myrdal (1963)), a chain reaction of positive feedback could form. These positive loops are essential to the development process: As these cycles are formed, the diffusion process becomes increasingly self sustaining, and characterized by autonomous dynamics leading to uncertain outcomes (Rotmans et al. (2001)). Institutional changes, market formation, the formation of technology specific advocacy coalitions, and the entry of firms and other organizations are involved in the display of these dynamics: the emergence of a new segment could induce entry by new firms, which would strengthen the technology specific coalition, thus improving the political sway of such a coalition to further align institutional framework, which may then open up new markets starting the cycle over again, (Jacobsson and Lauber (2006)).

Which specific conditions are needed in order for a take off like the one described here are difficult to predict. One of the necessary conditions is that a larger market must be formed. I will argue that in the United States, alterations in the regulatory framework act as the main catalyst in setting in motion the actions and reactions that effect the diffusion process in the case of renewable energy.

3.3 Low-Carbon Energy in The U.S.: Politics and Its' Impact on Technology Diffusion

[4]In the United States, the four elements of the formation stage are evident. Even though the current time period is still an early stage of the diffusion process, the data shows on the graphs, (appendix), that there have been a few sub-phases. 1980-1989 was the time period when the United States first started implementing wind power on a significant, albeit limited, basis. The Energy Security Act signed into law on

[4]Most law descriptions are taken from the EIA

June 30 1980 by President Jimmy Carter laid out the first institutional guidelines for American energy policy that covered all of the forms and sources of energy. In 1989, the Renewable Energy and Energy Efficiency Technology Competitiveness Act, was the legislation needed for a launching point into a new phase of development and diffusion. The next phase of growth was the first take off for solar energy in the U.S., its tenure was from 1990 until about 2000. During this period, there is a clear increase in the use of renewable energies (FigureB.13), however, it would seem as though there were still some forces at work which would not allow for renewable energy's full potential to be released. The third sub period starts from the turn of the century and continues today. Here we see an exponential growth in the use of renewable sources in the energy sector.

3.3.1 Common Themes; 1970 to 1989: Formation phase

By the start of the 1970's, the environmental movement was well established in the U.S. In April of 1970, Earth Day made its debut to the attention of millions. The energy crisis that started in 1973, and continued until the end of the decade, was a powerful force in demonstrating the interconnectivity between environmentalism and resource scarcity. During this time period, quality of life and natural resource degradation would forever be entwined. The crisis was not all bad. It served as the first catalyst towards the development of alternative energy sources. It was during these years that many new alternative energy sources in use today were pioneered, and new legislation at that time supported research and development, as well as installation of these renewable energy systems.

The year 1973, which saw a dramatic but short-lived jump in oil prices, marked a real turning point for electric power technologies. These resulting social fears called for government action, and in 1973 the U.S. government responded with the Emergency Petroleum Allocation Act. After the 1973 law, the Energy Policy and Conservation Act of 1975 sought to increase domestic oil production through price incentives, but these too were below world prices. As a result of the price controls holding down the domestic petroleum price, demand increased to record levels until 1978, (FRBNY (1981)).

When President Jimmy Carter came into power in the early 1970's, he created the Federal Energy Administration out of the earlier formed Federal Energy Office. The dichotomy between the parties' core beliefs are astounding between the two eras; the first, run by Nixon with Republican economic policies fostered an atmosphere of protectionism for the ingrained energy industry which after the Clean Air Act of 1970 was passed, was based mostly in oil. Carter, under a Democratic economic policy, argued that we should use less heat and electricity. During this time (Carter) there was also an increase in the amount of research and development for renewable energy sources, (Figure B.14).

The passage of the Public Utility Regulatory Policies Act of 1978, (PURPA, P.L. 95-617), was possibly the single most important event in the 1970's that created a market for renewable energy resources in electric power was . Before PURPA, electric utilities did not want to purchase electricity from non utility firms. However, PURPA amended the Federal Power Act by requiring electric utilities to purchase electricity offered by "qualifying" non utility producers, specifically including small facilities using renewable resources. The addition of Federal and, occasionally, State tax credits for projects using renewable resources, also set the stage for investments in new electric generating capacity, (EIA (1993)).

In summation, the 1970's started out with an energy crisis that made Americans more aware of their consumption of and demand for foreign energy sources. This started the process of reform that came mainly in the form of improvements to existing stocks of energy, and through price regulations. As the political climate changed in the 70's so too did the policy focus on energy. The government started to look at the development of alternative energy sources, and in particular, at non-nuclear renewable energy sources. At the end of the 70's the Public Utility Regulatory Policies Act, or PURPA, now required the large manufacturers of energy to link up with smaller manufactures, especially renewable sources, with the promise of "avoided costs" rates. This legislation allowed an opening for the fledgling market of renewable energy; it also allowed for greater opportunities for universities and other firms and institutes to experiment in many different directions. The decade of the 80's started out with high costs surrounding the renewable energy market. Through sufficient R&D, led by PURPA and continuing on through the passage of the Renewable Energy and Energy Efficiency Technology Competitiveness Act, the industry made large strides toward a future of energy independence, and with that, a greater use of the now cost efficient renewable energy sector.

3.3.2 Common Themes; 1989-1999: The Take Off

The second sub phase in the formative process begins in 1989, and continues up until 2000. This exciting phase of growth in the renewable energy sector was ushered in with the Renewable Energy and Energy Efficiency Technology Competitiveness Act, offering more than 300 million dollars to the advancement of renewable energy. This influx helped to foster all of the defining characteristics of the formative stage: Institutional change, market formation, increase in social-political networks, and the induced entry of new firms. Over the decade, the political climate was ripe for some large changes, changes which culminated in the greatest public awareness campaign about climate change ever attempted.

The Clean Air Act of 1990 started the reinforcement through an assessment of the motor vehicle sector, and called for sweeping reforms in the way that fuel was used. In 1992, the new Energy Policy Act outlined even greater restrictions on the energy market in the U.S. Among other things, the act gave greater tax exemptions to small scale energy producers, and increased funds for the use of renewable energy resources. By the mid to late 90's, the list of Industry Associations and advocacy groups had grown large enough to constitute a powerful constituency among policy makers. Deregulation of the energy sector started on the West Coast between 1998 and 2000. The deregulation was touted as a means of increasing competition. Deregulating the producers of energy did not have the desired effect of lowering the cost of energy. Deregulation also did not encourage new producers to create more power and drive down prices. Instead, with increasing demand for electricity, the producers of energy charged more for electricity, (Said (2001)). In 2000, Vice President Al Gore was in the running for the presidency of the United States. One of the main issues of his platform was energy independence and the increased use of renewable energy.

The 1990's may have seemed a little thin on new laws or acts concerning the growth of renewable energies. What we did see was growth in research and development of the renewable energy sector. This was partly due to external forces, the Exxon Valdiz event and the growing Climate Debate, coupled with a growing public awareness and acceptance that the energy system needed to be changed. It could also be justly argued that these developments were in part due to the political atmosphere of the day. With little to no resistance from the more conservative groups, most likely still giddy over the deregulation, the renewable energy movement was allowed to take off. As a result of the initial investments, a knowledge base was established, along with an advocacy coalition with industry associations, and various interest organizations. A positive feed back loop was also formed allowing the advocates of the technology to enact groundbreaking institutional change via the Renewable Energy and Energy Efficiency Technology Competitiveness Act. The improved political clout, allowed for subsequent diffusion of renewable energy sources throughout the 1990's, this is furthered by feed back from market formation, into the entry of various public groups, to enhanced political power enjoyed by the coalition, this was seen in the denial of the PURPA repeal in 1995.

3.3.3 Common Themes; 2000 and Beyond: The Beginning of Real Advancement

During the beginning of the new millennium, there were several acts and amendments passed in congress that furthered the advancement of renewable energy technology, while at the same time, curtailing further development in the more polluting energy industries. The United States Energy Association put out a plan for national energy security for a post 9-11 U.S. Broadly, this plan sets out to maintain the market share of renewable energy, while increasing domestic production of coal and oil industries. This was echoed in the proposition of the Energy Conservation Act of 2003.

A new light began to shine on the renewable energy industry. in 2004, Al Gore started General Investment Management, the company was, "a new London fund management firm that plans to create environment-friendly portfolios. Generation Investment will manage assets of institutional investors, such as pension funds, foundations and endowments, as well as those of 'high net worth individuals,' from offices in London and Washington, D.C.," (Wire (2004)). In 2006, Gore founded the Alliance for Climate Protection, and starred in the documentary film,"An Inconvenient Truth." The movie went on to win several awards including an Oscar for best documentary film. He also wrote,"An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It", which won a Grammy Award for Best Spoken Word Album in February, 2009, (grammy.com (2007)). In

2007, Gore was awarded the Nobel Peace Prize for...

> "their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change, (Commitee (2007))."

The turn of the century was also the turning point for the renewable energy sector. Finally after three decades of work and innovation the sector had set itself into a position of self realizing growth. The "nursing space" fought so hard for was now producing the fruits of labor. The nascent industry had grown into a contender on the global energy scene in just over 30 years. The specific advocacy coalition was now comprised of many industrial and private organizations. The strength of the constituency is seen by the effort and success of repelling the forces of the non-renewable interests throughout the law making process. Vice President Al Gore did more for the industry's acceptance in a few years than Greenpeace had in a few decades. The stage is now set for the continued growth of the renewable energy market, with the introduction of new firms, the increasing knowledge base, and the increasing political abilities of the coalition for renewable energy.

3.4 Financial Flows and Social Costs

Given that the forces for change between technological advancement and the political process are so intertwined, looking at the situation from a wider vantage point can give us a richer perspective. In the beginning of the formation process, and well up into the new millennium, as evident by the proposed bills in the house and congress, the Republican party has viewed the concept of renewable energy as one that was complementary to existing fossil fuel energy production (at best). While the Democratic parties, and others such as the Green party, pursued the policy of renewable energy as a replacement to the destructive nature of the energy system in the status quo.

The Democratic Party climate strategy throughout the 1970's and 1980's was based in the environmental movement of the 1960's and early 1970's, a movement of conservation and symbiotic relationship awareness between the Earth and the organisms living on it. In the early years the policy focus was on environmental conservation and sustainable resources. By the end of the 20th century, the main positions had changed little. The goal was to promote the use of renewable products such as energy sources and new standards on motor vehicles, a part of the energy debate that is sometimes glossed over as it has direct effects on the demands of consumers.

as the power of the tech specific coalition has grown, the current policy now looks into many facets of the debate. Not only is there involvement in clean energy, clean transportation, and energy conservation, now the bill includes statutes from home lighting and appliances to public institutions. The Democrats also have clear provisions for reducing the threat of global warming, and in transitioning into a clean energy economy. They envision that clean energy will make up 25 percent of U.S. energy by 2025, and that current energy production efficiency be improved by at least 15 percent by 2020. For greenhouse gases, emissions are to be reduced by 20 percent of their 2005 levels by 2020, 42 percent by 2030, and 83 percent by 2050, (Merchant (2009)). A bill presented in 2008 also proposes an International Clean Technology Fund, whose aim is to provide funding for emerging countries so as to make renewable energy production market competitive with fossil fuel energy production around the world.

In contrast, the Republican Party has historically viewed the climate change debate as just that, a debate. It is true that now, approaching 2010, there seems to be a growing consensus that this is a real phenomenon with far-reaching national and international effects. Environmental attitude began to change in the 1980s, during this time, the Reagan administration labeled environmental regulations a burden that needed to be eased if not completely erased. This produced a tsunami of backlash from environmentalists, and much of the public, Republicans nonetheless enjoyed a good deal of electoral success in arguing that "government is the problem, not the solution." This theme has been amplified in passing decades, one consequence of which has been a growing partisan divide over environmental protection (and other government programs), (Dunlap (n.d.)).

This divide was most noticeable among members of Congress, who tend to be more ideologically polarized than the general public for whom they represent. What had been a modest, but significant, difference in Republican and Democratic levels of pro-environmental voting in Congress since 1970, became a noticeable gap after the Republican takeover of the House of Representatives in 1994, (Dunlap (2001)). In the past decade, this gap has become a chasm in both the House and

Senate, as reflected in recent voting "scorecards" issued by the League of Conservation Voters, (Dunlap (n.d.)). See Gallup Poll results in the appendix. [5]

The wake of accumulating evidence suggesting climate change is being exacerbated by the use of fossil fuels is clearly being ignored. For example, here are some of the newest proposals in the GOP "Energy Plan," which has been referred to by some as the new "GOP pollution plan." The first proposal is H.R. 1813, Emergency Energy Cut the Red Tape Now Act of 2009, (Bachmann (n.d.*b*)).

> "Declares without force or effect all: (1) federal prohibitions against the leasing of federal Outer Continental Shelf, Bureau of Land Management, or National Forest lands or federal submerged lands for exploration, development, or production of oil, gas, or oil shale; (2) federal withdrawals of such lands from such leasing; or (3) federal prohibitions against the expenditure of federal funds for such leasing."

In effect, if passed into law this bill would remove all restrictions on offshore oil drilling, as well as drilling in national parks, all at tax payer expense. In addition the bill provided that the department of energy should take over all of the environmental reviews with respect to refineries, in essence eliminating environmental oversight.

The second part of the GOP plan is H.R.1810, Fast Tract Shale Act, (Bachmann (n.d.*a*)).

> "Repeals the prohibition under the Consolidated Appropriations Act, 2008 on the use of funds to: (1) prepare or publish final regulations regarding a commercial leasing program for oil shale (and tar sands) resources on public lands; or (2) conduct an oil shale lease sale pursuant to such Act."

Besides the fact that shale is a fossil fuel it might not sound like such a bad idea, at the very least it is better than the previous bill, H.R. 1813. But, when one looks

[5] Figures B.8, B.9, B.10, B.11, B.12

into the environmental damage caused by shale oil extraction, the mention of a bill like this should be abhorred. Take for example the disposal of mining wastes, spent shale (semi coke) and combustion ashes, and their needs for additional land use. According to a study by the European Academies Science Advisory Council, after processing, the waste material occupies a greater volume than the material extracted, and therefore cannot be wholly disposed underground. Also, the waste material may consist of several pollutants including sulfates, heavy metals, and polycylic aromatic hydrocarbons (PAHs), some of which are toxic and carcinogenic, (Tuvikene and Lindström-Seppä (1999)). To avoid contamination of the groundwater, the solid waste from the thermal treatment process is disposed in an open dump (landfill or "heaps"), not underground. As semicoke consists, in addition to minerals, up to 10 % organics that may pose hazard to the environment owing to leaching of toxic compounds as well as to the possibility of self-ignition, (Kahru and Põllumaa (2006), Kattel (2003)). This is just the damage that could be caused to the land, there is still much more damage done by water and air pollution. Water represents the major vector of transfer of oil shale industry pollutants. One environmental issue is to prevent noxious materials leaching from spent shale into the water supply, (EASAC (2007)). The oil shale processing is accompanied by the formation of large amounts of different process waters and waste waters containing phenols, tar and several other products, heavily separable and toxic to the environment, (Kahru and Põllumaa (2006)). A 2007 environmental impact statement issued by the US Bureau of Land Management stated that surface mining and retort operations produce two to ten US gallons of wastewater per ton of processed oil shale, (of Land Management (2007)). Carbon dioxide emissions from the production of shale oil and shale gas are higher than conventional oil production and a report for the European Union warns that increasing public concern about the adverse consequences of global warming may lead to opposition to oil shale development, (Bartis (2006)). Emissions arise from several sources. These include CO2 released by the decomposition of the kerogen and carbonate minerals in the extraction process - which also releases some methane - the generation of the energy needed to heat the shale and in the other oil and gas processing operations, and the mining of the rock and the disposal of waste, (Ots (2004), Aunela and Loosaar (1995)). As the varying mineral composition and calorific value of oil shale deposits varies widely, the actual values vary considerably. At best, the direct combustion of oil shales produces carbon emissions similar to those from the lowest form of coal, lignite, at 2.15 moles CO2/MJ ,(EASAC (2007)), an energy source which is also politically contentious due to its high emission levels, (Service (2004)).

As problematic as these two proposals are, there is yet a third proposal entitled H.R. 6953, Getting Resources Efficiently and Effectively Now (GREEN) Act, (Bachmann (n.d.*c*)).

> "Directs the President (or a designee) to review all projects for the exploration, development, or production of oil and gas resources under federal leases for lands (or submerged lands) located onshore or offshore to determine whether the projects comply with federal laws.
>
> Requires the projects to be approved and authorized to proceed upon a written finding by the President (or the designee) that they serve the public interest in responsible domestic oil and gas development and

> comply with federal laws.
>
> Shields decisions of the President from further administrative or judicial review, stay, or injunction, except with respect to an appeal filed by the applicant or permittee.
>
> Declares that the President's (or designee's) determinations pre-empt any state law."

There is nothing Green about this act, which the acronym uses to disguise its intent.

In addition to private costs, there are social costs of power generation as well which are larger than the private costs endured by consumers. When looking at the social costs, it is prudent to consider both subsidies and externalities formed by the production and consumption process. Unfortunately, there is no consensus on the magnitude of the subsidies that are given out every year (easily in the billions of taxpayer's dollars). Thus, to accurately quantify the total social costs is difficult to say the least. Instead, the rest of this section will focus on the subsidies for fossil fuels versus the subsidies of renewable energy. After this, we will look at some different viewpoints concerning the externality's role in the true social costs.

Over the thirty year period from 1978 until 2007, the fossil fuel industry as a whole has enjoyed over 24 billion dollars in subsidies. In contrast, the renewable energy sector, during the same time period, received 15 billion dollars of support, (Sissine (2008)). The years between 1980 and the early 1990's was a nascent period for the renewable energy sector with total outlays of around 1 to 3 billion dollars. This is dwarfed in comparison to the amounts spent on fossil fuels, (Administration (1999)). Looking at the years between 1992 and 1999 we find that funding for coal to range from 220 to 471 million dollars. In the same time period, funding for other fossil fuels like oil and natural gas ranged from 108 to 163 million dollars. The total outlays for fossil fuels then have a range of 328 to 634 million dollars, (Administration (1999)). The renewable energy sector during this time received 275 to 327 million dollars. These were the years under the presidency of William Clinton (D), the next section of time are the years under George W. Bush (R). During the Bush administration the Energy Policy Act of 2005 was initiated. Prior to this, the tax breaks for oil and gas companies had risen from about one and a half to two billion dollars, after the passage of the energy act, tax breaks for the oil companies started to skyrocket, starting at a little over one billion, this number increased 300% by 2006 to over 3 billion, (of the Earth (2008)). During the Bush administration, fossil fuel subsidies rose around 3.1 billion a year while similar subsidies for the renewable energy sector raises were about 1.4 billion, (Office (2007)). In 2006 alone, the fossil fuel sectors of energy received around 49 billion dollars while the renewable energy sector received about 6 to 7 billion (depending on the source); fossil fuels made up over 66% of the total subsidies to the energy sector while renewable energy received around 8%, (Doug Koplow (2006)). Clearly, the different administrations view the importance of the two sectors of the energy industry very differently.

There are many different viewpoints surrounding the social costs of producing fossil fuel energy, according to Northwestern University, the cost of air pollution in sectors regulated under the clean air act have been estimated at 9 trillion dollars between 1970 and 2000 (Jacobson (2009)).

"But the cost isn't just financial, said Jonathan Powers, former Army

> captain and Iraqi war veteran –it also costs lives.
>
> "While deployed to Iraq, over 70 percent of the convoys we sent out were focused on providing the troops fuel and water," Powers said." "These convoys became the number one target of insurgents in their IEDs [Improvised Explosive Devices] because the increased frequency of these trips."
>
> The frequency of trips goes hand in hand with a dependence on foreign oil."

The use and production of fossil fuels is said to cause damages to our environment and our health - inflicting even greater damage on the American economy and our quality of life. Fossil fuel combustion is one of the leading contributors to global warming, which, in addition to being a looming environmental and human catastrophe, could inflict massive economic damage as well. According to the Stern Report, a global temperature increase of 5 to 6 degrees Celsius could result in the permanent loss of 5 to 11 percent of global GDP, and possibly up to 7 to 14 percent of GDP (Stern (2008)). If these same losses were to have happened in 2007, the total would be around 7 trillion dollars (Database (2009)). In a 2008 report by the National Resources Defense Council projected losses of 360 billion dollars a year until 2100 given their projections of rising sea levels. The report also brings up the importance of the costs to adapting to sea level rise, building new sea walls and retrofitting older ones could cost between 2 and 20 million per mile of wall (if Global and Unchecked (n.d.)). Warmer weather will also affect weather patterns causing an increase in the severity of storms. The U.S. has seen an increase in the intensity of storms by 24 percent between 1948 and 2000 (Madsen and Figdor (2007)). The NRDC report also found that under status quo conditions, hurricanes fueled by climate change could cost the gulf region 422 billion between 2025 and 2100 (if Global and Unchecked (n.d.)).

In 2007, some researchers from the Lawrence Livermore National Laboratory and the Carnegie Institution at Stanford University concluded that global wheat farmers and corn growers lost 2.6 billion and 1.3 billion dollars respectively in 2002 (Lobell and Field (2007)). In a survey conducted by the U.S. Climate Change Science Program found that the thirty year impact of a trend increase in carbon dioxide could retard corn production in the Midwest by three percent (Program (2008)), this translates into a loss of about 116 million each year (Telleen-Lawton (2009)). Temperature changes also have an adverse effect on some livestock. Heat stress is already a significant factor for many livestock farmers across the country, this impact on the industry is as much as 2.4 billion dollars each year (St-Pierre et al. (2003)).

Then there are the public health issues of heat stroke, and all of the deaths and injuries brought about by the increasing intensity of storms. Hurricane Katrina, for instance, which struck the Gulf Coast in 2005 as a category 3 storm, killed 1,464 people in Louisiana and a total of 346 people in other states (of Health and Hospitals (2006)). A 2004 study by the Yale School of Forestry and Environmental Studies found that increasing the presence of smog-forming ozone by 10 parts per billion would lead to 319 deaths annually in New York City, and 3,767 deaths in other urban areas around the country (Conlon (2004)).

It is quite plain to see that the social costs of using fossil fuels far outweighs the actual financial costs normally attributed (such as the price of oil or gas). Given that the problems and costs are so large and widespread into every facet of American life, the need to find out a more efficient method of renewable energy technology transmission should be on the forefront of American policy decisions.

3.5 Data

The data on energy use, which is used to construct the green energy penetration variable, comes from the databases of the Energy Information Administration. The data consists of total energy production, by state, starting from 1960 until 2006. The energy production data are also broken down into type of fuel used to produce that energy; coal, natural gas, crude oil, nuclear electric power, and renewable energy. Since there are different ways in which to define the diffusion of renewable energy, use several dependent variables as well when exploring the validity of the proposed analytical model. One of the measures used is the percent change in funding approved by the U.S. government for renewable energy purposes. Many projects concerning renewable energy are still in the beginning stages of their life cycle, the way that the first diffusion variable is constructed only emphasizes the finished product of power transmission.

The population data was taken form the U.S. Census website, and the geographical variables were constructed using the U.S. Census data and data provided by the U.S. State Department. Data concerning the House Majority Party was from the U.S. House of Representatives, the Senate Majority Party was taken from the U.S. Senate's public information as well. The Presidential Party data is taken from various online encyclopedias. The data concerning the number of supporting government agencies was collected over a variety of areas drawn from the U.S. Department of Energy's Energy Efficiency and Renewable Energy sector, and from a resource website, Discoversolarenergy.com. The data with respect to the number of supporting firms in the industry was compiled using information found on Renewableenergyworld.com.

The novel aspect of this data set is that it maps the introduction of supporting government agencies and firms over time. To the best of my knowledge this has not been done before. The list of supporting firms is found to be a partial list of the some 15,000 firms engaged in some way or another with renewable energy.[6] Some other data that might be relevant are, that of the growth of the fossil fuel industry over the same time period. This information might lead to some interesting conclusions as to where the power of the politicians is being directed in relation to renewable energy, as opposed to looking at renewable energy by itself.

3.6 Model

Which factors encourage the diffusion of different types of low carbon energy production? In the models proposed by Keller ,(Keller (2002)) and Eaton, (Eaton and

[6] I hope to expand this list in later revisions because the feedback loop from the industry into a growing dissemination of technology seems like a plausible argument but currently our data does not show such a feedback mechanism as being statistically significant.

Kortum (1999)), it is geography that plays an important role in technology diffusion. In the model by Keller, (Keller (2004)), he states that R&D is a factor that effects the diffusion of technology. Barreto, (Barreto and Kemp (2008)) contend that only rich countries have the wherewithal to undertake R&D given a certain definition, and thus income per capita is also important.

The model used in here is one that is closely linked to the theory that has been discussed thus far. In our model, we use the geographical characteristics of a region as important determinates as to whether or not a certain type of renewable energy production is possible. As indicated in the data, a vast majority of renewable energy production is done in highly populated areas, and thus population is also controlled for in this study. The political orientation of the different branches of government, our main variables of interest, are included, as well as the number of supporting government agencies, and the number of supporting firms in the sector. The testable form regression takes the following form:

$$\begin{aligned} RenewableEnergyPenetration_t = \alpha_t + \beta_1 X_{geographics} + \beta_2 PopDen_t + \\ \beta_3 NationalHousePoliticalPower_t + \beta_4 NationalSenatePoliticalPower_t + \\ \beta_5 NationalSenatePoliticalPower_t + \beta_6 NationalPresidentialPower_t + \\ \beta_7 \#ofGovt.IndustrySupportGroups_t + \beta_8 \#ofFirmsinIndustry_t + \epsilon_t \quad (3.1) \end{aligned}$$

A random effects, MLE process is used for the estimation.

These relationships could suffer from endogenaity which would only permit statements concerning the correlation, as opposed to some causal effects, between these variables. Also, the magnitudes of the coefficients could be biased. Solutions to these problems are being undertaken at the time of this draft.[7]

3.7 Results

The results shown in Table B.2 give some of the main findings while the complete regression results are located in the appendix. The first column uses the amount, or level, of federal funds approved for renewable energy as a proxy for the diffusion, or penetration, of renewable energy. The main results extracted from this formulation show that when the Senate is controlled by a Democratic majority, the level of funding that the government approves for renewable energy increases by about 174 million dollars. The results also suggest some evidence of a feedback loop as described in the theory; that is, as the number of government agencies supporting renewable energy goes up by one, there is an increase in funding by about 28 million dollars. In contrast to the proposed theory, as the number of firms in the industry rises by one, the amount of funding alloted by the government drops by around 15 million dollars. Although this may seem surprising to some it is quite reasonable using certain assumptions. For example, assume that in the early years of the industry there were very few firms, and most of those were receiving heavy support

[7] It was also brought to our attention that the political party in power's agenda may take some time to be realized within their term of employment, this would suggest a lagged effect. This seems quite plausible and will also be included in the next draft.

from the government for testing new ideas, as the industry matures and more firms enter, more private money can be spent in the terms of R&D, thus as the number of firms in the industry grows, there is less need for federal funding.

The second column in Table B.2 uses the year-over-year percentage change in the government's funding of renewable energy as the dependent variable. Using this specification, the feedback loop is rendered insignificant, while Democratic control of the Senate indicates that, of the percent change in funding, 17.8 percent of that change is due to the Democratic Party holding a majority.

The third through the seventh column then decompose the percentage change in renewable energy funding into the different areas of renewable energy. For wind, geothermal, and solar power, the results show that having a Democratic majority in the Senate leads to a rise in the percentage change of 45.5, 30.3, and 29.7 percent, respectively, of the percent increase in funding to those respective areas. Within the areas of renewable energy there seems to be some evidence of the feedback loop; for the case of geothermal energy one more supporting government agency accounts for 6.98 percent of a one percentage change in funding, while a similar increase in government organizations with respect to the biological processes energy, has the funding decrease by 5.65 percent of the percentage change in funding to that sector. Also, concerning the biological processes, the results show that marginally increasing the number of firms in the renewable energy industry accounts for 2.37 percent of the percentage change in the funding.

