THE PERFORMANCE OF RENEWABLE PORTFOLIO STANDARDS IN THE UNITED STATES

By

Binlei Gong

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Agricultural, Food and Resource Economics

2011

ABSTRACT

THE PERFORMANCE OF RENEWABLE PORTFOLIO STANDARDS
IN THE UITED STATES

By

Binlei Gong

The Renewable Portfolio Standard (RPS) is a renewable energy policy that ensures a minimum amount of renewable energy in the portfolio of electric-generating resources serving a state. This article first analyzes theoretically expected effects of RPS on renewable energy quantities, electricity price, and emissions. With a balanced panel of 48 states for 1990-2008, this paper estimates causal impact of RPS through an econometric model. During these regressions, a new measure for RPS indicator has also been introduced to deal with the heterogeneity problem. This paper also account for the partial effect and the different trends of outcomes in the absence of RPS across states. The estimators imply that RPS on average are effective in having a positive impact on renewable energy share but not that efficient since significantly increasing the electricity price. This research also finds that strengthening RPS can reduce carbon and other emissions but these benefits cannot fully compensate the consumer surplus loss caused by RPS, which finally implies a national-wide RPS is likely to be inefficient even with emission concern. Finally, the breakeven price is estimated, which implies the policies' cost of reducing the emissions. This paper also does same analysis on regional level and concludes that RPS is likely to be efficient in Midwest and in West but not that efficient in Northeast and in South with emission concern.

This thesis is dedicated to my dear parents and to my grandfather in heaven.

谨以此文献给我亲爱的父母以及远在天堂的爷爷。

ACKNOWLEDGEMENTS

The completion of this thesis is a perfect ending for my two years graduate study at Michigan State University. It is my honor to be a member of the big family in the Department of Agricultural, Food and Resource Economics. I will never forget my friends and professors who studied and worked with me during the past 700 days.

First and foremost, I would like to especially thank my major professor, Dr. Jinhua Zhao, for his guidance to my research. I appreciate the initial research idea that he provided in 2009 as well as his continuous support since then.

I'd like to also thank members of my thesis committee, Dr. Soren Anderson and Dr. Thomas Dietz. They are the top researchers in Economics and Sociology, respectively. Dr. Anderson taught me a lot in the AEC835 econometrics class and gave me many suggestions on the empirical model in Section 4 of this thesis. Dr. Thomas Dietz provided me a whole page of study on climate change in the ESP 891 climate change and society course and the thoughts of environment concern of evaluating the policy in Section 4 and 6.

I am also grateful to the help of Dr. David Schweikhardt, who introduced the SSP analysis in EC 810 Institutional Economics class and instructed its specific application in my research in Section 3, Dr. Wooldridge, who gave suggestions on the econometric model with a different trends concern, and Dr Lindon Robison, who helped build my mathematical foundation to do the thesis through the calculus and statistics classes.

Thank you to David Perry for offering the Sierra Club member statistics information. Thank you to Dr. Lester Yuan from EPA for providing useful advice about my model. Thank you to Dr. Min Wang for being an amazing source of inspiration and comments.

Finally, I thank you to my family especially my father and mother for being my base, both mentally and financially. I miss you so much and would like to see you as soon as possible. I also give my best wish to my grandfather who passed away at the end of 2009 when I was in United States.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACP	Alternative Compliance Payment
ARP	Acid Rain Program
BFIN	Bioenergy Feedstock Information Network
CDC	Centers for Disease Control and Prevention
CDM	Clean Development Mechanism
CERs	Certified Emission Reductions
CO_2	Carbon Dioxide
DSIRE	Database of State Incentive for Renewables & Efficiency
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ESG	Economy of Scale Good
EUAs	EU allowances
GHG	Green House Gas
GWh	GigaWatt-Hour
IUG	Incompatible Use Good
LAUS	Local Area Unemployment Statistics
LCV	League of Conservation Voters

MWh	MegaWatt Hour
NCHS	National Center for Health Statistics
NO_X	Nitrogen Oxide
NREL	National Renewable Energy Laboratory
NVSS	National Vital Statistics System
OLS	Ordinary Least Square
PBF	Public Benefit Funds
PSM	Propensity Score Matching
REC	Renewable Energy Credits
RECLAIM	Regional Clean Air Incentives Market
RPS	Renewable Portfolio Standards
SCAQMD	South Coast Air Quality Management District
SO_2	Sulfur Dioxide
SSP	Situation-Structure-Performance
TSLS	Two Stage Least Square
WTP	Willingness To Pay

CHAPTER 1: INTRODUCTION

Renewable energy sources have been supported and subsidized in the electricity industry for decades because of the environmental benefits they bring despite their relatively high cost. As the electricity industry becomes more and more competitive and liberalized, public support for renewable energy nowadays is facing many challenges and changes. Thus, how to give incentives for the deployment of renewable energy sources while maintaining a competitive market is an issue many governments face in drafting policies.

Espey (2001) concludes that there are many options for promoting the use of renewable energies for electricity generation in the market economy including 1) support of voluntary measures such as dissemination of knowledge and information, 2) regulatory frameworks such as environmental standards or energy taxes, and 3) direct support mechanisms aimed at the regulation of prices or quantities. However, when competition is introduced, most of those support mechanisms may have distorting effects on competition and hence not efficient. Lack of efficient policy to deal with the new challenges limits the deployment of nation-level regulation on renewable energy.

Given this background, the past decade saw more and more states in the United States enacting state-level Renewable Portfolio Standards[1] (RPS). An RPS is a policy that ensures that a minimum amount of renewable energy (such as wind, solar, biomass, or geothermal energy but this mix varies state by state) is included in the portfolio of electric-generating resources serving a

[1] RPS policies are sometimes called “Renewable Energy Standards,” “Quota Systems,” or “Renewable Obligations.”

state. As of March 2011, 29 states[2] and the District of Columbia have mandatory renewable portfolio standards while 7 other states[3] have voluntary renewable portfolio goals. Table 1.1 presents the year of enactment, first year of requirement, final target and final year for all states with mandatory RPS policies.

Table 1.1 State mandatory RPS schedule and target

State	Year Enacted	First Year of Requirement	Final Target	Target Year
Arizona	1996	1999	15%	2025
California	2002	2003	33%	2020
Colorado	2004	2007	30%	2020
Connecticut	1998	2000	27%	2020
Delaware	2005	2007	25%	2026
Hawaii	2004	2005	20%	2020
Illinois	2007	2008	25%	2025
Iowa	1983	1999	105 MW (≈2%)	1999
Kansas	2009	2011	20%	2020
Maine	1997	2000	40%	2017
Maryland	2004	2006	22.5%	2020
Massachusetts	1997	2003	4%	2009
Michigan	2008	2012	10%	2015

---

[2] These 29 states are AZ, CA, CO, CT, DE, HI, IA, IL, KS, MA, MD, ME, MI, MN, MO, MT, NC, NH, NJ, NM, NV, NY, OH, OR, PA, RI, TX, WA and WI.

[3] These 7 states are ND, OK, SD, UT, VA, VT and WV.

Table 1.1 (cont'd)				
Minnesota	1994	2002	25%	2025
Missouri	2008	2011	15%	2021
Montana	2005	2008	15%	2015
Nevada	1997	2001	20%	2015
New Hampshire	2007	2008	24%	2025
New Jersey	1999	2001	25%	2021
New Mexico	2000	2002	20%	2020
New York	2004	2006	24%	2013
North Carolina	2007	2010	12.5%	2021
Ohio	2008	2009	25%	2025
Oregon	2007	2011	25%	2025
Pennsylvania	1998	2001	18%	2021
Rhode Island	2004	2007	16%	2020
Texas	1999	2002	5880 MW (≈4.4%)	2015
Wisconsin	1998	2000	10%	2015
Washington	2006	2012	15%	2020
Washington D.C.	2005	2007	11%	2022

Source: Database of State Incentive for Renewables & Efficiency (DSIRE) on www.dsireusa.org

However, although this trend of state energy policymaking aims to assist the development and deployment of renewable energy, few studies have examined the effect of RPS on renewable energy investment until recently. The existing papers overlooked or chose to ignore the heterogeneity problem of RPS indicator using either RPS dummy variable (Carley 2009; Olher 2009) or nominal RPS annual target (Kneifel 2008). No research has been found to deal with the different trends of outcomes in absence of RPS across states. Moreover, these studies have ignored the impacts on emissions, focusing only on prices and quantities, even though one of the primary purposes in enacting RPS is to respond to climate change. State-level RPS in the United States can be significant on the global scale because if its states were treated as countries, they would represent 35 of the world's top emitters (Marland et al., 2003; Peterson and Rose 2006). Therefore, it is important to take the impact of RPS on emissions into consideration.

The goal of this article is to examine the performance of these state-level RPS along three criteria: (1) renewable energy shares in the energy portfolio of both electricity capacity and generation; (2) average price which is related to consumer surplus in electricity market; and (3) emissions of carbon dioxide, nitrogen oxide, and sulfur dioxide from the electricity generation sector.

The remainder of this paper is structured as follows. Section 2 provides background information on RPS policies and previous literature in this field. Section 3 analyzes the theoretical impacts of RPS policies on renewable capacity and generation, electricity price, and emissions. Section 4 presents the empirical models for estimating these effects. Section 5 describes the data and gives summary statistics. Section 6 presents the estimation results and predicts changes in consumer welfare. Section 7 provides remarks and policy implications, while highlighting limitations and possible extensions.

CHAPTER 2: BACKGROUND

2.1 Overview of RPS policies in the United States

The popularity of state-level RPS policies has grown in recent years and they are increasingly common in the United States. These policies aim to facilitate the diversification of electricity capacity, speed renewable energy deployment, lessen reliance on fossil fuels, decrease renewable energy costs and reduce emissions (Carley 2009). However, policy objectives and the design of RPS programs vary considerably in structure, size, application, eligibility, and administration (Wiser et al 2007). This article explains these differences of RPS across states in Section 2.2.

As is mentioned in Section 1, 29 states and District of Columbia have mandatory RPS while 7 other states have voluntary renewable portfolio goals (see Figure 2.1). From this figure, it is clear that most of the states with the largest populations have enacted RPS, including California, Illinois, New York, Pennsylvania, and Texas. Non-RPS states are mainly located in the South and Mountain regions. This pattern might imply RPS policies in some states influence choices of other states in same region, or simply that states in the same region have similar incentive to enact RPS.

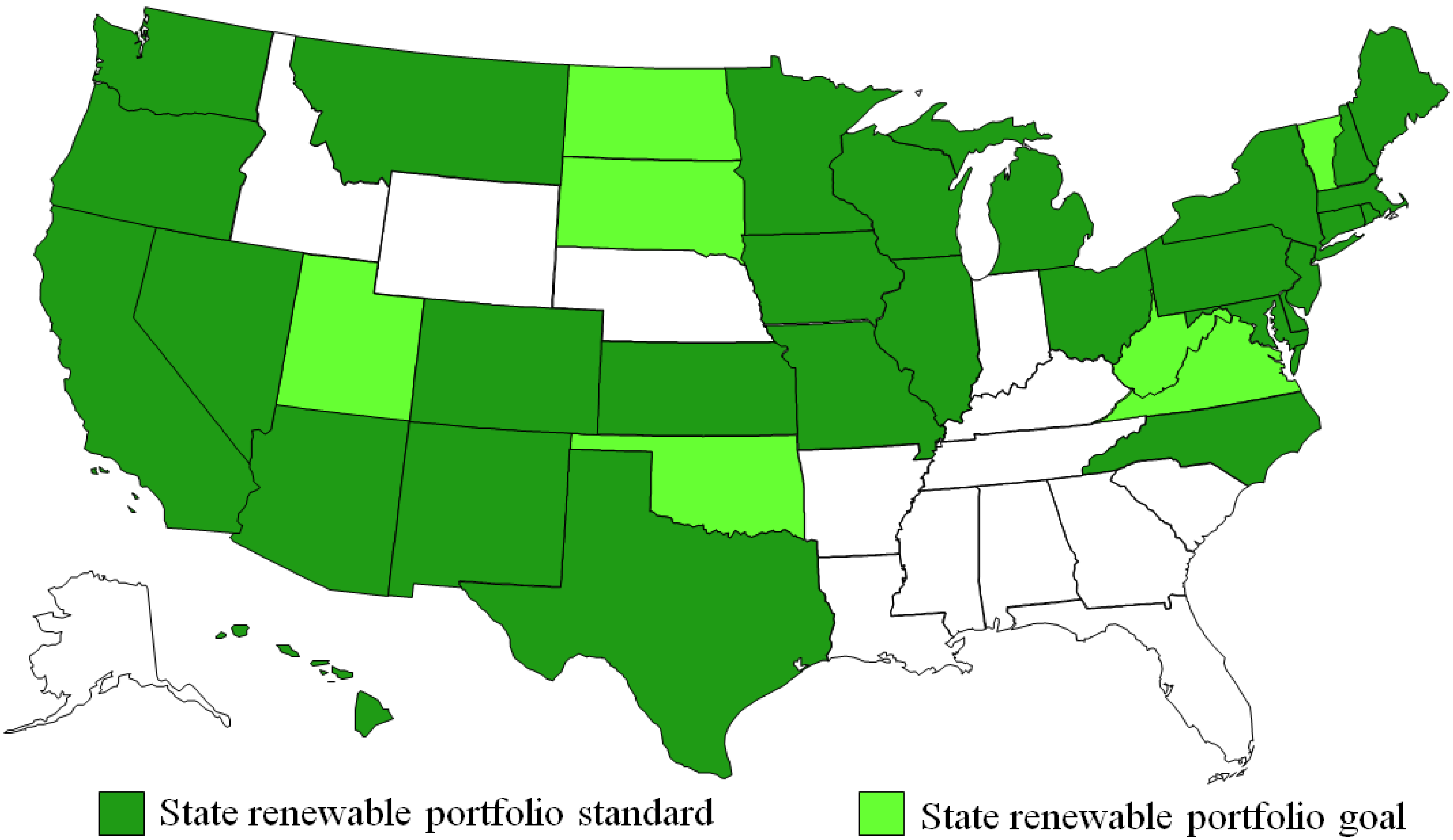

Figure 2.1 State Renewable Portfolio Standard and renewable portfolio goals

For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Source: www.dsireusa.org / March 2011

Figure 2.2 shows the state RPS timeline of enforcement and coverage of population and electricity generation, presenting both the year of initial enactment (in parentless) and the years of first requirement for RPS, as well as fraction of US population and electricity generation subject to state RPS from 1998 to 2012. This article assumes the population and generation ratio for each state maintain its 2009 level during the next three years because of lack of data for 2010, 2011, and 2012. For example, Wisconsin has 1.5% of US generation and 1.8% of US population in 2009. This article uses the same ratio for Wisconsin when calculating RPS coverage in population and generation in 2010, 2011, and 2012. Since the percentage of national population and generation for each state change slowly over short time scales, this assumption won't produce substantial error.

In this figure, it is clear that RPS have rocketed up since 1999. All the current RPS states have enforced or will enforce the policies before the end of 2012 when RPS will cover 70% of U.S. population and 62% of U.S. electricity generation. The difference between coverage of population and electricity generation is mainly caused by the enforcement of California in 2003, which has more than 12% of U.S. population but only produces about 5% of U.S. electricity.

Moreover, this figure shows that RPS deployments come in two main phases before and after the end of 2003. All the states enacted RPS before the end of 2003 also first enforced it before the end of 2003. There is no state that deployed RPS in 2003 and no states enforced RPS in 2004. These facts make the population and generation coverage curves in figure 2.2 maintain the same level around 2004 and increase again since 2005.

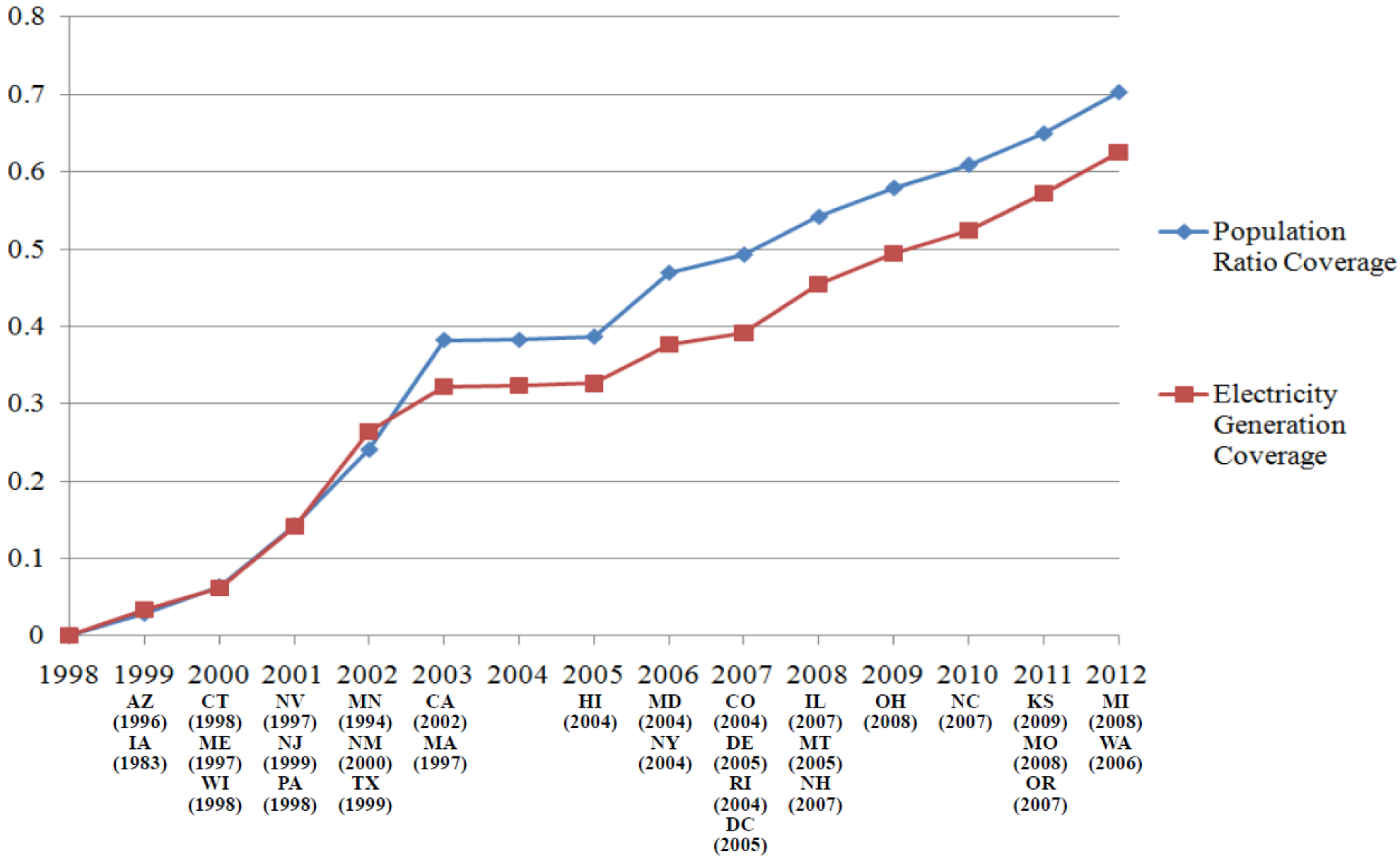

Figure 2.2 State RPS timeline and coverage of population and electricity generation

Source: EIA, Lawrence Berkeley National Laboratory and DSIRE

2.2 Features of RPS Policies

The key feature of RPS policies is the renewable energy share target required for every year or for a certain period. These targets vary across states and years. For example, the RPS in Massachusetts has an annual target that has increased each year since 2003, while the RPS in Washington has annual target that has increased every four years. However, the real effect of RPS is also dependent on other features of the policy besides the nominal target. One feature is the coverage of RPS, or the percentage of retail sales in a state-year that are required by law to comply with the RPS annual target. In some states, such as Minnesota and North Carolina, all the utilities must meet the target. In other states, such as Arizona and Illinois, some utilities are exempt from obligatory RPS. To some extent, the coverage of the policy would influence the final result. A second feature is the eligibility of renewable energy capacity that existed prior to the enactment of the RPS policy is determining compliance with the RPS requirement. In the 25 states[4] that have effective mandatory RPS before 2008, 20 credited existing capacity while the other 5 states can only use new capacity to meet the requirement. A third feature is the types of energy sources that are considered renewable energy. For example, wind, photo-voltaics, and biomass are regarded as renewable energy in most states, while geo-thermal, fuel cells, and land-fill gas are regarded as renewable energy only in some states. A fourth feature is the system of penalty for non-compliant power producers. Some states have explicit financial penalties for noncompliance, while some other states allow providers to pay an Alternative Compliance

[4] These 25 states are included in the 29 states in footnote but KS, MI, MO and OH.