Using the original renewable energy penetration variable, the results in the first column of Table B.3 indicate that the geographic variables are controlling for mostly all of the variation in renewable energy penetration. For example, the desert variable has a negative coefficient indicating that if a state has desert area, that this reduces the renewable energy penetration. This may seem odd as one of the main renewable energies is solar power, of which there is ample supply in the desert. What is a more likely scenario, is that if a state has a desert area, then there are fewer people to offend with a fossil fuel plant. Since increasing the amount of energy produced by fossil fuels without an equal increase in renewable energy reduces the penetration variable, this could explain why in desert states there is an increase in fossil fuel energy production over the increase in renewable energy production. The forest variable also has a negative coefficient. This too is a puzzle, due to the fact that wood burning energy is considered a renewable resource. An explanation here might be that the most prevalent types of renewable energy are hydro and wind power. The wind turbines need room to move and thus heavily wooded areas do not provide such a space. Also, the sparse population argument may also apply. The population density variable shows that as the population density rises, more renewable energy is used over fossil fuel energy. The positive coefficient also lends itself to the sparse population explanation of the other coefficients. Finally, the political power variables are insignificant.

3.8 Conclusions and Discussions

Given the overwhelming anecdotal evidence in support of the theory offered here, I would have expected to see a much larger effect placed on the political party in power. That said, the time frame that was used in this study had only about eight years where the Democrats enjoyed a political majority. Given the relatively small number of years in power, the estimated results are that much stronger in there validity. While reviewing the differences in the bi-party system of the U.S., the battle lines seem to be clearly drawn between the sides: the Democrats lend themselves toward more of a progressive movement of change, while Republicans are more apt to "stay the course" and support the status quo. As fossil fuel power generation has been the norm since the inception of condensed, controlled electricity, it is easy to see how one could perceive the Republican Party as being anti-renewable energy. To be sure, their own rhetoric on the subject seems to put them at odds with the necessary changes needed to advance the renewable energy movement.

The model put forth by Johnson, (Johnson and Jacobsson (2002)), has its foundations in real perceived movements in the spread of wind technology in Germany. They argue that in their country there was a political party responsible for retarding the growth of the wind and solar power movement. While their paper is very moving, their main weakness came from the lack of statistical evidence in support of such an accusation. Seeing a similar rift between the major powers of the U.S. prompted me to undertake a similar analysis of the American political situation centered around the growing debate over global warming, and renewable energy. The two main parties in the U.S., in comparison to Germany, also have very differing opinions about the issue as does the public that supports them at large. Since the gap is so pronounced in the anecdotal support, the decision to test this statistically was compelling.

The results show that, as one might expect, geography as well as population parameters are important determinates as to the spread of renewable energy. Looking further into the diffusion process, and consistent with the theory, it turns out that a Democratic majority in the Senate is indeed associated with higher levels and growth rates, of renewable energy. With respect to the feedback loop described in the model, the results did show some evidence of this phenomenon. With a greater amount of more precise data it is likely that this channel would become more pronounced.[8]

[8] As this draft is being written, a larger set data set of supporting firms has been identified and will be used in subsequent drafts.

As far as future work here is concerned, I would like to use the updated and more expansive data. There are also aspects in the econometric technique that could be refined in order to more accurately reflect real world information dissemination, i.e. there is probably some lag time after appointment before a particular administration's actions take effect in the real economy.

Chapter 4

Optimal Portfolio of Energy Content: Its not all about oil anymore

4.1 Introduction

The underlying theory used to evaluate potential energy plant projects is a "levelized cost" valuation approach. This valuation approach was very well suited for a regulated energy environment, as it takes under consideration known technology costs and passing costs in general on to the consumer. In order to make decisions regarding investment in different types of projects, power companies apply this method based on an internal target for return on equity, also known as the hurdle rate. However, this method fails to incorporate a more competitive environment, a growing and changing use of technology sources used to produce power, uncertain future cost streams, uncertain consumption levels, or investor risk capabilities.

Given that different generation technologies have different cost-risk profiles, there is great potential advantage in operating a diversified portfolio of plants for a utility. The levelized cost method does not give information to a utility, or a country, on the optimal technology choice for an additional power plant, given the current portfolio, because it does not take into account the correlations between the different risk-return profiles of the different generation technologies. The best technology choice would depend on the portfolio of plants that the country or utility already operates, and this interdependency needs to be captured by power valuation methodologies using a mean-variance portfolio theory approach. An efficient portfolio, as defined here, is one that minimizes cost risk contemporarily as well as minimizing the stream of compositional cost risk into future periods.

In this paper I revisit the Mean-Variance Portfolio (MVP) approach to optimal portfolio allocation in energy producing assets, with the extension of using Seemingly Unrelated Regression Estimation (SURE) and a plant level data set in order to answer the questions, 'Is the current energy portfolio in California efficient from a cost-risk view-point ?' and, 'What changes are needed to the energy portfolio in order for California to be able to meet its proposed Renewable Portfolio Standards (RPS)?' The testable hypothesis I approach are threefold: the first is testing for correlations between costs (returns) in order to validate the use of portfolio theory over the levelized cost method, the second is testing for correlations in the error terms in order to validate the use of SURE, and the third is testing whether or not using a SURE technique reduces the mean squared error when compared to the

OLS regressions. I then look at California's existing energy portfolio allocations, and compare these to the efficient frontiers, and then continue to evaluate California's Renewable Portfolio Standard against the efficient frontiers as well. My methodology is similar to Krey, (Krey and Zweifel (2006)), in that I use SURE techniques in order to control for correlations between shocks unaccounted for in the cost streams of different energy producing technologies. Along with Krey, this is the only other use of this technique, and the first time used on U.S. data. Using the new correlation information, and the detailed plant level data, I construct efficient frontiers in a cost-risk nexus of energy technologies. Given this frontier, I then compare California's actual portfolio allocation to the frontier in reference to portfolios that have the following attributes: minimum expected cost, minimum cost risk, the same expected cost , and the same cost risk (as the actual portfolio). Lastly, I look at national security issues pertaining to the different technologies as these relate to supply shocks.

To preview the results, I find that California's current portfolio allocation is inefficient as defined by this model. There is a need for increased energy being produced from renewable resources, including geothermal, solar, and wind, and some reduction in fossil resources, namely coal and natural gas. The potential reasons for this are the low costs (high return) and low cost variations in geothermal and wind power. In evaluating the Renewable Portfolio Standard under two scenarios, 20 and 33 percent renewable commercial energy, the 20 percent threshold could be met with a concentrated increase in geothermal and wind generated energy, and some increase in solar energy production. The results for the 33 percent case show that it is highly unlikely, given the current and planned assets, that this goal can be reached by its proposed completion date of 2020. In order to meet such a demand, there would need to be massive increases in geothermal and wind produced energy. Compared to the current portfolio, such increases would result in an decrease in total portfolio risk at around 8 percent, with an decrease of expected portfolio cost close to 10 percent.

This paper is organized as follows. In Section 1.1, I review the past literature in portfolio theory, and then more recent literature in its application towards energy producing assets. In Section 1.3, I review California's Renewable Portfolio Standard, including its legislative time line. In Section 2, I describe the main features of the models and methods used in the paper. In Section 3, I describe the data used in my estimations. In Section 4, I present my estimation results. Section 5 concludes the paper with a summary and some discussion.

4.1.1 Literature Review

The concept of portfolio theory was introduced formally by Markowitz (1952). In here, he builds on the premise that a portfolio of well chosen assets has reduced risk characteristics when no perfect mutual correlations between the return on each pair of assets exist. Thus, an efficient portfolio maximizes the expected return given some acceptable level of risk, or the efficient portfolio can minimize risk given an acceptable expected return. Fabozzi et al. (2002), postulate that portfolio theory continues to be the most important tool for constructing efficient portfolios for financial assets. As an ancillary case, portfolio risk may be reduced in a portfolio of well chosen generating technology options as a result of less than perfect correlations between their cost characteristics.

Recently, portfolio theory has been applied to real assets, such as those related to energy generation. Jansen et al. (2006), notes that the first application of portfolio theory to energy is due to Bar-Lev and Katz (1976); they examined whether U.S. power utility companies were efficient users of fossil fuel. In that paper, the costs of inputs include transportation overhead expenses, heating of oil lines, stock cleaning, and fuel handling facilities for coal, fuel storage, inventory and maintenance. Bar-Lev and Katz results showed that, compared to the efficient frontier, the actual operations of the utility companies were characterized by high rates of return, and therefore, excessive amounts of risk. They argued that the utility companies could be more efficient by purchasing fuel from the futures market at a guaranteed price.

Another study by Dayo and Adegbulugbe (1988) examined the long term optimal structure of the energy supply in Nigeria. They used a multi-period linear programming model of the total energy system to minimize direct fuel costs while achieving certain developmental objectives. Their results indicate that gas and petroleum play an important role in the Nigerian energy mix, with coal limited to a very small share (mainly because of the high cost of production and transportation at the time).

Nuclear power and solar energy were not considered part of the efficient frontier at all. In studies by Bar-Lev and Katz (1976), and Dayo and Adegbulugbe (1988), both fail to recognize the time varying covariances in energy prices. They also do not include any correlation of possible shocks that may affect primary energy prices. Lastly, only the unit costs of fuels enter into their calculations, this causes other private costs such as operation and management and capital use to be disregarded, as well as social costs such as health and climate change.

Humphreys and McClain (1998) attempt to correct some of the previous limitations by filtering out the systematic components of the covariance matrix of energy prices over time, using a more comprehensive definition of private cost, and including external costs. The covariance problem was solved by using a generalized autoregressive conditional heteroscedastic (GARCH) model to estimate the variances and covariances. By applying the GARCH model, the authors sought to filter out systematic changes in volatility in response to shocks. Their results suggested that a more efficient allocation would include a shift away from oil toward natural gas. By this shift, the overall portfolio volatility could be reduced at a given rate of expected return. By focusing on changes rather than levels, Humphreys and McClain (1998) introduce the investor's point of view of the financial portfolio approach. However, producers are mainly interested in the level of prices they have to pay for their inputs, with the expected future changes being of a second level importance. As is true with all of the previous studies, the authors fail to control for unobserved shocks affecting several generations of technologies at the same time.

4.1.1.1 The Value of Diversity in the Energy Market

Historically, driven by successive 'oil shocks' and geopolitical concerns over the distribution and transit of fossil fuels, discussion of energy diversity has been preoccupied with supply security, (Agency (1985); Verrastro and Ladislaw (2007)). On the other hand, debates on sustainable energy have tended to focus on environmental imperatives, and especially as of late, carbon dioxide and other greenhouse gas emissions, (Stern et al. (2006); Fuller et al. (2009)). Security of supply is clearly about more than diversity. What is less well recognized is that diversity is equally more than just a security of supply strategy, (Stirling (1994)).

At the root, the real inter linkages stem from the crucial, if neglected, fact that diversity is an intrinsic and irreducible property of an energy system takes as a whole, rather than an attribute of any individual option in that system, (Stirling (1994)). An understanding of diversity as an irreducible 'system property' requires a more comprehensive perspective. Doing so points to a more fundamental series of convergences between diversity and sustainability agendas. Transitions to truly sustainable energy systems will therefore require an unprecedented intensity of innovation in technology, institutions, and behavioral practices alike, (Stirling (2007)). It is in these more ambitious and general challenges of sustainability that we find the truly fundamental inter linkages between energy sustainability and energy diversity as an intrinsic system level property. Putting eggs in different energy baskets does not only help to hedge against uncertainty over energy supply disruptions, it also offers a precautionary strategy for greater resilience, flexibility, and adaptiveness in the face of other potential surprises, such as those arising from unexpected developments in environmental or engineering performance, (Brooks (1986); Stirling et al. (1999)). Similarly, pursuit of a diversity of energy resources and technologies offers a way to achieve greater sensitivity to the local geographical and cultural context, (Landau et al. (1996)). Deliberate diversification thus also offers a means for society at large to better accommodate the plural social values and polarized interests, which so often attend sustainability strategies, (Stirling (1997)).

It has long been recognized in the Economics and Business literature that institutional and technology diversity are key factors in achieving more effective and socially robust innovation, (Landau et al. (1996); Rosenberg (1998); Grabher and Stark (1997)). It is also through careful strategies of diversification that we can guard against premature commitment to what in the long run might prove to be suboptimal technological trajectories, (Arthur (1989)). It is only when we look at this broader picture that we can appreciate and realize the extensive significance of energy diversity. In other words, the real fundamental inter linkages between diversity and sustainability in energy production strategies lie in nurturing the sensitivity to context, accommodating plural values, hedging against ignorance, mitigating lock-in, and fostering innovation, (Dorfman (2008)).

Despite the attractions, diversity is not without its costs, (Weitzman (1992)). Indeed, deliberate diversification by definition involves prioritizing options that are otherwise assigned relatively low performance values, (David and Rothwell (1996)).

In addition, there are typically trade offs between diversity and transaction costs, (Williamson (1995, 1998)), and with forgone benefits such as coherence, (Cohendet et al. (1992)), accountability, (Grabher and Stark (1997)), standardization, (Cowan (1991)), and economies of scale, (Matthews and Mcgowan (1992)). Diversification may also retard learning effects for incumbents in favor of more marginal options. The value of the 'diversity premium' that is warranted in any particular energy mix will then be a function of the performance attributed to individual energy options, and the contributions that each makes to system diversity, (Stirling (1994)).

4.1.1.2 Recent Applications of Portfolio Analysis to Optimal Power Generation Portfolios

Recently there has been research singling out electricity. Berger et al. (2003) use Markowitz theory to examine existing and projected generation technology mixes in the European Union. According to their study, owing to their favorable expected returns and diversification effects, renewables that are characterized by high fixed, but low variable costs, figure prominently in efficient portfolios. A weakness of this study is the database used. Important components of costs are proxied by business indicators such as the S&P 500 index. In addition, external costs and common observed shocks are not taken into account.

Roques, Newbery, Nuttall, Neufville and Connors (2006); Roques, Nuttall, Newbery and De Neufville (2006) and Roques et al. (2008), apply stochastic optimization to determine whether nuclear power may serve as a hedge against uncertain gas and carbon prices. Here, high and uncertain capital costs and potential licensing delays cause the role of nuclear energy to be limited. Rather than estimating correlations between unit costs, the authors resort to the use of arbitrary correlation scenarios (Monte Carlo simulations). This arbitrariness is crucial because the stronger the correlation between the cost of nuclear power and other technologies, the weaker its portfolio diversification effect.

Jansen et al. (2006), also apply Markowitz theory to determine efficient portfolios of power generating technologies for the Netherlands for the year 2030. Their results suggest that diversification may yield a risk reduction of up to 20 percent at no extra loss of expected returns.

Awerbuch and Yang (2007), use portfolio theory optimization to evaluate the 2020 projected European Union business as usual electricity generation mix. Optimal generating portfolio mixes generally include greater shares of wind, nuclear, and other non fossil fuel technologies that often cost more on a stand alone engineering basis, but overall costs and risks are reduced because of the effect of portfolio diversification. Such diversity also enhances energy security.

Awerbuch et al. (2008), take the idea of a portfolio theory approach to the optimal mix of electricity generation in Scotland. The main concern here is that of climate change mitigation and the use of wind power driving up the overall cost of generating electricity. Their results show that the proposed mix developed by the National Grid Transco, does not insulate the country from price shocks as well as other portfolios containing more wind generated power. They also argue that reducing wind shares from their optimized level significantly increases the cost and risk of electricity generation in Scotland.

And finally, Krey and Zweifel (2006), apply portfolio theory to power technologies of the U.S.A. and Switzerland. This is the only paper (to the author's knowledge) that uses a SURE estimation strategy in order to filter out the systematic components of the covariance matrix (price and error correlations). The paper is also one of the pioneers in using diversification indices to relate the trade-off between efficiency and security of supply. The findings suggest that as of 2003 the U.S. could have gained in adopting a feasible portfolio with more fossil fuel production of electricity, at only a slightly reduced security of supply. The study also finds that the generation portfolio mix for Switzerland, during the same time period, consisted of shares identical to those found in the actual portfolio, meaning that the Swiss mix was efficient.

4.1.2 Renewable Portfolio Standards

California, like many other states, has a mandated Renewable Portfolio Standard (RPS). Established in 2002 under Senate Bill 1078, and accelerated in 2006 under Senate Bill 107, California's Renewables Portfolio Standard (RPS) is one of the most ambitious standards in the country. The RPS program requires electric corporations to increase procurement from eligible renewable energy resources by at least 1 percent of their retail sales annually, until they reach 20 percent reduction by 2010.

California RPS legislation, executive order, and energy action plan time line are as follows:

- Senate Bill 1078 (2002): Established the RPS program, requiring 20 percent renewable energy by 2017,
- 2003 Energy Action Plan I accelerated the 20 percent deadline to 2010,
- Senate Bill 107 (2006) codified the accelerated deadline into law,
- 2005 Energy Action Plan II examined a further goal of 33 percent by 2020,
- Assembly Bill 200 (2005) modified some requirements for electric corporations that serve customers outside of California, and have 60,000 or fewer customer accounts in California,
- Executive Order S-06-06 (2006) established targets to increase the production and use of bio-energy,
- Assembly Bill 1969 (2006) requires electric corporations to purchase, at a CPUC set price, renewable energy output from public water and wastewater facilities up to 1 megawatt (MW),
- Senate Bill 380 (2008) amends P.U. Code 399.20 making the feed-in tariff established by AB 1969 applicable to all eligible renewable generators (previously limited to water and wastewater facilities) and increases the program cap to 500 MW (previously set at 250 MW), and finally,

- Executive Order S-14-08 (2008) sets a target of 33 percent renewable energy by 2020.

4.2 Models and Methodology

In portfolio theory, risk is characterized as a variance of returns from a particular asset. The theory is concerned with minimizing risk for a given return, or maximizing return for a given level of risk, this through combining assets with differing risk characteristics into a diversified portfolio. Portfolio theory uses a partial equilibrium model whose credibility depends on its relationship with a broader general equilibrium model for the pricing of risk.

This general equilibrium model is provided by the Capital Asset Pricing Model (CAPM), which provides an overarching theory of the pricing of risk in a perfect market under equilibrium. The key principal of portfolio theory is that when considering the acquisition of a new asset, the relevant risk is not the absolute variance of that asset's returns, but its contribution to the portfolio's total variance. This contribution is not simply additive, but depends on the correlation between the variances of the asset in the portfolio. The CAPM utilizes the same principal as portfolio theory, but extends it to cover the entire asset class, r_m, usually interpreted as the entire market of equity stocks.

Under the CAPM, the expected returns, $E(r_j)$, on assets j are related to the risk free rate of return, r, the expected return on the overall market portfolio

$E(r_m)$, and β_j, the assets volatility relative to the market, that is:

$$E(r_j) = r + \beta_j \left[E(r_m) - r \right], \tag{4.1}$$

where:

$$\beta_j \equiv \frac{cov(r_j, r_m)}{Var(r_m)}. \tag{4.2}$$

An asset's risk can be divided into two distinct parts: that which can be attributed to variations in return in the aggregate market portfolio (non diversifiable risks), and variations that are firm, or technology, specific, driven by factors other than the market (diversifiable risks). The important insight behind the CAPM is that investors will only require a risk premium to cover the additional marginal contribution of the asset to the overall market portfolio risk. In other words, it is only the non diversifiable risks, as measured by β, that matter to an investor, since the CAPM assumes that the investor is able to eliminate all diversifiable risks through spreading their investments sufficiently widely. In principal, companies should consider a project's β when deciding upon the expected returns required from a particular project.

As noted above, portfolio theory essentially uses the same insight as that of the CAPM, namely that the investor should be concerned with the contribution of an asset's risk return profile to the total portfolio risk return. A major difference is that portfolio theory applies these insights onto a particular market sector, rather than to the market as a whole. A reason for doing this is that when it comes to electricity prices there are stakeholders, other than equity investors, who are affected by such riskiness. If information in market prices were complete, this would not matter, as individual preferences and strategic concerns, such as security of supply, would be priced into the market. Arguably, information in market prices is not complete, and thus equity markets do not bear the full costs of price volatility. As a result, the use of portfolio theory for a given sector departs from the assumption of the general equilibrium model of perfect markets, thus making the case that the risk-return relationship should be optimized at the sector level because of incomplete representation of the interests of all stakeholders in the CAP model.

This latter perspective indicates that portfolio theory is designed to identify those portfolios of generation mix at the sector level that are in some sense "optimal" (namely maximizing expected return, or minimizing expected cost, given a particular risk exposure, or minimizing risk given a particular expected cost or return). The key policy insight gained by this approach is to identify situations where the generation mix is suboptimal from a risk-return (cost) perspective, or to identify where incentives for new additions to the power generation portfolio do not improve the risk-return (cost) characteristics of the portfolio. These deviations from an "optimal" generation mix may then be considered as an externality not being adequately addressed by the market design, thus pointing to areas where policy intervention is required.

4.2.1 Appropriateness of Using MVP Theory to Analyze Energy Portfolios

In a liberalized as well as a fully regulated electricity market, the power producers face significant risks. One major difference in the liberalized setting is that investors can no longer push these risks on to the consumers or taxpayers automatically. In the new environment, investors now have additional risks to consider and to successfully incorporate into their investment strategy. Among these risks are the following,(IEA/NEA (2005)):

- economy-wide factors that affect the demand for electricity and the availability of labor and capital;
- factors under the control of the policy makers, such as regulatory and political risks, with possible implications for costs and financing conditions, and on earnings,including the cost of additional emissions controls;
- factors under the control of the company, such as the size and diversity of its investment program, the choice and the diversity of its generation technologies, and control of costs during construction and operation;
- the price and volume risks in the electricity market;
- fuel price and availability risks; and
- financial risks arising from the financing of investment; these can, in some cases, be mitigated by the capital structure of the company.

Different technologies will be affected by these risks differently. Some risks are an integral part of a specific technology; others constitute an interaction between the technology and the environment of operation in which this technology exists. Table 1 was reproduced from IEA/NEA (2005); it shows a qualitative view of the various types of risks faced in a liberalized energy market.

The traditional method used by investors in a fully regulated market was a "levelized cost" valuation approach. This type of valuation approach was well suited for that type of environment; as indicated on *Projected Costs of Generating Electricity* (2005),'(it) reflected the reality of long-term financing, passing on costs to the consumers, known technology paradigms, a predictable place in the merit order, a steady increase in consumption, and, in the presence of steady technological progress, no problem in securing a favorable position in the merit order for new plant'. The levelized cost method is still used in the current liberalized industry. In order to make decisions regarding investment in different types of projects, power companies apply this method based on an internal target for return on equity, also known as the hurdle rate.

While this method may still seem satisfactory with the power companies in a liberalized electric industry, the main concern of an investor is the profitability of an investment against the risk to the employed capital. The level of risk expected by an investor in a power plant will be internalized in the level of return expected on the investment. The greater the business and financial risks, the higher the return demanded. IEA/NEA (2005) indicates,'(the levelized cost) methodology for calculating generation costs does not take business risks in competitive markets adequately into account...it needs to be complemented by approaches that account for risks in future costs and revenues.'

The main draw-back to the levelized cost method is that it values projects on a stand-alone basis. Different generation technologies have different risk-return profiles, and, for a utility, there is great potential advantage in operating a diversified portfolio of plants. Because it does not take into account the correlations between the different risk-return profiles of the different generation technologies, the levelized cost method does not give information to a utility or a country on the optimal technology choice for an additional power plant, given the current portfolio. The best technology choice would depend on the portfolio of plants already in operation, and this interdependency needs to be captured by power valuation methodologies using a mean-variance portfolio theory approach.

Because energy planning is like investing in financial securities where financial portfolios are widely used to manage risk and maximize performance under unpredictable outcomes, portfolio theory is well suited to the problem of planning and evaluating electricity portfolios and strategies. In this sense, it is important to not view the choice of electricity generation as a cost of a particular technology today, but rather in terms of its portfolio cost. When portfolio theory is applied to electricity generation planning, conventional and renewable alternatives are evaluated, not on their stand-alone costs, but on their contribution to overall portfolio generating cost relative to their contribution to overall portfolio risk.

Portfolio theory improves decision making in the following ways. First, as the investor only needs to consider the portfolios on the efficient frontier, rather than the universe of all portfolios, it simplifies the portfolio selection process. Second, it quantifies the notion that diversification reduces risk.

4.2.2 Mean-variance Portfolio Theory

MVP, or portfolio theory (which will be used interchangeably), was initially developed as a tool in the context of financial portfolios, where it relates expected portfolio return to expected portfolio risk, defined as the year to year variation of portfolio returns. In one of the original specifications of the model as it applied to electricity markets, Awerbuch and Berger (2003) assumed that generating cost ($/kWh) was the inverse of a return (kWh/$).

$$Expected\,portfolio\,cost = X_1 E(C_1) + X_2 E(C_2), \tag{4.3}$$

where X_1 and X_2 are the fractional shares of the two technologies in the mix, and $E(C_1)$ and $E(C_2)$ are their expected levelized generating costs per kWh. Expected portfolio risk, $(E(\sigma_p))$, is the expected year to year variation in generating cost. It also serves as a weighted average of the individual technology cost variances, as they are tempered by their covariances:

$$Expected\ portfolio\ risk = E(\sigma_p) = \sqrt{X_1^2\sigma_1^2 + X_2^2\sigma_2^2 + 2X_1X_2\rho_{12}\sigma_1\sigma_2}, \qquad (4.4)$$

Where X_1 and X_2 are the fractional shares of the two technologies in the mix, σ_1 and σ_2 are the standard deviations of the holding period returns (HPRs) of the annual costs of technologies 1 and 2, and $\rho_{1,2}$ is their correlation coefficient.

In this scenario, portfolio risk is estimated as the standard deviation of the HPRs of future generating cost streams. The HPR is defined here as: $HPR = (EV - BV)/BV$ where EV is the ending value and BV is the initial value. [1] For fuel and other cost streams with annual reported values, EV can be seen as the cost in year $t+1$, and BV as the cost in year t. HPRs measure the rate of change in the cost stream from one year to the next. This is discussed in more detail in Berger (2003).

Each individual technology actually consists of a portfolio of cost streams (capital, fuel, O&M, and CO_2 for example). Total risk for an individual technology is σ_T. In this case, the weights, $X_1, X_2, ...$, are the fractional share of total levelized cost represented by each individual cost stream.

The correlation coefficient,ρ, is a measure of diversity. Lower ρ among portfolio components creates greater diversity, which in turn reduces portfolio risk ρ_p. As a general rule, portfolio risk falls with increasing diversity, as risk here is

[1](Brealey (2007),has a detailed discussion about HPRs)

measured by an absence of correlation between portfolio components. For example, adding a renewable technology to a risky generating mix will lower the expected portfolio cost at any level of risk, even if the technology costs more (Awerbuch (2006)). The pure fuel less technology has a $\sigma_i = 0$. This lowers σ_p, since two of the three terms in Equation 4.4 will reduce to zero. It is then easy to see that σ_p declines as $\rho_{i,j}$ falls below 1. For the case of a renewable technology, fuel risk is zero, and thus its correlation with fossil fuel costs is zero as well.

The MVP equation used in this study is more akin to:

$$E(r_p) = \sum_{i=1}^{N} X_i E(r_i), \tag{4.5}$$

where, the expected return, $E(r_p)$ of portfolio P containing N assets i [expected return,$E(r_i)$,standard deviation,σ_i] in proportion X_i is the weighted average of the expected returns of the N assets.

The portfolio standard deviation σ_p is defined by:

$$\sigma_p = \sqrt{\sum_{i=1}^{NP} X_i^2 \sigma_i^2 + \sum_{i=1}^{N} \sum_{j=1, i \neq j}^{N} X_i X_j \rho_{ij} \sigma_i \sigma_j}, \tag{4.6}$$

where ρ_{ij} represents the correlation between the returns r_i and r_j of the two assets.

4.2.3 Seemingly Unrelated Regression Estimation

In view of Equation 4.2.2, portfolio risk σ_p depends on individual standard errors, σ_i, and the correlations between returns, ρ_{ij}. It is important to derive estimates of the covariance matrix that are reasonably time invariant (as argued earlier) in each time series of electricity generation costs considered, doing so calls for the estimation of predicted values, $\hat{R}_{i,t} = R_{i,t} - \hat{u}_{i,t}$, that do not contain a systematic shift. Such values can be computed from the residuals, $\hat{u}_{i,t}$, of the following autoregressive process of order j:

$$R_{i,t} = \alpha_{i,0} + \sum_{j=1}^{n} \alpha_{ij} * R_{i,t-j} + u_{i,t}, \tag{4.7}$$

where $R_{i,t}$ is the return for technology i in year t, $\alpha_{i,0}$ is a constant for technology i, α_{ij} is the coefficient of the return lagged j years, $R_{i,t-j}$ is the dependent variable (rate of return) lagged j years, and $u_{i,t}$ is the error term for technology i in year t.

If the shocks causing volatility in the returns were uncorrelated across technologies, one could estimate the expected return for each electricity generating technology separately to obtain residuals, $\hat{u}_{i,t}$, and thus values for $\hat{R}_{i,t}$. It has been shown in previous research by Krey and Zweifel (2006), that the error terms are significantly correlated across energy sources. The appropriate econometric method to exploit this information into giving more precise estimates of α_{ij}, $u_{i,t}$, σ_i, and σ_{ij} is called seemingly unrelated regression estimation (SURE). The SURE model consists of n regression equations, where n is the number of electricity generating technologies, each of which satisfies the requirements of the standard regression model. The assumption that is specific to SURE is that the covariance matrix

$E(uu')$ is not diagonal, with I the nxn identity matrix, that is:

$$E(uu') = \begin{vmatrix} \sigma_{i,i}I & \sigma_{i,k}I \\ \sigma_{k,j}I & \sigma_{k,k}I \end{vmatrix}$$

.

By contrast, traditional ordinary least squares estimation would be appropriate if the disturbance terms of technologies i and k were not correlated. However, this is not the case for U.S. power technologies. In summation, SURE allows one to estimate simultaneously the expected returns of all power generation technologies in one regression, while taking into account the possible correlation of error terms across equations.

4.2.4 Models for Supply Concerns and National Security

4.2.4.1 The Shannon-Wiener Index

The fewer technologies a power system has, the fewer the number of suppliers, and the more the system is exposed to the effects of collusion and monopoly. One measure of diversity is entropy, also known as the SW index:

$$SW = -\sum_{i=1}^{m}(p_i * ln(p_i)), \tag{4.8}$$

where p_i is the proportion of generation represented by the ith type of generation technology. A value below 1.00 indicates a system that is highly concentrated and therefore subject to the risks of collusion and monopoly, a situation leading to increased interrupted supply and/or price hikes.

4.2.4.2 The Herfindahl-Hirschman Index

Another measure of the security of supply is the HH index:

$$HH = \sum_{i=1}^{m} p_i^2, \tag{4.9}$$

where p_i is the share of the ith technology, usually expressed as a percentage. An HH index equal to 10,000 is then the case of a monopoly. An HH below 1000 is taken by antitrust agencies as an indication of no concentration, James (1992). Rothwell contends that an HH greater that 1800 is interpreted as being problematic in terms of exposure to supply risk, (Rothwell (2009)).

4.2.4.3 The Sharpe Ratio

The Sharpe ratio is a measure of return-to-risk and is given by:

$$SR = ER_p/\sigma_p, \tag{4.10}$$

where $E(R_p)$ is the expected return of the efficient portfolio, while σ_p represents the volatility (standard deviation) of the efficient portfolio. The higher the value of the SR, the better.

4.3 The Data

The data needed to determine the efficient frontier in the method described above are the following:

- Costs: capital, fuel, O&M, and CO_2; per unit of generation (kWh or mWh) per technology,
- The standard deviation of each cost component,
- The correlation factors between all cost components, and
- Total generation costs for each technology.

4.3.1 Preliminary Data Analysis

The primary data set is obtained from the Federal Energy Regulation Committee, and contains plant level data on all Investor Operated Utilities in the United States for the years 1994-2009. Other data resources are also used, and noted, including the U.S. Department of Energy, the International Energy Agency, the Energy Information Association, the Environmental Protection Agency and the California Energy Commission.

The data includes 131 total plants. Of those 37 are hydro, 33 natural gas, 38 geothermal, 10 coal, 9 petroleum, and four are nuclear. The primary data set is a plant level data set including: a comprehensive balance sheet, statement of income for the year, statement of cash flows, construction work, construction overhead, operations and maintenance expenses, installed capacity, net generation, plant costs, production expenses, and fuel expenses.

The capital costs include: land and land rights, structures and improvements, and equipment costs.

The operations and management costs include: operator, supervisor, and engineer, coolants and water, steam expenses, steam from other sources, steam transfered, electric expenses, misc. steam or nuclear power expenses, rents, allowances, maintenance supervision and engineering, maintenance of structures, maintenance of boiler or reactor plant, maintenance of electric plant, and maintenance of misc. steam or nuclear plant.

4.3.2 Constructing Holding Period Returns

Table C.2 has a breakdown of all of the holding period returns. I first construct the holding period returns for different cost parameters associated with energy production. These costs are investment, fuel expenses, operations and management, and potential CO_2 costs. The investment cost data comes from a World Bank analysis covering a large number of projects, and estimates the standard deviation of construction period outlays for thermal plants at 23 and 38 percent for large hydro plants. The estimates for wind and solar risk were determined from developer interviews in Awerbuch et al. (2005), and from CEC staff, Klein and Rednam (2007). The construction cost for existing vintages is estimated at around 0 percent. This would suggest that 'new' assets are riskier than existing capacity assets. The continuing capital cost data are taken directly from the balance sheets of the energy plants. These include land and land rights, structures and improvements and equipment costs as reported to the FERC. All costs are taken on a post-tax/credit basis. Because the COG report did not estimate existing coal and nuclear technology costs, these are estimated using the TECHPOLE database.

Fuel cost risks come directly from the balance sheets of the energy plants as reported to the FERC. Annual price observations were used on the assumption that they would eliminate seasonal variations that could potentially bias the results. Electricity generators usually purchase fuel through spot and contract markets, this fact makes using the annual observations appropriate as well. The holding period return standard deviations of fuel costs range from .049 for coal to .346 for nuclear. The renewable technologies and geothermal energy require no fuel outlays and thus there is no fuel cost risk.

The risks of operating and maintenance costs are difficult to estimate. Typically, these estimates exist in corporate records, but often these records are not available to the public. The U.S. Energy Information Agency and the Federal Energy Regulatory Commission databases maintain records covering every generator operated by a publicly owned utility. This data was used to estimate the HPR standard deviations for the operations and management costs. Different technologies show different year-to-year fluctuations in maintenance costs, ranging from .153 for hydro and geothermal power to .042 for petroleum.

The CO_2 costs are derived by multiplying 1kg of CO_2 per kWh for coal,

.062kg CO_2 per 1cf of natural gas (Ophardt (2004)), and 317kg for one barrel of oil (Kent (1974)). Applying a base cost of first,$0, then, $12 per ton of carbon (which reflects the SCC's findings), and finally $20 per ton of carbon (Tol (2005)). This cost can be interpreted as the expected market price of CO_2. For example, under California's proposed Emissions Trading Scheme (ETS). Alternatively, in the absence of such policies (ETS), the cost of CO_2 can be interpreted as the shadow price of CO_2, estimated on the basis of the economic cost of CO_2 emissions and of CO_2 abatement costs, (Krey and Zweifel (2006)).

4.4 Estimation and Regression Results

4.4.1 OLS Estimation Results

Ordinary Least Squares estimation is executed as a benchmark to test the improvements, if any, of the SURE method. The full tables of all the results are located in the Appendix to this chapter. Starting first at the hydro-power estimation, two-thirds of the reported coefficients are not statistically significant, while the remaining third have varied levels of significance levels. This lack of statistical power suggests that using the OLS method to derive credible correlation coefficients needed in the portfolio optimization process would lead to incorrect or biased estimates of the costs and risks associated with said portfolio. The OLS regression for natural gas has even less statistical power, as only one of fifteen coefficients is significant. There is also little to no statistical significance in the geo-power, coal, or nuclear power regressions. The only OLS regression that does have significant statistical power is that of petroleum based power assets. This may be due to the nature of petroleum power usage techniques, i.e. petroleum power is very expensive to produce. For this reason, it is only used during very high peak power conditions, and thus, it may stand to reason that it would behave differently than the other types of energy assets which are mainly for base load transmission. In summation, the lack of statistical significance in these regressions comes from the underlying interconnected nature of the assets, in costs (returns) as well as in unobserved shocks to the error terms.

4.4.2 Correlation Estimation Results

After the costs have been constructed, we can then look at the correlations between both costs and the residual terms. First we run the OLS regressions to get coefficient estimates and the estimates of the residuals. I then use these to determine if there is evidence of correlation between the factors of interest. This step will provide evidence helpful in determining in two respects. First, if there are correlations between the costs, this would lead to the conclusion that, the OLS method is not providing efficient estimates of the residuals leading to biased estimates of the coefficients. Secondly, this step allows us to see the correlations in the OLS residuals which is the evidence needed to go forward with the SURE technique. Tables C.3 through C.8 give the results of the OLS estimations. Table C.9 gives the correlation results.

Recall the reason for using the SURE technique to increase estimation efficiency is to account for the correlations in unobserved shocks. Table C.9 provides evidence supporting this notion. The figures indicate strong correlations relating to returns. For example, coal and natural gas show a correlation of about .70. These correlations provide ample evidence of the interconnections between the costs of the different generating technologies, and thus, as noted, the OLS estimates of the residuals are leading to biased estimates of the coefficients.

The second section of Table C.9 shows the correlations between the error terms, which represent the components due to unobserved shocks. Here the correlations remain substantial, with about half of the correlations above 20 percent. These correlations show that, when determining additional generating assets, there is a place for further testing using SURE techniques and the appropriate use of the portfolio method.

4.4.3 SURE results

In order to have clean unbiased correlation coefficients, we need to have statistically significant estimated coefficients in the autoregressive estimation process. By running each of the regressions simultaneously, we can eliminate the common unobserved shocks to the innovation terms, thereby decreasing the bias included in the estimation of the correlation coefficients needed for proper portfolio analysis. When we apply the SURE methodology, the regression results are of increased statistical significance across the board; now over half of all coefficients in all of the regressions are statistically significant, with the significance levels in the expected pattern concerning a first order auto-regressive process. We can conclude from these results that using the SURE method was necessary in order to obtain unbiased correlation coefficient estimates.

4.4.4 OLS and SURE: Comparative Results

4.4.4.1 Comparing Correlations

Given the evidence acquired from the OLS regressions, the SURE strategy is now employed. Due to the differences in data availability across the different energy producing assets, multiple SURE's are run. The results of these estimations can be found in Tables C.10, C.11, and C.12. Using the results of the SURE technique, the correlations are again computed. The results show the correlations in the residuals under the assumption that their correlations are no longer containing any information that would affect the estimates of the coefficients. In Table C.13, we see that the calculated correlations, after the SURE treatment, differ from the OLS results. Using the unbiased correlation results of the SURE method, we now have all of the components necessary to develop reliable results using the MVP method of efficient power generation frontiers.

4.4.4.2 Comparing Regressions

Theoretically, accounting for the correlations in the residuals should give more precise estimates of the coefficients by reducing their standard errors, and should result in improved "z/t" scores. The improved estimates should also result in a smaller mean squared error (RMSE) when compared to the OLS regressions, and should lead to a better F-Statistic/Chi2 result as well.

The comparative results of the OLS and SURE methods are presented in Table C.14. The summarized results compare the RMSE, R^2, Chi2 and corresponding P values. In every instance, the RMSE of all of the regressions is lower in the SURE method, due to the improved "z/t" scores of most of the coefficients. As can be seen in the table, the "goodness of fit" of the regressions are higher in the SURE, with the largest gains in the natural gas and coal equations. This result would suggest that the shocks to the residuals are most correlated in these two equations. This is due to the fact that coal and natural gas are direct substitutes for each other, thus prompting their apparent correlation (but then also giving rise to the importance of the revealed seemingly unrelated correlations as well). The F-stat/Chi2 statistic improves over each equation as well when comparing the SURE to the OLS regressions which in turn leads to the improved probability scores of that statistic.

4.5 Efficient Power Generation Frontiers

Using all we have found, we can now start to form the efficient frontiers. We start with the ability to have any mix of technologies available. By doing this we initially disregard the vintage assets. The latter are included in later estimations. The cost-risk nexus shows that the efficient frontier lies on a curve starting at solar, which has the lowest cost variation, goes through geothermal, which has the lowest cost, and ends at the "same variance" portfolio mix. Hydro power and nuclear power offer moderate to low costs, but at too great a risk when compared to the other options available for producing energy. Wind and natural gas are within the efficient boundary and would be more attractive if they offered lower costs or less cost variation risk. These costs experienced in California may have been hampered by the age of the plants, and the reliance on natural gas. The high risk profile of the state energy mix is due, in part, to a substantial amount of hydro, nuclear, and coal energy production.

The portfolios of interest are the ones that lie along the efficient frontier between the portfolio with the minimum variance (MV) and the portfolio with the maximum expected return, or minimum expected cost (MEC) . The latest data available for the mix of electricity used in California are from 2008 (California Energy Commission), and we use this portfolio as a reference point in order to more clearly show the directions that policy could take to move toward a more efficient mix of energy producing technologies. Using this portfolio as a reference, there will be two other portfolios of interest, a portfolio that has the same risk level involved, but that could produce a higher return, i.e. lower cost, (SV), and one that looks at achieving the same expected cost but at a lower exposure to risk (SEC).

The results for this specification are illustrated in Figure C.3, and the calculated asset shares are shown in Table C.15. The table shows that under the case of no restrictions, the portfolio with the lowest cost, or highest return, is one made up entirely of the geothermal energy asset. This is due to the low cost of $/kWh. The portfolio that minimizes the cost risk is made up entirely of the solar asset.

This is because of the low standard deviation of the cost risk due to relatively stable solar costs in the time period studied. The portfolio that has the same expected cost (or same return) at a lower risk in relation to the actual portfolio used consists of 74.7 percent geothermal and 25.3 percent solar assets. This allocation is chosen because of the low cost risk of both assets and the low overall cost in the geothermal asset. The portfolio the gives the same expected risk, but a lower cost (higher return) when compared to the actual portfolio contains 50 percent geothermal, 38 percent nuclear, and 12 percent wind assets. This mix is determined by the low cost (high return) of the geothermal and nuclear assets, and the risk associated with the nuclear asset.

4.5.1 Upper and Lower Energy Generation Bounds

The baseline and realizable results are differ from the unrestricted results in that they now include the vintage assets. In the baseline and realizable model, the maximums and minimums are constructed assuming there will be no new investment in coal, nuclear and hydro technologies. The upper-bound on the baseline case allows for the addition of 10 percent over the current generation share. A 10 percent upper-bound for solar technologies, 25 percent for geothermal, and 30 percent for wind, (Lesser et al. (2007)). Lower bounds for technologies yet to be built are zero. Upper-bounds for existing technologies are capped by generation share in the realizable case scenario. In the realizable case, lower-bounds are limited by a 50 percent generation share, except for coal and natural gas (5%) and nuclear and hydro (80%) of generation shares. In the baseline case, lower-bounds are limited by a 75 percent generation share, except for coal and gas (2.5%) and nuclear and hydro (40%) of generation shares. These upper and lower bounds can be found in Tables C.16 and C.18.

4.5.1.1 Efficient Portfolios: Baseline Case Results

The efficient allocations of assets given these new restrictions are shown in Table C.17. As compared to the unrestricted case, there are significant differences. Firstly, because of the maximum thresholds, there is a greater diversity in the types of assets used. Also there is a greater dependence on fossil fuels and on a diversity of renewable energy assets. One difference from the actual portfolio are the large reductions in natural gas produced energy. This is due to the high cost per kWh (low return) shown in the data. This said, there are few alternatives for base load energy and the shift represented in the efficient portfolio calls for a move from natural gas to coal. There is also a significant increase in solar and wind power. The wind power increase is based on the low cost needed to generate kWh of electricity, and the increase in solar is due to its low perceived cost risk. The large increase in petroleum based energy is also due to the temperance factor that accompanies the low cost risk. Due to its risk, there are also a slight reduction in nuclear.

Table C.20 shows the baseline results for the Renewable Portfolio Standards (RPS) case. Due to the mandated amounts of renewable energy needed, the most striking difference between the actual portfolio and those proposed are the increased levels of solar and wind power needed. Because of the high cost of the natural gas relative to coal in producing energy, there remains a pronounced shift from natural gas to coal These results reflect the findings of, Commission (2009), where it states that in order to reach these levels,

> 'The magnitude of the infrastructure that California will have to plan, permit, procure, develop, and integrate in the next ten years is immense and unprecedented. This goal is more attainable with a commitment of significant new staff resources in both the public and private sectors...Several factors outside direct state control could undermine the gains realized through the various reform initiatives. These external risks could delay attainment of the 33% RPS target well beyond 2020, especially if California continues on its current renewable resource contracting path.'

The RPS for California was recently raised from 20 to 33 percent of retail electricity being produced from renewable resources, (Executive Order S-14-08, 2008). Results are provided for both scenarios in the tables of this chapter.

4.5.1.2 Efficient Portfolios: Realizable Case Results

The realizable case results reflect a more moderate use of the current vintage assets (as opposed to the minimal use in the baseline case). The realizable case still takes into account the proposed closures and additions to the power system. The maximum limits on the renewable energy technologies are tempered to reflect current growth trends in the respective industries, (Commission (2009)). In the realizable case study the addition of a CO_2 charge had the effect of depressing expected returns across the board. The constraints on the use of biomass technology, and the low return on natural gas, deters the reduction of energy produced by coal.

Table C.18 gives the maximums and minimums represented in the realizable case up to the year 2020. A graphic representation of the efficient frontier in this case is shown in Figure C.5. Again, these results reflect current vintage assets as well as closures and new plants currently proposed to come on line through 2020. Given these constraints, Table C.19 shows the new allocations of assets across the interested portfolios. When compared to the actual portfolio, we see once again the need for more solar and wind assets. Almost all of the other assets are in a reasonable range respective to the actual portfolio. The only one that is a little high is natural gas, and that is due to its low kWh/$ yield. Adding in the CO_2 charge brings a slight shift into natural gas, but again the main focus of change is on the maximizing of solar assets, and a marked increase in both wind and biomass technologies.

Turning back to the RPS case, Table C.21 shows these results. Here we see a needed reduction in coal power assets, a moderate use of natural gas (which again would have been higher if the costs were lower), substantial increases in both solar and wind power, and a moderate to large increase in biomass power. Including the CO_2 charge exacerbates these needed increases in the renewable energy assets. Given our current use, and currently planned increase in the assets, the 33 percent RPS is not attainable. As shown in Figure C.7, we are thus running beyond the attainable efficient area. To achieve such efficiency would require a massive increase in wind, biomass, and solar produced energy. Relative to the current portfolio, these increases would result in an increase in total portfolio risk at around 9 percent, with an increase of expected portfolio return close to 20 percent.

4.6 Supply Concerns and National Security Results

In order to compare the actual portfolio and the portfolios proposed by this study in terms of supply risk, we use indices of diversity, concentration, and risk. The results are shown in Figures C.8 and C.9, and in Tables C.22 and C.23. The Shannon-Wiener index measures entropy, or the risk of collusion and monopolistic behavior correlated with intense concentrations of supply. A value below 1 is considered problematic in terms or supply interruption/risk. For the actual portfolio the Shannon-Wiener index score is 1.612. Excluding the non-restricted and the minimum variance realizable portfolios, the other proposed portfolios all score higher (less concentration risk) with a range of 1.66 - 1.867. These results indicate that while our actual portfolios' current mix is in no immediate danger of the risks associated with the Shannon-Wiener index, the present portfolio can be improved upon in almost any of the proposed portfolio allocations in this study.

An alternate way to address the issue of optimal portfolios in use is the The Herfindahl-Hirschman index, a method of concentration commonly used by the U.S. justice department in determining anti-trust legislation. A Herfindahl-Hirschman index score of 10,000 is associated with a monopolistic environment while an index score below 1000 indicates there is no concentration in the industry. A Herfindahl-Hirschman index score greater than 1800 may be problematic in terms of supply risk, (Rothwell (2009)).

The actual portfolio used here shows a Herfindahl-Hirschman index score of 2802.22, which could be interpreted as problematic. As before, with the exclusion of the unrestricted and minimum variance realizable portfolio allocations, all of the other proposed portfolio allocations preform better with a range of 1776.78 - 2550, with the same expected return baseline scenario and the same variance realizable scenario preforming best. Concerning the renewable portfolio standards scenarios, the range is 1738 - 2484, with the 33 percent case preforming best in that category. The results here show that there are optimal portfolios available that offer insulation from supply risk shocks.

The third measure used is the Sharpe ratio, a measure of risk-to-return for a portfolio allocation where a higher value is preferred over a lower one. The Sharpe ratio value for the actual portfolio is 1.742. All of the other same variance, and same expected return portfolios presented here, have higher Sharpe ratio values ranging from 1.999 - 2.993. Again, suggesting room for improvement.

4.7 Summary and Conclusions

In this chapter I explore two questions, 'Is the current energy portfolio in California efficient from the view-point of the investor?' and, 'What changes are needed to the portfolio in order for California to be able to meet its proposed Renewable Portfolio Standards (RPS)?' This is done by developing an efficient energy frontier, and then using that information to construct an efficient portfolio of energy producing assets from an cost-risk point of view. Using precise data, directly from the energy producing companies at the plant level, leads to less biased results. Further, instead of using the least squares method of regression estimation or Monte Carlo simulation, which is typical of portfolio theory construction, I use methods of the frontier of portfolio theory, namely the SURE technique. Based on the results, such a technique is certainly warranted. It provides more precise estimates of risk and return for our portfolio analysis as compared with alternate, traditional methods.

Given these estimates, I then use the most recent energy portfolio profile in California and compared its allocations to some alternate portfolio allocations giving either the same cost at lower risk, or the same risk factor with a lower cost. I found that there is much room for improvement, even when taking into account the vintage asset use and proposed plant construction.

Another purpose of the analysis was to asses the renewable portfolio standard set into law by California, along with the efficient allocations of energy to support those standards. I find that the 20 percent case is able to be met with the current technology and distribution available today. One troubling finding was that given our current technology and use of existing assets and transmission methods, unless a considerable amount of funding and effort is put into increasing the production and importation of renewable energy, achieving a 33 percent renewable energy portfolio seems far out of reach.

With respect to the supply/national security issues, it would seem that the move towards renewable energy is helping to mitigate that risk. California in particular is a state that has many energy production options, and thus does not have much of an issue with supply interruption risk.

Since the methods used in this paper can easily be applied to any other state, be it in the U.S. or another of autonomous sovereign power, it would be very interesting to see these results for other parts of the world.

Appendix A

Chapter 2

A.1 Alternate Regression Models

The Constant Coefficients Model

If there are neither significant country, nor significant temporal effects, we could pool all of the data and run an ordinary least squares regression model. This type of panel model has constant coefficients, where constant refers to both intercepts and slopes.

The Random Effects Model

William H. Greene (2001) refers to the random effects model as a regression with a random constant term. One way to handle the error term in such a model is to assume that the intercept is a random variable. The random outcome is a function of a mean value plus a random error. This cross-sectional specific error term indicates the deviation from the constant of the cross-sectional unit (in this paper, country) must be uncorrelated with the errors of the variables.

Error Components Model

If, however, the random effects model depends on both the cross-section and the time series within it, the error components models are referred to as a two-way random effects model. In this case, the error term should be uncorrelated with the time series component and the cross-sectional error. The orthogonality of these components allows the full error to be decomposed into cross-sectional specific, temporal, and individual error components.

Dynamic Panel Models

Consider the model:

$$EF_{it} = \alpha + \beta X_{it} + \mu_i + \epsilon_{it},$$

$$where$$

$$\epsilon_{it} = \rho \epsilon_{i,t-1} + \zeta_{it}, \tag{A.1}$$

and where $|\rho| < 1$ and ζ_{it} is independent and identically distributed (iid) with zero mean and variance $\sigma_z * \sigma_z$. If μ_i are assumed to be fixed parameters, then the model is a fixed-effects model. If μ_i are assumed to be realizations of an iid process with zero mean and variance $\sigma_z * \sigma_z$, then it is a random-effects model. If there is autocorrelation among the variables, it needs to be dealt with. One can use one or more of the following tests for residual autocorrelation.

The Durbin-Watson test for first-order autocorrelation was modified by

Bhargava et al. (1982) to handle balanced panel data. Baltagi and Wu (1999) modified it further to handle unbalanced panel and equally spaced data. Alternatively, an autoregression on lags of the residuals may indicate the presence or absence of autocorrelation and the need for dynamic panel analysis. If there is autocorrelation from one period to another, it is possible to analyze the "differences in differences" of these observations, using the first or last as a baseline, Wooldridge (2003).

A.2 Figures and Tables

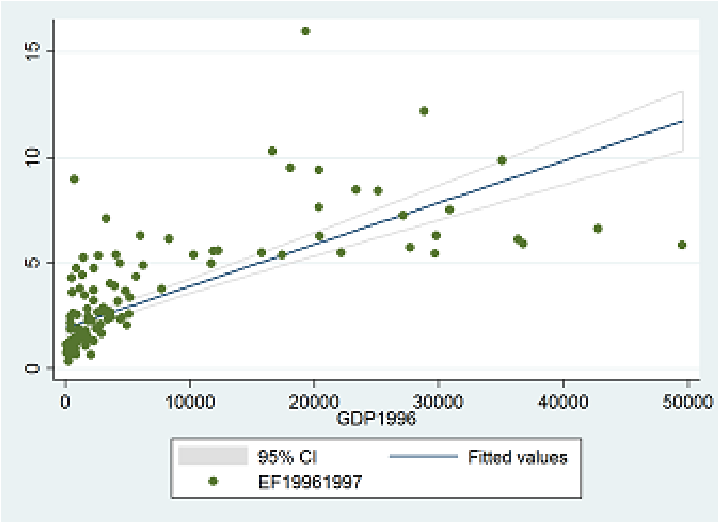

Figure A.1: Cross-Sectional Scale Effect of GDP Growth on Eco Footprint: 1996

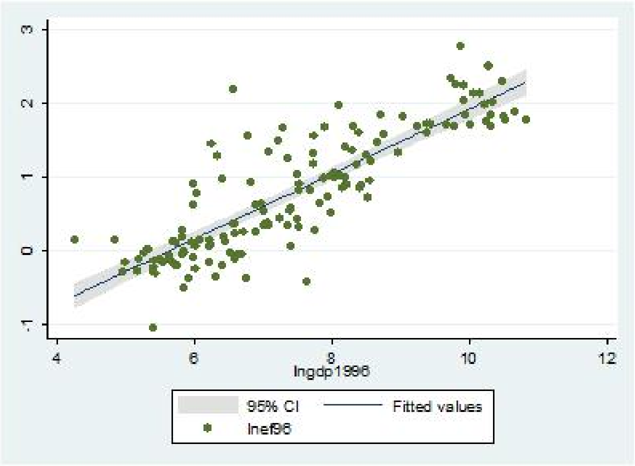

Figure A.2: Cross-Sectional Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1996

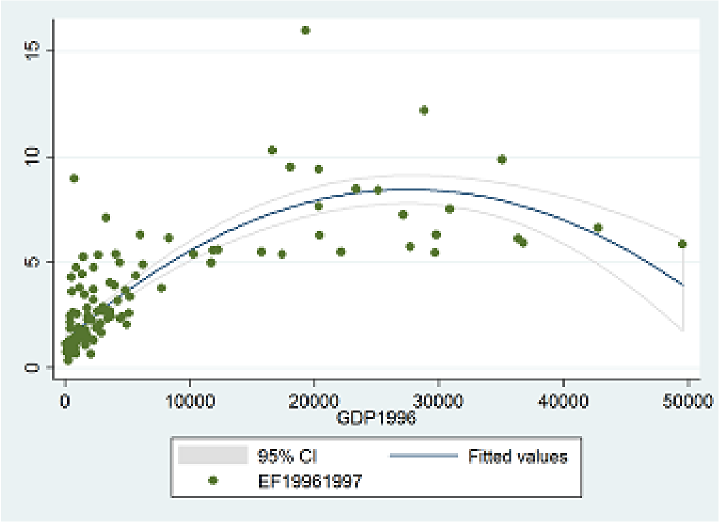

Figure A.3: Cross-Sectional Evidence of Environmental Improvement Effect of GDP Growth on Eco Footprint: 1996