Payment (ACP) in lieu of renewable generation. Other states have no such systems (Yin and Powers, 2010).

The coverage of RPS and the treatment of existing capacity vary across states, which, however, will lead to a heterogeneity problem when using only the nominal annual target to estimate the impact of RPS without controlling those two features. For example, Colorado and Massachusetts both have 5% nominal RPS annual target in 2010. But this requirement (5%) covers 94% of state sales in Colorado and 86% of state sales in Massachusetts, which makes the real effect of RPS different and thus it cannot be reflected by the nominal annual target. Yin and Powers (2010) creates a new variable to solve the heterogeneity problem. Therefore, our article proposes a new variable based on their study which indicates the combined effects of nominal annual target, RPS coverage, and the treatment of existing capacity. We assume that the existing renewable energy capacity will keep the same existing annual generation after the deployment of RPS. Then, the effective indicator of RPS level is given by:

$$(1) \quad RPS_{IT} = \frac{NOMINALTARGET_{IT} \times COVERAGE_{IT} \times ESALE_{IT} + NONELIGIBLE_{IT}}{ESALE_{IT}}$$

where $NOMINALTARGET_{IT}$ is the nominal annual target shown in RPS policies for state *I* in year *T*, $COVERAGE_{IT}$ represents the fraction of statewide load ultimately obligated by existing RPS policies for state *I* in year *T*, $ESALE_{IT}$ is the total retail sales in all sector for state *I* in year *T*, and $NONELIGIBLE_{IT}$ is the generation from renewable energy capacity prior to RPS enactment but not eligible in meeting the requirement for state *I* in year *T*. Thus RPS_{IT} represents the effective renewable energy share in retail sales implicitly required by RPS in state *I* in year *T*.

This variable quantifies the effective stringency of a state RPS in a certain year. Compared with the indicator in the research of Yin and Powers, this paper adds non-eligible existing generation rather than subtracting eligible existing generation because the effective target is an annual requirement rather than an incremental requirement.

However, it is widely admitted that simply making a percentage requirement for all the individual local utilities to invest in renewable energy systems would be an inefficient way to achieving a state-wide target. Thus, all the RPS states expect California, Iowa, Hawaii, and New York are enforced through a credit-trading mechanism, such as renewable energy credits (RECs) or renewable energy certificates, to help utilities who generate more renewable energy than requirement to make benefits and to help utilities who cannot generate enough renewable energy to meet requirement to comply with their renewable energy obligations. Renewable energy producers are credited with one REC for every 1,000 KWh of electricity they generates in states with REC market. A certifying agency gives each REC a unique identification number to make sure it does not get double-counted. The green energy is then fed into the electrical grid (by mandate), and the accompanying REC can then be sold on the open market.

2.3 How It Works: Rights and Duties in RPS Institution

According to RPS, selected electric utilities have the duty to maintain their sales of eligible renewable energy resources no less than the minimal requirement, which is usually a percentage of the entire electric-generating energy package. However, some states' RPS policies cover only some kinds of utilities, which means some utility companies are exempt. For example, in

Arizona, investor-owned utilities and electric power cooperatives serving retail customers in Arizona must comply, while distribution companies with more than half of their customers outside Arizona are exempt.

Moreover, some states have RPS policies that are enforced through credit-trading mechanism. If a utility produces more renewable-generated electricity than its individual requirements, the utility can either sell the extra REC to another utility or instead retain it for future use. If the utility generates less renewable energy than required, the utility has the duty to buy the credits to meet the requirement. At the end of every compliance year, the administrators calculate whether or not the utility has met the requirement. If it has not, the utility has the duty to compensate the shortage in a specified period but also the right to choose whether it will meet this requirement by its own production or purchasing RECs from other producers. Otherwise, the utility will be fined in states with a financial penalty system.

2.4 Previous Literature on RPS Impacts and Effectiveness

As many U.S. states and other countries have RPS policies, both economists and policymakers are interested in the effectiveness and efficiency of these policies. Research first focused on these renewable energy policies in the 1990s. Deregulation and liberalization in industrialized countries has led to the introduction of competition in the formerly strongly regulated power markets. As a result, using price regulation mechanisms to favor renewable energies is considered inappropriate, because they distort the competitive market. It is under this situation that some economists offered theoretical analyses of the Renewable Portfolio Standards

(Rader and Norgaard 1996) and compared RPS with traditional regulations (Espey 2001). These researchers analyzed the advantages and disadvantages of RPS theoretically without empirical evidence.

Many case studies (Gouchoe et al. 2002, Langniss and Wiser 2003, Olher 2010) examine the experience of some RPS states. Langniss and Wiser (2003) report positive results on the deployment of RPS in Texas, which is one of the biggest energy producing states with large amounts of potential wind energy. Gouchoe and his colleagues (2002) examined ten state financial-incentive programs in six states using a case-study approach in order to clarify the key factors—both internal and external to the program—that influence their effectiveness at stimulating deployment of renewable energy technologies. Olher (2010) emphasizes the indirect impacts associated with Illinois' RPS (enacted in 2007) including a change in the laws concerning the planning and zoning for wind energy, development of a market for renewable energy credits, and awareness of problems with the transmission grid.

As experience has accumulated, historical data after the deployment of RPS is available for research. Ohler (2009) uses data from 1990-2006 that covers the sixteen states that enacted and began enforcing an RP standard to evaluate the impact of RPS policies on renewable shares and electricity prices. He attempts to estimate impact of RPS separately for each state, finding that the direction and magnitude varies across states. For some states, RPS policies have positive effects on renewable energy shares and prices, while the effect is negative in other states.

Other researchers (Carley 2009, Powers and Yin 2010) use state-level panel data to evaluate the average impact of RPS. Carley (2009) uses a variant of a standard fixed effects model, referred to as fixed effects vector decomposition, with state-level data from 1998 to 2006. His findings indicate that RPS implementation has positive effect on the total renewable energy generation but is not a significant predictor of the renewable energy share. In contrast, Yin and Powers (2010) suggest a significant and positive effect of RPS on renewable energy share. They introduce a new measure for the stringency of RPS that explicitly accounts for some RPS design features that may have a significant impact on the strength of an RPS. However, they only estimate the effect on renewable energy share in capacity rather than in generation. The Energy Information Administration (EIA) altered its definition of renewable energy in 2000, which makes it difficult to collect annual renewable generation data under the same statistical standard within their panel data from 1993 to 2006. Our article solves the problem by recalculating the annual renewable generation under the same definition of renewable energy during this period. Yin also collaborated with Lyon to study the determinants of RPS adoption (Lyon and Yin 2007). They find that states with poor air quality, strong environmental preferences among the public and the state legislature, and the presence of organized renewable developers are more likely to adopt RPS policies.

Apart from the impact on renewable energy shares, some papers evaluate the impact of RPS policies on electricity prices. Palmer and Burtraw (2005) conclude that RPS policies could raise economic costs and electricity prices. Bernow and his colleagues (1997) suggest a national RPS with tradable credits would have little impact on market prices of electricity. Elliot et al (2003), however, predicts a lower price after the enactment of RPS policies. Fischer (2006) argues that it is the relative elasticities of electricity supply from both fossil and renewable energy sources, as well as the availability of other baseload generation, that leads to the different directions of effects in previous studies.

2.5 Development of RPS and Selected Variables

Olher (2009) and Carley (2009) both indicated that RPS policies have demonstrated positive returns in some states while other states might still struggle in developing renewable energy. It is predictable that the trend of these variables varies across state. This article compares between states with different features to exploit in what kinds of state do RPS work well.

In order to briefly explore the possible different effect of RPS in different states, this subsection graphs the trend of adjusted RPS annual target and other variables from 1990 to 2008 for groups of states with different features and compares those variables across the groups. The selected variables include the renewable energy shares in electricity capacity and electricity generation that is non-hydro renewable, and the average retail real electricity price in all sectors (2008 cent/KWh). The data sources of these variables are explained in Section 5.

Before comparing states with different characteristics, Figure 2.3 graphs the average level of adjusted RPS annual target and selected variables for all the contiguous 48 states year by year from 1990 to 2008.

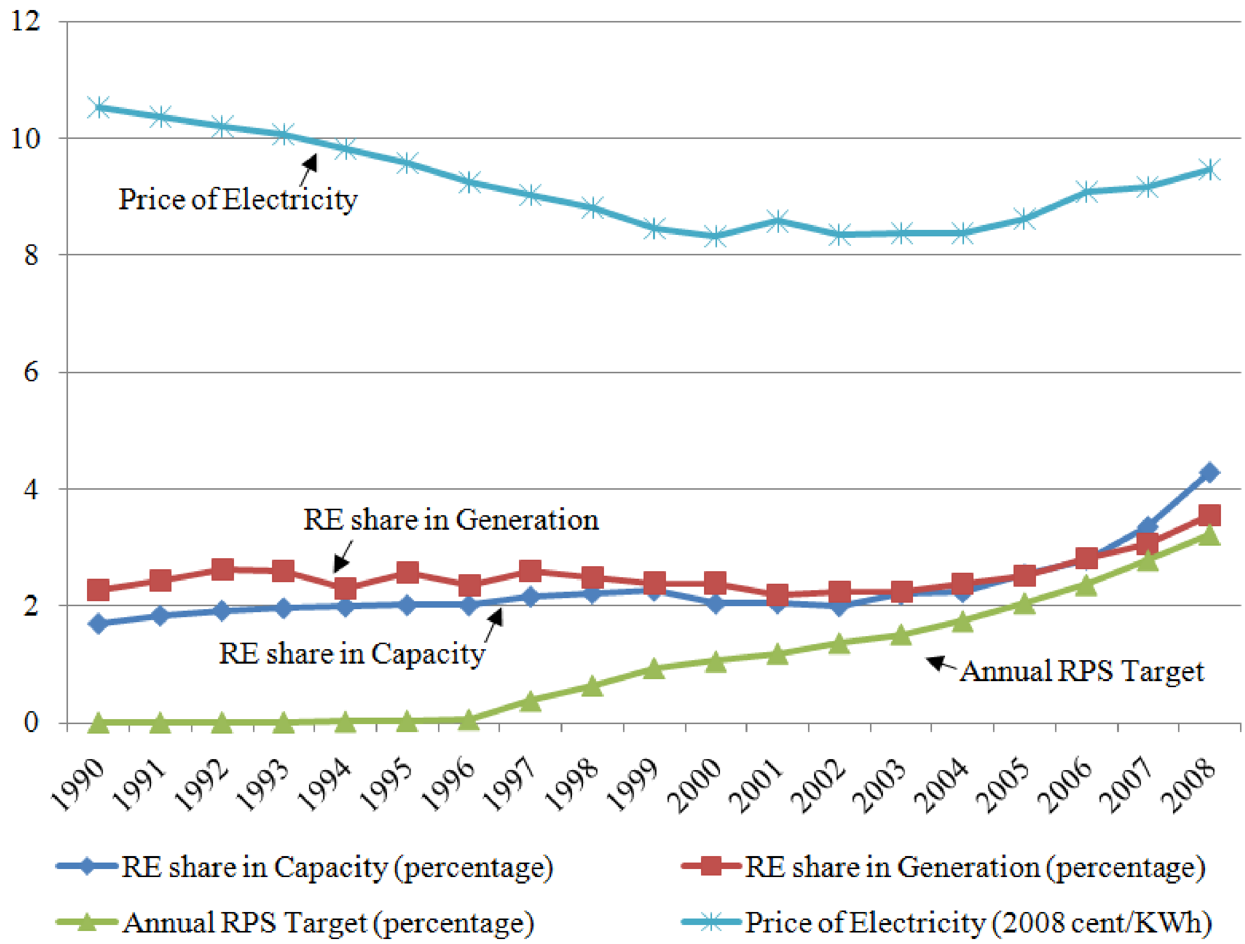

Figure 2.3 RPS annual target and key variables for 48 lower states

According to the graph, both the renewable energy shares in capacity and in generation keep constant during 1990's but both apparently start increasing since the beginning of 21 century when more and more states enact RPS that increases the average adjusted RPS annual target year by year. The growth rate in capacity is higher than that in generation. However, both the growth rates of renewable energy share in capacity and generation are lower than the growth rate of annual RPS target, which implies that one percentage increase in annual RPS target can cause less than one percentage increase of in capacity and generation. The real electricity price first decreases in the 1990's, then keep constant at the beginning of the 2000's, and finally start to increase since 2005.

2.5.1 Northeast vs. Midwest vs. South vs. West

States in the same region have something in common such as energy potential, industry distribution, REC market and so on. Therefore, it is possible that RPS are more likely to be relatively attractive renewable energy policies in some regions while unattractive policies in other regions.

Figure 2.4 gives the average level of adjusted RPS annual target and selected variables for each of the four regions, including the Northeast, Midwest, South, and West. First, the Northwest has the highest average RPS annual target level and the highest electricity price among all the regions. However, both the real renewable energy share in capacity and generation did not witness apparent increase within these 19 years. Second, the RPS annual target is not that strict in the Midwest but the renewable energy share in both the capacity and generation increases very fast, especially in recent years. At the same time, the price increase is slower than that in other regions. Third, it is easy to conclude that RPS policies are not that popular in South by Figure 2.4. The average RPS annual target is zero until 2005 and still under 1 percentage in 2008. And the renewable energy share in capacity and generation both stay around 2 percentage during these 19 years without significant increase. Finally, the West is another region that has strict RPS on average. However, in contrast to the Northeast, renewable energy share in capacity and generation grew quickly following 2000.

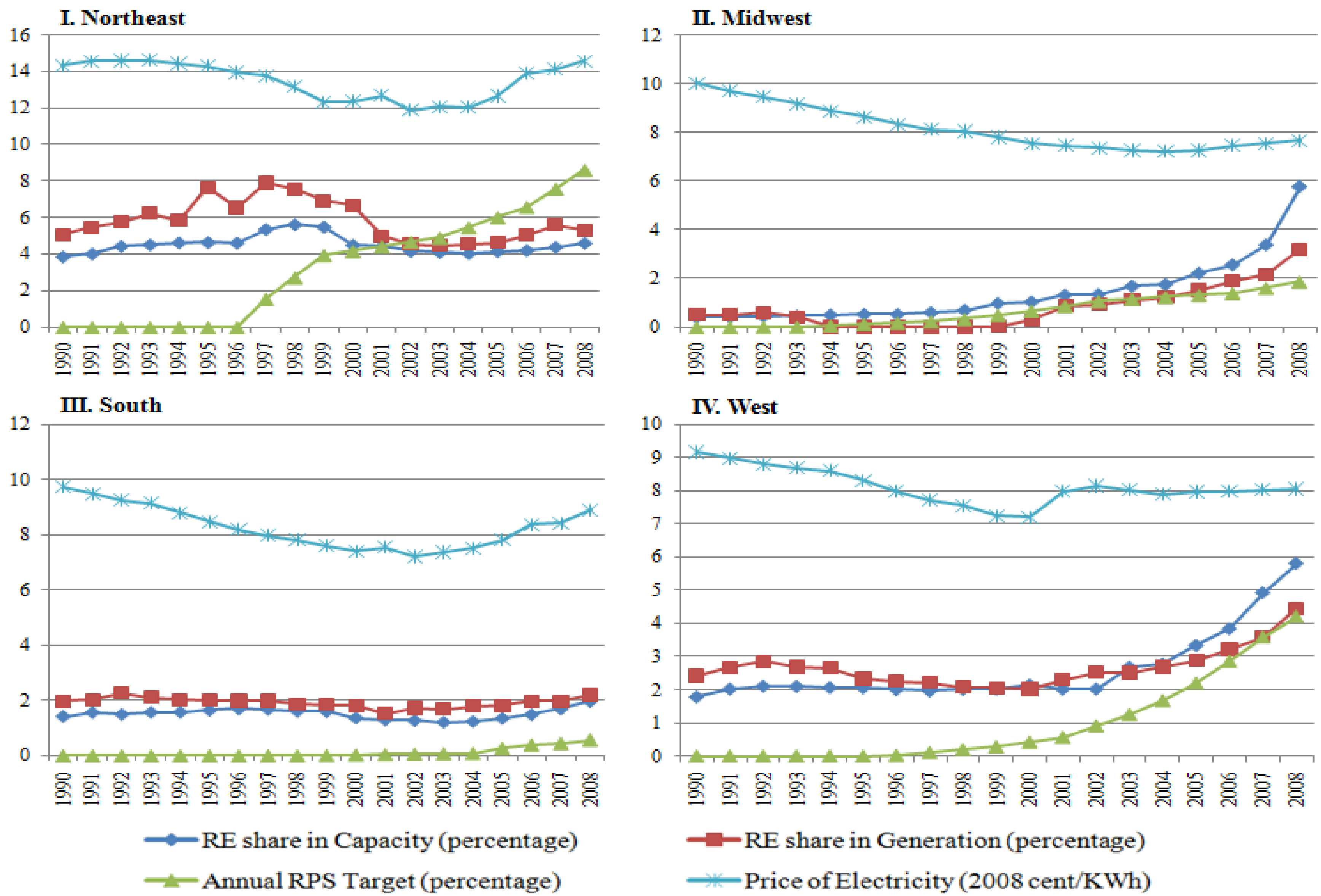

Figure 2.4 RPS annual target and key variables for each region

This figure implies that it is more likely that RPS policies functioned well in Midwest and West. States in Northeast have promoted the strictest policies but might not be on track to meet their RPS requirement. The problem of estimating the effect of RPS in the South is that RPS policies have not been adopted widely in those states.

2.5.2 Early-RPS States vs. Late- RPS States vs. Non-RPS States

Section 2.1 mentions there are two phases when many states enacted RPS intensively. This article divides the 48 lower states into three groups: 13 early-RPS states that enacted and enforced RPS no later than 2003; 15 late-RPS states enacted and enforced the policies since 2004; 20 non-RPS state that never adopt RPS.

Figure 2.5 graphs the selected variables for each of the three groups. It is clear that even without RPS policies, renewable energy share would likely have increased since renewable energy shares increased in non-RPS states. On the other hand, the incentive of RPS is not significant until around 2004 because early adopted states have no significant increase in renewable energy share in capacity and generation before 2004.

Figure 2.6 gives another perspective by directly comparing each of the features including renewable energy share in capacity, renewable energy share in generation, adjusted RPS annual target, and real electricity prices cross these three groups over time, respectively.