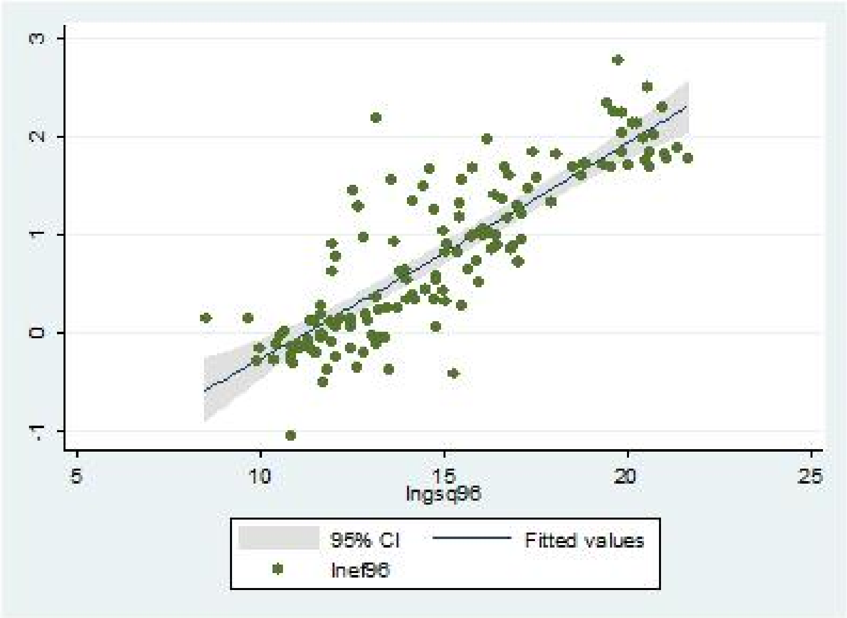

Figure A.4: Cross-Sectional Evidence of Environmental Improvement Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1996

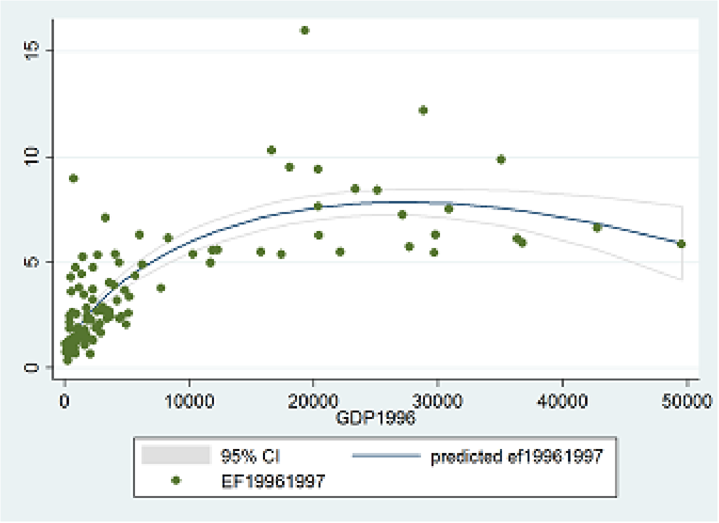

Figure A.5: Cross-Sectional Evidence of a Re-Emerging Scale Effect: 1996

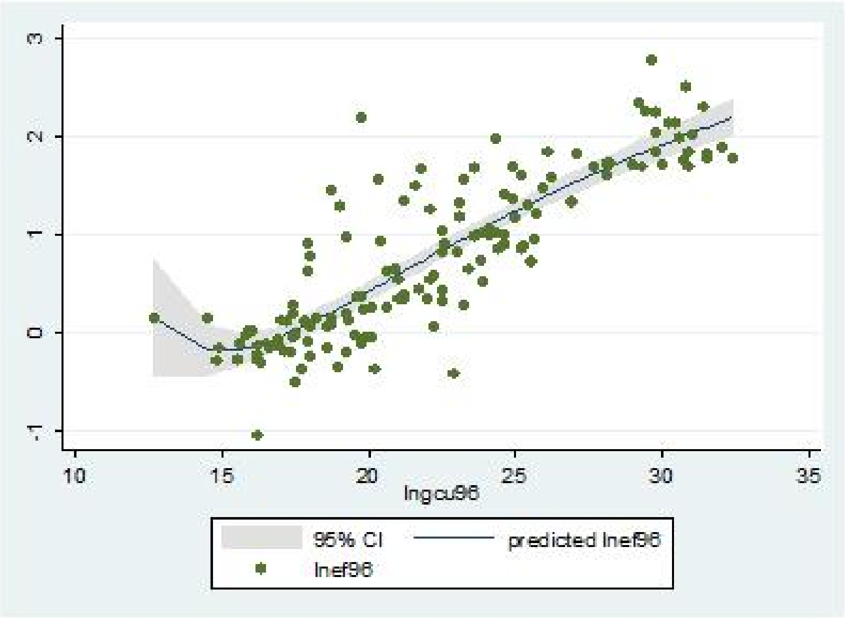

Figure A.6: Cross-Sectional Evidence of a Re-Emerging Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1996

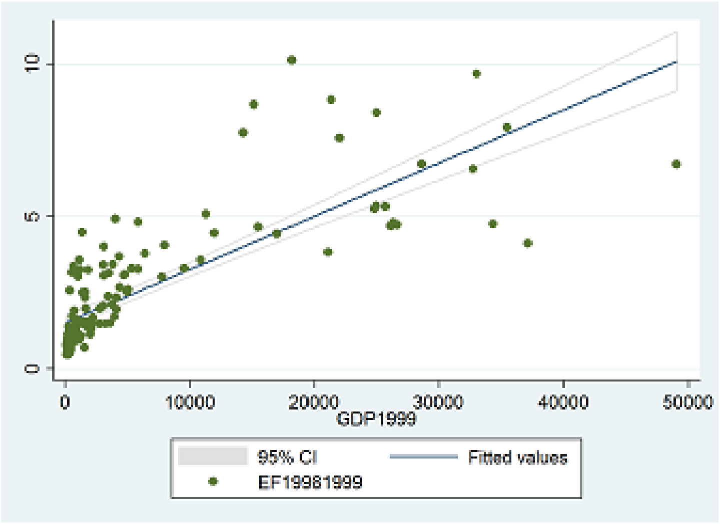

Figure A.7: Cross-Sectional Scale Effect of GDP Growth on Eco Footprint: 1999

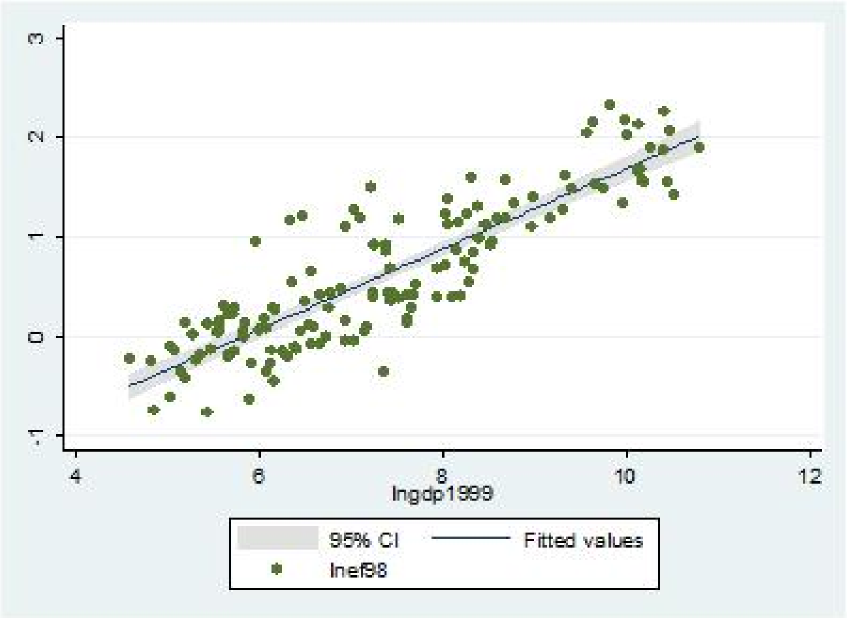

Figure A.8: Cross-Sectional Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1999

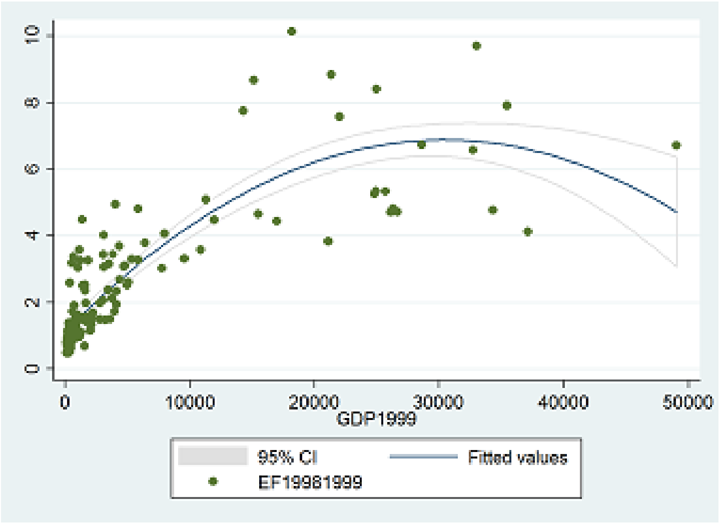

Figure A.9: Cross-Sectional Evidence of Environmental Improvement Effect of GDP Growth on Eco Footprint: 1999

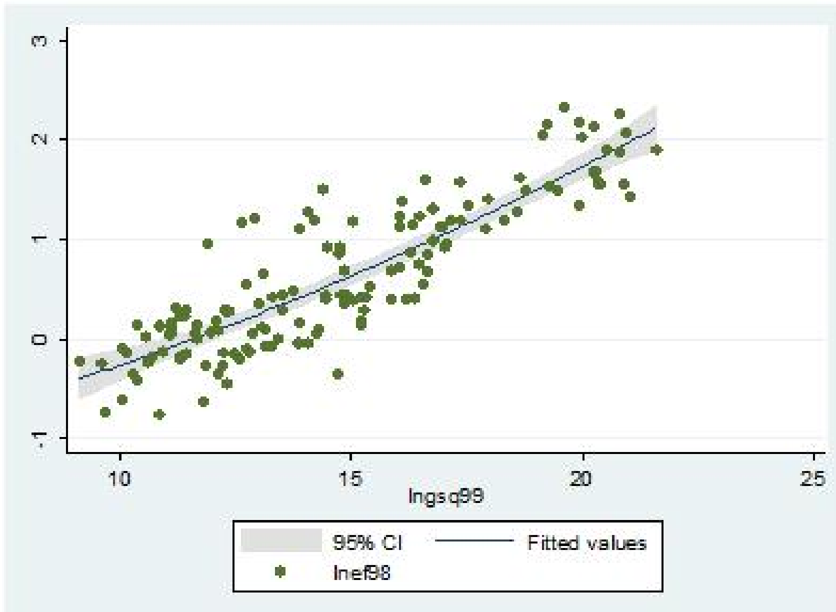

Figure A.10: Cross-Sectional Evidence of Environmental Improvement Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1999

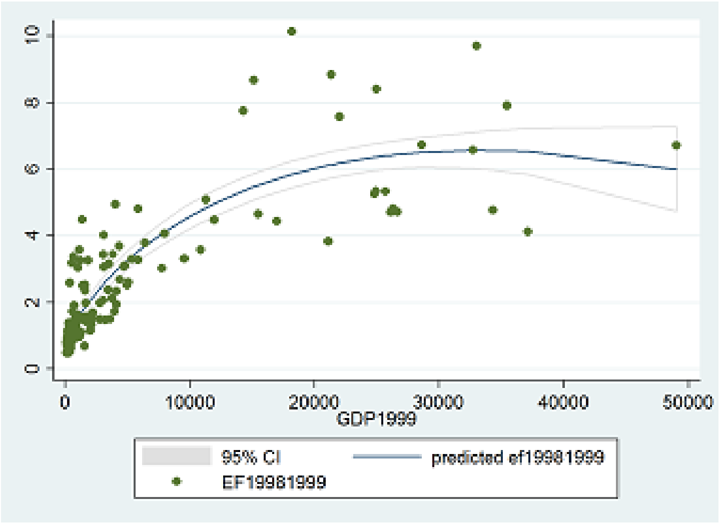

Figure A.11: Cross-Sectional Evidence of a Re-Emerging Scale Effect: 1999

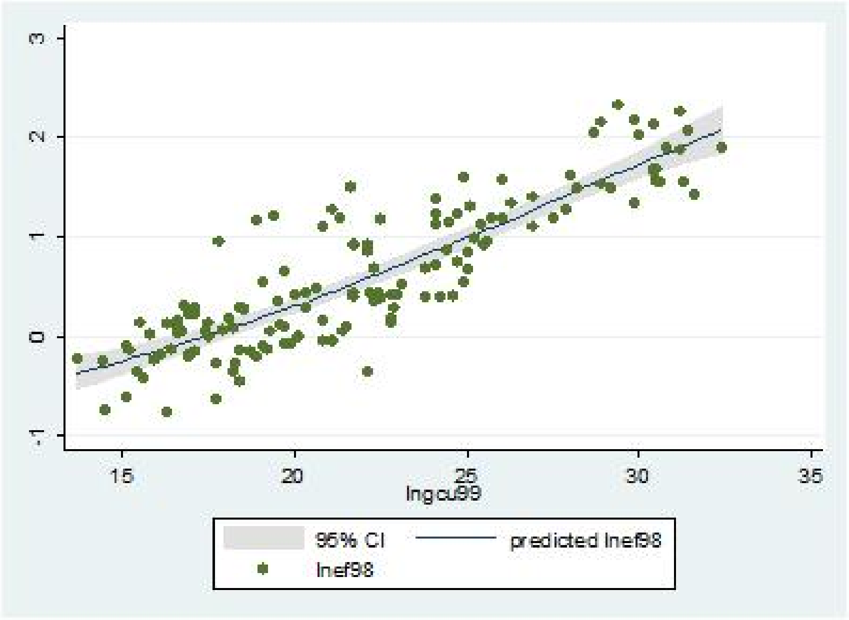

Figure A.12: Cross-Sectional Evidence of a Re-Emerging Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 1999

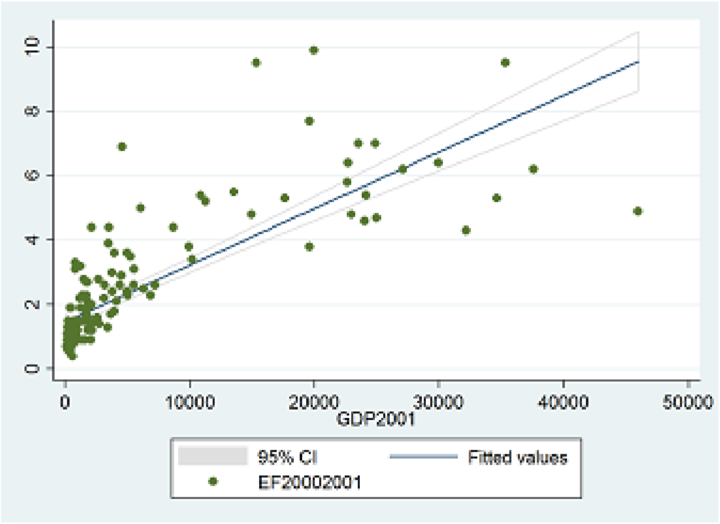

Figure A.13: Cross-Sectional Scale Effect of GDP Growth on Eco Footprint: 2001

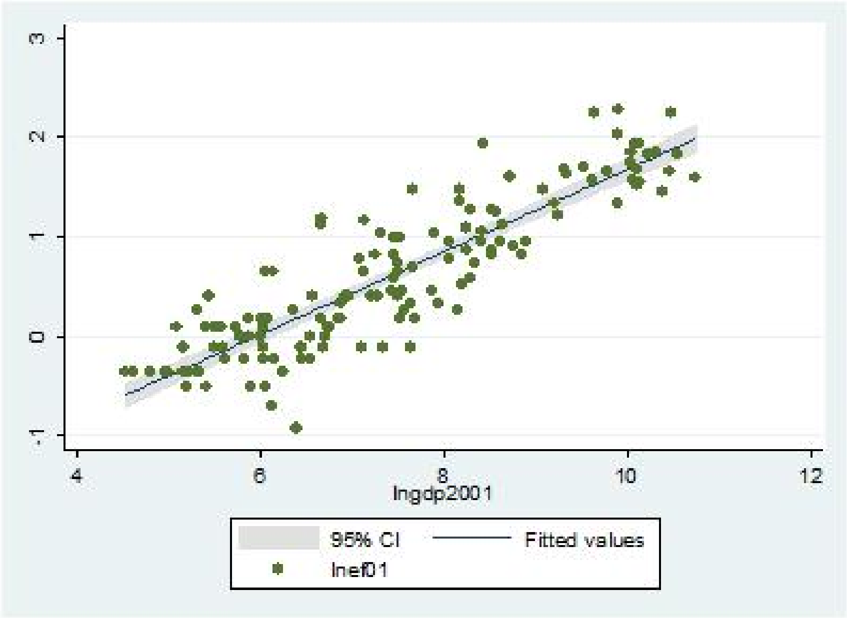

Figure A.14: Cross-Sectional Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2001

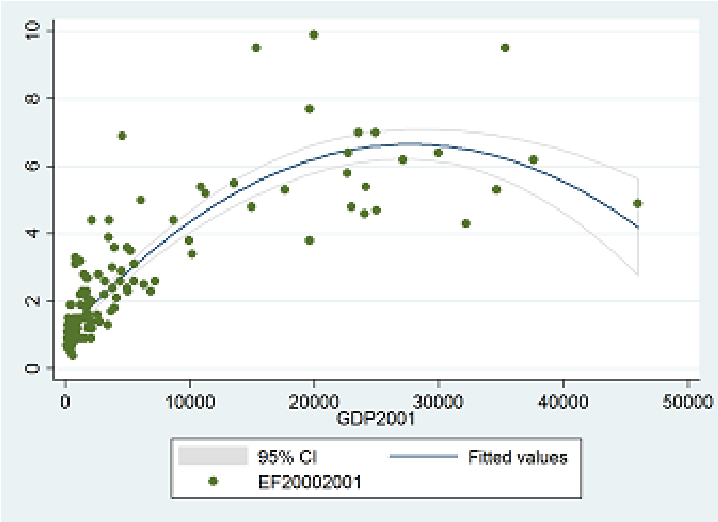

Figure A.15: Cross-Sectional Evidence of Environmental Improvement Effect of GDP Growth on Eco Footprint: 2001

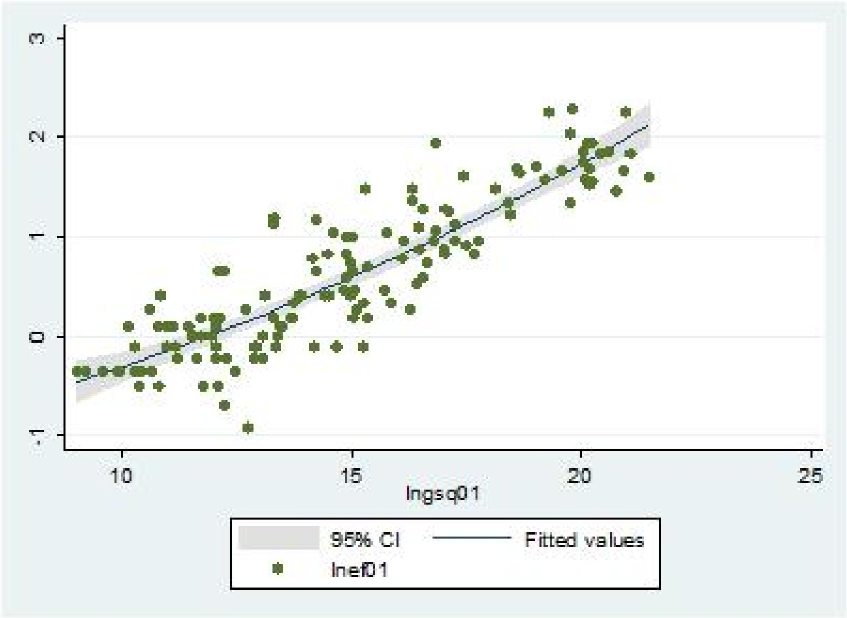

Figure A.16: Cross-Sectional Evidence of Environmental Improvement Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2001

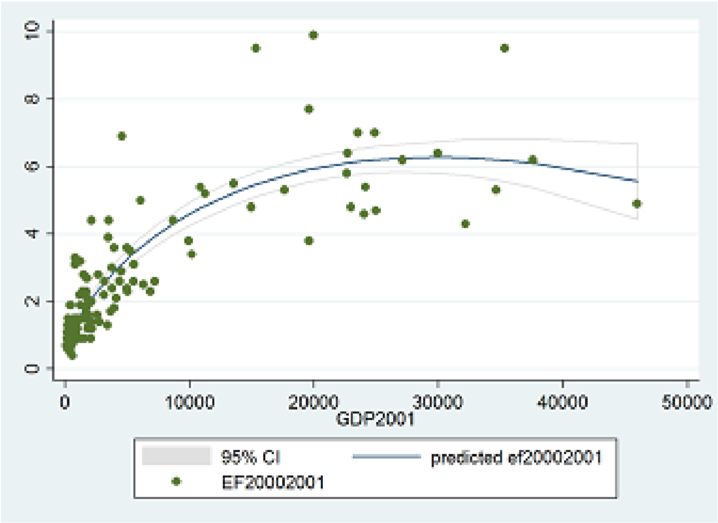

Figure A.17: Cross-Sectional Evidence of a Re-Emerging Scale Effect: 2001

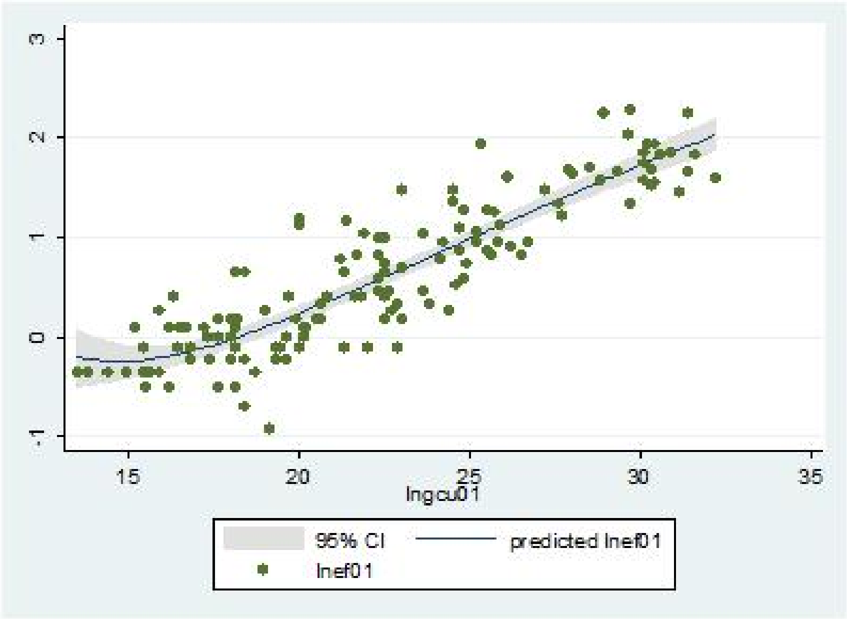

Figure A.18: Cross-Sectional Evidence of a Re-Emerging Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2001

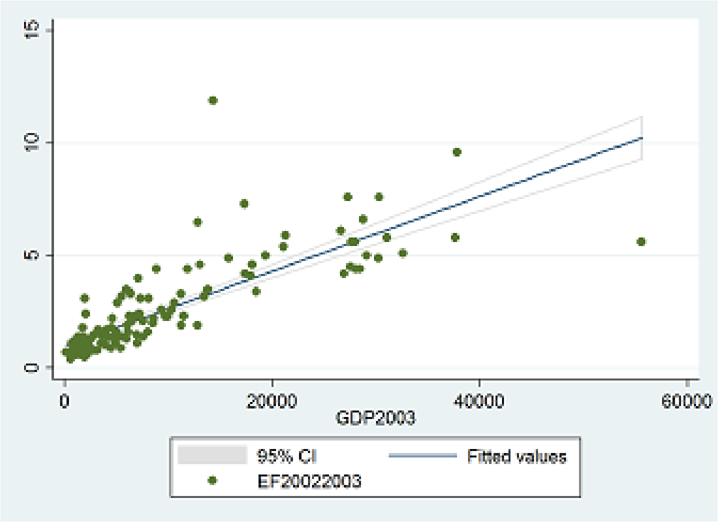

Figure A.19: Cross-Sectional Scale Effect of GDP Growth on Eco Footprint: 2003

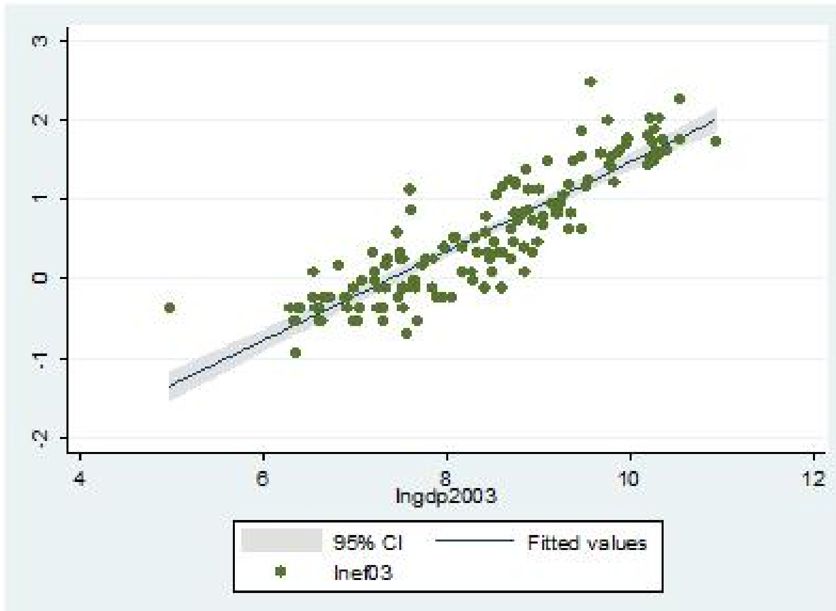

Figure A.20: Cross-Sectional Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2003

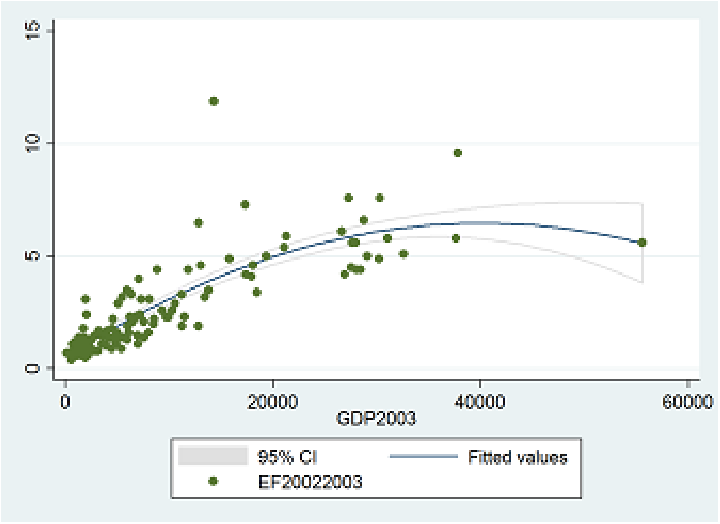

Figure A.21: Cross-Sectional Evidence of Environmental Improvement Effect of GDP Growth on Eco Footprint: 2003

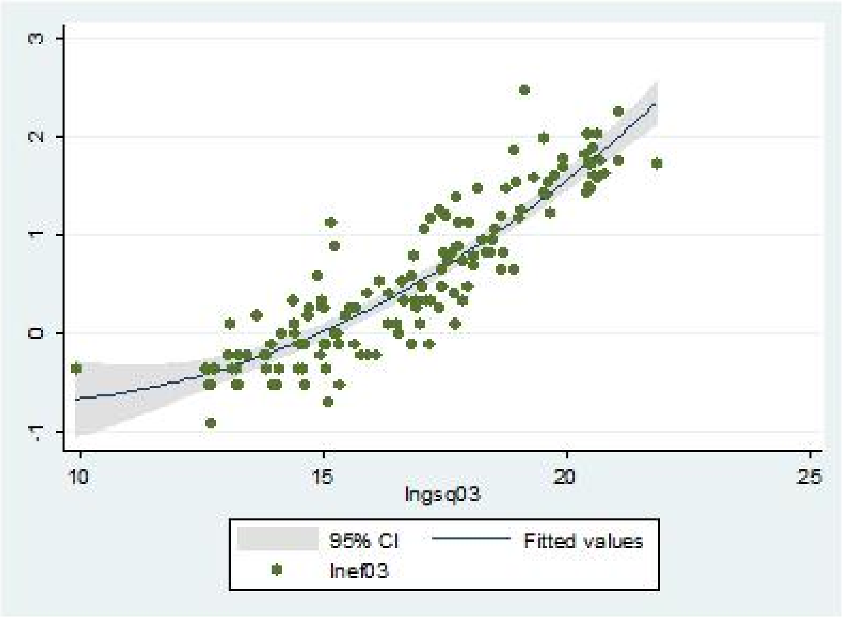

Figure A.22: Cross-Sectional Evidence of Environmental Improvement Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2003

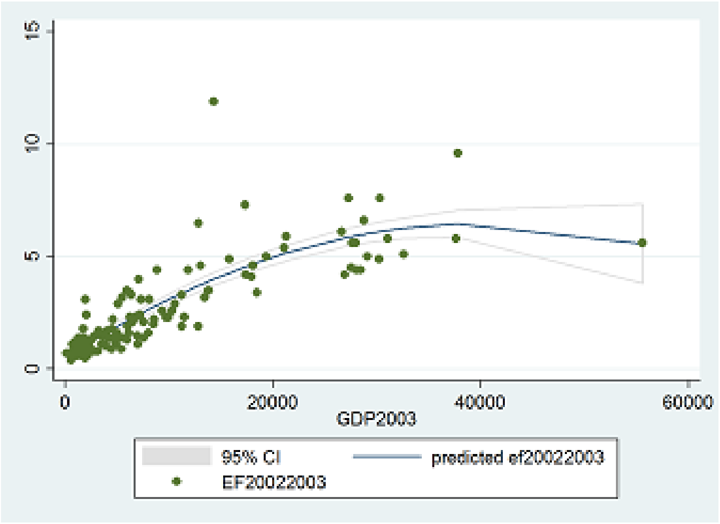

Figure A.23: Cross-Sectional Evidence of a Re-Emerging Scale Effect: 2003

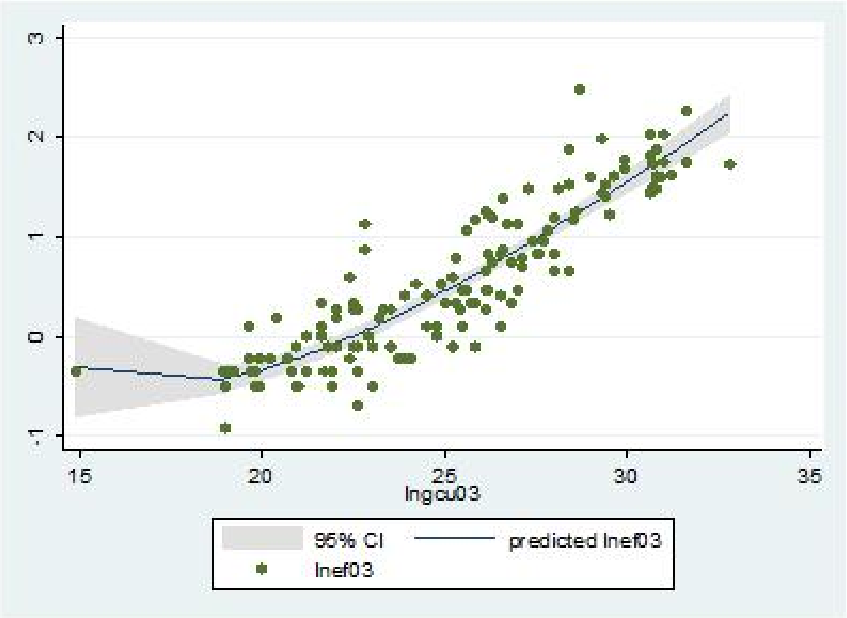

Figure A.24: Cross-Sectional Evidence of a Re-Emerging Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: 2003

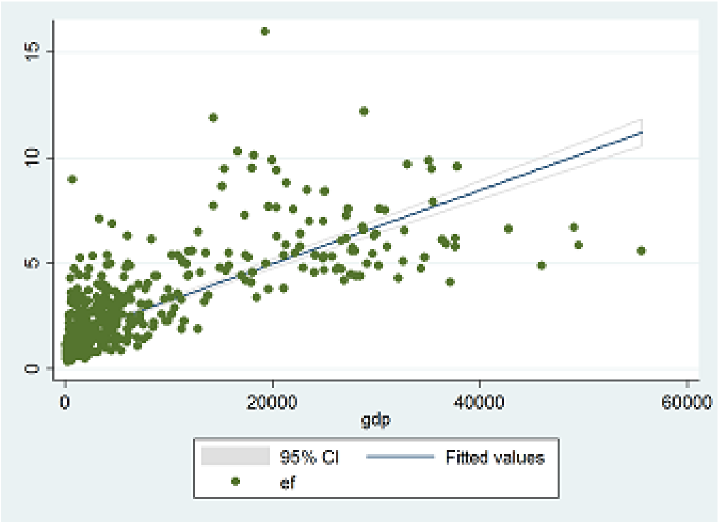

Figure A.25: Panel (Pooled) Scale Effect of GDP Growth on Eco Footprint: All Years

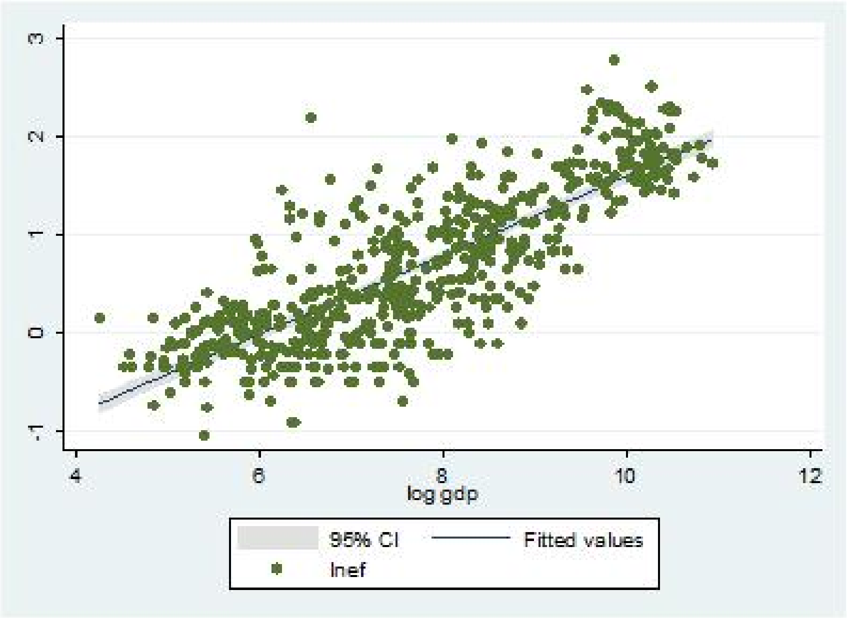

Figure A.26: Panel (Pooled) Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: All Years

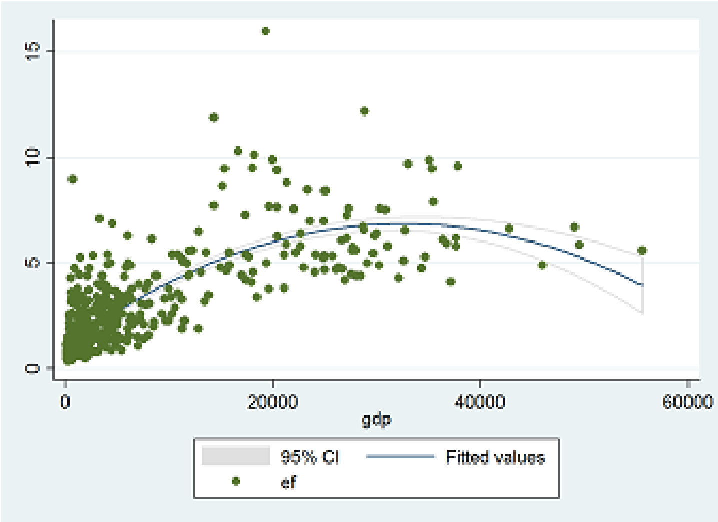

Figure A.27: Panel (Pooled) Evidence of Environmental Improvement Effect of GDP Growth on Eco Footprint: All Years

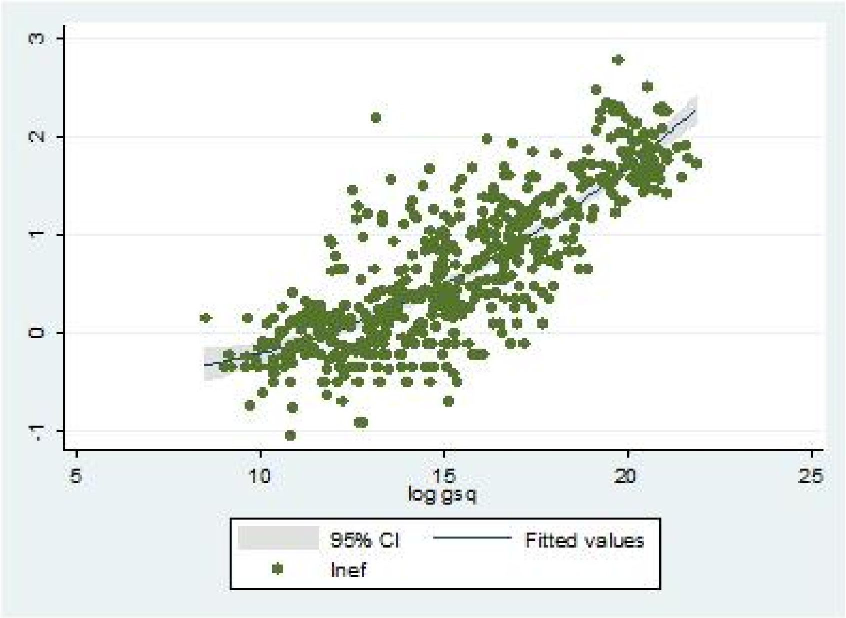

Figure A.28: Panel (Pooled) Evidence of Environmental Improvement Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: All Years

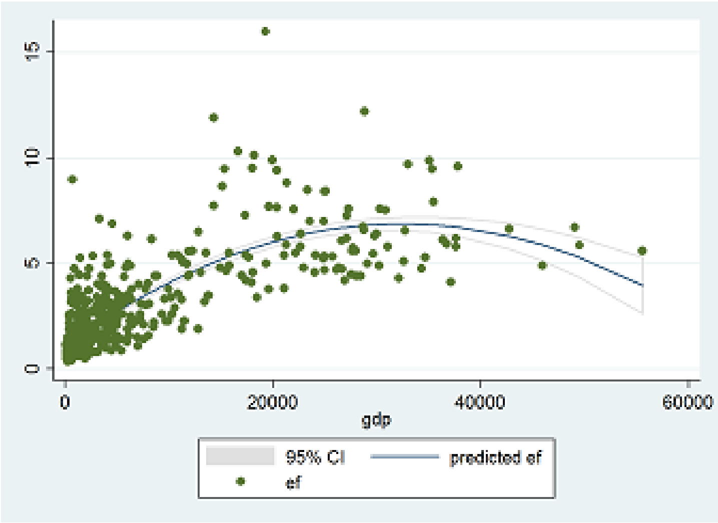

Figure A.29: Panel (Pooled) Evidence of a Re-Emerging Scale Effect: All Years

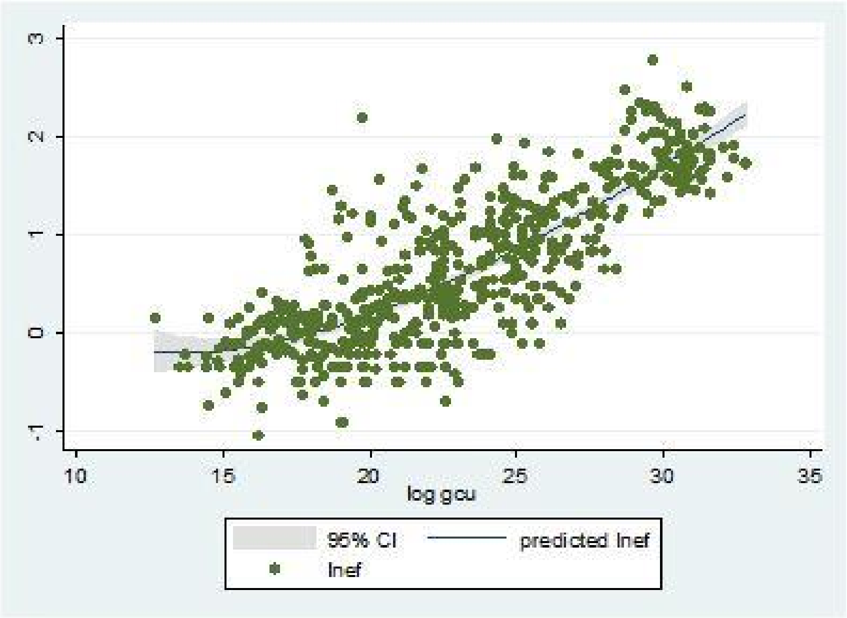

Figure A.30: Panel (Pooled) Evidence of a Re-Emerging Scale Effect of Log Normalized GDP Growth on Log Normalized Eco Footprint: All Years

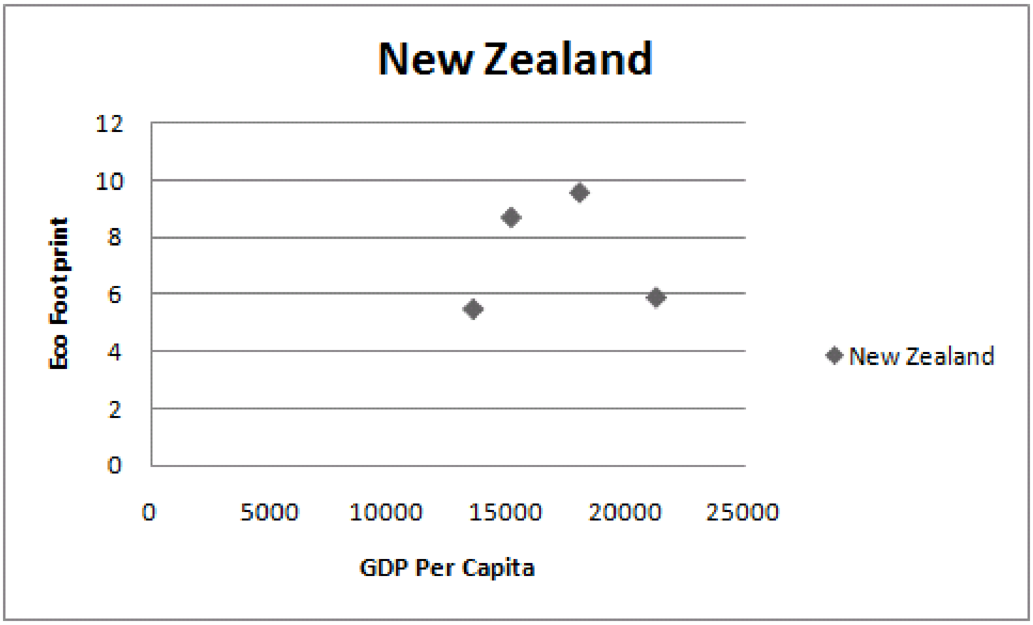

Figure A.31: Panel New Zealand EKC Representation

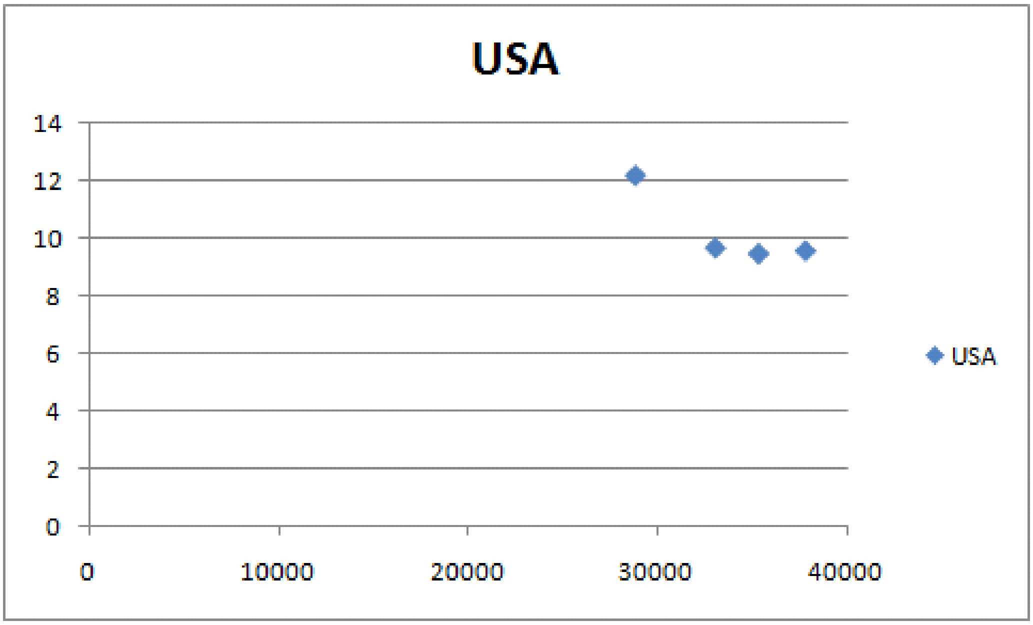

Figure A.32: Panel U.S.A. EKC Representation

Table A.1: Cross-Sectional Results 1996

GDP Config/EF	EF	EF	EF
Linear	0.198***	0.519***	0.684***[a]
-	(0.0284)	(0.0588)	(0.0905)[b]
Quad	-	-9.41e-06***	-2.05e-05***
-	-	(1.51e-06)	(5.01e-06)
Cubic	-	-	0**
-	-	-	(0)
Constant	1.938***	1.314***	1.108***
-	(0.156)	(0.149)	(0.163)
Observations	143	143	143
R-squared	0.521	0.683	0.694

[a]*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$
[b]Robust standard errors in parentheses

Table A.2: Log Normalized Cross-Sectional Results 1996

GDP Config/EF	EF	EF	EF
Linear	0.440***	0	0
	(0.0229)	(0)	(0)
Quad		0.220***	0.337
		(0.0114)	(1.995)
Cubit			-0.0780
			(1.329)
Constant	-2.479***	-2.479***	-2.480***
	(0.174)	(0.174)	(0.175)
Observations	143	143	143
R^2	0.724	0.724	0.724

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.3: Cross-Sectional Results 1999

GDP Config/EF	EF	EF	EF
Linear	0.175***	0.378***	0.541***[a]
-	(0.0199)	(0.0489)	(0.0727)[b]
Quad	-	-6.22e-06***	-1.73e-05***
-	-	(1.47e-06)	(4.23e-06)
Cubic	-	-	0***
-	-	-	(0)
Constant	1.521***	1.140***	0.938***
-	(0.0972)	(0.0967)	(0.105)
Observations	143	143	143
R-squared	0.640	0.742	0.760

[a]*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$
[b]Robust standard errors in parentheses

Table A.4: Log Normalized Cross-Sectional Results 1999

GDP Config/EF	EF	EF	EF
Linear	0.404***	0	0
	(0.0188)	(0)	(0)
Quad		0.202***	2.896*
		(0.00940)	(1.587)
Cubit			-1.795*
			(1.058)
Constant	-2.354***	-2.354***	-2.366***
	(0.142)	(0.142)	(0.141)
Observations	143	143	143
R^2	0.766	0.766	0.771

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.5: Cross-Sectional Results 2001

GDP Config/EF	EF	EF	EF
Linear	0.176***	0.406***	0.528***[a]
-	(0.0214)	(0.0382)	(0.0701)[b]
Quad	-	-7.34e-06***	-1.63e-05***
-	-	(1.10e-06)	(4.42e-06)
Cubic	-	-	0**
-	-	-	(0)
Constant	1.470***	1.035***	0.887***
-	(0.104)	(0.0808)	(0.0889)
Observations	143	143	143
R-squared	0.633	0.762	0.772

[a]*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$

[b]Robust standard errors in parentheses

Table A.6: Log Normalized Cross-Sectional Results 2001

GDP Config/EF	EF	EF	EF
Linear	0.415***	2.891	3.390
	(0.0185)	(71.57)	(71.62)
Quad		-1.238	-2.845
		(35.79)	(35.86)
Cubit			0.904
			(1.012)
Constant	-2.469***	-2.468***	-2.465***
	(0.140)	(0.141)	(0.141)
Observations	143	143	143
R^2	0.782	0.782	0.783

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A.7: Cross-Sectional Results 2003

GDP Config/EF	EF	EF	EF
Linear	0.166***	0.298***	0.312***[a]
-	(0.0184)	(0.0268)	(0.0659)[b]
Quad	-	-3.72e-06***	-4.56e-06
-	-	(6.46e-7)	(3.37e-06)
Cubic	-	-	0
-	-	-	(0)
Constant	0.981***	0.497***	0.462***
-	(0.127)	(0.0772)	(0.145)
Observations	143	143	143
R-squared	0.667	0.735	0.735

[a] *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$
[b] Robust standard errors in parentheses

Table A.8: Log Normalized Cross-Sectional Results 2003

GDP Config/EF	EF	EF	EF
Linear	0.560***	0	0
	(0.0247)	(0)	(0)
Quad		0.280***	-0.821
		(0.0123)	(1.577)
Cubit			0.734
			(1.052)
Constant	-4.129***	-4.129***	-4.131***
	(0.209)	(0.209)	(0.210)
Observations	143	143	143
R^2	0.785	0.785	0.786

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.9: Panel: Fixed Effects

GDP Config/EF	EF	EF	EF
Linear	-0.0395**	-0.0724***	-0.0574[a]
-	(0.0196)	(0.0236)	(0.0383)[b]
Quad	-	1.19e-06	-3.95e-08
-	-	(9.59e-07)	(2.98e-06)
Cubic	-	-	-0
-	-	-	(0)
Constant	2.862***	2.911***	2.904***
-	(0.131)	(0.118)	(0.115)
Observations	572	572	572
Number of id	143	143	143
R-squared	0.015	0.022	0.023

[a]*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$
[b]Robust standard errors in parentheses

Table A.10: Panel: Log Normalized Fixed Effects

GDP Config/EF	EF	EF	EF
Linear	-0.0609***	-348.2	-333.3
	(0.0163)	(302.1)	(302.5)
Quad		174.0	167.1
		(151.1)	(151.2)
Cubit			-0.337
			(0.333)
Constant	1.111***	1.115***	1.109***
	(0.125)	(0.125)	(0.125)
Observations	572	572	572
Number of id	143	143	143
R^2	0.032	0.035	0.037

*** p<0.01, ** p<0.05, * p<0.1
Standard errors in parentheses

Table A.11: Panel Table

Variables	FE	RE	MLE	Pooled
Linear	-0.0574	0.125***	0.0585	0.417***[a]
	(0.0383)	(0.0400)	(0.0391)	(0.0320)[b]
Quad	-3.95e-08	1.65e-06	2.91e-06	-9.45e-06***
	(2.98e-06)	(2.13e-06)	(2.04e-06)	(1.89e-06)
Cubit	0	-0	-0	6.07e-11**
	(0)	(0)	(0)	(0)
Constant	2.904***	1.771***	2.032***	0.985***
	(0.115)	(0.105)	(0.174)	(0.0853)
Observations	572	572	572	572
Number of id	143	143	143	143
R-squared	0.023	.	.	.

[a]*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$

[b]Robust standard errors in parentheses

Table A.12: Log Normalized Panel Table

Variables	FE	RE	MLE	Pooled	Pooled
Linear	-333.3			0.402***	0
	(302.5)			(0.0120)	(0)
Quad	167.1	0.826	0.616		0.444
	(151.2)	(0.655)	(0.508)		(0.992)
Cubit	-0.337	-0.496	-0.407		-0.162
	(0.333)	(0.437)	(0.338)		(0.661)
Constant	1.109***	-0.609***	0.562***	-2.431***	-2.431***
	(0.125)	(0.130)	(0.154)	(0.0936)	(0.0937)
Observations	572	572	572	572	572
R^2	0.037	.	.	0.664	0.664
Number of id	143	143	143		

*** p<0.01, ** p<0.05, * p<0.1

Standard errors in parentheses

Table A.13: Eco Footprint Input Factors

Eco. Footprint Input Factors	
Crop Land	Grazing Land
Forest: Timber	Forest: Fuel Wood
Fishing	CO_2: Fossil Fuels
Nuclear Build-up	Built-up Land
Water per Cap. ($m^3/year$)	Water Usage %
Bio-capacity	H.D.I.