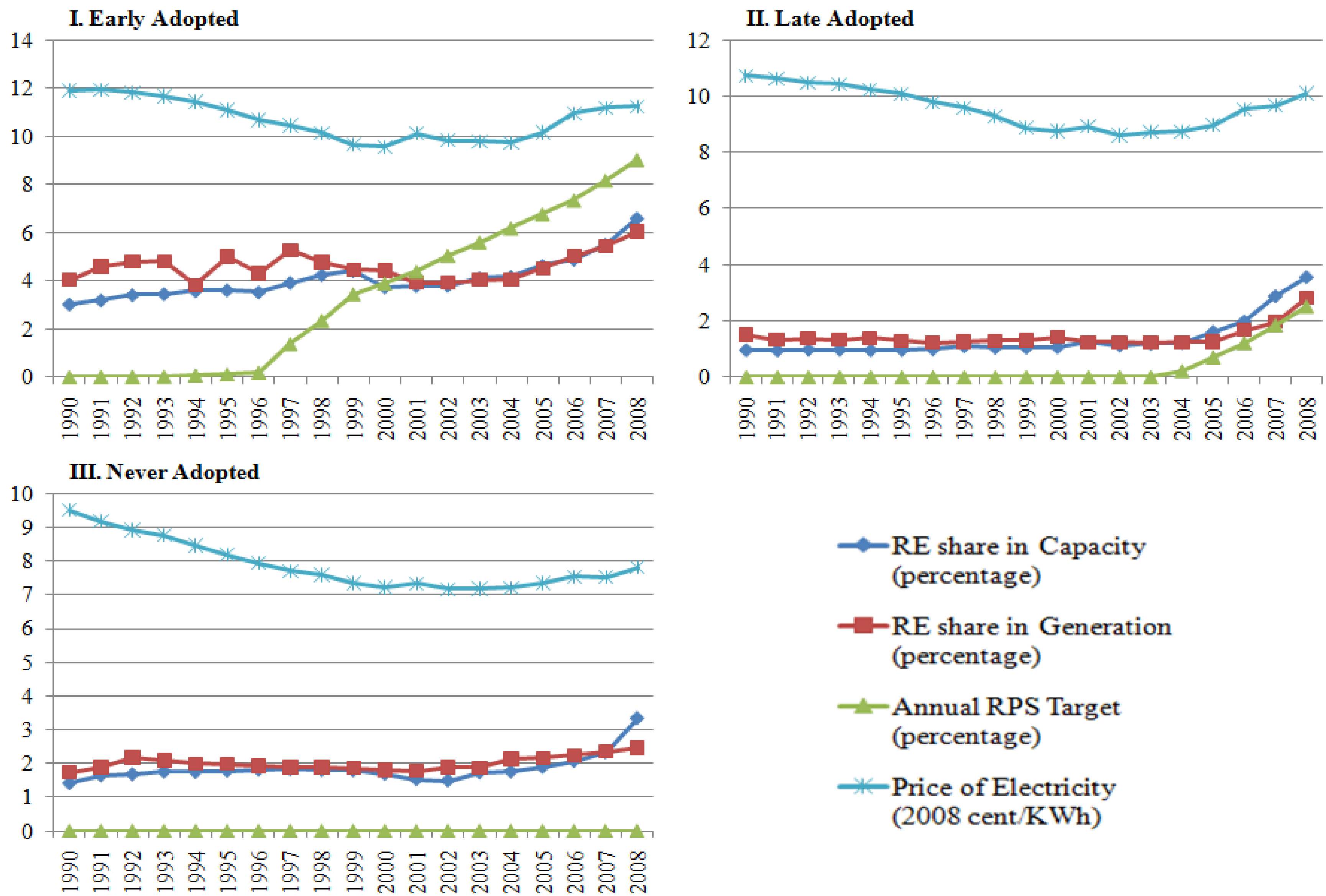

Figure 2.5 RPS annual target and key variables for early-RPS, late-RPS, and non-RPS state

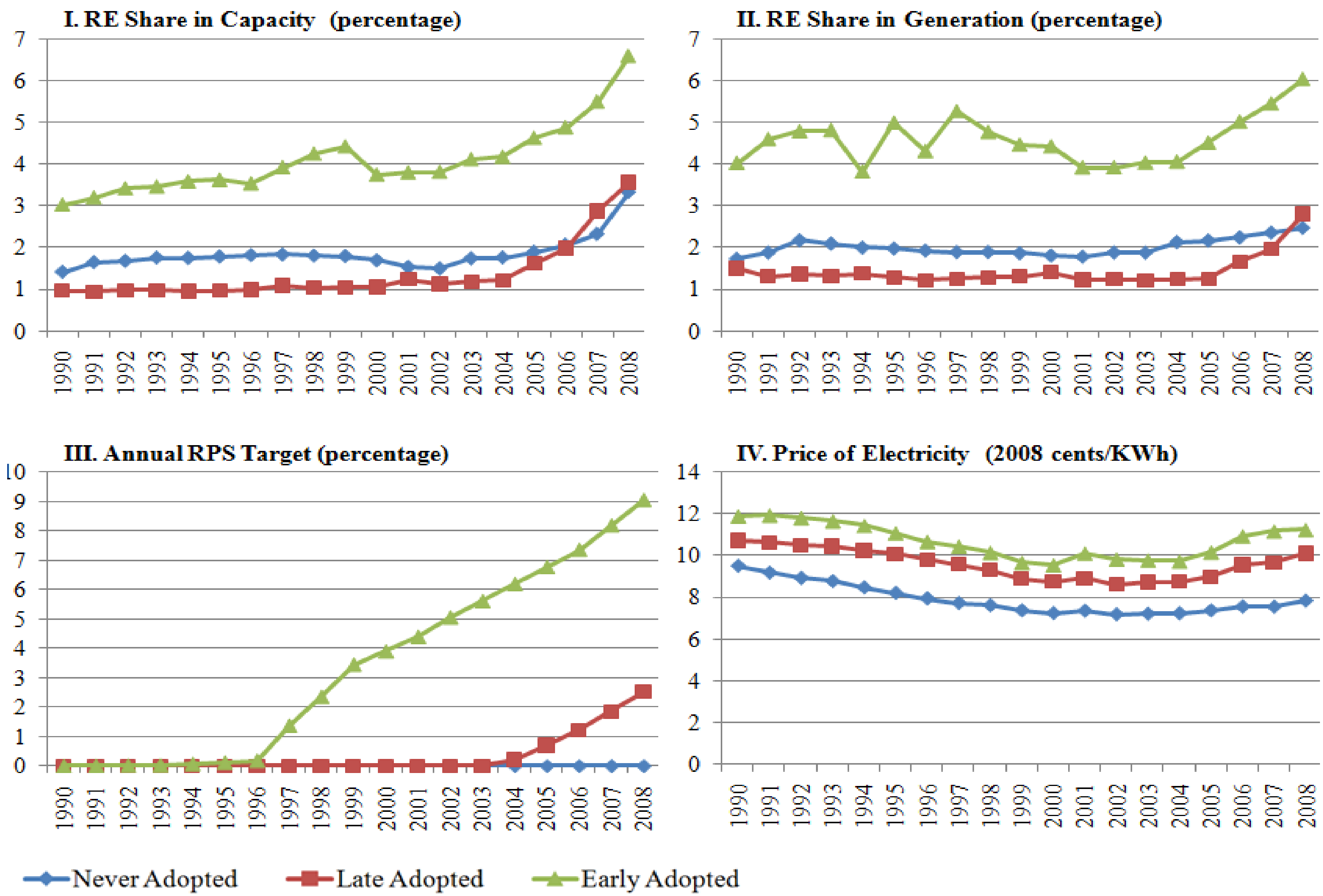

Figure 2.6 Comparison in key variables among early-, late-, and never-adopters

Figure 2.6 - I and II show the renewable energy share in capacity and generation from 1990 to 2008, respectively. According to the figure, "early adopters" are significantly different from "late adopters" and "never adopters" in three aspects: 1) they have higher renewable energy during the period; 2) develop faster with a larger gap in 2008 than in 1990; and 3) the ratio fluctuates up and down with a bigger standard deviation. The difference between "late adopters" and "never adopters" is not that obvious before 2005. However, the average renewable energy shares of "late adopters" increases faster than that of "never adopters" since 2004 when "late adopters" started enacting and enforcing RPS one by one. These findings imply that RPS policies are likely to significantly encourage the development of renewable energy industry since 2004 and "early adopters" have a better foundation of renewable energy investment than "late adopters" and "never adopters". On the other hand, the different trends in generation during the 1990's across groups when most states have no RPS implies that states might have different trends in absence of the policies in later years.

Figure 2.6 - III and IV show the annual RPS target and real electricity price from 1990 to 2008, respectively. "Early adopters" on average has the highest electricity price while "never adopters" on average has the lowest price during this period. However, the average real price first decreases and then increases with almost the same trend among groups. The tiny little increasing gap between RPS states ("early adopters" and "late adopters") and non-RPS states ("never adopters") might indicate that enacting RPS could slightly increase electricity price.

2.5.3 Low vs. Medium vs. High States in Renewable Energy Potentials

The development of renewable energy industry and the incremental renewable energy share in a state might be based on the renewable energy potential, mainly solar, biomass, and wind. This article assumes states with higher renewable energy potential will have more incentive for renewable energy producers to invest renewable energy installment, which might increase the renewable energy share in capacity and generation. The following three subsections compare states by their potential in solar, biomass, and wind, respectively.

2.5.3.1 Solar Energy Potential

National Renewable Energy Laboratory (NREL) developed a sun index which is defined as an index of the amount of direct sunlight received in each state and accounts for latitude and cloud cover[5]. This article derives a new solar energy index, *SOLAR* with a mean of 1 for 48 states.

48 lower states have been divided into three groups according to their ranks in *SOLAR*: 16 low solar states with the lowest value of this solar index; 16 medium solar states in the middle of the ranking list; and 16 high solar states with the highest value of solar index.

Figure 2.7 and Figure 2.8 gives the comparison of key variables of low-, medium-, and high-solar states from different perspectives. They show that the effect of RPS is more significant in medium and high solar states with a richer solar energy index. The renewable energy share in capacity and generation in the early 1990's is all around 2 percent across group. This implies that high solar states have no obvious incentive to invest on renewable energy at that

[5] The amount of direct sunlight was derived from the Renewable Resource Data Center. The sun index was calculated as the average hours of peak direct sunlight hours per year for 1960-1990.

time. The average adjusted RPS annual targets in rich solar states are not higher than low solar states, which imply rich solar states have no significant incentive to enact or strengthen this renewable energy policy. However, the growth rate of renewable energy share is lower, equal, and higher than the growth rate in RPS annual target in low-, medium-, and high solar states respectively. Therefore, a possible reason is that the magnitude of RPS effect on renewable energy share is based on its solar energy potential.

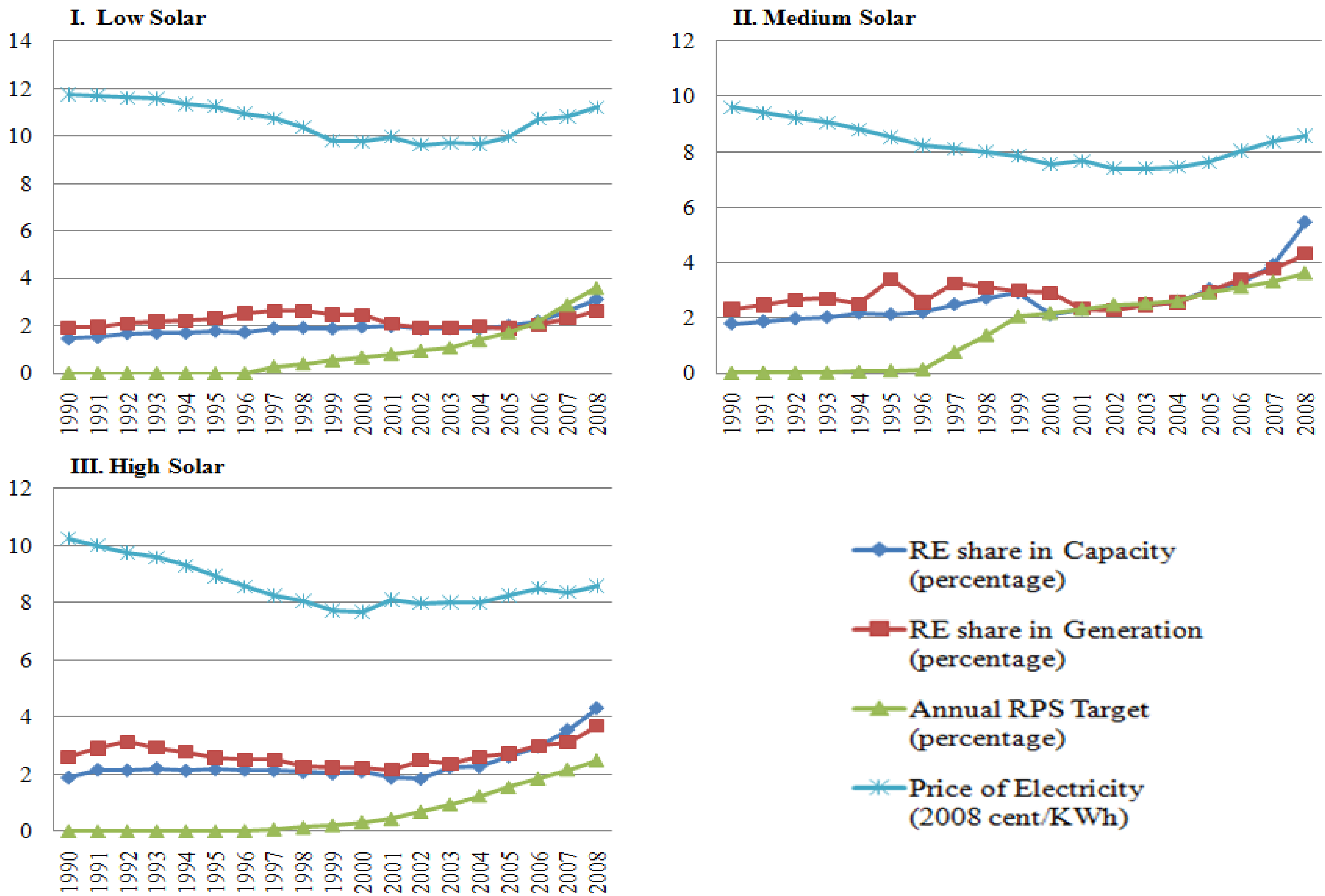

Figure 2.7 RPS annual target and key variables for low-, medium-, and high-solar states

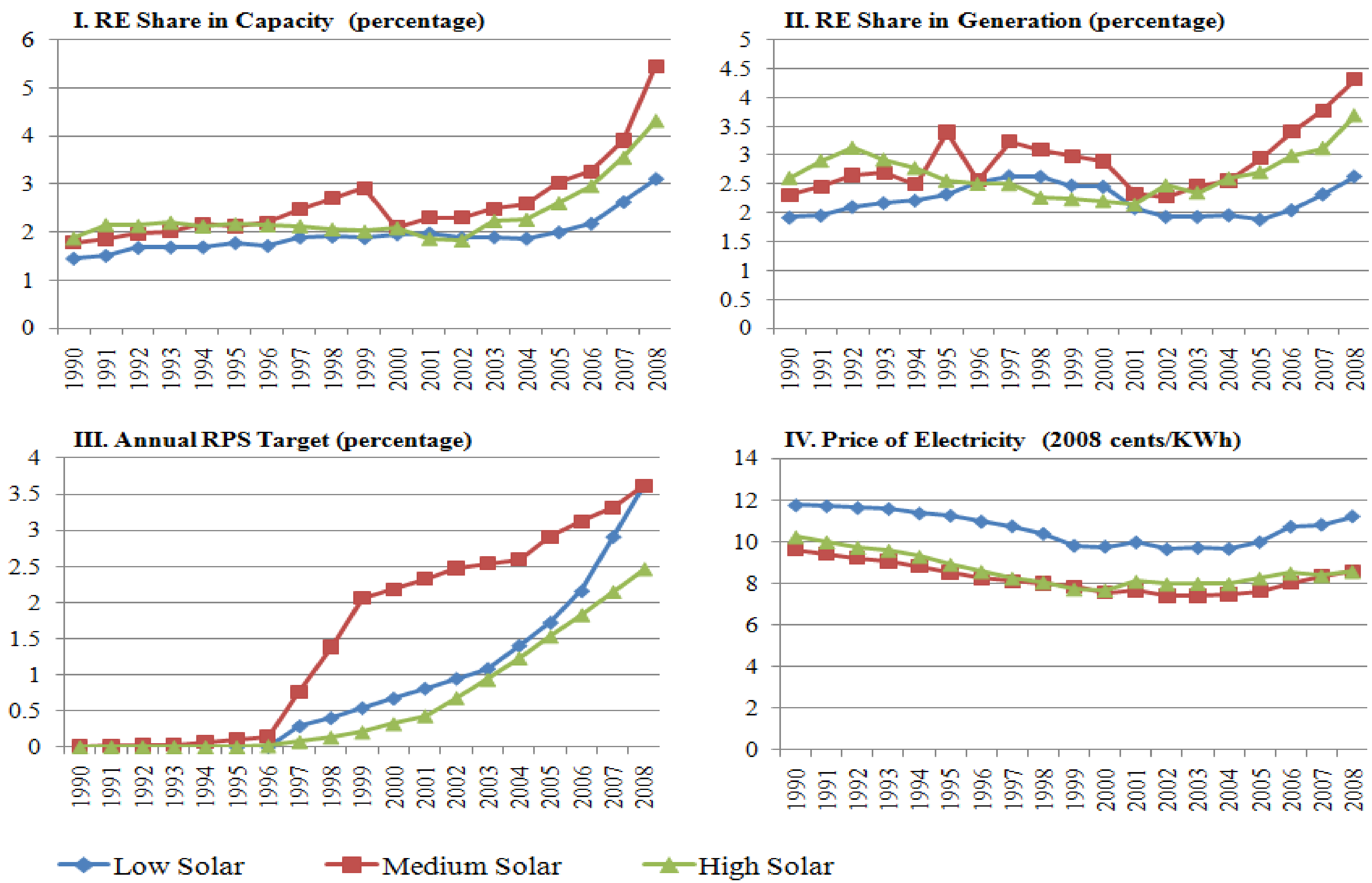

Figure 2.8 Comparison in key variables among low-, medium-, and high-solar states

2.5.3.2 Biomass Energy Potential

Biomass energy is another important renewable energy source. Bioenergy Feedstock Information Network (BFIN) collected data of an Estimated Annual Cumulative Biomass Resources Available (dry million ton/year) when delivery cost is less than $50. Based on the variable, this article develops a biomass energy density, *BIOMASS*, which indicates the biomass resource per unit area with a mean of 1 for 48 states.

Similar as section 2.5.3.1 about solar energy, 48 lower states here have been divided into three groups according to their ranks in *BIOMASS*: 16 low biomass states with the lowest value of this biomass index; 16 medium biomass states in the middle of the ranking list; and 16 high biomass states with the highest value of biomass index.

Figure 2.9 and Figure 2.10 gives the comparison of key variables of low-, medium-, and high-biomass states from different perspectives. They show that states with low biomass energy density have higher renewable energy level during 1990's and higher RPS annual target. However, after the deployment of RPS, high biomass states with highest biomass density have higher growth rate in renewable energy share. This result also shows that biomass energy potential might not be an incentive for renewable energy share without the deployment of RPS. But states with higher biomass energy potential can benefit more on renewable energy development once they enacted RPS.

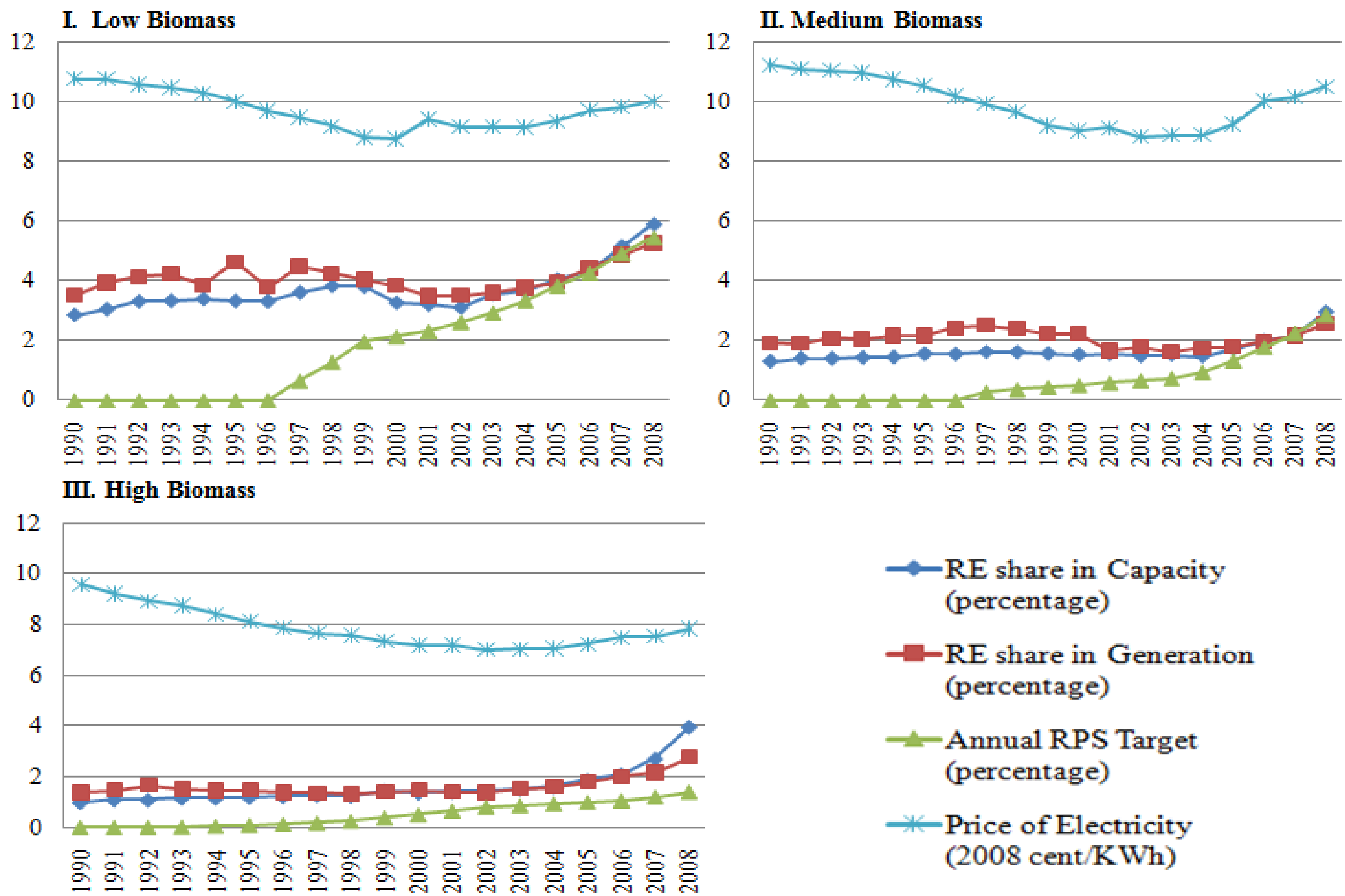

Figure 2.9 RPS annual target and key variables for low-, medium-, and high-biomass states

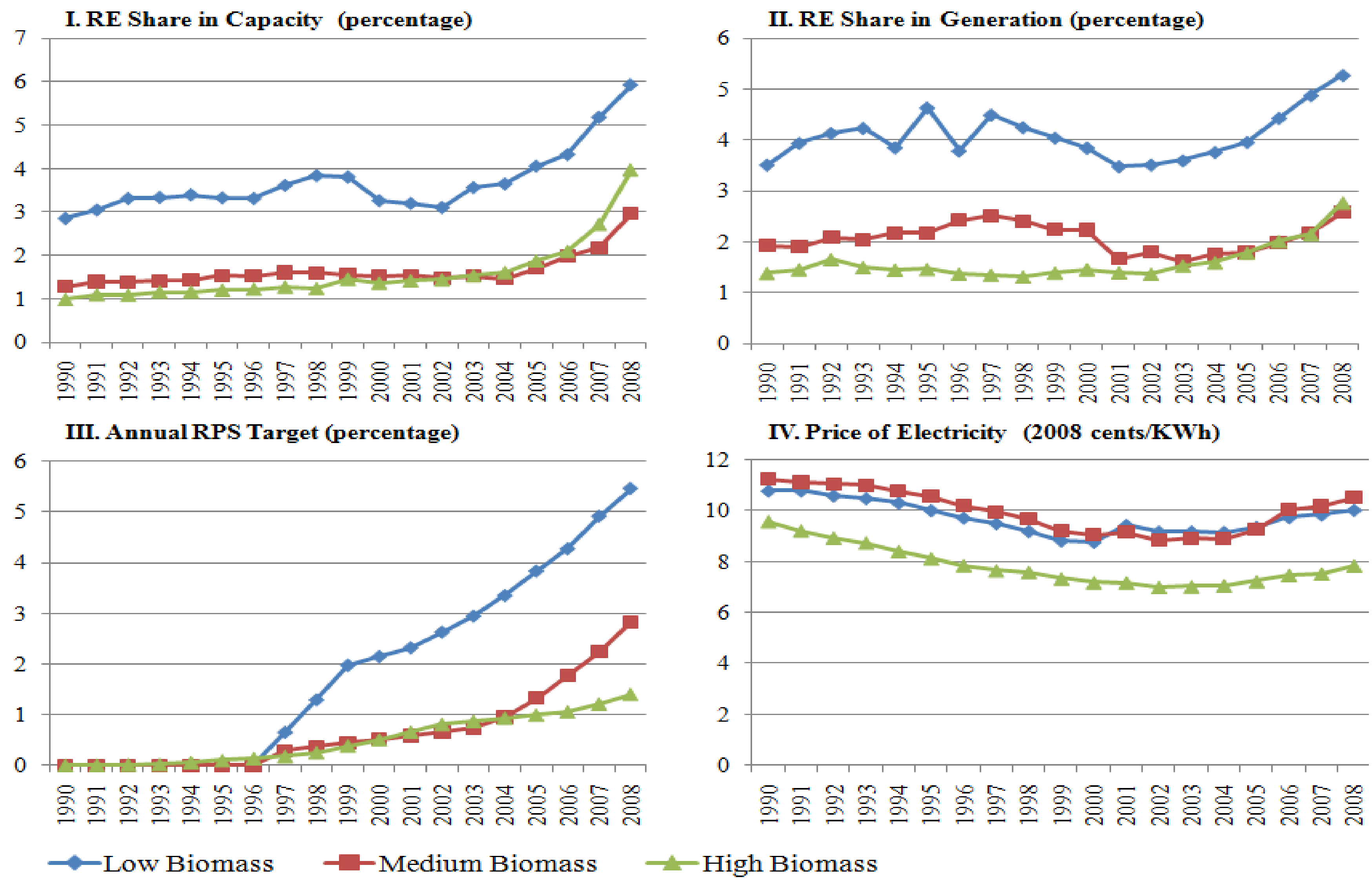

Figure 2.10 Comparison in key variables among low-, medium-, and high-biomass states

2.5.3.3 Wind Energy Potential

The U.S. Department of Energy's Wind and Water Power Program published Wind Potential Annual Generation[6] for each state. Based on this variable, a wind energy potential density index, *WIND*, can be derived to show the wind potential per unit area with a mean of 1 for 48 states.

48 lower states again have been divided into three groups according to their ranks in *WIND*: 16 low wind states with the lowest value of this wind index; 16 medium wind states in the middle of the ranking list; and 16 high wind states with the highest number of wind index.

Figure 2.11 and Figure 2.12 gives the comparison of key variables of low-, medium-, and high-wind states from different perspectives. They show that renewable energy industries in states with highest wind potential density are almost zero until 1998. States with middle level of wind potential density develops renewable energy earlier in the 1990's and the RPS policies are stricter with a higher average annual target but renewable energy shares do not witness significant increase. States with poor wind potential also haven't received big benefit from RPS. However, although the average annual target in states with highest wind potential are not very high, the renewable energy industry witness big improvement after 2000 when more and more states enact RPS.

---

[6] Wind Potential Annual Generation (GWh) for areas>=30% capacity factor at 80 m. Data is available at http://www.windpoweringamerica.gov/wind_maps.asp.

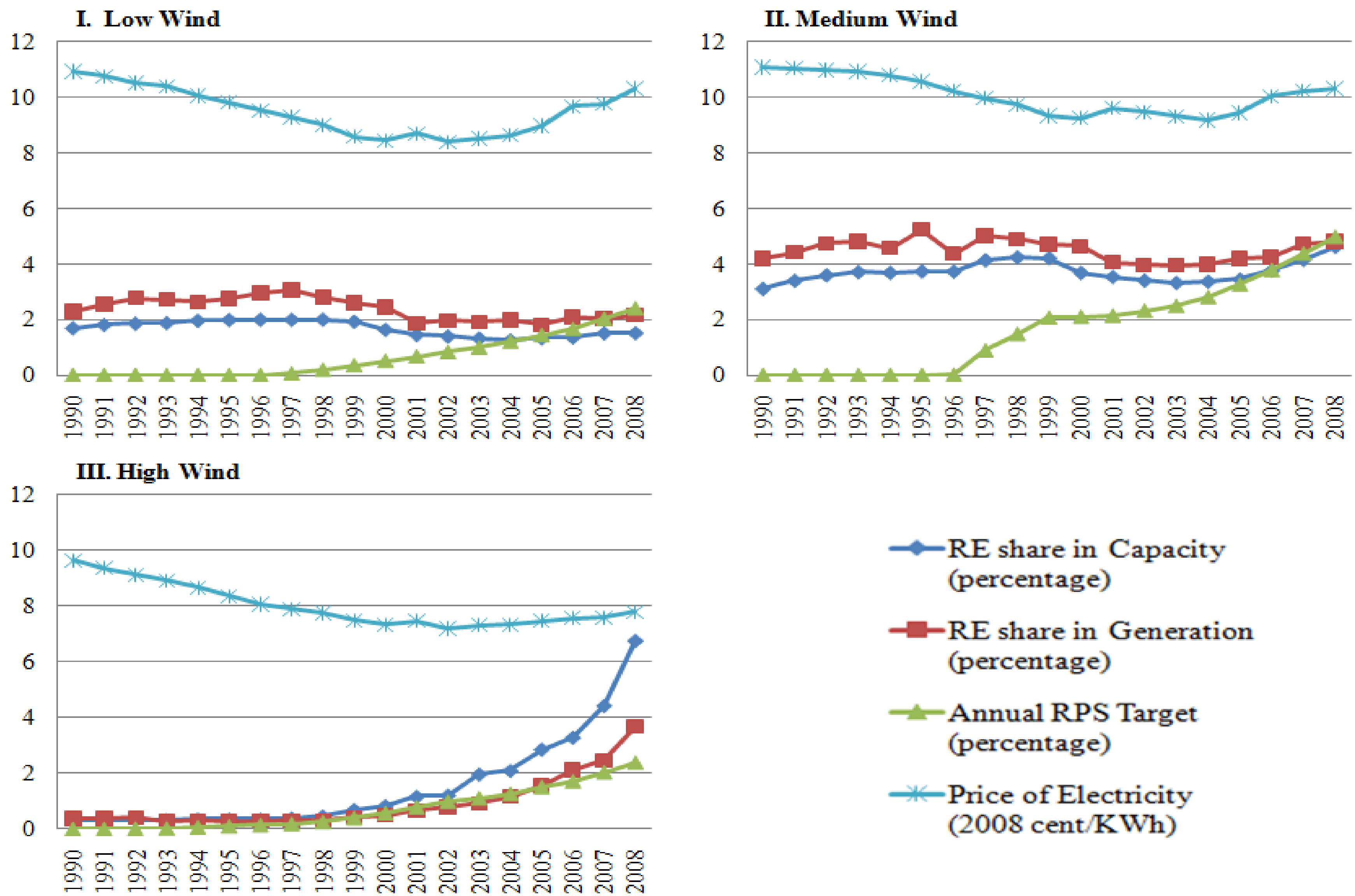

Figure 2.11 RPS annual target and key variables for low-, medium-, and high-wind states

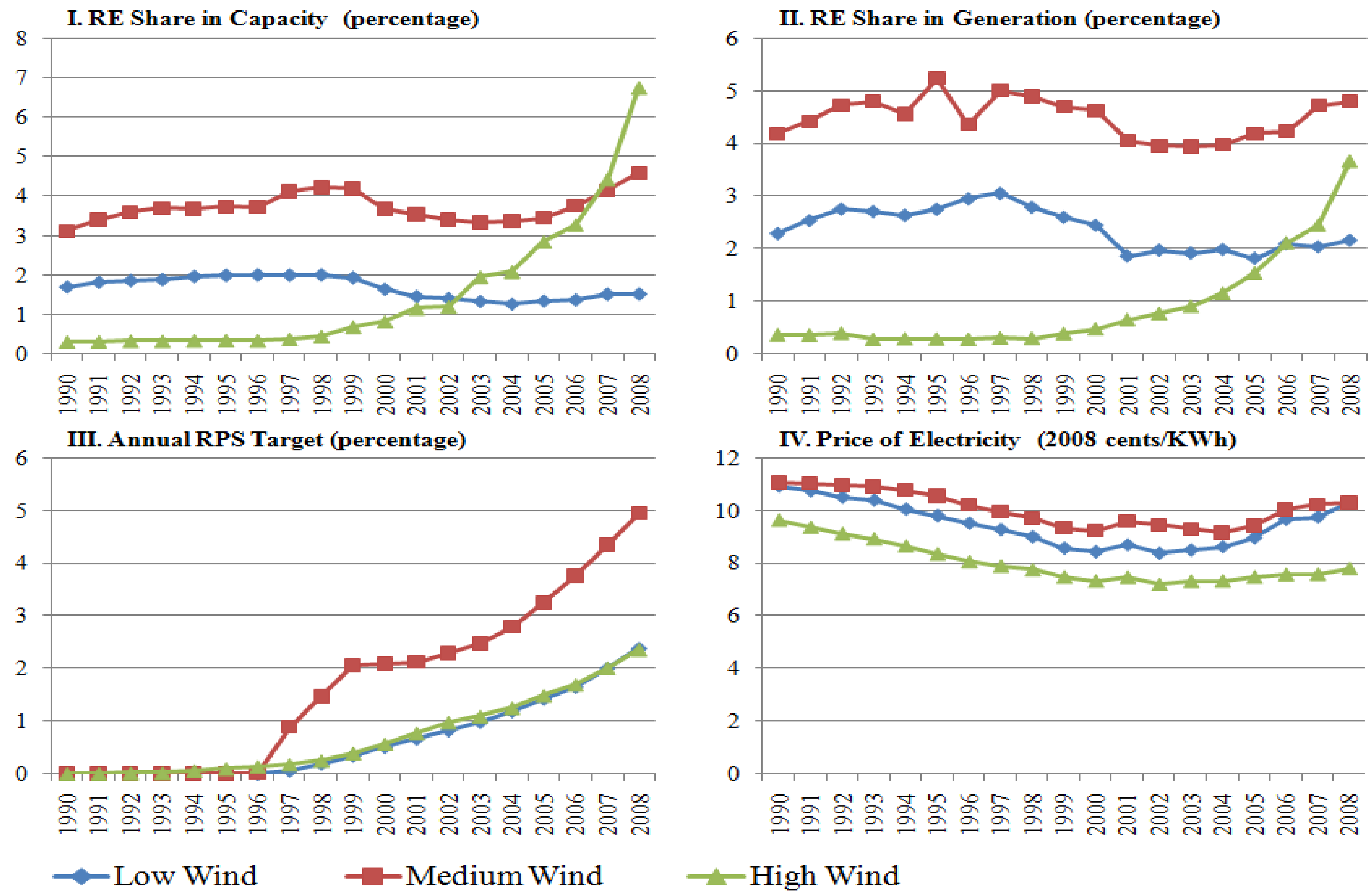

Figure 2.12 Comparison in key variables among low-, medium-, and high-wind states

2.5.3.4 Conclusion on Renewable Energy Potential

According to the analyses above, states with rich renewable energy potential have no significant incentive for earlier investment of renewable energy industry and earlier deployment of RPS policies. But once those states have the policies, they are more likely to see greater improvement of the renewable energy industry. Therefore, it is likely that the effect of RPS partially depends on the renewable energy potentials. Therefore, adding the interactions between the policies and the renewable energy potential is an eligible concern to catch the partial effect of RPS.

However, this fact could be the result of trends that would have happened anyway. More specifically, the RPS might have no effect and the underlying trend is different across states. If this is the case, the different trend in renewable energy development might depend on renewable energy potential since the average trend increases faster in states with high renewable energy potentials. One possible reason is that the technology for renewable energy is improving over time and hence the advantages of states with high renewable energy potentials can be expend in recent years, which leads to a faster increase in renewable energy development in absence of RPS. Thus, the interactions between renewable energy potential and time could also be added into the model to observe this possible assumption.

2.5.4 Before vs. After the deployment of RPS

This article has compared selected variables between states with different features above. However, states in the same group did not enact RPS in the same year in those comparisons. In order to reflect the effect of RPS more precisely, Figure 2.13 graphs the simple relationship between key variables and the deployment of RPS. The bottom axis shows the years before and after each state enacted RPS, and year 0 is the first year in which each state deployed the policy. Though some caution is needed in reading Figure 2.13 because nothing else is being controlled for across state, it shows on average the economic performance before and after the deployment of RPS.

It shows that the real electricity price stops decreasing after the deployment of RPS. Compared with OLS regression line derived by the last four years' data before the enactment of RPS which can estimate the future price if nothing changes, the real world real electricity price after the deployment of RPS is above the OLS regression line. This implies that enacting RPS might increase the price of electricity. Renewable energy share in capacity increases but the renewable energy share in generation has no significant increase after the enactment of RPS. Again, compared with what the OLS regression line estimated if each state doesn't pass RPS, the real renewable energy share in capacity after RPS is higher than expected while the real renewable energy share in generation is almost the same as predicted, which implies RPS might have positive effect on renewable energy share in capacity but have no significant or even negative effect on renewable energy share in generation.

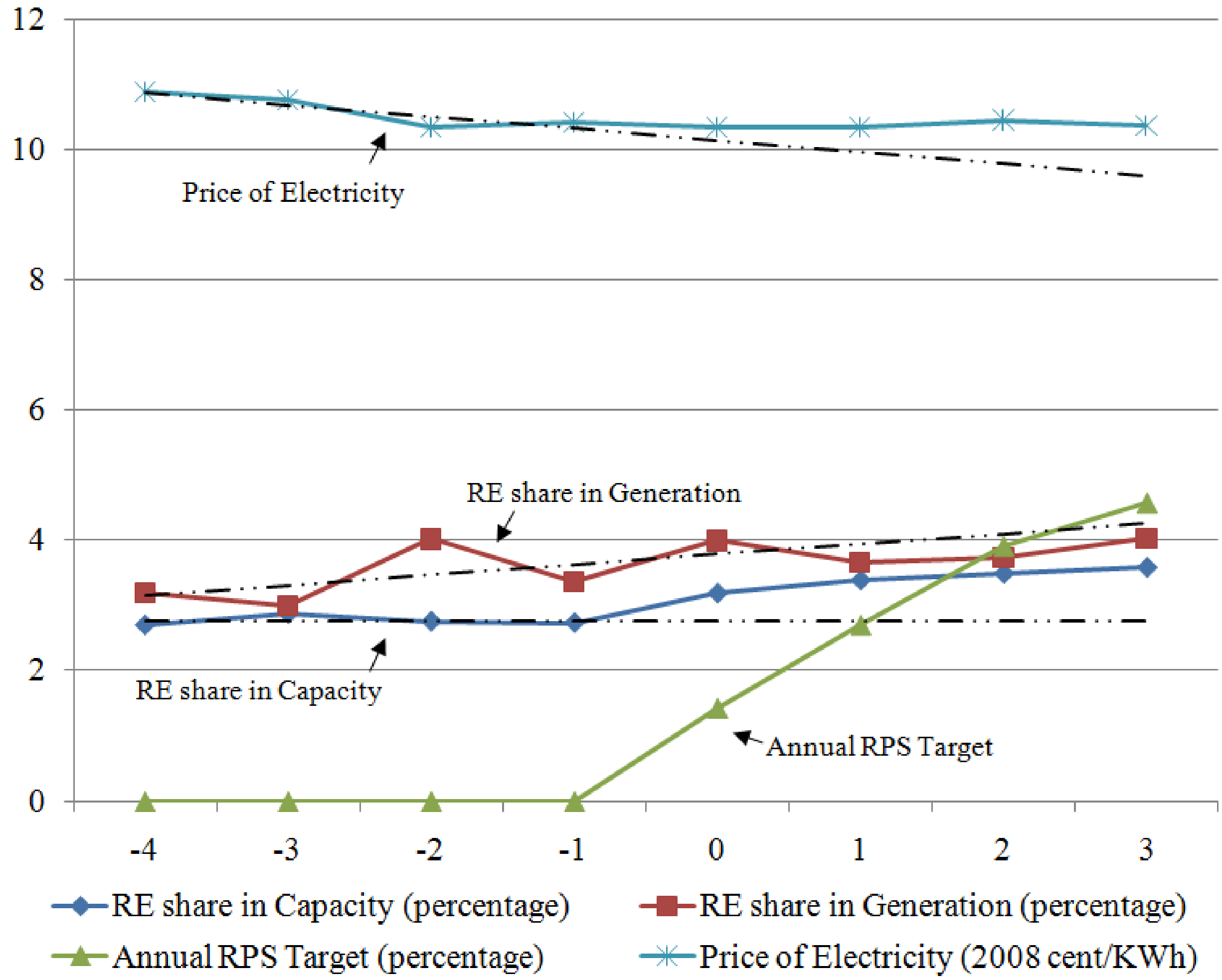

Figure 2.13 RPS annual target and key variables before and after the deployment of RPS

Notes: a) This figure shows the average of 18 states including AZ, CA, CT, ME, MA, MN, NV, NJ, NM, PA, TX, and WI (Early Adopters) and CA, CO, DE, MD, MT, NY, and RI (Late Adopters). IA, IL, KS, MI, MO, NH, NC, OR, OH, WA are not in the group because the dataset from 1990 to 2008 cannot cover some of eight years around the deployment for those states. b) The horizontal axis shows the years before and after each state enacted RPS. Year 0 is the first year in which each state deployed the policy. c) the dotted lines represent the OLS regression lines for ONLY the last four years before the deployment of RPS, which implies the trend in absence of RPS.

To sum up, when other factors not controlled, the correlation between RPS and electricity price is significantly positive. On the other hand, renewable energy share in capacity is also very likely to increase because of RPS while renewable energy share in generation might not be stimulated by the policies. However, the effect of RPS might vary across region. What's more, although more renewable energy potential cannot directly encourage the development of renewable energy industry and the deployment of RPS, states with rich renewable energy potential might be more likely to achieve their primary goal and develops renewable energy investment when they passed their RPS policies.

2.5.5 Features in Each States

Section 2.5 groups states based on features including region, adoption time, solar potential, biomass potential, and wind potential and compares the key variables across groups. Table 2.1 gives the groups that each state belongs to in this section.