Table A.14: Eco Footprint Data: Africa

Country/Region	Eco FP C.S.	Eco FP '96-'97	'98-'99	2000-'01	'02-'03
Algeria	1.6	1.79	1.55	1.5	1.6
Angola	1	.82	.87	.8	1
Benin	.8	.97	1.15	1	.8
Botswana	1.6	1.68	1.48	1.3	1.6
Burkina Faso	1	.9	1.18	1.1	1
Burundi	.7	.75	.48	.7	.7
Cameroon	.8	.89	1.11	.9	.8
Cen. African Rep.	.9	1.12	1.25	1.1	.9
Chad	1	.75	1.02	1.3	1
Congo	.6	.69	.92	.9	.6
Dem. Rep. Congo	.6	1.15	.8	.7	.6
Cote d'Ivoire	.7	.95	.92	.9	.7
Egypt	1.4	1.7	1.49	1.5	1.4
Eritrea	.7	.35	.79	.7	.7
Ethiopia	.8	.85	.78	.7	.8
Gabon	1.4	2.06	2.12	1.7	1.4
Gambia	1.4	.99	1	1.1	1.4
Ghana	1	1.12	1.7	1.1	1
Guinea	.9	.85	1.21	1	.9
Guinea-Bissau	.7	.8	.7	.7	.7
Kenya	.8	1.15	1.09	.9	.8
Lesotho	.8	.7	.86	.6	.8
Liberia	.7	1.16	.91	.7	.7
Libya	3.4	4.36	3.28	3.1	3.4
Madagascar	.7	.93	.88	.8	.7
Malawi	.6	.87	.87	.7	.6
Mali	.8	.86	1.14	1.1	.8
Mauritania	1.3	1.22	1.33	1.1	1.3
Mauritius	1.9	2.45	1.5	2.4	1.9
Morocco	.9	1.56	1.1	.9	.9
Mozambique	.6	.76	.47	.7	.6
Namibia	1.1	.66	1.47	1.6	1.1
Niger	1.1	.97	1.15	1.1	1.1
Nigeria	1.2	1.31	1.33	1.2	1.2
Rwanda	.7	.9	1.06	.7	.7

Table A.15: Eco Footprint Data: Africa Cont

Sengal	1.2	1.06	1.31	1.2	1.2
Sierra Leone	.7	.73	.54	.9	.7
Somalia	.4	.97	1.05	.4	.4
Rep. S. Africa	2.3	4.04	4.02	2.8	2.3
Sudan	1	1.14	1.06	1	1
Swaziland	1.1	-	-	-	-
Uni. Rep. Tanzania	.7	1.02	1.03	.9	.7
Togo	.9	.82	.86	.9	.9
Tunisia	1.5	2.27	1.69	1.4	1.5
Uganda	1.1	.88	1.06	1.5	1.1
Zambia	.6	1.21	1.26	.8	.6
Zimbabwe	.9	1.45	1.32	1	.9

Table A.16: Eco Footprint Data: Middle East

Country/Region	Eco FP C.S.	Eco FP '96-'97	'98-'99	2000-'01	'02-'03
Afghanistan	.1	-	-	-	-
Armenia	1.1	1.16	.88	1	1.1
Azerbaijan	1.7	2.18	1.73	1.5	1.7
Georgia	.8	1.14	.91	.8	.8
Iran	2.4	2.47	1.98	2.1	2.4
Iraq	.9	-	-	-	-
Israel	4.6	5.4	4.44	5.3	4.6
Jordan	1.8	1.71	1.55	1.9	1.8
Kazakhstan	4	4.45	3.58	2.8	4
Kuwait	7.3	10.31	7.75	9.5	7.3
Kyrgyzstan	1.3	1.87	1.14	1.1	1.3
Lebanon	2.9	3.19	2.61	2.3	2.9
Saudi Arabia	4.6	6.15	4.07	4.4	4.6
Syria	1.7	2.56	1.62	1.9	1.7
Tajikistan	.6	.9	.66	.6	.6
Turkey	2.1	2.73	1.98	2	2.1
Turkmenistan	3.5	3.62	3.18	3.1	3.5
Uni. Arab Emirates	11.9	15.99	10.13	9.9	11.9
Uzbekistan	1.8	2.65	1.91	1.9	1.8
Yemen	.8	.69	.71	.7	.8

Table A.17: Eco Footprint Data: Asia/Oceania

Country/Region	Eco FP C.S.	Eco FP '96-'97	'98-'99	2000-'01	'02-'03
Australia	6.6	8.49	7.58	7.7	6.6
Bangladesh	.5	.6	.53	.6	.5
Cambodia	.7	.83	.83	1.1	.7
China	1.6	8.98	1.54	1.5	1.6
India	.8	1.06	.77	.8	.8
Indonesia	1.1	1.48	1.13	1.2	1.1
Japan	4.4	5.94	4.77	4.3	4.4
Korea, DPR	1.4	1.92	3.04	1.5	1.4
Korea, Rep.	4.1	5.6	3.31	3.4	4.1
Lao PDR	.9	.91	.82	1	.9
Malaysia	2.2	3.68	3.16	3	2.2
Mongolia	3.1	4.3	2.58	1.9	3.1
Myanmar	.9	1.07	.7	.9	.9
Nepal	.7	1.01	.83	.6	.7
New Zealand	5.9	9.54	8.68	5.5	5.9
Pakistan	.6	1.09	.64	.7	.6
Papua New Guinea	2.4	1.4	1.42	1.3	2.4
Philippines	1.1	1.42	1.17	1.2	1.1
Sri Lanka	1	.95	1	1.1	1
Thailand	1.4	2.7	1.53	1.6	1.4
Viet Nam	.9	.95	.76	.8	.9

Table A.18: Eco Footprint Data: Cen.& S. America

Country/Region	Eco FP C.S.	Eco FP '96-'97	'98-'99	2000-'01	'02-'03
Argentina	2.3	3.79	3.03	2.6	2.3
Bolivia	1.3	1.29	.96	1.2	1.3
Brazil	2.1	2.6	2.38	2.2	2.1
Chile	2.3	3.39	3.11	2.6	2.3
Colombia	1.3	1.9	1.34	1.3	1.3
Costa Rica	2	2.77	1.95	2.1	2
Cuba	1.5	2.1	1.49	1.4	1.5
Dominican Rep.	1.6	1.37	1.53	1.6	1.6
Ecuador	1.5	2.26	1.54	1.8	1.5
El Salvador	1.4	1.55	1.19	1.2	1.4
Guatemala	1.3	1.4	1.42	1.2	1.3
Haiti	.6	.78	.82	.5	.6
Honduras	1.3	1.43	1.34	1.4	1.3
Jamaica	1.7	2.68	2.07	2.6	1.7
Mexico	2.6	2.69	2.52	2.5	2.6
Nicaragua	1.2	1.26	1.53	1.1	1.2
Panama	1.9	2.35	1.72	1.8	1.9
Paraguay	1.6	2.84	2.51	2.2	1.6
Peru	.9	1.33	1.15	.9	.9
Trin./Tobago	3.1	2.43	3.3	2.3	3.1
Uruguay	1.9	4.91	3.79	2.6	1.9
Venezuela	2.2	2.88	2.34	2.4	2.2

Table A.19: Eco Footprint Data: Can., U.S.A, Europe

Country/Region	Eco FP C.S.	Eco FP '96-'97	'98-'99	2000-'01	'02-'03
Canada	7.6	7.66	8.84	6.4	7.6
U.S.A.	9.6	12.22	9.7	9.5	9.6
Austria	4.9	5.45	4.73	4.6	4.9
Bel./Lux.	5.6	5.88	6.72	4.9	5.6
Czech Rep.	4.9	6.3	4.82	5	4.9
Denmark	5.8	9.88	6.58	6.4	5.8
Estonia	6.5	7.12	4.94	6.9	6.5
Finland	7.6	8.45	8.42	7	7.6
France	5.6	7.27	5.26	5.8	5.6
Germany	4.5	6.31	4.71	4.8	4.5
Greece	5	5.58	5.09	5.4	5
Hungary	3.5	5.01	3.08	3.5	3.5
Ireland	5	9.43	5.33	6.2	5
Italy	4.2	5.51	3.84	3.8	4.2
Latvia	2.6	3.74	3.43	4.4	2.6
Lithuania	4.4	4.76	3.07	3.9	4.4
Netherlands	4.4	5.75	4.81	4.7	4.4
Poland	3.3	5.4	3.7	3.6	3.3
Portugal	4.2	4.99	4.47	5.2	4.2
Slovakia	3.2	3.94	3.44	3.6	3.2
Slovenia	3.4	5.4	3.58	3.8	3.4
Spain	5.4	5.5	4.66	4.8	5.4
Sweden	6.1	7.53	6.73	7	6.1
U.K.	5.6	6.29	5.35	5.4	5.6
Albania	1.4	1.86	.96	1.5	1.4
Belarus	3.3	5.27	3.27	3.2	3.3
Bosnia/Herz.	2.3	1.29	1.05	2.3	2.3
Bulgaria	3.1	3.81	2.36	2.7	3.1
Croatia	2.9	2.35	2.69	2.9	2.9
Macedonia, FYR	2.3	3.24	3.26	2.3	2.3
Rep. Moldova	1.3	2.47	1.38	1.2	1.3
Norway	5.8	6.13	7.92	6.2	5.8
Romania	2.4	3.49	2.52	2.7	2.4
Russian Fed.	4.4	5.36	4.49	4.4	4.4
Switzerland	5.1	6.63	4.12	5.3	5.1
Ukraine	3.2	4.76	3.37	3.3	3.2

Table A.20: GDP per Capita by Country

Country	GDP pCap.	Country	GDP pCap.	Country	GDP pCap.
Algiera	6500	Angola	5600	Benin	1500
Botswana	16400	Burkina Faso	1300	Burundi	400
Cameroon	2100	C. African Rep.	700	Chad	1700
Congo	3700	DR. Congo	300	Cote d'Ivoire	1700
Egypt	5500	Eritrea	800	Ethiopia	800
Gabon	14100	Gambia	1300	Ghana	1400
Guinea	1100	Guinea-Bissau	500	Kenya	1700
Lesotho	1300	Liberia	400	Libya	12300
Madagascar	1100	Malawi	800	Mali	1000
Mauritania	2000	Mauritius	11200	Morocco	4100
Mozambique	800	Namibia	5200	Niger	700
Nigeria	2000	Rwanda	900	Senegal	1700
Sierra Leone	700	Somalia	600	R. S. Africa	9800
Sudan	2200	Swaziland	4800	U. R. Tanzania	1300
Togo	800	Tunisia	7500	Uganda	900
Zambia	1300	Zimbabwe	200	Afghanistan	1000
Armenia	4900	Azerbaijan	7700	Georgia	4700
Iran	10600	Iraq	3600	Israel	25800
Jordan	4900	Kazakhstan	11100	Kuwait	39300
Kyrgyzstan	2000	Lebanon	11300	Saudi Arabia	23200
Syria	4500	Tajikistan	1800	Turkey	12900
Turkmenistan	5200	U.A.E.	37300	Uzbekistan	2300
Yemen	2300	Australia	36300	Bangladesh	1300
Cambodia	1800	China	5300	India	2700
Indonesia	3700	Japan	33600	DPR Korea	1900
Rep. Korea	24800	Lao PDR	2100	Malaysia	13300
Mongolia	3200	Myanmar	1900	Nepal	1200
New Zealand	26400	Pakistan	2600	Papua N. G.	2000
Philippines	3400	Sri Lanka	4100	Thailand	7900
Viet Nam	2600	Argentina	13300	Bolivia	4000
Brazil	9700	Chile	13900	Colombia	6700
Costa Rica	10300	Cuba	4500	Dom. Rep.	7000
Ecuador	7200	El Salvador	5800	Guatemala	4700
Haiti	1300	Honduras	4100	Jamaica	7700
Mexico	12800	Nicaragua	2600	Panama	10300
Paraguay	4500	Peru	7800	Trin/Toba	18300
Uruguay	11600	Venezuela	12200	Canada	38400
U.S.A.	45800	Austria	38400	Bel/Lux	80500

Table A.21: GDP per Capita by Country Cont.

Czech Rep.	24200	Denmark	37400	Estonia	21100
Finland	35300	France	33200	Germany	34200
Greece	29200	Hungary	19000	Ireland	43100
Italy	30400	Latvia	17400	Lithuania	17700
Netherlands	38500	Poland	16300	Portugal	21700
Slovakia	20300	Slovenia	27200	Spain	30100
Sweden	36500	U.K.	35100	Albania	6300
Belarus	10900	Bos/Herz	7000	Bulgaria	11300
Croatia	15500	FYR Macedonia	8500	Rep. Moldova	2900
Norway	53000	Romania	11400	Russian Fed.	14700
Serbia/Mont	10400	Switzerland	41100	Ukraine	6900

Appendix B

Chapter 3

B.1 Figures and Tables

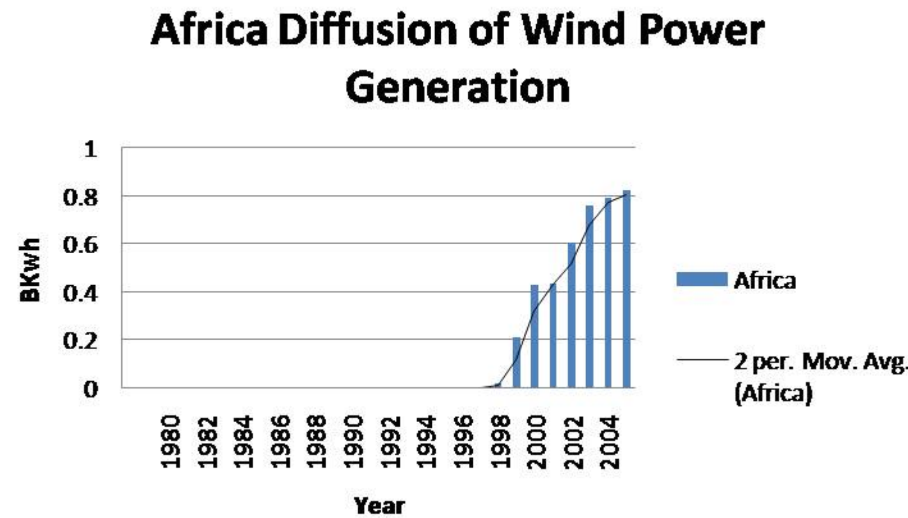

Figure B.1: Africa: Wind Power Technology Diffusion

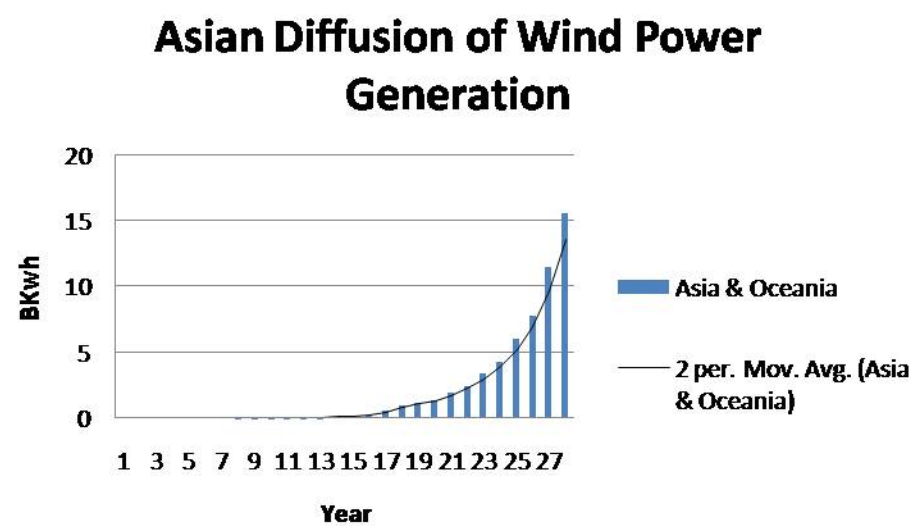

Figure B.2: Asia: Wind Power Technology Diffusion

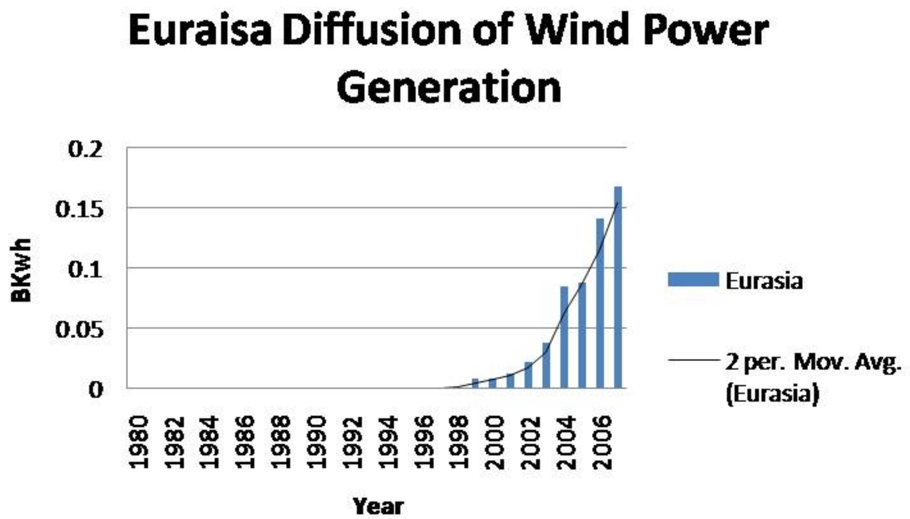

Figure B.3: Eurasia: Wind Power Technology Diffusion

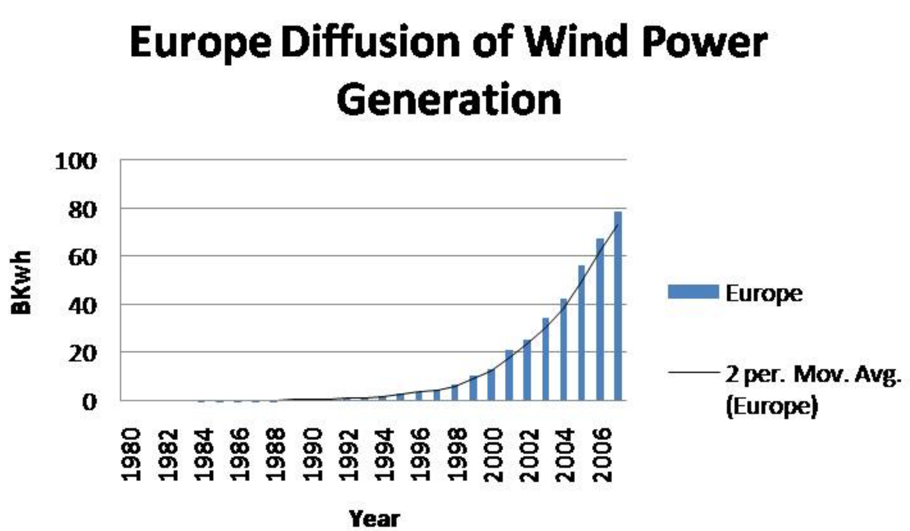

Figure B.4: Europe: Wind Power Technology Diffusion

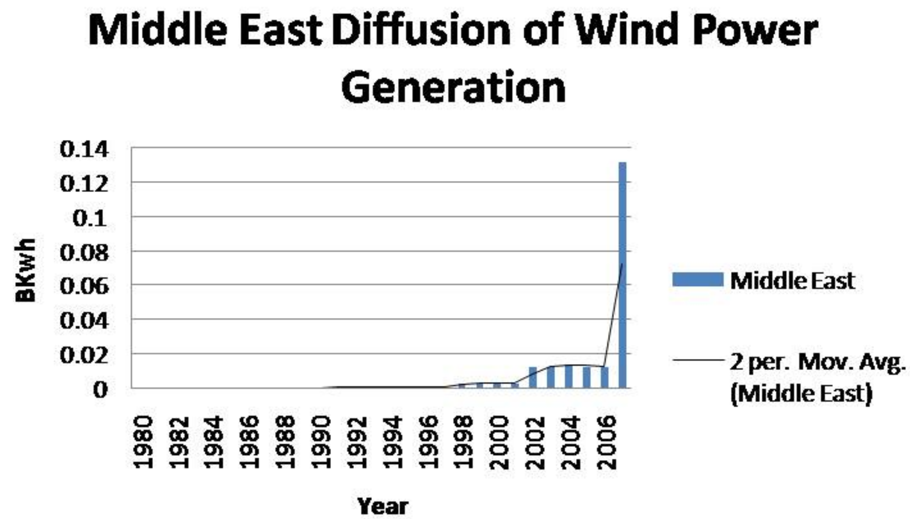

Figure B.5: Middle East: Wind Power Technology Diffusion

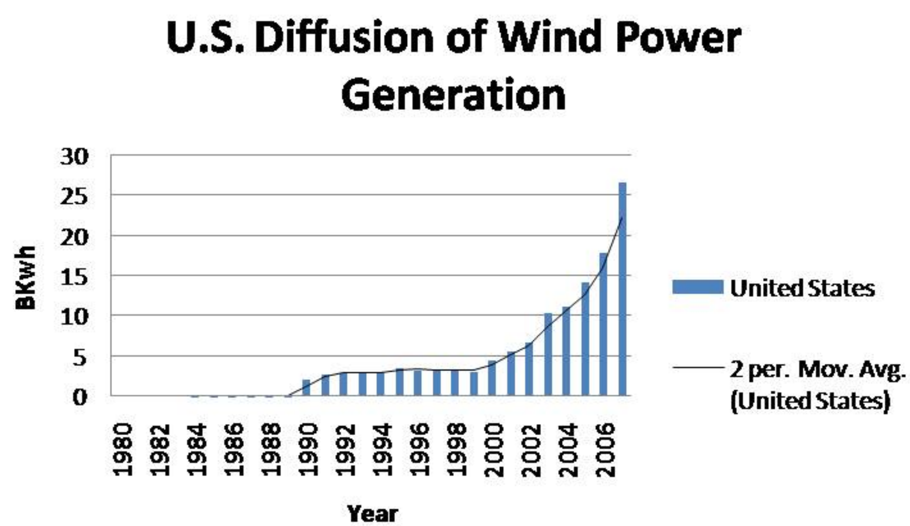

Figure B.6: U.S.A.: Wind Power Technology Diffusion

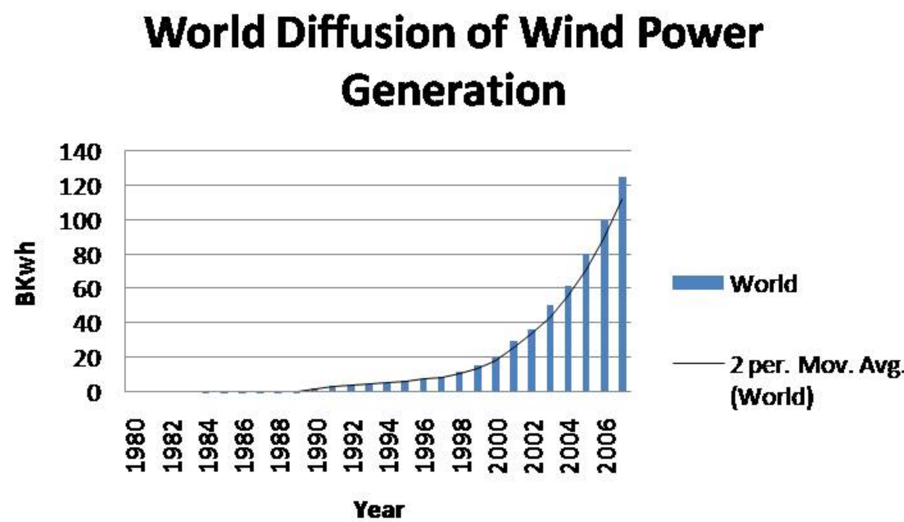

Figure B.7: World: Wind Power Technology Diffusion

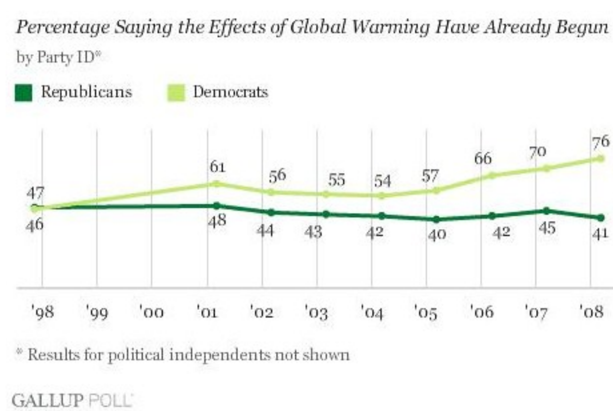

Figure B.8: Gallup Poll: Has Global Warming Begun

Table B.1: World Energy Production by Source

World Energy Production	
Source:	Percentage:
Petroleum	35%
Coal	25%
Gas	21%
Nuclear	6%
Hydro	10%
Biomass	2%
All Other Renewable	1%

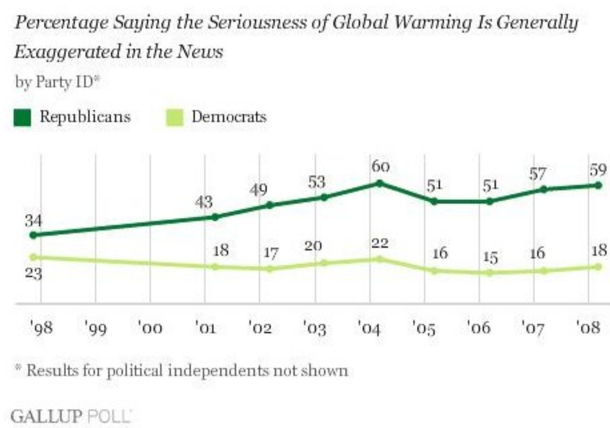

Figure B.9: Gallup Poll: Is Global Warming Exaggerated

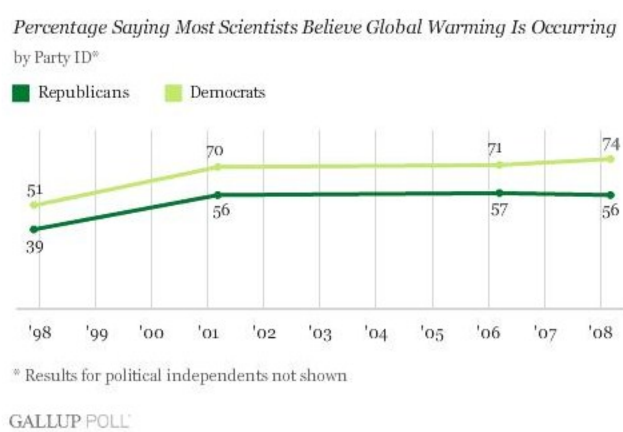

Figure B.10: Gallup Poll: Do Scientists' Believe in Global Warming

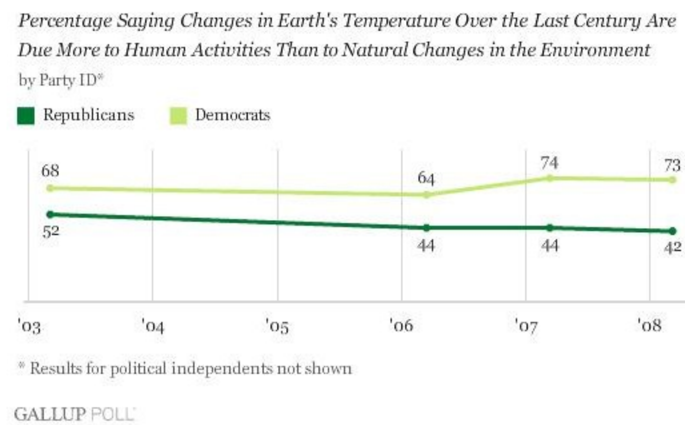

Figure B.11: Gallup Poll: Do Humans Cause Global Warming

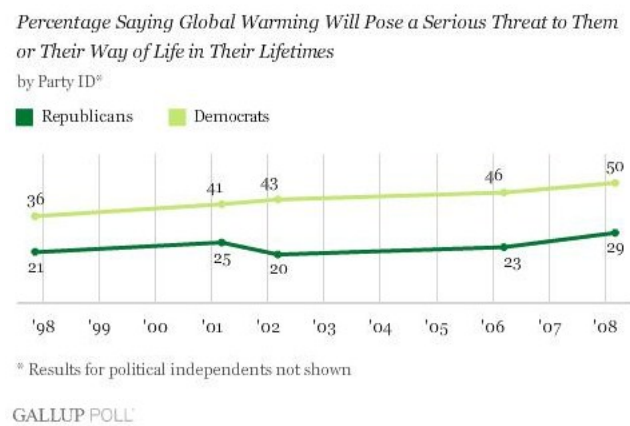

Figure B.12: Gallup Poll: Is Global Warming a Serious Threat

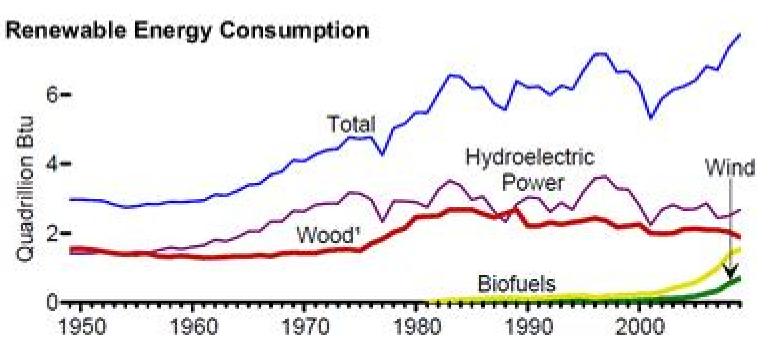

Figure B.13: Timeline of Renewable Energy Consumption

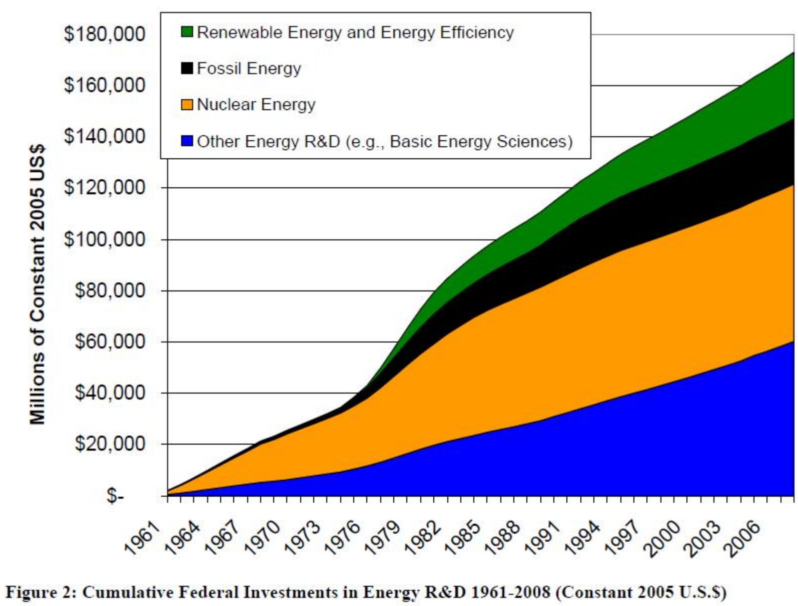

Figure B.14: U.S.A. Energy Related R&D

Table B.2: Renewable Energy Funding and Specific Technology Penetration Results

VARIABLES	(1) Renewable Funding	(2) % change Funding	(3) % change wind	(4) % change geo	(5) % change solar	(6) % change bio	(7) % change hydro
ocean	0.147	-1.14e-07	-8.57e-08	-5.95e-08	-8.59e-08	-9.36e-08	-3.98e-05
	(682.2)	(0.00102)	(0.00183)	(0.00163)	(0.00150)	(0.00152)	(1.098)
desert	0.00818	-6.68e-09	-5.03e-09	-3.49e-09	-5.04e-09	-5.49e-09	-2.33e-06
	(998.3)	(0.00150)	(0.00268)	(0.00238)	(0.00220)	(0.00223)	(1.606)
forest	-0.243	1.88e-07	1.42e-07	9.84e-08	1.42e-07	1.55e-07	6.58e-05
	(927.8)	(0.00139)	(0.00249)	(0.00222)	(0.00204)	(0.00207)	(1.493)
mountains	-0.0885	6.84e-08	5.14e-08	3.57e-08	5.16e-08	5.62e-08	2.39e-05
	(710.3)	(0.00107)	(0.00191)	(0.00170)	(0.00156)	(0.00158)	(1.143)
geothermal activity	-0.117	9.04e-08	6.81e-08	4.73e-08	6.83e-08	7.43e-08	3.16e-05
	(729.2)	(0.00109)	(0.00196)	(0.00174)	(0.00160)	(0.00163)	(1.173)
population density	-0.00121	9.35e-10	7.03e-10	4.89e-10	7.05e-10	7.68e-10	3.27e-07
	(2.420)	(3.62e-06)	(6.49e-06)	(5.77e-06)	(5.31e-06)	(5.39e-06)	(0.00389)
Democrats Controlling the House	-186889	0.188	0.0110	0.412	-0.0562	-0.120	-57.95
	(129444)	(0.193)	(0.345)	(0.307)	(0.283)	(0.287)	(206.6)
Democrats Controlling Senate	173722***	0.178**	0.455***	0.303**	0.297**	0.0669	51.58
	(56700)	(0.0871)	(0.156)	(0.139)	(0.128)	(0.130)	(93.49)
Democratic President	-71427	0.00320	-0.0311	0.00645	0.00367	0.184	12.16
	(54180)	(0.0805)	(0.144)	(0.128)	(0.118)	(0.120)	(86.41)
number of supporting government agencies	27828*	0.0308	0.0409	0.0698**	0.00632	-0.0565*	-30.34
	(14908)	(0.0216)	(0.0387)	(0.0344)	(0.0317)	(0.0321)	(23.16)
number of supporting firms in the industry	-15048**	-0.00774	-0.0157	-0.0220	-0.000463	0.0237*	12.41
	(6033)	(0.00877)	(0.0157)	(0.0140)	(0.0129)	(0.0131)	(9.418)
Constant	20354	-1.081*	-0.988	-2.119**	-0.376	1.029	609.4
	(381316)	(0.560)	(1.004)	(0.892)	(0.822)	(0.833)	(600.9)
Observations	1350	1300	1300	1300	1300	1300	1300
Number of year	27	26	26	26	26	26	26
R^2	.	.	.	.	.	.	.