Table 2.1 Groups that each state belongs to

Feature / State	Region	Enactment	Solar	Biomass	Wind	Included
Section #	2.5.1	2.5.2	2.5.3.1	2.5.3.2	2.5.3.3	2.5.4
Alabama	South	Non-RPS	Medium	High	Low	No
Arizona	West	Early-RPS	High	Low	Medium	Yes
Arkansas	South	Non-RPS	High	High	Medium	No
California	West	Early-RPS	High	Low	Medium	Yes
Colorado	West	Late-RPS	High	Low	High	Yes
Connecticut	Northeast	Early-RPS	Low	Medium	Low	Yes
Delaware	South	Late-RPS	Medium	Medium	Low	Yes
Florida	South	Non-RPS	High	Low	Low	No
Georgia	South	Non-RPS	High	Medium	Low	No
Idaho	West	Non-RPS	High	Low	Medium	No
Illinois	Midwest	Late-RPS	Low	High	High	No
Indiana	Midwest	Non-RPS	Low	High	High	No
Iowa	Midwest	Early-RPS	Medium	High	High	No
Kansas	Midwest	Late-RPS	High	Medium	High	No
Kentucky	South	Non-RPS	Medium	High	Low	No

Table 2.1 (cont'd)						
Louisiana	South	Non-RPS	Medium	High	Low	No
Maine	Northeast	Early-RPS	Medium	Low	Medium	Yes
Maryland	South	Late-RPS	Medium	Medium	Medium	Yes
Massachusetts	Northeast	Early-RPS	Low	Medium	Medium	Yes
Michigan	Midwest	Late-RPS	Low	Medium	Medium	No
Minnesota	Midwest	Early-RPS	Medium	High	High	Yes
Mississippi	South	Non-RPS	High	High	Low	No
Missouri	Midwest	Late-RPS	Medium	High	High	No
Montana	West	Late-RPS	Medium	Low	High	Yes
Nebraska	Midwest	Non-RPS	Medium	High	High	No
Nevada	West	Early-RPS	High	Low	Low	Yes
New Hampshire	Northeast	Late-RPS	Low	Medium	Medium	No
New Jersey	Northeast	Early-RPS	Low	Low	Low	Yes
New Mexico	West	Early-RPS	High	Low	High	Yes
New York	Northeast	Late-RPS	Low	Medium	Medium	Yes
North Carolina	South	Late-RPS	Medium	Medium	Low	No
North Dakota	Midwest	Non-RPS	Medium	High	High	No
Ohio	Midwest	Late-RPS	Low	High	Medium	No
Oklahoma	South	Non-RPS	High	Medium	High	No
Oregon	West	Late-RPS	Low	Low	Medium	No
Pennsylvania	Northeast	Early-RPS	Low	Medium	Low	Yes
Rhode Island	Northeast	Late-RPS	Low	Low	Low	Yes
South Carolina	South	Non-RPS	High	High	Low	No
South Dakota	Midwest	Non-RPS	Medium	Medium	High	No
Tennessee	South	Non-RPS	Medium	High	Low	No
Texas	South	Early-RPS	High	Low	High	Yes
Utah	West	Non-RPS	High	Low	Medium	No
Vermont	Northeast	Non-RPS	Low	Low	Medium	No
Virginia	South	Non-RPS	Medium	Medium	Low	No
Washington	West	Late-RPS	Low	Medium	Medium	No
West Virginia	South	Non-RPS	Low	Medium	Medium	No
Wisconsin	Midwest	Early-RPS	Low	High	High	Yes
Wyoming	West	Non-RPS	High	Low	High	No

2.6 Other Policies for Renewable Energy

Besides Renewable Portfolio Standards, there are some other rules, regulations and policies that have been implemented in some states that might change the incentives for renewable electricity investment including:

Public Benefit Funds (PBF): Many states have funds, often called "Public Benefit Funds," which typically are state-level programs developed to support energy efficiency and renewable energy projects. The funds are collected either through a small charge on the bill of every electric customer or through specified contributions from utilities. There are recently 17 states have PBF to partly subsidize renewable generation.

Net Metering: Net metering is an electricity policy for consumers who own (generally small) renewable energy facilities and produce more electricity than self-consumed and feed the extra electricity back onto the grid. Thus this is a state-level consumer-based renewable energy incentive that in 43 states encourages consumers to invest in renewable energy capacity and then sell the RECs from this generation to earn benefit.

Mandatory Green Power Option: Eight states have passed legislation that requires certain electric utilities to offer customers the option of buying electricity generated from renewable resources, commonly known as green power. Retail providers are allowed to charge extra for the "clean" electricity that is either self-generation or the renewable energy credits (RECs) brought from other renewable energy providers.

CHAPTER 3: CONCEPTUAL MODEL

This section provides a substantive framework to understanding the effect of RPS on 1) renewable energy share in both capacity and generation; 2) real price of electricity; and 3) emissions. Then, three related hypotheses of the effect on those three aspects are given for further testing. A Situation-Structure-Performance (SSP) analysis is used to identify the main sources of interdependences, the relevant structures required to sort out these interdependences, and their corresponding performance in the context of RPS.

In the impact analysis of SSP theory (see Schmid, 1987; 2001 for details), institutional alternatives (with and without RPS in this research) are an independent variable. The dependent variable is some measure of substantive performance (change in renewable energy share in capacity and generation, electricity price, and emissions in this case). Schmid (2004) in his book explains that the set of independent variables with which institutional variables interact contains those aspects of the environment (character of goods) that create human interdependence. This will be termed the "*Situation*." The "*Structure*" of institutional variables then sort out and order the interdependence and influence the outcome or "*Performance*." The functional form and diagrammatic form are also given in the book as:

Performance = function of institution X, or institution Y, holding situation constant.

and

Situation → institutional structure → performance

3.1 Effect on Renewable Energy Share in Capacity and Generation

3.1.1 Situation: Renewable Energy as Economies of Scale Good

As with fossil fuels, Economies of Scale also exists in generating renewable energy. Both fossil and renewable energy need large capital investment including land, warehouses, and equipment. However, the huge amount of existing fossil fuels capacity decreases its average cost and marginal cost. Compared with conventional energy firms that started their business one or two hundred years ago, renewable energy firms nowadays start business in a more competitive market with more low-price substitutes. Therefore there might be less space for renewable energy to expand production and enjoy the economy of scale to be market competitive without policy promotion. Even when periodic energy crises lead to significant fluctuations in fossil fuels price, which have provided renewable energy industry with some opportunities, firms still hesitate to invest in solar and wind energy even when current energy prices make the investment look profitable because they can’t be sure if the price will last.

3.1.2 Structure and Performance: A1, A2, A3 and P1, P2, P3

Figure 3.1 provides the hypothesized average cost of conventional energy and renewable energy as Economy of Scale Goods (ESG) as well as the weighted average cost of a generation portfolio that includes both conventional energy and renewable energy. The specific Alternatives (A1, A2, and A3) and Performances (P1, P2, and P3) mentioned in this subsection is listed in Table 3.1.

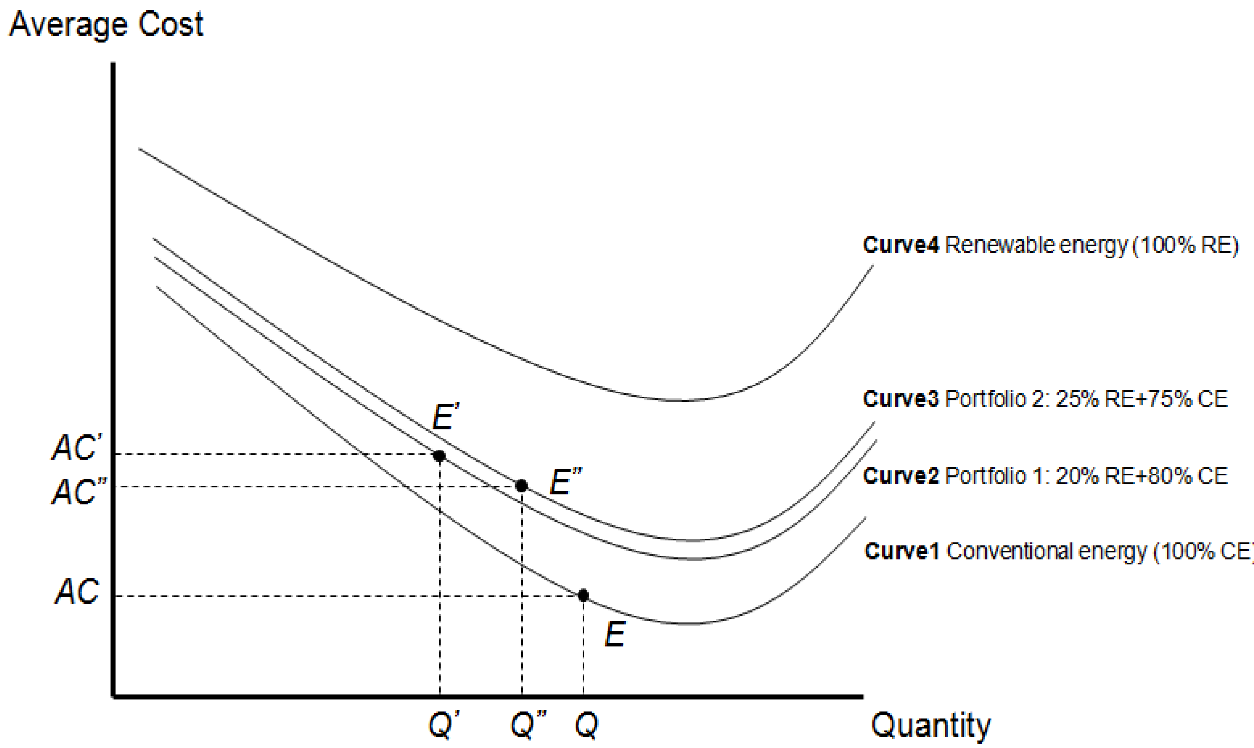

Figure 3.1 Energy generation as economy of scale goods

In this graph, the fossil fuels providers choose the equilibrium ***E*** with quantity ***Q*** and average cost ***AC*** before the support of renewable energy since curve 1 is below all the other curves. This is also the structure of non-RPS state as **A1**. Therefore, equilibrium ***E*** is the allocation of performance **P1**. This equilibrium is more likely to be unchanged without policy support because the average cost of a small generation of renewable energy is much higher than ***AC***.

After the deployment of a mandatory RPS policy that requires 20% (assumed) of renewable-generated electricity, the electricity suppliers can only make the choice above the Curve 2. Then the new average cost will be higher than ***AC***, which will change the supply curve of electricity market and decrease the electricity consumed to ***Q'*** with a new average cost of ***AC'*** if utilities choose to include exactly 20% of renewable energy in their energy portfolio. Without a REC market as **A2**, RPS policy only protect the renewable energy generated within the minimal requirement from direct compete with fossil fuels. Therefore, the performance **P2** is that no one would be likely to produce more than the minimal required amount of renewable energy.

However, if there is a REC market in the RPS state (structure **A3**), a firm's decision of whether to produce renewable energy over the minimal requirement dependent on the other firms' renewable energy cost and the market price rather than its own conventional energy cost. If the average cost of renewable energy for a firm is lower than the market average level which is the REC price, it might actually choose to produce at ***E''*** with a renewable energy share of 25% and sell the renewable energy over the minimal requirement (5%****Q''***) to other companies through REC market. This system can help further reduce the average cost of renewable energy by Economy of Scale character in intensive production of renewable energy. Therefore, the performance **P3** is that RPS might increase the renewable energy share even more than the minimal requirement.

In short, RPS can divide self-generated conventional energy and renewable energy into two markets without direct competition within the minimal requirement. What's more, the credit trading system (REC) could further help avoid self-generated renewable energy from direct competing with self generated conventional energy over the minimal requirement but competes with renewable energy generated by other utilities. To sum up, the enactment of RPS especially with a promised increasing annual target for a long-run gives renewable energy firms incentives to invest, research and develop, which increase the renewable energy generated in the energy portfolio. Table 3.1 gives Situation, Structure, and Performance (SSP) Analysis of both conventional and renewable energy as Economies of Scale Goods (ESG).

Table 3.1 SSP analysis matrix: renewable energy as Economies of Scale Goods

Situation: Physical Characteristics of goods / services that create unavoidable human interdependence.	**Structure:** Alternative institutions (rules) that determine relative rights/duties of parties.	**Performance:** Economic performance consequence of institutional alternatives.
ECS: Generation of renewable energy has declining cost for another physical unit of production. Generation of traditional energy has the same characteristic. Example: Electric utilities – cost of electricity generated by conventional energy is declining cost good; cost of electricity generated by renewable energy is declining cost good. The positive effect of ESG mainly exists ONLY within the same energy source.	A1: No renewable energy requirement. Allow convention energy and renewable energy to compete as two inputs, which means one can fully substitute the other. (It's the rule of non-RPS states) A2: Require a minimal share of input as renewable energy **with self generated price**. It implies self-generated renewable energy is prevented from direct competition with fossil fuels but ONLY within the minimal requirement. (It's the rule of RPS states without REC market) A3: Require a minimal share of input as renewable energy **with market price**. It makes self-generated renewable energy competing with renewable energy generated by other utilities rather than conventional energy BOTH within and over the minimal requirement. (It's the rule of RPS states with REC market)	P1: Renewable energy cannot provide a competitive price to conventional price under existing capacity and technology. Renewable energy share is supposed to keep in a low level in the energy portfolio. P2: Increase of renewable energy share will most likely to keep the same space as the increase in RPS minimal requirement. Exempt from direct competition with traditional energy within the minimal requirement, the increase speed of renewable energy share should be faster than P1. P3: Utilities whose self-generated price is lower than the market price can produce more renewable energy and sell the credit beyond the their minimal requirements while utilities whose self-generated price is higher than market can produce less renewable energy and buy the credit to meet the minimal requirement. The more INTENSITY of renewable energy generation than P2 makes the market price is lower than the weighted average self-generated price in P2 because of economies of scale. Renewable energy is more competitive and its share will develops faster than P2 and P1.

3.2 Effect on Electricity Price

3.2.1 Situation: Air as an Incompatible Use Good

Air is an Incompatible Use Good. If the power plants use the air for the disposal of carbon and other emissions, residents cannot maintain the quality of atmosphere and prevent climate change. Therefore, a negative externality is inevitable. Schmid (2004) notes there are two methods to define externalities. Some scholars view externality as a by-product of some production process. In this case, emission is a by-product when generating electricity. Alternatively, air may be seen as another input necessary to produce electricity rather than a by-product. The Coase Lesson emphases if rights are fully specified and transaction costs are positive, the assignment of rights to one party or another impact the allocation of resources and thus has clear efficiency implications (Mercuro, Steven 2006). Schmid (2004) mentioned that it is rights that determine whose interests are a cost to others. It is these rights that make it possible for one person's interests to become a cost to another. Given human interdependence and conflicting interests, there necessarily are winners and losers. To have a right of the air is to have the opportunity to require others to pay you to give it up. Samuels speaks of the "inevitability of non-compensated losses." Therefore, the question in the electricity sector is who owns the air, or what is the initial location of the property right of air? Without this prerequisite, transaction cannot start.

3.2.2 Structure and Performance: A4, A5, A6 and P4, P5, P6

Table 3.2 gives the SSP chart when air is regarded as Incompatible Use Good. Alternatives (A4, A5, and A6) and Performances (P4, P5, and P6) in this chart will be explained as follows:

For states without RPS, **A4** implies that utilities have the right to use air for disposal of carbon and other emissions as much as they want. Without the regulation and penalty, air is a free input and utilities would like to use more input to replace other expensive inputs such as land and labor. This structure will lead to performance **P4**, which keeps a high share of free air in the input portfolio and hence a low level of the average cost. The decreasing cost shifts the supply curve and lead to a lower market price of electricity.

Renewable energy produces less emission but on average cost more than fossil fuels, thus RPS could be regarded as a policy to charge producer for using more air. Under this policy as **A5**, producers have to change their input portfolio by using less air because it is not free anymore. However, the increased price of air will lead to inevitable higher cost of electricity when the prices of other inputs keep constant, which could decrease the electricity supply and increase the electricity price. This is the performance **P5** under **A5**.

In RPS states with REC market as **A6**, there is a market price of air that is the same for each utility and usually is lower than the weighted average level in **A5** because of economies of scale. As a new input, RECs can perfectly substitute air in the input portfolio with a lower price for some utilities. The cost function then transfers from C=F(land, labor, …, air) to C=(land, labor, …, air, RECS). The price of electricity of **P6** is more likely to be lower than **P5** but higher than **P4** since RECs is cheaper than the weighted average price of air in **A5** but not equal to zero as in **A4**.

According to whether a state has RPS policy and REC market, all the states can be divided into three groups that differ on the property right allocation of air. Regardless of other emission limit policies, those three groups imply three different structures (A4, A5, and A6) that determine relative rights/duties of parties, which will then lead to different economic performance in electricity price (P4, P5, and P6). Table 3.2 gives Situation, Structure, and Performance (SSP) Analysis of air as an Incompatible Use Good (IUG).

Table 3.2 SSP analysis matrix: Air as an Incompatible Use Good

Situation: Physical Characteristics of goods / services that create unavoidable human interdependence. IUG: Two or more uses of air that are incompatible. If utility uses atmosphere for the disposal of carbon and other emissions, residents cannot use it for prevention of climate change. Key issue(s): Is the use right assigned to utility or residents? Example: Utility intends to use the air for the disposal of carbon and other emissions in the production of electricity. Residents intend to limit the carbon and other emissions in the air and prevent climate change.	**Structure:** Alternative institutions (rules) that determine relative rights/duties of parties. A4: Alienable use right assigned to Utility. Duty of noninterference assigned to residents. (It's the rule of non-RPS states) A5: Utility has the regulatory duty to meet the minimal requirement of renewable energy in the portfolio only through self-producing. There is no right of alienation to residents. (It's the rule of RPS states without REC market) A6: Utility has the regulatory duty to meet the minimal requirement of renewable energy in the portfolio through either producing by itself or buying credits in the market. At the same time, Utility can also choose to sell the credit on the market if its renewable energy share is beyond the minimal requirement. There is no right of alienation to Residents. (It's the rule of RPS states with REC market)	**Performance:** Economic performance consequence of institutional alternatives. P4: Price of electricity that assumed should be lower than P2 and P3 because utility has the right of air and can use it as a free input. Therefore, utility's input portfolio includes more air and has a lower average cost. The supply of electricity is larger than P2 and P3, which leads to a lowest electricity price. P5: Price of electricity that assumed should be higher than P4 and P6 because utility bears the cost of carbon and other emissions only by self-produced renewable energy, which means utility has to pay for the air as an input. This implies a higher cost and less supply of electricity no matter how utility changes its input portfolio. P6: Price of electricity that assumed should be lower than P5 but higher than P1 because the price of air as an input is not free but utility has an additional choice of RECs as an input which can perfectly substitute air.

3.3 Effect on Emissions

The U.S. National Academies[7] regards RPS as examples of measures that overlap with a Green House Gas (GHG) pricing policy, in the sense that they are intended to reduce GHG emissions. It means as a renewable energy policy, state authorities enact RPS mainly for the purpose of limiting climate change. However, effects of RPS on carbon and other emissions are through its effect on renewable energy share and its effect on electricity price which are explained in the two subsections above. This article assumes point ***E*** with price ***P*** and quantity ***Q*** is the electricity market equilibrium for a state without RPS in Figure 3.2 and uses this graph to explain how the change in renewable energy share and electricity price could lead to a change in carbon and other emissions in this subsection

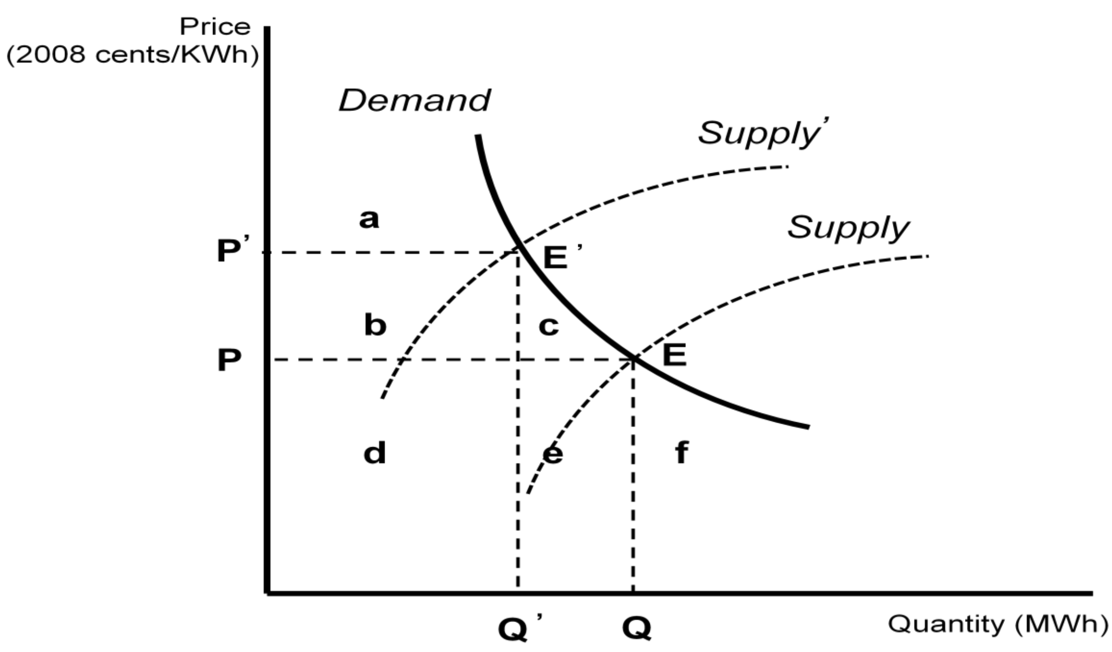

Figure 3.2 Demand and supply of electricity market before and after the deployment of RPS

[7] U.S. National Academies of Science Panel on Advancing the Science of Climate Change. 2010. *Limiting the Magnitude of Future Climate Change*. Washington, D.C.: National Academies Press.