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B.3: Renewable Energy Penetration Results

VARIABLES	(1) R.E.P.	(2) R.E.P.	(3) R.E.P.	(4) R.E.P.
ocean	0.146***	0.145***	0.145***	0.145***
	(0.0198)	(0.0198)	(0.0198)	(0.0198)
desert	-0.159***	-0.159***	-0.159***	-0.159***
	(0.0290)	(0.0290)	(0.0290)	(0.0290)
forest	-0.0306	-0.0293	-0.0290	-0.0290
	(0.0270)	(0.0270)	(0.0270)	(0.0270)
mountains	0.0524**	0.0529**	0.0530**	0.0530**
	(0.0207)	(0.0206)	(0.0206)	(0.0206)
geothermal activity	0.0997***	0.100***	0.100***	0.100***
	(0.0212)	(0.0212)	(0.0212)	(0.0212)
population density	0.000136*	0.000143**	0.000144**	0.000144**
	(7.02e-05)	(7.03e-05)	(7.03e-05)	(7.03e-05)
countryhousepolpow		0.0256	-0.00760	-0.00764
		(0.0193)	(0.0510)	(0.0510)
countrysenatepolpow		-0.0196	-0.00890	-0.00921
		(0.0185)	(0.0223)	(0.0225)
countryprespolpow		0.00891	0.00396	0.00419
		(0.0188)	(0.0214)	(0.0215)
ofsupportinggovorg			0.000121	5.34e-05
			(0.00588)	(0.00591)
offirmsinindustry			-0.000721	-0.000690
			(0.00238)	(0.00239)
congresselecyr				-0.00202
				(0.0176)
Constant	0.196***	0.185***	0.241	0.243
	(0.0349)	(0.0381)	(0.154)	(0.155)
Observations	1350	1350	1350	1350
R^2	.	.	.	.
Number of year	27	27	27	27

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix C

Chapter 4

C.1 Figures and Tables

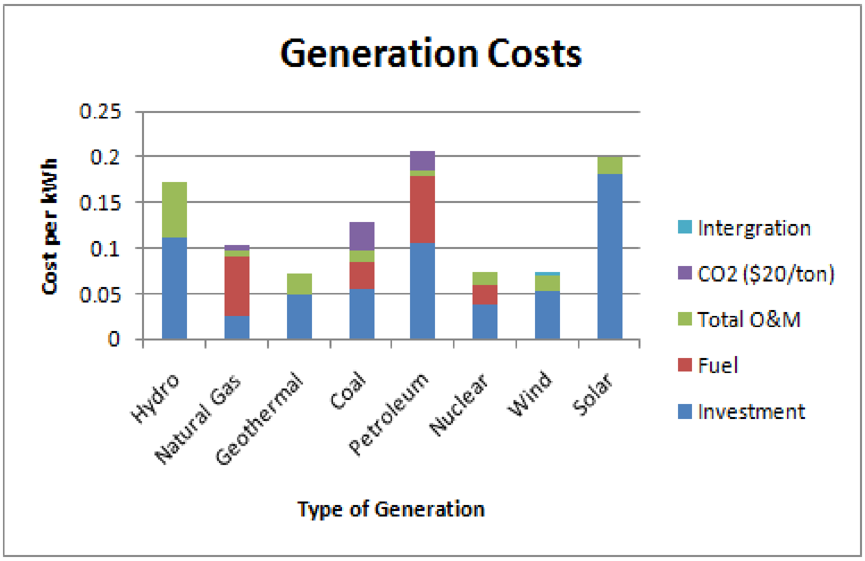

Figure C.1: Generation Costs

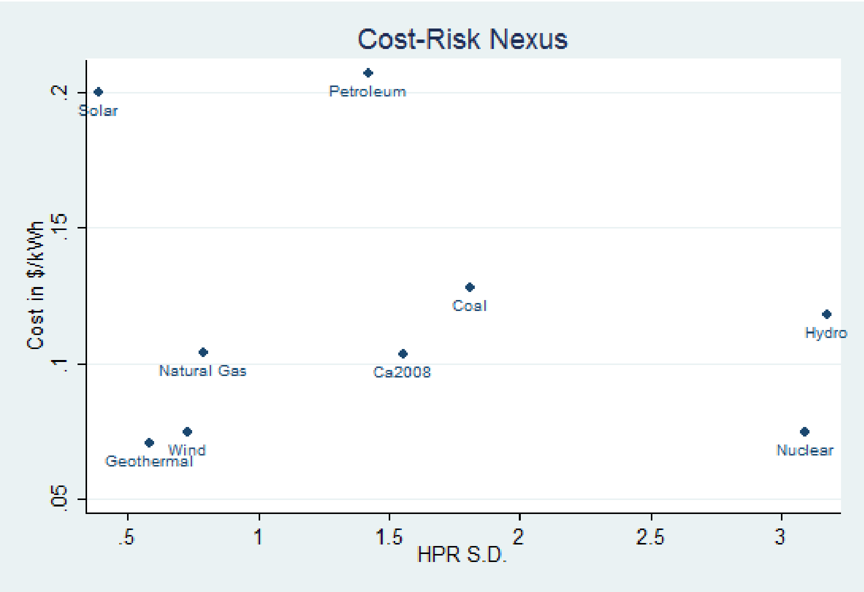

Figure C.2: Cost-Risk Nexus

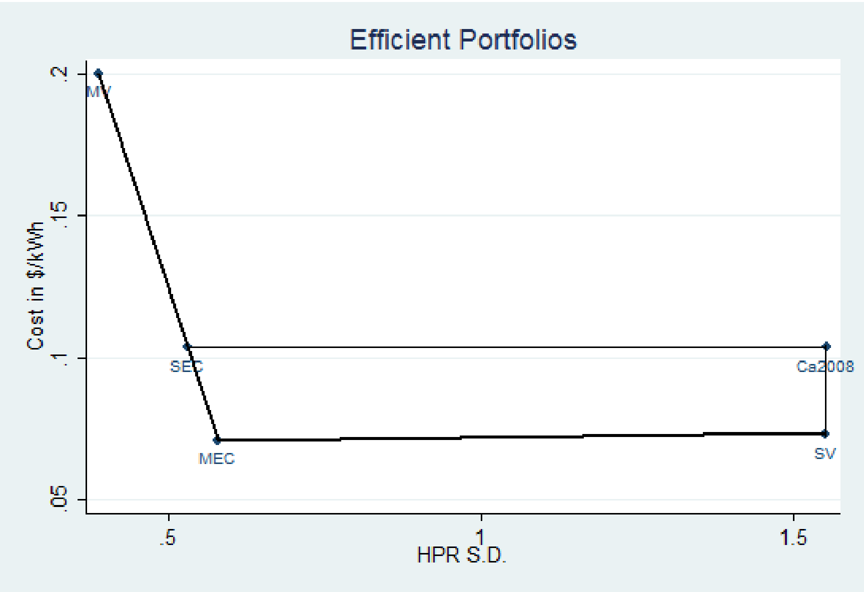

Figure C.3: Efficient Portfolios: No Restrictions

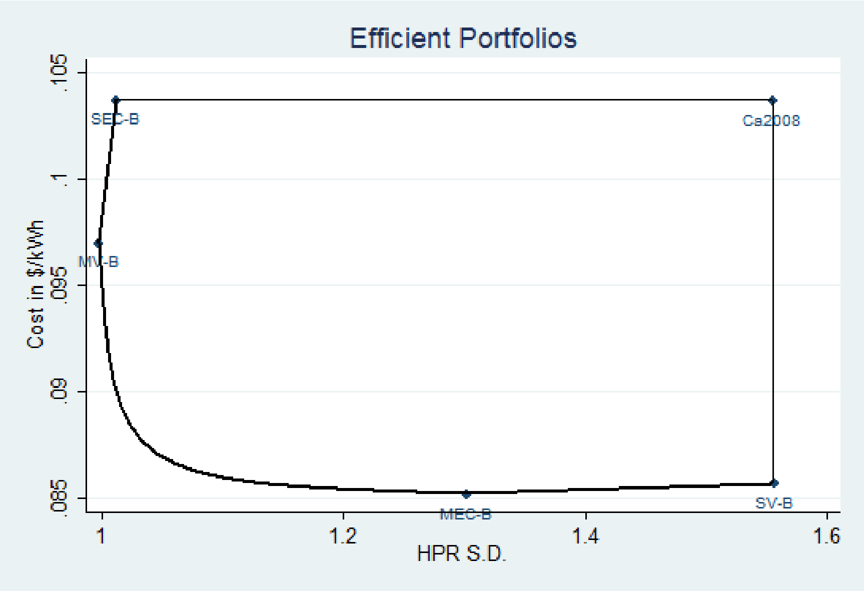

Figure C.4: Efficient Portfolios: Baseline Results

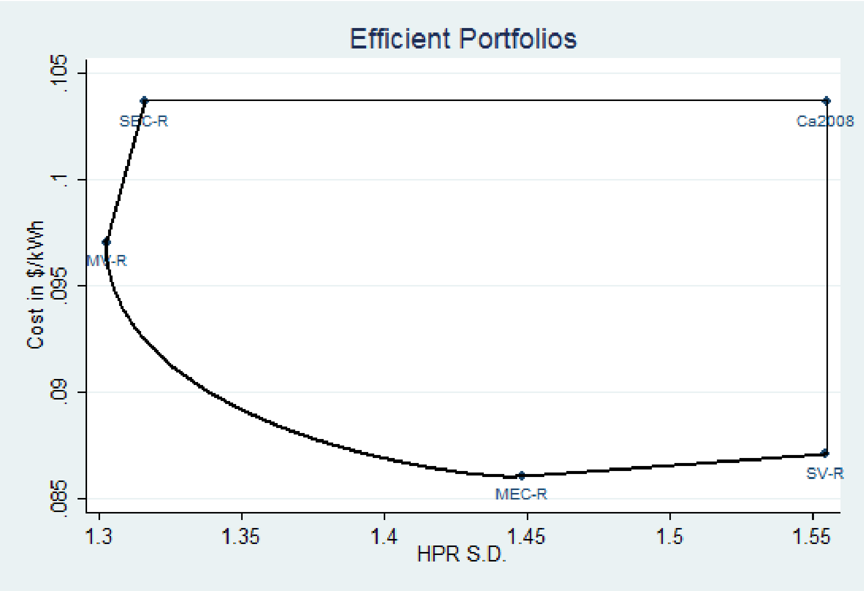

Figure C.5: Efficient Portfolios: Realizable Results

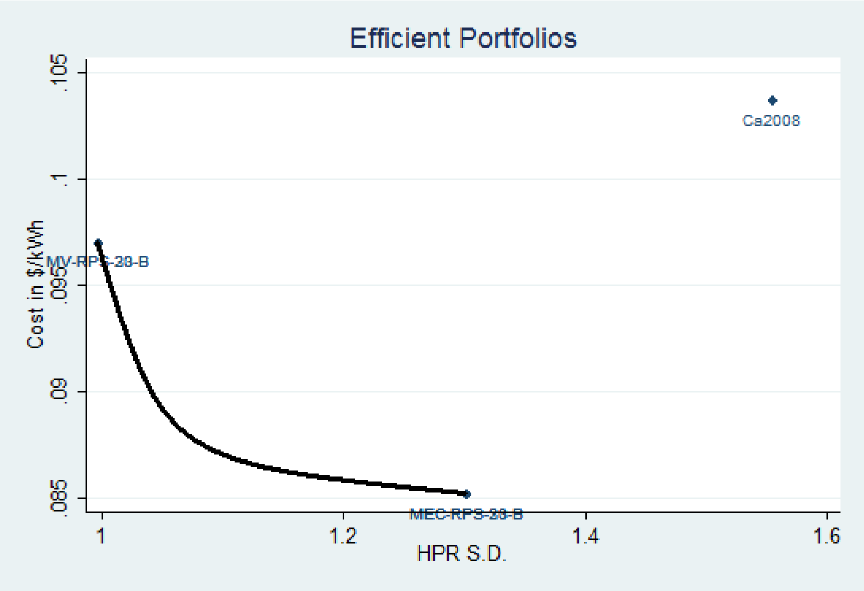

Figure C.6: Efficient Portfolios: RPS 20%,33% Baseline

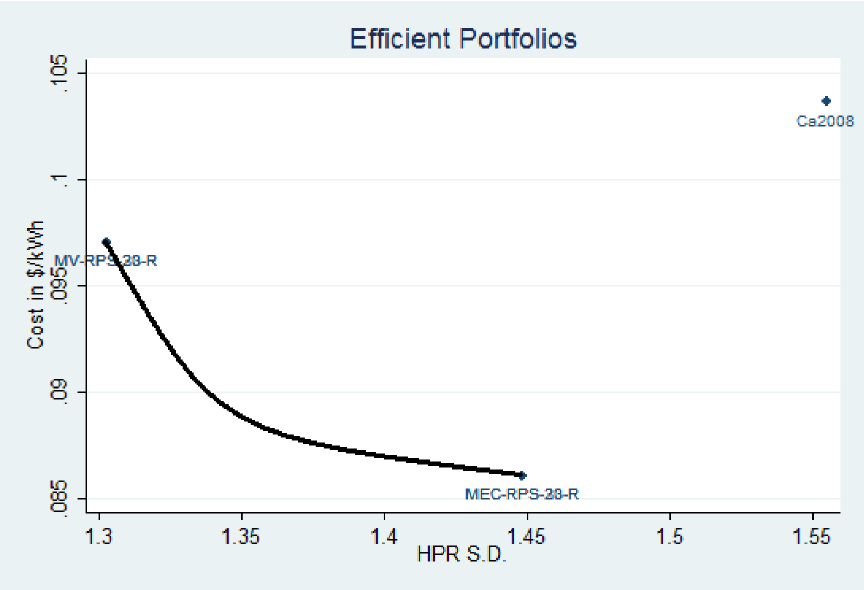

Figure C.7: Efficient Portfolios: RPS 20%,33% Realizable

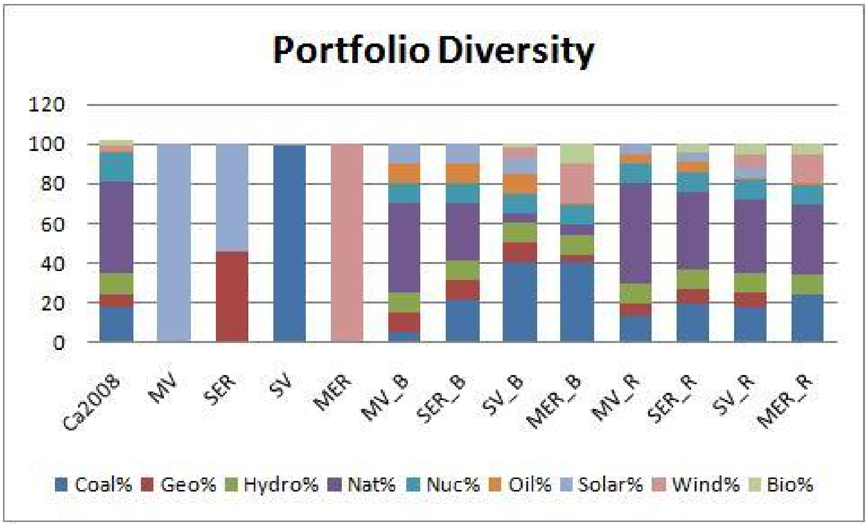

Figure C.8: Portfolio Diversity

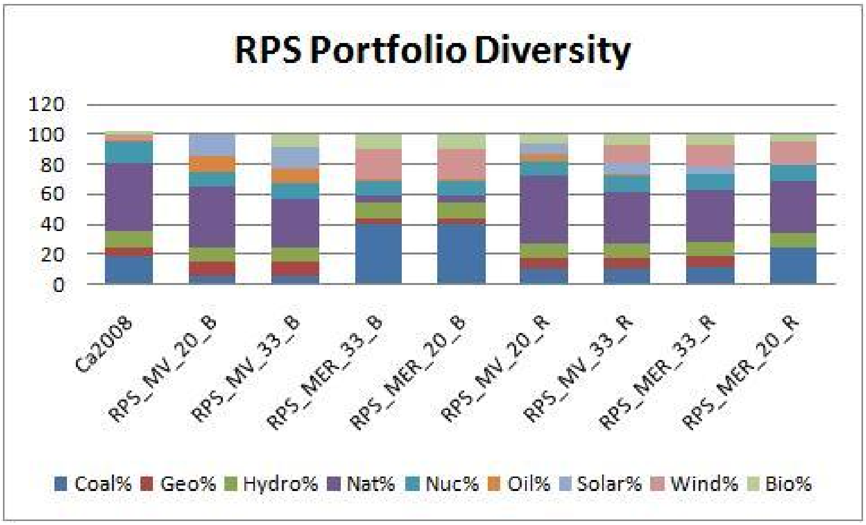

Figure C.9: RPS Portfolio Diversity

Technology	Unit Size	Lead Time	Capital Cost/kW	Operating cost	Fuel prices	CO_2 emissions	Regulatory risk
Natural Gas	Medium	Short	Low	Low	High	Medium	Low
Coal	Large	Long	High	Medium	Medium	High	High
Nuclear	Very Large	Long	High	Medium	Low	Nil	High
Hydro	Large	Long	Very High	Very Low	Nil	Nil	High
Wind	Small	Short	High	Very Low	Nil	Nil	Medium
Petroleum	Small	Very Short	Low	Low	High	Medium	Medium
Solar	Very Small	Very Short	Very High	Very Low	Nil	Nil	Low
IEA/NEA (2005).							

Table C.1: Qualitative Comparisons

	Capital Investment	Fuel	O&M	CO_2
Hydro	.35	*	.153	*
Natural Gas	.20	.291	.105	.26
Geothermal	.20	*	.153	*
Coal	.35	.049	.054	.26
Petroleum	.35	.312	.042	.26
Nuclear	.40	.346	.055	*
Wind	.20	*	.08	*
Solar	.10	*	.073	*

Table C.2: Year-to-Year Holding Period Returns' Standard Deviations

VARIABLES	hr2009
hr2008	0.246
	(0.199)
hr2007	0.139*
	(0.0711)
hr2005	0.323**
	(0.171)
hr2002	0.600***
	(0.171)
hr1997	0.0674*
	(0.0385)
hr1996	-0.0706*
	(0.0360)
Constant	0.0123
	(0.0153)
Observations	37
R^2	0.991

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.3: Hydro OLS Regression

VARIABLES	nr2009
nr2008	0.771
	(0.483)
nr2007	0.162
	(0.509)
nr2006	-0.284
	(0.331)
nr2005	0.429
	(0.534)
nr2004	-0.964
	(0.635)
nr2003	1.055
	(0.628)
nr1994	-0.0857*
	(0.0463)
Constant	3.750*
	(1.828)
Observations	33
R^2	0.822

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.4: Natural Gas OLS Regression

VARIABLES	geor2009
geor2008	-0.0655
	(0.129)
geor2007	-0.247
	(0.173)
geor2006	-0.114
	(0.143)
geor2001	-0.221*
	(0.125)
geor2000	-0.175
	(0.138)
geor1999	0.0975
	(0.132)
geor1998	-0.232
	(0.145)
geor1997	0.0279
	(0.126)
geor1996	0.0715
	(0.139)
geor1995	0.121
	(0.146)
geor1994	0.114
	(0.0792)
Constant	24.26***
	(6.698)
Observations	38
R^2	0.583

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.5: Geothermal OLS Regression

VARIABLES	cr2009
cr2008	-1.138
	(1.276)
cr2007	1.319
	(1.407)
cr2006	-0.969
	(0.860)
cr2005	-0.241
	(1.004)
cr2004	-0.341
	(0.396)
cr2003	0.0665
	(0.781)
cr2002	0.127
	(0.853)
cr2001	-0.964
	(1.199)
Constant	29.77
	(25.08)
Observations	10
R^2	0.869

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table C.6: Coal OLS Regression

VARIABLES	or2009
or2008	0.977**
	(0.0236)
or2007	2.552**
	(0.138)
or2006	-0.630**
	(0.0270)
or2005	-0.471*
	(0.0473)
or2004	-1.170**
	(0.0538)
or2003	0.332*
	(0.0269)
or2002	-0.862**
	(0.0287)
Constant	-0.0664
	(0.0316)
Observations	9
R^2	1.000

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.7: Petroleum OLS Regression

VARIABLES	nur2009
nur2008	0.935
	(0.784)
nur2007	0.0763
	(0.576)
Constant	0.915
	(1.103)
Observations	4
R^2	0.998

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.8: Nuclear OLS Regression

	Hydro	Natural Gas	Geothermal	Coal	Oil	Nuclear
1) Correlations between returns						
Hydro	1					
Natural Gas	-.1103	1				
Geothermal	-.4097	-.8071	1			
Coal	-.2382	.6994	.0840	1		
Oil	.2171	-.0553	-.2977	-.1301	1	
Nuclear	-.1038	.2676	.6109	.1771	-.0287	1
2) Correlations between $\hat{u}_{i,t}$ residuals, OLS, from Equation 4.7						
Hydro	1					
Natural Gas	.6885	1				
Geothermal	-.1432	.1212	1			
Coal	.5742	.4066	-.4608	1		
Oil	-.1453	.2516	.3851	.2616	1	
Nuclear	-.5609	-.6967	.1368	-.2445	.1396	1

Table C.9: Correlation Coefficients

VARIABLES	(1) hr2009	(2) nr2009	(3) geor2009	(4) cr2009	(5) or2009
hr2008	1.017***				
	(0.0184)				
hr2007	-0.615***				
	(0.0178)				
nr2008		6.938***			
		(0.308)			
nr2007		-6.439***			
		(0.300)			
geor2008			0.721***		
			(0.0810)		
geor2007			0.891**		
			(0.357)		
cr2006				-1.400***	
				(0.247)	
cr2005				0.366**	
				(0.183)	
or2008					0.975***
					(0.00769)
or2007					2.540***
					(0.0454)
Constant	-0.0476***	8.557***	4.507	18.13**	-0.0662***
	(0.00133)	(0.156)	(6.734)	(7.376)	(0.0104)
Observations	9	9	9	9	9
R^2	1.000	0.997	0.941	0.773	1.000

*** p<0.01, ** p<0.05, * p<0.1

Standard errors in parentheses

Table C.10: SURE Regression Results, least observations

VARIABLES	(1) hr2009	(2) nr2009	(3) geor2009	(4) cr2009
hr2008	1.118***			
	(0.0118)			
hr2007	-0.478***			
	(0.00864)			
hr2006	-0.00742			
	(0.00579)			
nr2008		-5.661**		
		(2.567)		
nr2007		5.871**		
		(2.438)		
nr2006		0.148		
		(0.173)		
geor2008			0.660***	
			(0.111)	
geor2007			-0.260	
			(0.356)	
geor2006			-0.238	
			(0.192)	
cr2008				-0.811**
				(0.387)
cr2007				0.934**
				(0.435)
cr2006				-1.113***
				(0.260)
Constant	-0.0442***	2.462	25.79***	30.35***
	(0.000671)	(1.732)	(8.039)	(7.858)
Observations	10	10	10	10
R^2	1.000	0.902	0.847	0.854

*** p<0.01, ** p<0.05, * p<0.1

Standard errors in parentheses

Table C.11: SURE Regression Results, fewer observations

	(1)	(2)	(3)
VARIABLES	hr2009	nr2009	geor2009
hr2008	0.436***		
	(0.168)		
hr2007	0.191***		
	(0.0578)		
hr2006	0.214**		
	(0.105)		
hr2005	0.277**		
	(0.119)		
nr2008		0.890***	
		(0.340)	
nr2007		0.0544	
		(0.359)	
nr2006		-0.291	
		(0.232)	
nr2005		0.464	
		(0.376)	
geor2008			-0.110
			(0.104)
geor2007			-0.239*
			(0.145)
geor2006			-0.142
			(0.112)
geor2005			-0.133
			(0.117)
Constant	0.00637	3.813***	28.35***
	(0.0118)	(1.272)	(6.036)
Observations	33	33	33
R^2	0.992	0.818	0.575

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table C.12: SURE Regression Results, most observations

	Hydro	Natural Gas	Geothermal	Coal	Oil	Nuclear
1) Correlations between $\hat{u}_{i,t}$ residuals, OLS, from Equation 4.7						
Hydro	1					
Natural Gas	.6885	1				
Geothermal	-.1432	.1212	1			
Coal	.5742	.4066	-.4608	1		
Oil	-.1453	.2516	.3851	.2616	1	
Nuclear	-.5609	-.6967	.1368	-.2445	.1396	1
2) Correlations between $\hat{u}_{i,t}$ residuals, after SURE, from Equation 4.7						
Hydro	1					
Natural Gas	.2920	1				
Geothermal	-.1187	-.1060	1			
Coal	-.2500	.2646	.3414	1		
Oil	.0124	.1482	.1128	.5893	1	
Nuclear	-	-	-	-	-	1

Table C.13: Comparing Correlation Coefficients

Equation	Estimation Method	RMSE	R^2	F-Stat/Chi2	P-Values
Hydro	OLS	.04447	.9847	155.46	0.0000
Hydro	SURE	.0318864	.9924	4627.15	0.0000
Natural Gas	OLS	2.1529	.6650	22.09	0.0008
Natural Gas	SURE	1.563722	.8177	164.08	0.0000
Geothermal	OLS	.40071	.2983	2.05	0.0615
Geothermal	SURE	.3104115	.5755	45.47	0.0001
Coal	OLS	1.5847	.1755	.83	0.6952
Coal	SURE	.5299631	.8539	64.34	0.0000
Petroleum	OLS	.02654	.9984	709.33	0.0289
Petroleum	SURE	.0091827	.9998	44817.32	0.0000
Nuclear	OLS	1.0332	.9935	231.41	0.0464
Nuclear	SURE	-	-	-	-

Table C.14: Comparing OLS and SURE Regressions

	Ca2008	MV	SEC	SV	MEC
Expected Cost	.1036	.2	.1036	.073	.071
Risk	1.56	.39	.519	1.56	.58
Hydro	11%				
Natural Gas	45.7%				
Geothermal	6.2%		74.7%	50%	100%
Coal	18.2%				
Petroleum	1%				
Nuclear	14.4%			38%	
Wind	2.6%			12%	
Solar	.3%	100%	25.3%		

Table C.15: Efficient Portfolio Mix: No Restrictions

	Baseline Case	
	Lower Limit (%)	Upper Limit (%)
Hydro	7.75	20
Natural Gas	2.5	60.27
Geothermal	1.1	25
Coal	2.5	20
Petroleum	0	2
Nuclear	4.7	15.84
Solar	0	10
Wind	.45	30