On one hand, this article predicts a higher price of electricity if this state enacts RPS in Table 3.2 when air is regarded as IUG. This is because after the deployment of RPS, ***Supply*** curve of electricity market in Figure 3.2 will shift northwest to ***Supply'***, which will result a new equilibrium with a higher price ***P'*** and a fewer quantity ***Q'***. The utilities will then reduce their production from ***Q*** to ***Q'***. In Figure 3.2, the difference between ***Q*** and ***Q'*** will never be generated after the enactment of RPS. Therefore, the carbon and other emissions that used to be discharged for this amount of electricity could be saved and never be disposed into air.

On the other hand, for the generation ***Q'*** that still exists, the renewable energy share in this amount is supposed to increase after the deployment of RPS when renewable energy is considered as ESG in Table 3.1. Therefore, the existed generation ***Q'*** has fewer emissions compared with the emissions from the same amount of electricity generated before the enactment of RPS.

To sum up, compared with the emissions before the deployment of RPS, part of the electricity (***Q***-***Q'***) will never be generated and hence no emissions discharged while the amount left (***Q'***) will produce fewer emissions. Therefore, the total reduced carbon and other emissions are the result of both renewable energy share increase and electricity price increase. If this RPS state then builds a REC market while keeping the annual target constant, the renewable energy share in capacity and generation will increase, which will reduce the emission based on the SSP analysis in Table 3.1. On the other hand, however, the electricity price will decrease compared with the condition of the same RPS but no REC market, which will stimulate consumption and increase emissions according to the SSP analysis in Table 3.2 if the speed of reducing per unit emissions by increase renewable energy share cannot keep up with the increasing speed of consumption and generation. Therefore, whether having a REC market will finally increase or decrease the emission dependent on the relative magnitude of its effect on electricity price and renewable energy share.

3.4 Conclusion and Hypotheses

According to the analysis above, this paper compares and concludes the performances (renewable energy share, price of electricity, and carbon and other emissions) among non-RPS states, RPS states without REC market, and RPS states with REC market in Table 3.3.

Table 3.3 Caparison among non-RPS states, RPS states without and with REC market

	Renewable Energy Share	Electricity Price	Carbon and Other Emissions
non-RPS states	LOW	LOW	HIGH
RPS states without REC market	MIDDLE	HIGH	?
RPS states with REC market	HIGH	MIDDLE	?

Table 3.3 concludes that among the three types of states, non-RPS states are expected to have the lowest renewable energy share and electricity price but the highest carbon and other emissions. RPS states without REC market are more likely to have the middle-level renewable energy share and highest electricity price. RPS states with REC market are predicted to have the highest renewable energy share and middle-level of electricity price. The comparison on carbon and other emissions for states with and without REC market depends on the related

magnitude of their difference in renewable energy share and electricity price.

This article mainly focuses on RPS rather than REC. Hence the comparison in Table 3.3 can be simplified to the comparison between states with and without RPS by combining RPS states with and without REC market. Then it is clear than RPS states on average are expected to have higher renewable energy share and electricity price but fewer carbon and other emissions than non-RPS states.

On the other hand, the comparison results between non-RPS states and RPS states can also be applied to the comparison between lax-RPS states with lower targets and strict-RPS states with higher targets. In other words, the direction of changes in renewable energy share, electricity price, and carbon and other emissions after the deployment of RPS is supposed to be the same as strengthening RPS by increasing the annual target. Therefore, this paper gives three hypotheses as follows:

Hypothesis 1: Renewable energy share in both capacity and generation will INCREASE when deploys or strengthens RPS.

Hypothesis 2: Average price of electricity in all sectors will INCREASE when deploys or strengthens RPS.

Hypothesis 3: Carbon and other emissions including in electricity sector will DECREASE when deploys or strengthens RPS.

CHAPTER 4: EMPIRICAL MODEL

In this section, empirical model is given for the purpose of testing the three hypotheses at the end of Section 3 and estimating the magnitudes of these effects of RPS. Then this section shows the approach to estimate the change in consumer surplus and evaluate the value of the change in emissions when enacting or strengthening RPS. Finally, the equations to derive the effect of RPS on the total welfare of consumers are built. All the estimations are under the assumption that the adjusted RPS annual target will increase by 1 percentage.

4.1 Effect on Renewable Energy Share and Electricity Price

This subsection attempts to answer the question: what is the impact of RPS on: 1) renewable energy share in capacity; 2) renewable energy share in generation; and 3) electricity prices through a Least Square Dummy Variable (LSDV) model using Ordinary Least Square (OLS) approach on a balanced panel data of $48\times19=912$ observations (one for each state-year from 1990 to 2008 in the contiguous United States).

4.1.1 Basic LSDV Model

As more and more states deploy RPS, many studies prefer to use panel data. This is because Panel data are particularly useful in answering questions about the dynamics of change such as long-term or cumulative effects of RPS which are normally hard to analyze by using cross-sectional data. This paper uses a balanced panel of $48\times19=912$ observations for the LSDV model, which is consisted of equation (2), (3), and (4):

(2) $R_{IT} = \beta_{10} + \beta_{11}RPS_{IT} + \beta'_{12}W'_{IT} + \beta'_{13}Y' + \beta'_{14}I' + \varepsilon_{RIT}$

(3) $RR_{IT} = \beta_{20} + \beta_{21}RPS_{IT} + \beta'_{22}W'_{IT} + \beta'_{23}Y' + \beta'_{24}I' + \varepsilon_{RRIT}$

(4) $\log P_{IT} = \beta_{30} + \beta_{31}RPS_{IT} + \beta'_{32}W'_{IT} + \beta'_{33}Y' + \beta'_{34}I' + \varepsilon_{PIT}$

where R_{IT} represents the percentage of electric power industry capacity that is non-hydro renewable for state *I* in year *T*, RR_{IT} represents the percentage of electric power industry generation that is non-hydro renewable for state *I* in year *T*, and P_{IT} represents the average price of electricity across all sectors (2008 cent / MWh) for state *I* in year *T*. ε_{RIT}, ε_{RRIT} and ε_{PIT} are random error items for equation (2), (3) and (4), respectively. All of the dependent variables in the three equations depend on: 1) RPS_{IT}, the percentage of adjusted RPS annual target for state *I* in year *T*; 2) W'_{IT} vector various social and economic variables that might have an effect on renewable energy share and electricity price; 3) Y' and I' vector 18 year dummies and 47 state dummies other than the default year (1990) and state (Arizona), respectively.

This article includes the social and economic variables in the regression analysis including governor's political party, natural gas price, electricity import ratio, annual electricity sales, population density, unemployment rate, and personal income.

a. Governor's Political Party: the Republic Party and the Democratic Party have different environmental policies and preference. They not only affect the deployment of such environmental policies through personal power but also through affecting public attitude by news media such as MSNBC on the Left[8] and FOX News on the Right[9]., (McCright, Dunlap, 2010), which allow Americans to obtain their news from outlets that reinforce their political beliefs (e.g., Hindman 2009; Iyengar and Hahn 2009). This paper induces the dummy variables *DEMOCARTIC* and *OTHERPARTIES* to indicate if the state governor is a Democrat and from other parties than Republic Party and Democratic Party, respectively.

b. Natural Gas Price: The difference between price of renewable energy and conventional energy to some extent decides the development of renewable energy. If the conventional energy price increases, it is easier for renewable energy to be profitable given a certain technology. This article uses real price of natural gas, *INPUTPRICE*, as an independent variable because renewable energy is likely to replace the natural gas based on former studies (Olher 2009).

c. Electricity Import Ratio: This article also includes *IMPORT*, a measure of percentage electricity a state imports or exports, as the independent variable because states with high electricity import rate might spend more funding on investing renewable energy in order to diversify the energy pool and generates more electricity for self-consumption.

d. Retail Sales of Electricity: If a state has high annual retail sales of electricity, *ESALE*, electricity price might be high since the demand of electricity is high. Then the utilities have

---

8 environmental organizations, science advocacy organizations, and Democratic policy-makers on the Left which believe the negative environmental consequences of industrial capitalism represented by climate change

9 conservative think tanks, industry associations, and Republican policy-makers on the Right which is defending the economic system from such charges

more incentives to invest on renewable energy to increase supply.

e. State Population Density: State population density, *POPDENSITY*, in a state might also affect the real renewable energy share since high population density states might need more energy diversity and supply. On the other hand, the electricity price might be higher in those states because of a higher demand.

f. Unemployment Rate: States with higher unemployment rate, *UNEMPLOY*, might more likely to attract renewable energy industry because it needs a lot of labor input. At the same time, this industry can provide more job opportunities, which might receive some preferential treatment such as tax relief by the state authorities.

g. Personal Income: The average generation cost of renewable energy is higher than that of conventional energy, which may lead to higher electricity price if one state makes strict RPS policy to develop renewable energy industry. It is easier for state with higher average personal income to accept RPS because richer residents may have higher willingness to pay for green energy and can afford higher utility fee. Therefore, real 2008 thousand dollars of income per capita in each state and year, *INCOMELEVEL*, has been added.

4.1.2 Potential Problem of the Basic Model and Solutions

There are several potential problem of the basic model that could bias the estimated effects of RPS and their Standard Error. This article discuss the effects of other RPS features and other renewable energy policies, the concerns with partial effect of RPS, different trends in the absence of RPS across states, and the potential serial correlation to violate standard errors. Econometric technologies are used to improve the basic model for the purpose of deriving unbiased estimation and correct standard errors.

4.1.2.1 Other RPS features and other renewable energy policies

Although this article induces the effective RPS target combining features of RPS including nominal annual target, coverage among utilities, and the eligibility of existing renewable capacity to deal with the concern that RPS policies are heterogeneous, there are still other features of RPS which vary across states but cannot include into the adjusted RPS annual target. This article also adds the REC market dummy, *REC*, and some other RPS features including *RECATEGORY*, the number of sources that are considered renewable energy and *PENALTY*, financial penalty dummy into the new equations to control those characters when estimating the effects of RPS annual target.

Johnson (2010) controls some other renewable policies in order to estimate the unbiased effect of RPS. This article creates the three dummy variables into the basic model including: 1) *PBF* to measure if a state has state-level Public Benefit Funds; 2) *NM* to measure if a state has state-level Net Metering system; and 3) *MGPO* to measure if a state has state-level Mandatory Green Power Option.

4.1.2.2 Different Trends Concern in Absence of RPS

This article wants to estimate the causal effect of RPS using non-experimental data. The "Identification Assumption" for the basic model above is that states with and without RPS would have the same trend in outcomes in the absence of RPS. In other word, the growth rate of renewable energy share and electricity price won't vary across state if all the states didn't enact RPS, which is clearly not realistic. The pre-2000 trends for "early adopters" in Figure 2.6 were quite different from that in "late adopters" and "never adopters", which suggests that the "same trend" assumption is difficult to be hold in the post-2000 data. Therefore, this paper worries that a simple comparison of outcomes for all the RPS and non-RPS states using the basic model will give a biased estimate of the causal effect even after adding interactions.

To account for the problem of different trends of outcomes in the absence of RPS, this paper uses the "fixed effects" (basic model) regression with state-specific linear trends added as control variables, where each state has its own linear trend in the absence of the program. The method is to add the interactions between each of the state dummy variables (expect for Arizona) with linear time trends (year #) besides the state dummies and year dummies in the basic model.

4.1.2.3 Interaction Effect Concern

Graphs in Section 2.5 have provided an image that RPS might affect renewable energy share and electricity price differently depending on other variables such as renewable energy potential. In other words, there might be some partial effects of the dependent variables with respect to the adjusted RPS annual target to depend on the magnitude of yet other variables. In order to estimate the partial effect of RPS, this article adds some interactions into the basic model.

According to the graphs and analysis in Section 2.5.3, it makes sense to have the resource base variables (*SOLAR*, *BIOMASS* and *WIND*) interact with the adjusted RPS annual target, RPS_{IT}. This article assumes an additional increase in annual target yields a higher renewable energy share increase and a lower electricity price increase for states with richer renewable energy potential.

The different economic performances of RPS on renewable energy share and electricity price across region that emerged in Section 2.5.1 makes the interactions between the adjusted annual target and region dummies a necessary consideration. This article assumes an additional increase in annual target yields a higher renewable energy share for states in the Midwest and West.

Figure 2.2 in Section 2 shows that there are two main phases when states intensively enforced PRS, first from 1999 to 2003 and second since 2005. This article assumes the condition changed between those two phases and thus defines a new dummy, *TIME1*, to measure whether the year is before 2004 and cross this variable with the RPS policy variable.

Moreover, the effects of RPS requirements also depend on whether there is a REC market and whether there is a financial penalty mechanism since these two systems could change the difficulty to meet a certain requirement and the willingness to meet a certain requirement, respectively. Hence, the interaction between *RPS* and *REC* as well as the interaction between *RPS* and *PENALTY* are both added in to the new equations.

As is known, renewable energy base in a state significantly influence the development of in-state renewable energy industry and this impact might be through not only the annual RPS target but also varies in state with and without REC market and across years. Besides the interactions related to *RPS*, this article hence also includes 1×3 interactions between *REC* with each of the three renewable energy potential variables (*SOLAR*, *BIOMASS*, and *WIND*) and 18×3 interactions between each of the 18 year dummy variables (from 1991 to 2008) and each of the three renewable energy potential variables (*SOLAR*, *BIOMASS*, and *WIND*).

4.1.2.4 The New Model and Serial Correlation Test

After considering the effects of other RPS features and other renewable energy policies, the concerns of partial effect of RPS, and different trends in absence of RPS, the new equations (5), (6), and (7) are given:

(5) $R_{IT} = \gamma_{10} + \gamma_{11}RPS_{IT} + \gamma'_{12}W'_{IT} + \gamma'_{13}Y' + \gamma'_{14}I' + \gamma'_{15}R'_{IT} + \gamma'_{16}RPS_{IT} * E'_{IT} + \gamma'_{17}Z'_{IT} * M'_{IT} + \gamma'_{18}I' * T + \lambda_{RIT}$

(6) $RR_{IT} = \gamma_{20} + \gamma_{21}RPS_{IT} + \gamma'_{22}W'_{IT} + \gamma'_{23}Y' + \gamma'_{24}I' + \gamma'_{25}R'_{IT} + \gamma'_{26}RPS_{IT} * E'_{IT} + \gamma'_{27}Z'_{IT} * M'_{IT} + \gamma'_{28}I' * T + \lambda_{RRIT}$

(7) $\log P_{IT} = \gamma_{30} + \gamma_{31}RPS_{IT} + \gamma'_{32}W'_{IT} + \gamma'_{33}Y' + \gamma'_{34}I' + \gamma'_{35}R'_{IT} + \gamma'_{36}RPS_{IT} * E'_{IT} + \gamma'_{37}Z'_{IT} * M'_{IT} + \gamma'_{38}I' * T + \lambda_{PIT}$

Compared with equations (2), (3), and (4) in the basic model, equations (5), (6), and (7) add four groups of independent variables (the last four items expect the error items in each of the equations) including: 1) R'_{IT} vector other RPS-related features including the number of eligible renewable energy, *RECATEGORY*, financial penalty mechanism dummy variable, *PENALTY*, and REC market dummy variable, *REC*, as well as three other renewable policies dummies including *PBF*, *NM*, and *MGPO* that are discussed in Section 4.1.2.1; 2) $RPS_{IT} * E'_{IT}$ vector the RPS related interactions. According to Section 4.1.2.2, E'_{IT} vector 9 variables including three renewable energy potential indices (*SOLAR*, *BIOMASS*, and *WIND*), three region dummies including *region2* (Midwest), *region3* (South), and *region4* (West), period dummy variable, *TIME1*, financial penalty mechanism dummy variable, *PENALTY*, and REC market dummy variable, *REC*; 3) $Z'_{IT} * M'_{IT}$ vector other interactions related to renewable energy indices which are also mentioned in Section 4.1.2.2. In this item, Z'_{IT} vector three renewable energy potential indices (*SOLAR*, *BIOMASS*, and *WIND*), while M'_{IT} vector REC market dummy variable, *REC*, and 18 year dummies (1991-2008); 4) $I' * T$ vector the interactions between state dummies and year that are mentioned in Section 4.1.2.3 for the purpose of controlling state-specific trends.

This article worries that the CLR assumption of $\mathrm{corr}(\varepsilon_T, \varepsilon_{T-1}) = 0$ is broken when using the panel data. The error terms are then not independently distributed across the observations and are not strictly random. This article tests the CLR assumption and corrects for the potential serial correlation in the standard errors if $\mathrm{corr}(\varepsilon_T, \varepsilon_{T-1}) \neq 0$. This paper regresses the residuals of the new equations on their lagged values and tests to see if the coefficient of *RPS* is significant. If it is, this paper will "cluster" standard errors by state.

4.1.3 Prediction of RPS Impacts

After running OLS regression on equation (5), (6), and (7), the estimated partial effects of RPS annual target are: 1) $\hat{\gamma}_{11} + \sum \hat{\gamma}'_{16} E'_{IT}$ on renewable energy share in capacity; 2) $\hat{\gamma}_{21} + \sum \hat{\gamma}'_{26} E'_{IT}$ on renewable energy share in generation; 3) $\hat{\gamma}_{31} + \sum \hat{\gamma}'_{36} E'_{IT}$ on electricity price. However, the interesting value of E'_I should be plugged in order to derive the effect of RPS. Since the focus is on the average effect of RPS, this article is interested in estimating the average RPS impact with a mean level of E'_I and hence should put the mean value of E'_I. However, this process cannot tell if the estimates are statistically different from zero since no standard error information has been given. This article reruns the revised regression (equation (5*), (6*), and (7*)) which replace $RPS_{IT} * E'_{IT}$ by $RPS_{IT} * feE'_{IT}$ ($RPS_{IT} * (E'_{IT} - \bar{E}'_{IT})$) in the equations (5), (6), and (7). In this process, $\bar{E}'_I$ vector the mean value for each of the nine variables in E'_I for the balanced panel of 48×19=912 observations. The new coefficients on *REC* ($\hat{\gamma}^*_{11}$, $\hat{\gamma}^*_{21}$, and $\hat{\gamma}^*_{31}$) also predict the estimated average effect of RPS, which should be the same as the estimation of $\hat{\gamma}_{11}+\sum\hat{\gamma}'_{16}\overline{E}'_{IT}$, $\hat{\gamma}_{21}+\sum\hat{\gamma}'_{26}\overline{E}'_{IT}$, and $\hat{\gamma}_{31}+\sum\hat{\gamma}'_{36}\overline{E}'_{IT}$, respectively. But the revised regressions also provide the standard error information to show if the estimates are significantly different from zero.

Besides the national average effect of RPS, this article also estimates the regional average effect of RPS for each of the four regions to predict the different performance across regions. In order to estimate the average RPS impacts for the states in Northeast, this article reruns the equation (5), (6), and (7) but replace $RPS_{IT} * E'_{IT}$ by $RPS_{IT} * feE'_{IT}$ ($RPS_{IT} * (E'_{IT} - \overline{E}'_{IT})$). However, $\overline{E}'_{I}$ here vector the mean value of the states in Northeast rather than the mean of all the 48 lower states. The estimated average effects of RPS for Midwest, South, and West can be predicted in the same method.

4.1.4 Conclusion

The effects of RPS on renewable energy share in capacity, renewable energy share in generation, and electricity price can be estimated by OLS regressions. Section 6 reports all the estimation results of the OLS estimators.

This article assumes that 1 percentage increase in adjusted RPS annual target can 1) increase the renewable energy share in capacity by $\boldsymbol{\alpha}$ percentage; 2) increase the renewable energy share in generation by $\boldsymbol{\beta}$ percentage; and 3) increase the electricity price by $\boldsymbol{\gamma}$ percent at this point to make the following analysis easier to be understood.

4.2 RPS Impacts on Consumer Surplus, Emissions, and Total Consumer Welfare

The empirical model of renewable energy share and electricity price can give an answer of the first two hypotheses in the conceptual model. The estimators can predict what the changes in renewable energy share and electricity price are if the adjusted RPS annual target increased by 1 percentage. However, these predictions seems too abstract to readers since it is very hard for them to imagine the effect if electricity price increased by certain percentages. This article uses these estimators to further predict the effect of RPS on electricity consumers. After strengthening the RPS by 1 percentage, the change in electricity price can change the electricity consumed and also the consumer surplus, which explicitly relates to consumers' total benefit and welfare. One the other hand, the conceptual model also notes the change in both renewable energy share and electricity price can lead to change in emissions, which can implicitly affect consumers' total benefit and welfare such as breathing the fresh air and enjoying beautiful scenery. Therefore, the effect of RPS on consumers' welfare is the summation of its effect on consumer surplus and emissions. The following two subsections will analyze the change value in consumer surplus and emissions when the adjusted RPS annual target increased by 1 percentage, respectively. The brief procedures of the effect on consumer welfare are summarized in Figure 4.1.

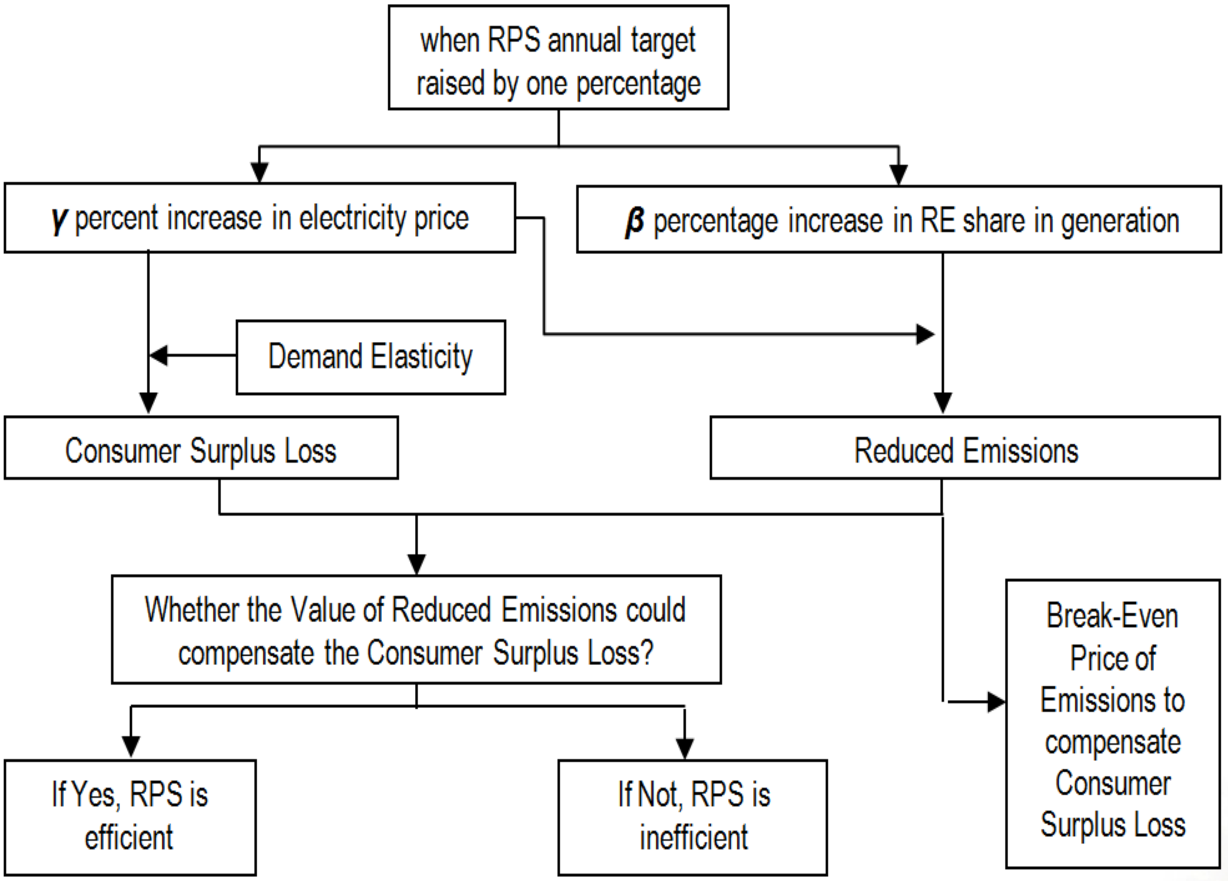

Figure 4.1 Procedures of estimating consumer's total welfare

4.2.1 Effect on Consumer Surplus

Renewable Portfolio Standards are a state-level regulations that requires retail electricity providers to use a fraction of their electricity from renewable sources. Thus it is a policy on the supply side of the electricity retail market, which means the RPS annual target is a determinant of electricity supply. On the other hand, the homogeneity of electricity generated by renewable energy and conventional energy results no shift on the electricity demand curve when enacting or strengthening RPS. Therefore, Figure 3.2 in section 3.3 can be used again to analyze the change in consumer surplus when adjusted RPS annual target increased by 1 percentage.

This article assumes the adjusted RPS annual target increased from $\boldsymbol{\sigma}$ percentage to $\boldsymbol{\sigma +1}$ percentage. Point ***E*** with price ***P*** and quantity ***Q*** is the electricity market equilibrium when the adjusted RPS annual target is $\boldsymbol{\sigma}$ percentage in Figure 3.2. This article uses the average real electricity price and electricity sales from 1990 to 2008 as price ***P*** and quantity ***Q***.

After the increase in RPS annual target, ***Supply*** curve of electricity market will shift northwest to ***Supply'*** while ***Demand*** curve remains the same. The movement could lead to a higher price ***P'*** and a smaller quantity ***Q'***, which makes a consumer surplus loss of the area ***b+c*** in the Figure 3.2. According to the assumption in Section 4.1, ***P'*** is $\boldsymbol{\gamma}$ percent higher than ***P***. The consumer surplus loss, area ***b+c***, can be derived if the demand elasticity can be estimated to predict the new quantity ***Q'*** through equation (8). The electricity consumers in this article refer to all the individuals, firms, organizations that use electricity in all sectors including residential, commercial, industrial, transportation, and other sectors.

(8) $e_{Q,P} = \frac{\% \cdot change \cdot in \cdot Q \cdot demanded}{\% \cdot change \cdot in \cdot P} \Rightarrow \% \cdot change \cdot in \cdot Q \cdot demanded = e_{Q,P} \times \% \cdot change \cdot in \cdot P$

where $e_{Q,P}$ is the demand elasticity of the electricity market.

In order to estimate the demand elasticity, this paper establishes the demand - supply model of U.S. electricity market in demand equation (9) and supply equation (10)

(9) $\log Q_{IT} = \omega_0 + \omega_1 \log P_{IT} + \omega_2 T' + \omega_3 I' + \xi_{DIT}$

(10) $\log P_{IT} = \nu_0 + \nu_1 \log Q_{IT} + \nu_2 RPS_{IT} + \nu_3 T' + \nu_3 I' + \xi_{PIT}$

where Q_{IT} is the electricity quantity sale for state *I* in year *T*, P_{IT} represents the all sectors average price of electricity (2008 cent / MWh) for state *I* in year *T*. ω_1 is the demand elasticity $e_{Q,P}$ in U.S. electricity market that this paper tries to estimate. T' and I' vector 18 year dummies and 47 state dummies, respectively.

It is clear in equation (9) and (10) that market price for electricity is jointly determined by the intersection of supply curve with demand curve. If the demand curve shifts (i.e. the popularity of home appliances can increase electricity demanded holding price fixed), then price will change. So the error term in the demand function without controlling the popularity of home appliances is correlated with the market price, which is an independent variable in the equation. Therefore, price in the demand equation could be an endogenous variable. Another way to think about the endogeneity concern is the following: shifts in the demand curve only lead to market price and quantity pairs that trace out the slope of the supply curve. Shifts in the supply curve lead to market price and quantity pairs that trace out the slope of the demand curve. In general, the simple correlation between market prices and quantities will neither trace out the slope of the demand curve nor the slope of the supply curve; it will be some mixture of the two. The goal with Two-Stage Least Square (TSLS) regression using a pure supply shifter to be the instrument is to identify variation in market prices that we are pretty sure is coming from the supply curve shifting. By focusing only on variation in prices that can be predicted by an eligible instrument, and then correlating quantities with this variation, this article can estimate unbiased demand elasticity.

Because RPS can only affect the supply side rather than the demand curve directly, the adjusted RPS annual target appears in the supply equation rather than the demand equation. This characteristic makes adjusted RPS annual target an eligible instrument for the electricity price in the demand equation. The TSLS approach can estimate unbiased demand elasticity $\hat{\omega}_1$ in the equation (9). In order to test the robustness of the estimator, this article also then adds more controls including governor's political party, natural gas price, electricity import ratio, population density, and unemployment rate.

However, in a very short run, rigid demand of electricity is an eligible concern, which implies the demand elasticity is perfectly inelastic in a short term. Therefore, besides the estimated demand elasticity, this article also estimate the consumer surplus and consumer welfare under the assumption that demand elasticity is 0 in Section 6.

Then this article derives the consumer surplus loss (area ***b+c*** in the Figure 3.2) when adjusted RPS annual target increased by 1 percentage through equation (11):

(11) $$\Delta CS = -(Q+\hat{Q}')/2 \times (\hat{P}'\text{-}P) = -(Q-\Delta\hat{Q}/2) \times \Delta\hat{P} = -Q \times \Delta\hat{P} + \hat{\omega}_1 \times \Delta\hat{P}^2 / 2$$

where ΔCS represents the change in consumer surplus when adjusted RPS annual target increased by 1 percentage. Q and P are the average annual electricity sales and electricity price for the contiguous United States, respectively. $\hat{Q}'$ and $\hat{P}'$ are the estimated annual electricity sales and electricity price for the 48 lower RPS states if all these states increase their adjusted RPS annual target by 1 percentage. $\hat{\omega}_1$ is the average estimated demand elasticity from 1990 to 2008 for those 48 RPS states.

4.2.2 Effect on Emissions

U.S. National Academies of Science[10] notes that limiting the magnitude of future climate change will require significant reductions in climate forcing, and Greenhouse Gas (GHGs) as well as other air pollutions emitted by the energy sector, which is the single largest contributor. Hence, strategies to limit climate change typically focus on reducing emissions from the energy sector is not a preference but a necessity. These strategies can be grouped into four major categories: (a) reductions in demand quantity; (b) efficiency improvements; (c) replace “dirty” energy by “clean” energy that emits few GHGs and other pollutions; and (d) direct capture of CO_2 or other GHGs during or after fossil fuel combustion.

Renewable Portfolio Standards could be regarded as a regulation to limit GHGs and other air pollution through method (a) and (c). Followed by Figure 3.2 in section 3.3 and the story in section 4.2.1, 1 percentage increase in RPS annual target reduces carbon and other emissions through cutting the electricity consumed, ***Q-Q’***, by method (a) and improving the renewable energy share for the remained quantity, ***Q’***, by method (c). Since Energy Information

---

[10] U.S. National Academies of Science Panel on Advancing the Science of Climate Change. 2010. *Advancing the Science of Climate Change*. Washington, D.C.: National Academies Press.

Administration (EIA) only gives the annual "Electric Power Industry Emissions Estimates" for each energy source for carbon dioxide, sulfur dioxide, and nitrogen oxide, this article only estimates the reduced amount of these three emissions although RPS can also reduce other emissions.

Therefore, the reduced emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide can be shown in equation (12), (13), and (14), respectively:

(12) $$\Delta CO_2 = (\hat{Q}' - Q) \times \sum_{i=1}^{6} \delta_i X_i + \hat{Q}' \times \sum_{i=1}^{6} \delta_i (\hat{X}'_i - X_i) X_i$$

(13) $$\Delta SO_2 = (\hat{Q}' - Q) \times \sum_{i=1}^{6} \eta_i X_i + \hat{Q}' \times \sum_{i=1}^{6} \eta_i (\hat{X}'_i - X_i) X_i$$

(14) $$\Delta NO_x = (\hat{Q}' - Q) \times \sum_{i=1}^{6} \rho_i X_i + \hat{Q}' \times \sum_{i=1}^{6} \rho_i (\hat{X}'_i - X_i) X_i$$

where ΔCO_2, ΔSO_2, and ΔNO_x refers to the change in carbon dioxide, sulfur dioxide, and nitrogen oxide emissions in electricity industry, respectively. Q is the average annual electricity sales for the contiguous United States from 1990 to 2008 from 1990 to 2008. $\hat{Q}'$ is the estimated annual electricity sales for the all the states if all these states increase their adjusted RPS annual target by 1 percentage.

X_1, X_2, X_3, X_4, X_5, and X_6 represent the average share of non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource in the electricity package from 1990 to 2008, respectively. The share of different energy source in this package (X_1, X_2, X_3, X_4, X_5, and X_6) is assumed to be the same as the average level for the lower 48 states from 1990-2008, which is given in the Figure 4.2.

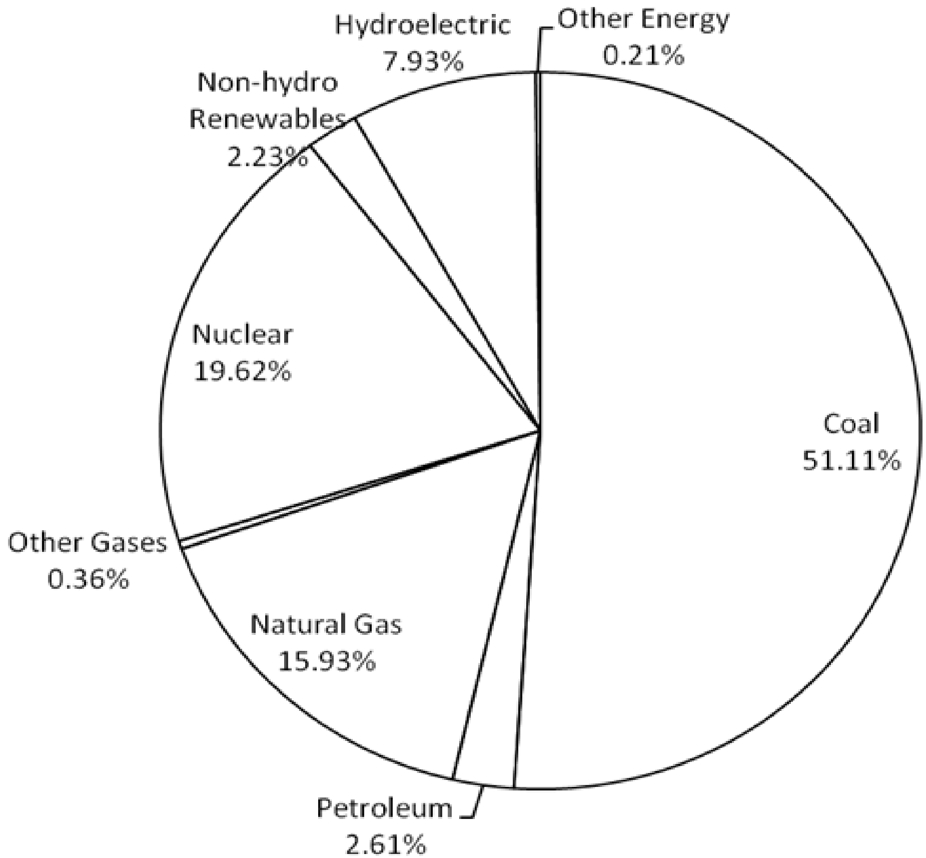

Figure 4.2 Pie Chart of Energy Consumption by Fuel Source

$\hat{X}_1'$, $\hat{X}_2'$, $\hat{X}_3'$, $\hat{X}_4'$, $\hat{X}_5'$, and $\hat{X}_6'$ represent the estimated new average share of non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource in the electricity package if all these states increase their adjusted RPS annual target by 1 percentage, respectively. Renewable energy is produced to replace fossil fuels. Figure 4.3 shows that coal and petroleum decreased year by year while RE and natural gas increased. Therefore, this article assumes the incremental RE substitutes coal and petrol in proportion. The share of coal and petroleum in the portfolio decreased by 4.3% (from 52.7% in 1990 to 48.3% in 2008) and 3.0% (from 3.9% in 1990 to 0.9% in 2008), respectively. Thus in assumption 1, this paper replaces coal and petroleum by incremental share of renewable using the ratio of 1.465 to 1, which is the same as 4.3% to 3.0%.

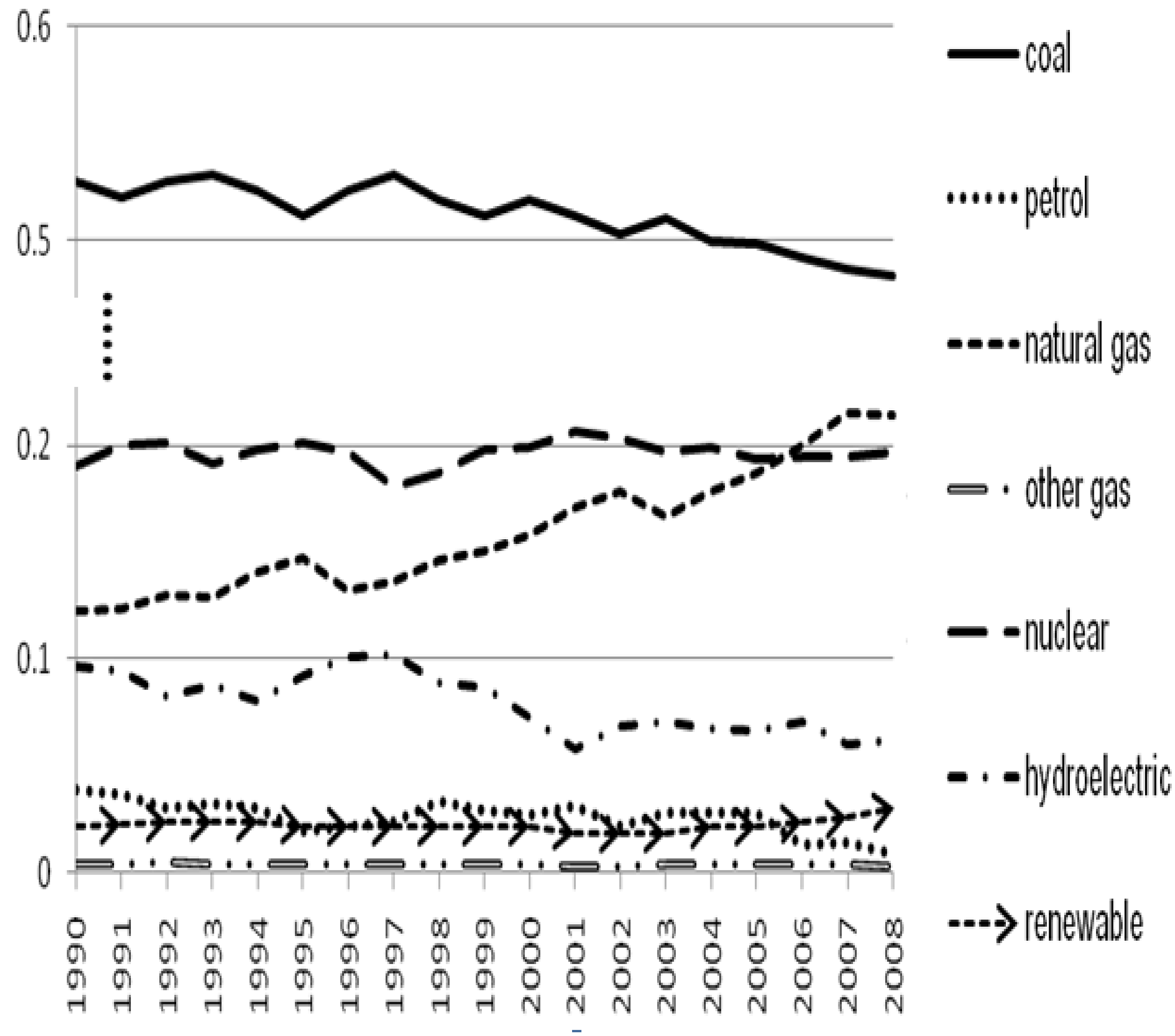

Figure 4.3 Energy Consumption Ratio Tendency by Fuel Source from 1990 to 2008

However, Olher (2009) notes that renewable generation will replace natural gas generation instead of coal generation. Therefore, this paper assumes the $\boldsymbol{\beta}$ percentages increased renewable energy share makes the natural gas share decreased by $\boldsymbol{\beta}$ percentages while the share of other gas, coal, petroleum, other resource in the electricity package keeps the same when RPS annual target increased by 1 percentage as assumption 2.