Table C.16: Upper and Lower Technology Limits: Baseline

	Ca2008	MV-B	SEC-B	SV-B	MEC-B
Expected Cost	.1036	.0969	.1036	.0857	.0852
Risk	1.55	.998	1.01	1.55	1.30
Hydro	11%	7.75%	7.75%	18.7%	7.7%
Natural Gas	45.7%	20.05%	43.05%	7.96%	19%
Geothermal	6.2%	25%	25%	25%	25%
Coal	18.2%	2.5%	2.5%	2.5%	2.5%
Petroleum	1%				
Nuclear	14.4%	4.7%	4.7%	15.84%	15.8%
Wind	2.6%	30%	7%	30%	30%
Solar	.3%	10%	10%		

Table C.17: Efficient Portfolio Mix: Baseline Restrictions

	Realizable Case: Ca. 2020	
	Lower Limit (%)	Upper Limit (%)
Hydro	14.5	18.1
Natural Gas	5	45.7
Geothermal	2.2	25
Coal	5	18.2
Petroleum	0	1
Nuclear	9.8	14.4
Wind	.9	30
Solar	0	10

Table C.18: Upper and Lower Technology Limits: Realizable

	Ca2008	MV-R	SEC-R	SV-R	MEC-R
Expected Cost	.1036	.0970	.1036	.0871	.0861
Risk	1.55	1.30	1.31	1.55	1.45
Hydro	11%	14.5%	14.5%	18.1%	14.5%
Natural Gas	45.7%	5.7%	28.4%	5.5%	11.1%
Geothermal	6.2%	25%	25%	25%	25%
Coal	18.2%	5%	5%	7%	5%
Petroleum	1%				
Nuclear	14.4%	9.8%	9.8%	14.4%	14.4%
Wind	2.6%	30%	7.3%	30%	30%
Solar	.3%	10%	10%		

Table C.19: Efficient Portfolio Mix: Realizable Case

	Ca2008	MV-RPS-20-B	MV-RPS-33-B	MEC-RPS-33-B	MEC-RPS-20-B
Expected Return	.1036	.0970	.0970	.0852	.0852
Risk	1.55	.998	.998	1.30	1.30
Hydro	11%	7.75%	7.75%	7.7%	7.7%
Natural Gas	45.7%	20.05%	20.05%	19.%	19.%
Geothermal	6.2%	25%	25%	25%	25%
Coal	18.2%	2.5%	2.5%	2.5%	2.5%
Petroleum	1%				
Nuclear	14.4%	4.7%	4.7%	15.8%	15.8%
Wind	2.6%	30%	30%	30%	30%
Solar	.3%	10%	10%		

Table C.20: Efficient Portfolio Mix: RPS Baseline Cases

	Ca2008	MV-RPS-20-R	MV-RPS-33-R	MEC-RPS-33-R	MEC-RPS-20-R
Expected Cost	.1036	.0970	.0970	.0861	.0861
Risk	1.55	1.30	1.30	1.45	1.45
Hydro	11%	14.5%	14.5%	14.5%	14.5%
Natural Gas	45.7%	5.7%	5.7%	11.1%	11.1%
Geothermal	6.2%	25%	25%	25%	25%
Coal	18.2%	5%	5%	5%	5%
Petroleum	1%				
Nuclear	14.4%	9.8%	9.8%	14.4%	14.4%
Wind	2.6%	30%	30%	30%	30%
Solar	.3%	10%	10%		

Table C.21: Efficient Portfolio Mix: RPS Realizable Cases

	Ca2008	MV	SER	SV	MEC	MV-B	SEC-B	SV-B	MEC-B	MV-R	SEC-R	SV-R	MEC-R
SW Index	1.621	0	.69	.02	0	1.66	1.84	1.867	1.704	1.558	1.769	1.853	1.651
HH Index	2802.22	10000	5032	9940.18	10000	2550	1771.78	2118	2342	2968	2222.08	2053.58	2252
SR	1.742	3.769	6.596	5.125	2.389	1.246	2.154	2.993	2.844	1.493	1.999	2.042	2.134

Table C.22: Portfolio Diversity

	Ca2008	MV-20B	MV-33B	MEC-33B	MEC-20B	MV-20R	MV-33R	MEC-33R	MEC-20R
SW Index	1.612	1.722	1.922	1.704	1.704	1.741	1.949	1.902	1.651
HH Index	2802.22	2250	1738	2342	2342	2484	1820	1886	2252
SR	1.742	1.32	1.68	2.84	2.84	1.61	1.92	1.97	2.13

Table C.23: RPS Portfolio Diversity

Bibliography

Administration, E. I. (1999), "Overview of federal energy research and development", *Federal Energy Market Interventions 1999: Primary Energy* .

Afuah, A. and Utterback, J. (1997), "Responding to structural industry changes: a technological evolution perspective", *Industrial and Corporate Change* , Vol. 6, Oxford Univ Press, pp. 183–202.

Agency, C. (1996), "CIA World Factbook, published online".

Agency, C. (2001), "CIA world factbook 2001", *Found at: http://www.cia.gov/cia/publications/factbook* .

Agency, C. and States, U. (1999), *World Factbook 1999.*, Central Intelligence Agency.

Agency-CIA, C. (2003), 'The World Factbook'.

Agency, I. E. (1985), Energy technology policy, Technical report, Paris:IEA.

Aldy, J. E. (2005), "An environmental kuznets curve analysis of u.s. state-level carbon dioxide emissions", *The Journal of Environment & Development* .

Antweiler, W., Copeland, B. and Taylor, M. (1998), "Is Free Trade Good for the Environment?", *NBER Working Paper* .

Arthur, W. (1989), "Competing technologies, increasing returns, and lock-in by historical events", *The economic journal* , Vol. 99, JSTOR, pp. 116–131.

Aunela, L., H. E. K. V. L. K. M. A. S. T. L. J. and Loosaar, J. (1995), "Emissions from Estonian oil shale power plants", *Oil Shale* , Vol. 12, pp. 165–177.

Awerbuch, S. (2006), "Portfolio-based electricity generation planning: policy implications for renewables and energy security", *Mitigation and adaptation strategies* *for global change* , Vol. 11, Springer, pp. 693–710.

Awerbuch, S. and Berger, M. (2003), "Applying portfolio theory to EU electricity planning and policy-making", *IEA/EET working paper* .

Awerbuch, S., Jansen, J. and Beurskens, L. (2008), "The Role of Wind Generation in Enhancing Scotland's Energy Diversity and Security", *Analytical Methods for Energy Diversity and Security, Elsevier, Oxford* .

Awerbuch, S., Jansen, J., Buerskens, L. and Drennen, T. (2005), "The Cost of Geothermal Energy in the Western US Region: A Portfolio-Based Approach", *Sandia National Laboratories* .

Awerbuch, S. and Yang, S. (2007), "Efficient electricity generating portfolios for Europe: maximising energy security and climate change mitigation", *EIB Papers* , European Investment Bank, Economic and Financial Studies.

Bachmann, M. (n.d.*a*), "H.r. 1810".

Bachmann, M. (n.d.*b*), "H.r. 1813".

Bachmann, M. (n.d.*c*), "H.r. 6953".

Bagliani, Marco Bravo, G. and Dalmazzone, S. (2008), "A consumption-based approach to environmental kuznets curves using the ecological footprint indicator", *Ecological Economics* .

Baltagi, B. (2001), "Economic Analysis of Panel Data", *New York: John* .

Baltagi, B. H. and Wu, P. X. (1999), "Unequally spaced panel data regressions with ar(1) disturbances", *Econometric Theory* , Vol. 15, pp. 814–823.

Bar-Lev, D. and Katz, S. (1976), "A portfolio approach to fossil fuel procurement in the electric utility industry", *Journal of Finance* , Vol. 31, JSTOR, pp. 933–947.

Barreto, L. and Kemp, R. (2008), "Inclusion of technology diffusion in energy-systems models: some gaps and needs", *Journal of Cleaner Production* , Vol. 16, Elsevier, pp. 95–101.

Bartis, J. (2006), "Unconventional liquid fuels overview. 2006 boston world oil conference", *Association for the study of peak oil and gas* .

Berger, M. (2003), Portfolio analysis of EU electricity generating mixes and its implications for renewables, PhD thesis, Ph. D. Dissertation, Technischen Universit "at Wien, Vienna, March.

Berger, M., Awerbuch, S. and Haas, R. (2003), "Versorgungssicherheit und Diversifizierung der Energieversorgung in der EU", *Federal office for Transportation, Innovation and Technology* .

Bhargava, A., Franzini, L. and Narendranathan, W. (1982), "Serial correlation and the fixed effects model", *Review of Economic Studies* , Vol. 49, pp. 533–49.

Binswanger, M. (2001), "Technological progress and sustainable development: what about the rebound effect?", *Ecological Economics* , Vol. 36, pp. 119–132.

Board, E. S. A., Agency, E. and States, U. (2004), *EPA's Fourth External Review Draft of Air Quality Criteria for Particulate Matter*, US Environmental Protection Agency.

Bonaccorsi, A. and Giuri, P. (2000), "When shakeout doesn't occur The evolution of the turboprop engine industry", *Research Policy* , Vol. 29, Elsevier, pp. 847–870.

Brealey, R. (2007), *Principles of corporate finance*, Tata McGraw-Hill.

Brooks, H. (1986), "The typology of surprises in technology, institutions and development", *Sustainable development of the biosphere. Cambridge University Press, Cambridge, UK* , pp. 2325–348.

Bruce, N., Perez-Padilla, R. and Albalak, R. (2000), "Indoor air pollution in developing countries: a major environmental and public health challenge", *Bulletin of the World Health Organization* , Vol. 78, SciELO Public Health, pp. 1078–1092.

Carlsson, B. and Jacobsson, S. (1997), "Variety and Technology Policy-how do technological systems originate and what are the policy conclusions", *Systems of Innovation: Technologies, Institutions and Organizations, Pinter, London* , pp. 266–297.

Carrol, G. (1997), "Long-term evolutionary changes in organisational populations: theory, models and empirical findings in industrial demography", *Industrial and Corporate Change* , Vol. 6, pp. 119–143.

Cohendet, P., Llerena, P. and Sorge, A. (1992), "Technological diversity and coherence in Europe: an analytical overview", *Revue d'économie industrielle* , Vol. 59, éditions techniques et économiques, pp. 9–26.

Comin, D. and Hobijn, B. (2005), 'Lobbies and technology diffusion'.

Commission, C. P. U. (2009), 33% rps implementation analysis preliminary results, Technical report, California Public Utilities Commission.

Commitee, T. N. P. (2007), "Nobel peace prize 2007", *nobelprize.org* .

Conlon, M. (2004), ""study links smog increases to urban us deaths."", *Reuters* .

Cowan, R. (1991), "Tortoises and hares: choice among technologies of unknown merit", *The economic journal* , Vol. 101, JSTOR, pp. 801–814.

Database, W. B. D. I. (2009), Gross domestic product 2007 [fact sheet], Technical report, World Bank.

David, P. and Rothwell, G. (1996), "Standardization, diversity and learning: Strategies for the coevolution of technology and industrial capacity", *International Journal of Industrial Organization* , Vol. 14, Elsevier, pp. 181–201.

Davies, A. (1996), "Innovation in large technical systems: the case of telecommunications", *Industrial and Corporate Change* , Vol. 5, Oxford Univ Press, pp. 1143–1180.

Dayo, F. and Adegbulugbe, A. (1988), "Utilization of Nigerian natural gas resources: Potentials and opportunities", *Energy policy* , Vol. 16, Elsevier, pp. 122–130.

Deininger, K. and Squire, L. (1996), "A new dataset measuring income inequality", *World Bank Economic Review* .

Dollar, D. and Kraay, A. (2003), "Institutions, trade, and growth", *Journal of Monetary Economics* , Vol. 50, Elsevier, pp. 133–162.

Dollar, D. and Kraay, A. (2004), "Trade, Growth, and Poverty*", *The Economic Journal* , Vol. 114, Blackwell Synergy, pp. 22–49.

Dorfman, P. (2008), "Nuclear Consultation: Public Trust in Government", *Nuclear consultation working group: London* .

Doug Koplow, Earth Track, I. C. M. (2006), "Subsidies in the us energy sector: Magnitude, causes, and options for reform", *Subsidies and Sustainable Development:*

Political Economy Aspects .

Dunlap, R. E. (n.d.), “Climate-change views: Republican-democratic gaps expand”.

Dunlap, R.E., X. C. . M. A. (2001), “Politics and environment in america: Partisan and ideological cleavages in public support for environmentalism.”, *Environmental Politics* .

EASAC (2007), “A study on the eu oil shale industry viewed in the light of the estonian experience”, *Committee on Industry, Research and Energy of the European Parliament* .

Eaton, J. and Kortum, S. (1999), “International technology diffusion: Theory and measurement”, *International Economic Review* , The Economics Department of the University of Pennsylvania, and the Osaka University Institute of Social and Economic Research Association, pp. 537–570.

Edwards, S. (1997), “Trade Policy, Growth, and Income Distribution”, *AMERICAN ECONOMIC REVIEW* , Vol. 87, AMERICAN ECONOMIC ASSOCIATION, pp. 205–210.

EIA (1993), Renewable resources in the u.s. electricity supply, Technical report, DOE.

EIA (2002), Petroleum chronology of events 1970 - 2000, Technical report, DOE.

EIA (2008*a*), Form eia-9, Technical report, DOE.

EIA (2008*b*), Form eia-906, Technical report, DOE.

EIA (2008*c*), International energy statistics, Technical report, DOE.

Ekins, P. (1997), “The kuznets curve for the environment and economic growth: examining the evidence”, *Environment and Planning A* .

EPA, P. (n.d.), “Impacts on Air Quality”.

EPA, U. (1975), “Air Pollutants and Their Sources in Air Pollution Control Orientation Course”, *Air Pollution Training Institute, Atlanta, GA* , p. 422.

Ericsson, W. and Maitland, I. (1989), “Healthy industries and public policy”, *Industry Vitalization. Pergamon Press, New York* .

EWEA, 1999. Forum for Energy and Development, Greenpeace, 1999. WindForce 10. A blueprint to achieve 10% of the worlds electricity from wind power by 2020. (1999).

Fabozzi, F., Gupta, F. and Markowitz, H. (2002), "The legacy of modern portfolio theory", *The journal of investing* , Vol. 11, Institutional Investor Journals, pp. 7–22.

FRBNY (1981), "Frbny quarterly review", *FRBNY Quarterly Review* .

Freeman, C. and Louçã, F. (2002), *As time goes by: from the industrial revolutions to the information revolution*, Oxford University Press.

Fuller, M., Portis, S. and Kammen, D. (2009), "Toward a Low-Carbon Economy: Municipal Financing for Energy Efficiency and Solar Power", *Environment: Science and Policy for Sustainable Development* , Vol. 51, Heldref Publications, pp. 22–33.

Grabher, G. and Stark, D. (1997), "Organizing diversity: evolutionary theory, network analysis and postsocialism", *Regional Studies* , Vol. 31, Routledge, pp. 533–544.

grammy.com (2007), "Catagory 79", *grammy.com* .

Greene, W. (2001), Fixed and random effects in nonlinear models, Working Papers 01-01, New York University, Leonard N. Stern School of Business, Department of Economics.

Grossman, G. M. and Krueger, A. B. (1991), Environmental impacts of a north american free trade agreement, NBER Working Papers 3914, National Bureau of Economic Research, Inc.

Grossman, G. M. and Krueger, A. B. (1994), Economic growth and the environment, NBER Working Papers 4634, National Bureau of Economic Research, Inc.

Humphreys, H. and McClain, K. (1998), "Reducing the impacts of energy price volatility through dynamic portfolio selection", *The Energy Journal* , Vol. 19, International Association for Energy Economics, pp. 107–132.

if Global, W. and Unchecked, W. (n.d.), "The Cost of Climate Change".

Jacobson, L. (2009), "Fossil fuel: An american addiction", *Medill Reports Washing-*

ton .

Jacobsson, S. and Bergek, A. (2004), “Transforming the energy sector: the evolution of technological systems in renewable energy technology”, *Industrial and Corporate Change* , Vol. 13, Oxford Univ Press, pp. 815–849.

Jacobsson, S. and Lauber, V. (2006), “The politics and policy of energy system transformation explaining the German diffusion of renewable energy technology”, *Energy Policy* , Vol. 34, Elsevier, pp. 256–276.

James, C. (1992), “Overview of the 1992 Horizontal Merger Guidelines”, *Antitrust LJ* , Vol. 61, HeinOnline, p. 447.

Jansen, J., Beurskens, L. and van Tilburg, X. (2006), “Application of portfolio analysis to the Dutch generating mix”, *Energy research Center at the Netherlands (ECN) report C-05-100* .

Johnson, A. and Jacobsson, S. (2002), The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries, *in* ‘Winter 2002 Danish Research Unit for Industrial Dynamics Conference, Aalborg, Denmark, January’, pp. 17–19.

Kahru, A. and Põllumaa, L. (2006), “Environmental hazard of the waste streams of Estonian oil shale industry: an ecotoxicological review”, *Oil Shale* , Vol. 23, Estonian Academy Publishers, 7 Estonia Blvd, EE 0100, Tallinn, 10143, Estonia,, pp. 53–93.

Kattel, T. (2003), “Design of a new oil shale surface mine”, *Oil Shale* , Vol. 20, ESTONIAN ACADEMY PUBLISHERS, pp. 511–514.

Keller, W. (2002), “Geographic localization of international technology diffusion”, *American Economic Review* , Vol. 92, American Economic Association Publications, pp. 120–142.

Keller, W. (2004), “International technology diffusion”, *Journal of Economic Literature* , Vol. 42, American Economic Association Publications, pp. 752–782.

Kemp, R., Schot, J. and Hoogma, R. (1998), “Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management”, *Technology Analysis & Strategic Management* , Vol. 10, Routledge, pp. 175–198.

Kent, J. (1974), *Riegel’s handbook of industrial chemistry*, Van Nostrand Reinhold

New York.

Klein, J. and Rednam, A. (2007), "Comparative costs of california central station electricity generation technologies", *California Energy Commission Final Staff Report* .

Klepper, S. (1997), "Industry life cycles", *Industrial and corporate change* , Vol. 6, Oxford Univ Press, pp. 145–182.

Krey, B. and Zweifel, P. (2006), "Efficient electricity portfolios for Switzerland and the United States", *University of Zurich, Working Paper No* , Vol. 602.

Landau, R., Taylor, T. and Wright, G. (1996), *The mosaic of economic growth*, Stanford Univ Pr.

Lesser, J., Lowengrub, P., Yang, S., Office, C. E. C. R. E., Commission, C. E. and Bates White, L. (2007), *A mean-variance portfolio optimization of California's generation mix to 2020: achieving California's 33 percent renewable portfolio standard goal*, Consultant report, California Energy Commission.
URL: *http://books.google.com/books?id=A9ZROAAACAAJ*

Levinthal, D. (1998), "The slow pace of rapid technological change: gradualism and punctuation in technological change", *Industrial and corporate change* , Vol. 7, Oxford Univ Press, pp. 217–247.

Lobell, D. and Field, C. (2007), "Global scale climate–crop yield relationships and the impacts of recent warming", *Environ. Res* , Vol. 14002.

Loh, J. and for Nature, W. W. F. (1999), *Living Planet Report 1999*, WWF International.

Loh, J. and for Nature, W. W. F. (2000), *Living Planet Report 2000*, WWF–World Wide Fund for Nature.

Loh, J., Programme, U. N. E., Fund, W. W. and Centre, W. C. M. (2002), *Living Planet Report: 2002*, WWF International.

Loh, J., Randers, J., MacGillivray, A., Kapos, V., Jenkins, M., Groombridge, B. and Cox, N. (1998), "Living planet report, 1998", *Gland: WWF International* .

Loh, J., Wackernagel, M., Centre, U. W. C. M., Network, G., for Nature, W. W. F. and (Organization, W. (2004), *Living Planet Report: 2004*, WWF-World Wide

Fund for Nature.

Madsen, T. and Figdor, E. (2007), "When it rains, it pours: global warming and the rising frequency of extreme precipitation in the United States", *Report prepared by Environment America Research and Policy Center, Boston* .

Markowitz, H. (1952), "Portfolio selection", *Journal of finance* , Vol. 7, JSTOR, pp. 77–91.

Maskell, P. (2001), "Towards a knowledge-based theory of the geographical cluster", *Industrial and corporate change* , Vol. 10, Oxford Univ Press, pp. 921–943.

Matthews, M. and Mcgowan, F. (1992), "Reconciling diversity and scale: some questions of method in the assessment of the costs and benefits of European integration", *Revue d'économie industrielle* , Vol. 59, éditions techniques et économiques, pp. 222–234.

Merchant, B. (2009), "Guide to the democrats' energy and climate bill: the greenest in us history?", *NY Times* .

Myrdal, G. and Myrdal, G. (1963), *Economic theory and under-developed regions*, University Paperbacks.

Nahman, A. and Antrobus, G. (2005), "The environmental kuznets curve: A literature survey", *South African Journal of Economics* , Vol. 73, pp. 105–120.

of Health, L. D. and Hospitals (2006), Hurricane katrina deceased reports: Reports of missing and deceased august 2, 2006, Technical report, Louisiana Dept. of Health and Hospitals.

of Land Management, B. (2007), Draft oil shale and tar sands resource management plan amendments to address land use allocations in colorado, utah, and wyoming and programmatic environmental impact statement, Technical report, U.S. Department of the Interior.

of Representitives, U. H. (1989), Title 42, chap 125, section 12001, Technical report, U.S. House of Repersentitives.

of the Earth, F. (2008), "An analysis of $32.9 billion in tax breaks, subsidies and other handouts the oil & gas industry will receive by 2013.", *Big Oil, Bigger Givaways* .

Office, U. S. G. A. (2007), “Federal electricity subsidies”, *Report to Congressional Requestors* .

Ophardt, C. E. (2004), Energy assesment, Technical report, Elmhurst College.

Ots, A. (2004), “Oil shale fuel combustion”, *Trükitud Tallinna Raamatutrükikojas. Tallin* .

Porter, M. (1998), “Clusters and the new economics of competition”, *Harvard business review* , Vol. 76, pp. 77–90.

POWER: A survey history of electric power technology since 1945 (2000), IEEE History Center, chapter 3.

Program, U. S. C. C. S. (2008), The effects of climate change on agriculture, land resources, water resources, and biodiversity in the united states, Technical report, United States Climate Change Science Program.

Projected Costs of Generating Electricity (2005), IEA.

Rhodes, R. (1997), *Understanding governance: policy networks, governance, reflexivity and accountability*, Open University Press Buckingham.

Rodrguez, F. and Rodrik, D. (1999), Trade policy and economic growth: A sceptic’s guide to the cross-national evidence, CEPR Discussion Papers 2143, C.E.P.R. Discussion Papers.

Roques, F., Newbery, D. and Nuttall, W. (2008), “Fuel mix diversification incentives in liberalized electricity markets: a mean-variance portfolio theory approach”, *Energy Economics* , Vol. 30, Elsevier, pp. 1831–1849.

Roques, F., Newbery, D., Nuttall, W., Neufville, R. and Connors, S. (2006), “Valuing portfolio diversification for a utility: Application to a Nuclear Power Investment when Fuel, Electricity, and Carbon Prices are Uncertain”, *The Energy Journal* , Vol. 27, pp. 1–23.

Roques, F., Nuttall, W., Newbery, D. and De Neufville, R. (2006), “Nuclear power: a hedge against uncertain gas and carbon prices?”.

Rosenberg, N. (1998), “Uncertainty and technological change”, *The Economic Impact of Knowledge* , pp. 17–34.

Rothman, D. S. (1998), "Environmental kuznets curves–real progress or passing the buck?: A case for consumption-based approaches", *Ecological Economics* , Vol. 25, pp. 177–194.

Rothwell, G. (2009), "Market Power in Uranium Enrichment", *Science & Global Security* , Vol. 17, Routledge, pp. 132–154.

Rotmans, J., Kemp, R. and van Asselt, M. (2001), "More evolution than revolution", *Transition Management in Public Policy, Foresight* , Vol. 3, pp. 15–31.

Rynes, Sara Weber, C. and Milkovich, G. (1988), "The effects of market survey rates, job evaluation and job gender on job pay", *CAHRS Working Paper Series* .

Sabatier, P. (1998), "The advocacy coalition framework: revisions and relevance for Europe", *Journal of European Public Policy* , Vol. 5, Routledge, pp. 98–130.

Said, C. (2001), "The energy crunch: A year later", *San Francisco Chronicle* .

Scitovsky, T. (1954), "Two concepts of external economies", *The Journal of Political Economy* , The University of Chicago Press, pp. 143–151.

Service, E. N. (2004), "Greenpeace germany protests brown coal power stations", *Environment News Service* .

Sissine, F. (2008), "Renewable energy r&d funding history: A comparison with funding for nuclear energy, fossil energy, and energy efficiency r&d", *CRS Report for Congress* .

Smith, A. (2000), "Policy networks and advocacy coalitions: explaining policy change and stability in UK industrial pollution policy?", *Environment and Planning C* , Vol. 18, PION LTD, pp. 95–114.

Smith, A. and Nicholson, J. (1895), *An Inquiry into the Nature and Causes of the Wealth of Nations*, T. Nelson.

St-Pierre, N., Cobanov, B. and Schnitkey, G. (2003), "Economic Losses from Heat Stress by US Livestock Industries 1", *Journal of Dairy Science* , Vol. 86, Am Dairy Sci Assoc, pp. 52–77.

Staff, M. (2002), "The california energy crisis: Myths and facts", *Committee on Government Reform, U.S. House of Representatives* .

Staff, S. G. (2001), “Energy crisis overview: How we got here”, *San Francisco Chronicle* .

Stern, N. (2008), “The economics of climate change”, *American Economic Review* , Vol. 98, American Economic Association Publications, pp. 1–37.

Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S. and Dietz, S. (2006), “Stern Review: The economics of climate change”, HM Thresury.

Stirling, A. (1994), “Diversity and ignorance in electricity supply investment: Addressing the solution rather than the problem”, *Energy Policy* , Vol. 22, Elsevier, pp. 195–216.

Stirling, A. (1997), “Multi-criteria mapping”, *Valuing nature?: ethics, economics and the environment* , Routledge, p. 186.

Stirling, A. (2007), “A general framework for analysing diversity in science, technology and society”, *Journal of the Royal Society Interface* , Vol. 4, The Royal Society, p. 707.

Stirling, A. et al. (1999), “On science and precaution in the management of technological risk”, *Report to the EU Forward Studies Unit, IPTS. MS, Seville.[IS]* .

Suri, V. and Chapman, D. (1998), “Economic growth, trade and energy: implications for the environmental kuznets curve”, *Ecological Economics* , Vol. 25, pp. 195–208.

Telleen-Lawton, T. (2009), Hotter fields, lower yields: How global warming could hurt americas farms, Technical report, Environment America Research & Policy Center.

Tol, R. (2005), “The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties”, *Energy policy* , Vol. 33, Elsevier, pp. 2064–2074.

Tuvikene, A., H. S. K. K. R. O. M. U. and Lindström-Seppä, P. (1999), “Oil shale processing as a source of aquatic pollution: monitoring of the biologic effects in caged and feral freshwater fish”, *Environmental health perspectives* , Vol. 107, pp. 745–752.

Unruh, G. (2000), “Understanding carbon lock-in”, *Energy Policy* , Vol. 28, Elsevier, pp. 817–830.

Van de Ven, A. and Garud, R. (1989), "A framework for understanding the emergence of new industries", *Research on technological innovation, management and policy* , Vol. 4, pp. 195–225.

Verrastro, F. and Ladislaw, S. (2007), "Providing energy security in an interdependent world", *The Washington Quarterly* , Vol. 30, Routledge, pp. 95–104.

Weitzman, M. (1992), "On diversity", *The Quarterly Journal of Economics* , Vol. 107, JSTOR, pp. 363–405.

Williamson, O. (1995), "Transaction cost economics and organization theory", *Organization theory: from Chester Barnard to the present and beyond* , pp. 207–256.

Williamson, O. (1998), "Transaction cost economics: how it works; where it is headed", *De Economist* , Vol. 146, Springer, pp. 23–58.

Wire, T. (2004), "Business today", *St. Petersburg Times* .

Wooldridge, J. M. (2003), "Cluster-sample methods in applied econometrics", *American Economic Review* , Vol. 93, pp. 133–138.

Zucchet, M. J. (2002), "Renewable resource electricity in the changing regulatory environment", *DOE* .