δ_1, δ_2, δ_3, δ_4, δ_5, and δ_6 represent the per unit carbon dioxide emission by non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource, respectively. η_1, η_2, η_3, η_4, η_5, and η_6 represent the per unit sulfur dioxide emission by non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource, respectively. ρ_1, ρ_2, ρ_3, ρ_4, ρ_5, and ρ_6 represent the per unit Nitrogen oxide emission by non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource, respectively.

In order to evaluate the value of the reduced emissions, this article tries to find the monetary value of per unit carbon dioxide, sulfur dioxide, and nitrogen oxide emissions. Then the effect on emission can be quantified as equation (15):

(15) $$\Delta Emission = \Delta CO_2 \times \mu_1 + \Delta SO_2 \times \mu_2 + \Delta NO_x \times \mu_3$$

where ΔCO_2, ΔSO_2, and ΔNO_x refers to the difference in carbon dioxide, sulfur dioxide, and nitrogen oxide emissions in electricity industry before and after 1 percentage increase in RPS annual target, respectively. μ_1, μ_2, and μ_3 represent per unit monetary value of carbon dioxide, sulfur dioxide, and nitrogen oxide emissions. Therefore, $\Delta Emission$ is the value of the difference in emissions before and after 1 percentage increase in RPS annual target.

4.2.3 Conclusion

Section 4.2.1 and Section 4.2.2 gives the approach to estimate the effect of RPS on consumer surplus and emission value, respectively. Finally, equation (16) represents the change in total consumer welfare when adjusted RPS annual target increased by 1 percentage.

(16) $\Delta ConsumerWelfare = \Delta CS - \Delta Emission$

where $\Delta ConsumerWelfare$ is the total consumer welfare change when adjusted RPS annual target increased by 1 percentage. ΔCS and $\Delta Emission$ represent the change in consumer surplus and emission value of carbon dioxide, sulfur dioxide, and nitrogen oxide when adjusted RPS annual target increased by 1 percentage, respectively. This article indicates a negative ΔCS since price increase leads to loss in consumer surplus and a negative $\Delta Emission$ since emissions are likely to be reduced.

If $\Delta ConsumerWelfare$ is positive, it means the monetary value of emission is big enough to fully compensate the consumer's surplus loss. Then this policy is efficient when environmental concerns are considered. However, since this paper only estimates the reduced amount and value of carbon dioxide, sulfur dioxide, and nitrogen oxide emissions while ignores the reduced amount and value of other emissions like mercury, this research only conclude RPS on average are not that efficient or more likely to be inefficient rather than a flat statement that RPS are inefficient if the value of reduced carbon dioxide, sulfur dioxide, and nitrogen oxide emissions cannot fully compensate the consumer surplus loss.

However, it is very hard, actually almost impossible, to find the real monetary value of carbon dioxide, sulfur dioxide, and nitrogen oxide emissions. This article tries to use market price of the emissions to predict the value of reduced emissions although the estimation is very likely to be biased. On the other hand, since carbon is the most crucial emission in climate change and is likely to account for very great proportion of all the reduced emissions, this article estimates the breakeven price for carbon dioxide that can make the value of reduced carbon emissions equal to the loss in consumer surplus. Equation (17) gives the method to derive the breakeven price for carbon dioxide:

(17) $\$CO_2 = \Delta CS / \Delta CO_2$

where ΔCS represents the change in consumer surplus when adjusted RPS annual target increased by 1 percentage, ΔCO_2 refers to the difference in carbon dioxide before and after 1 percentage increase in RPS annual target. Therefore, $\$CO_2$ is the breakeven price for carbon dioxide.

If the real monetary value of carbon dioxide is higher than the breakeven price, RPS can be efficient renewable energy policies. On the other hand, this breakeven price to some extent can be regarded as a reference when U.S. policymakers price carbon emissions.

This paper also estimates RPS's impacts on the consumer surplus, emissions, and consumer welfare for each of the four regions based on the estimated effect of RPS on renewable energy share and electricity price for each of the four regions. The procedures are all the same as the procedure to estimate RPS's impacts for the 48 lower states but using the regional average $\hat{Q}$ and $\hat{P}$.

CHAPTER 5: DATA DESCRIPTION

Table 5.1 provides descriptive statistics for the key variable of interest and other variables used in the equations in section 4.1 with a total balanced panel of 48 × 19 = 912 observations. The statistics for some other variables in section 4.2 are given in Table 6.3 in Section 6.

Table 5.1 Summary statistics

	Mean	Std. Dev.	Min	Max	Unit
I. Independent variables					
1. RPS annual target					
NOMINALTARGET	1.0456	3.887	0	35	percentage
RPS	1.0201	3.646	0	32.55	percentage
2. other RPS feature					
COVERAGE	18.197	35.99	0	100	percentage
NONELIGIBLE	.03518	.2570	0	2.146	1,000 gigawatt-hour
RECATEGORY	1.4539	2.968	0	9	--
REC	.10855	.3112	0	1	--
PENALTY	.07675	.2663	0	1	--
3. other policies					
PBF	.1875	.391	0	1	--
NM	.3662	.482	0	1	--
MGPO	.0329	.178	0	1	--
4. other factors					
DEMOCARTIC	.44956	.4977	0	1	--
OTHERPARTIES	.02412	.1535	0	1	--
IMPORT	-23.198	55.22	-303.6	82.75	percentage
INPUTPRICE	5.2784	2.26	1.671	18.09	2008 cents/million Btu
ESALE	67.66	60.72	4.704	347	1,000 gigawatt-hour
POPDENSITY	.18228	.2474	0.0047	1.171	people per square mile
UNEMPLOYMENT	5.0753	1.353	2.255	11.29	percentage
INCOMELEVEL	34.39	5.94	21.60	57.74	2008 thousand $

Table 5.1 (cont'd)					
5. interaction related					
SOLAR	1.0000	.11819	.7601	1.350	--
BIOMASS	1.0000	.70501	0	2.925	--
WIND	1.0000	1.6002	0	5.313	--
REGION2	.25000	.43325	0	1	--
REGION3	.33333	.47166	0	1	--
REGION4	.22917	.42053	0	1	--
TIME1	.7368	.4406	0	1	--
II. Dependent variables					
R	2.29758	3.3904	0	26.58	percentage
RR	2.5895	4.1459	0	37.14	percentage
P	9.1809	2.6782	5.026	17.79	2008 cents/KWh
III. Others					
GENERATION	75.2	65.3	1.107	405	1,000 gigawatt-hour
REGENERATION	1.6849	3.459	0	25.1	1,000 gigawatt-hour
CAPACITY	17.516	15.799	.563	105	1,000 gigawatt
RECAPACITY	.3762	.86362	0	7.71	1,000 gigawatt
No. of Obs.	912				

NOMINALTARGET counts the nominal required percentage of eligible renewable energy in the portfolio of electric-generating sources for a certain year[11], which is written in the RPS policies. This article uses the data from Lawrence Berkeley National Laboratory and Database of State Incentive for Renewables & Efficiency (DSIRE).

[11] For those years that have no specific target after the enactment, we assume there is an implicit requirement that increase equally year by year until to the year with an explicit requirement. For example, in Rhode Island's case, the RPS law have been enacted in 2004 and targets 3% in 2007 and 3.5% in 2008. Thus we estimate the target percentage from 2003 to be: 0(2003), 0.75(2004), 1.5(2005), 2.25(2006), 3(2007) with a 0.75% annual incremental rate and 3.5(2008) as required. To Iowa and Texas that have quantity rather than ratio requirement, this article estimates the approximate ratio according to the RE quantity required and the total electricity capacity and generation as previous studies did.

This paper lists other RPS feature variables in Table 5.1 in order to assess the difference between states' RPS policies other than the nominal renewable ratio target: 1) *REC* is a dummy variable that devotes whether a state has established credit trading mechanism; 2) *COVERAGE* is the percentage of total retail sales in a state-year that are required by law to comply with the RPS annual target; 3) *NONELIGIBLE* represents the generation (1×10^3 gigawatt-hour) of the renewable energy capacity existed prior to the enactment of the RPS policy and not eligible to meet the RPS requirement; 4) *RECATEGORY* refers to the number of energy source in the eleven chosen categories[12] that is regarded as renewable energy in the state; 5) *PENALTY* is a dummy variable if the state has financial mechanism to incentive for compliance by either an explicit financial penalty for noncompliance or an Alternative Compliance Payment. The three dummy variables about other renewable energy policies including: 1) *PBF* to measure if a state has state-level Public Benefit Funds; 2) *NM* to measure if a state has state-level Net Metering system; and 3) *MGPO* to measure if a state has state-level Mandatory Green Power Option. All data for these five variables are from Lawrence Berkeley National Laboratory and DISIRE.

ESALE is the annual retail sales (1×10^3 gigawatt-hour) in all sectors for each state. *GENERATION* is the total Electric Power Industry Generation (1×10^3 gigawatt-hour) for each state. This article also includes *IMPORT*, a measure of percentage electricity a state imports or exports[13]. In other words, it is an index to tell the difference between electricity sales, *ESALE*,

[12] these nine energy sources include wind, photovoltaic, solar thermal, biomass, geothermal, small hydroelectric, fuel cells, land fill gas, tidal/ocean, wave/thermal, and energy efficiency.

[13] $IMPORT = (ESALE - GENERATION) \times 100 / ESALE$.

and in-state generation, *GENERATION*. Data about electricity sales and in-state generation is provided by the Energy Information Administration (EIA). According to equation (1), *RPS* can be derived after having the data for *NOMINALTARGET*, *COVERAGE*, *ESALE*, and *NONELIGIBLE*.

EIA also provides data for the following variables: 1) Electric Power Industry Generation (1×10^3 gigawatt-hour) from non-hydro renewable energy, *RENEWABLEGEN*; 2) total annual Electric Power Industry Capacity (1×10^3 gigawatt), *CAPACITY*; 3) Electric Power Industry Capacity (1×10^3 gigawatt) from non-hydro renewable energy, *RECAPACITY*; 4) Average Retail Prices (cents/KWh) for all sectors in a state. This article uses the inflation calculator[14] to transfer the nominal Retail Prices into real currency values of Retail Prices (2008 cents/KWh), *P*. Previous studies focus more on the effect on capacity since EIA revised its definition of renewable energy in 2000, which makes generation not a suitable dependent variable (Yin 2010). Beginning with 2001 data in EIA, non-biogenic municipal solid waste and tire-derived fuels are reclassified as non-renewable energy sources and included in “Other”. In order to make a consistent statistical standard for the renewable energy generation data, this article revises the data before 2001 by deleting the non-biogenic municipal solid waste and tire-derived fuels out of the renewable energy generation. However, EIA only has the data of total municipal solid waste rather than non-biogenic municipal solid waste. This article estimates the non-biogenic municipal solid waste using the annual non-biogenic ratio in municipal solid waste[15]. Therefore,

---

[14] http://www.usinflationcalculator.com/

[15] Ratio is 0.34-0.42 for 1990-2000, which is available in Table 1 of the report “Methodology for

this article revises *RENEWABLEGEN* to *REGENERATION*, which is under the same definition of renewable energy for data from 1990 to 2008. The renewable energy share in capacity, *R*, and renewable energy share in generation, *RR*, can be derived through *RECAPACITY* divided by *CAPACITY* and *REGENERATION* divided by *GENERATION*, respectively.

The data of nominal natural gas price (cents per million Btu) is also provided by the Energy Information Administration (EIA). Thus, *INPUTPRICE* can be derived by the same inflation calculator as the one used in retail electricity price. This article also calculate division average price according to the same database. For those missing and unpublished data, I estimate them the same as the division[16] average price which those states belong to.

UNEMPLOY represents state's unemployment rate in population. This article assumes previous year's employment information will affect recent year's investment of renewable energy installment. The Local Area Unemployment Statistics (LAUS) program[17] provides annual unemployment rate for each county. This article uses this county-level database and take the weighted average unemployment rate for each state.

Real 2008 thousand dollars of income per capita in each state and year, *INCOMELEVEL*, could be collected from U.S. Dept. of Commerce, Bureau of Economic Analysis.

In order to control the impact of various political parties, this paper regards Republic Party as

---

Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy" from EIA.

[16] The nine divisions include New England, Mid-Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific.

[17] Data is available on http://www.bls.gov/lau/

the base and defines the dummy variables *DEMOCARTIC* and *OTHERPARTIES* to indicate if the state governor is a Democrat and from other parties than Republic Party and Democratic Party, respectively. The name of all the governors and their term of office for all the states are available from Wikipedia under the topics of "Political party strength in (State Name)". This paper verifies this information through each state government's website.

Based on the state population data[18] and state land area (square miles) data[19] both from U.S. Census Bureau, the population density (people per square mile), *POPDENSITY* can be derived.

This article creates a solar index, a biomass, index and a wind index to indicate the renewable energy potential in a state. Renewable energy index includes: 1) Solar energy potential, *SOLAR*, is derived by sun index[20]. This article divides this sun index by its mean in the 48 states to make *SOLAR*, a new solar energy potential index with a mean of 1; 2) Biomass density can be calculated through biomass resources[21] divided by state land area. This article divides this biomass density index by its mean in the 48 states to make *BIOMASS*, a new biomass energy potential index with a

---

[18] Source: Population Estimates Program, Population Division, U.S. Census Bureau, Washington, DC 20233. http://www.census.gov/popest/archives/1990s/ST-99-03.txt

[19] 2000 Geography and Environment, Source: QuickFacts: US Census Bureau Land area, 2000 (square miles). http://www.datamasher.org/user-data-sets/state-land-area-square-miles

[20] The sun index is defined as an index of the amount of direct sunlight received in each state and accounts for latitude and cloud cover. California is indexed at 1. The amount of direct sunlight was derived from numbers provided by the Renewable Resource Data Center. The sun index was calculated as the average annual number of hours of peak direct sunlight hours from 1960 to 1990.

[21] Estimated Annual Cumulative Biomass Resources Available (dry ton/year) when delivery cost is less than $50. Data is from Bioenergy Feedstock Information Network (BFIN).

mean of 1; 3) Wind density can be calculated through wind generation[22] divided by state land area. This article divides this wind density index by its mean in the 48 states to make *WIND*, a new wind energy potential index with a mean of 1.

[22] Wind Potential Annual Generation (GWh) for areas>=30% capacity factor at 80 m. Data from The U.S. Department of Energy's Wind and Water Power Program.

CHAPTER 6: ESTIMATION RESULTS

6.1 Prediction on Renewable Energy share and Electricity Price

6.1.1 Estimations for All the 48 Lower States

According to the testing for serial correlation in Appendix 2-13, this article should “cluster" the standard errors by state for both the basic model and the advanced ones. Table 6.1, Table 6.2, and Table 6.3 reports the estimation of the basic model and the advanced ones. Each table is the estimation of the same dependent variable, first renewable energy share in capacity (Table 6.1), second renewable energy share in generation (Table 6.2), and third log of electricity price (Table 6.3). Within each of the three tables, the first column is the estimation of the basic model; the second column is the estimation when adding other RPS features and other renewable energy policies into the basic model as discussed in Section 4.1.2.1; the third column is the estimation when adding the interactions between each of the state dummy variables (expect for Arizona) with linear time trends (year #) with different trends concern as discussed in Section 4.1.2.2 into the equation in the second column; and the fourth column is the estimation of the final advanced model (one of the equation (5*), (6*), and (7*)) when adding all the interactions mentioned in Section 4.1.2.3 into the equation used in the third column. This article lists each equation for each column of the three tables in Appendix 1. In these three tables, “*fe(* X_{IT} *)*” refers to the variable *X* minus its mean ($X_{IT} - \bar{X}_{IT}$) of all the 48 $\times$19 = 912 observations for all the 48 lower states.

Table 6.1 OLS regression results of the capacity equations for all the 48 states

Column #	(1)	(2)	(3)	(4)
Equation #	2	2*	2**	5*
RPS	-0.0392	-0.0437	0.0203	0.390*
	(0.047)	(0.038)	(0.037)	(0.194)
*RPS*feSOLAR*	--	--	--	-1.895**
	--	--	--	(0.740)
*RPS*feBIOMASS*	--	--	--	0.125
	--	--	--	(0.245)
*RPS*feWIND*	--	--	--	0.194
	--	--	--	(0.196)
*RPS*feREGION2*	--	--	--	-0.141
	--	--	--	(0.588)
*RPS*feREGION3*	--	--	--	-0.0332
	--	--	--	(0.166)
*RPS*feREGION4*	--	--	--	0.62***
	--	--	--	(0.167)
*RPS*feTIME1*	--	--	--	0.0288
	--	--	--	(0.025)
*RPS*feREC*	--	--	--	-0.0887
	--	--	--	(0.088)
*RPS*fePENALTY*	--	--	--	-0.39***
	--	--	--	(0.092)
REC	--	1.59*	1.228**	1.671
	--	(0.859)	(0.548)	(4.915)
PENALTY	--	-2.086**	-1.939**	0.018
	--	(0.998)	(0.910)	(0.900)
RECATEGORY	--	0.0493	0.0664	-0.0325
	--	(0.051)	(0.041)	(0.023)
PBF	--	0.643**	0.133	-0.0986
	--	(0.308)	(0.359)	(0.219)
NM	--	-0.714**	0.0158	0.142
	--	(0.286)	(0.158)	(0.141)
MGPO	--	3.42***	1.623**	0.913*
	--	(1.247)	(0.662)	(0.491)

Table 6.1 (cont'd)				
DEMOCARTIC	0.370*	0.197	0.215**	0.186**
	(0.207)	(0.147)	(0.100)	(0.077)
OTHERPARTIES	1.451**	1.29***	0.95	-0.114
	(0.641)	(0.461)	(0.569)	(0.215)
INPUTPRICE	-0.163**	-0.125**	-0.117**	-0.0699*
	(0.069)	(0.062)	(0.048)	(0.039)
IMPORT	0.017**	0.02***	0.0128	-0.00027
	(0.008)	(0.006)	(0.009)	(0.004)
ESALE	0.0004	0.0119	0.0148	0.0107
	(0.015)	(0.011)	(0.030)	(0.014)
POPDENSITY	-0.03***	-0.02***	-0.00178	-0.00553
	(0.010)	(0.007)	(0.007)	(0.008)
UNEMPLOY	0.112	0.164	-0.139	-0.0188
	(0.149)	(0.101)	(0.109)	(0.085)
INCOMELEVEL	0.26***	0.30***	0.0406	-0.00701
	(0.090)	(0.073)	(0.113)	(0.088)
*SOLAR*REC*	--	--	--	0.186
	--	--	--	(3.720)
*BIOMASS*REC*	--	--	--	-0.867
	--	--	--	(0.818)
*WIND*REC*	--	--	--	-0.23
	--	--	--	(0.223)
Y' SOLAR*	--	--	--	yes
Y' BIOMASS*	--	--	--	yes
Y' WIND*	--	--	--	yes
*T*state dummies*	--	--	yes	yes
year fixed effects	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes
*cons_*	-6.084*	-8.71***	0.523	0.189
	(3.220)	(2.522)	(3.671)	(3.130)
R-square	0.8707	0.9024	0.9451	0.9746
No. of Obs.	912	912	912	912

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

Table 6.2 OLS regression results of the generation equations for all the 48 states

Column #	(1)	(2)	(3)	(4)
Equation #	3	3*	3**	6*
RPS	-0.088***	-0.10***	-0.104	0.289*
	(0.035)	(0.030)	(0.068)	(0.162)
*RPS*feSOLAR*	--	--	--	-1.79*
	--	--	--	(1.000)
*RPS*feBIOMASS*	--	--	--	0.249
	--	--	--	(0.208)
*RPS*feWIND*	--	--	--	0.00958
	--	--	--	(0.160)
*RPS*feREGION2*	--	--	--	0.421
	--	--	--	(0.658)
*RPS*feREGION3*	--	--	--	0.154
	--	--	--	(0.314)
*RPS*feREGION4*	--	--	--	0.65***
	--	--	--	(0.144)
*RPS*feTIME1*	--	--	--	0.00992
	--	--	--	(0.023)
*RPS*feREC*	--	--	--	-0.0696
	--	--	--	(0.151)
*RPS*fePENALTY*	--	--	--	-0.254
	--	--	--	(0.166)
REC	--	0.556	-0.0314	-5.459
	--	(0.611)	(0.523)	(5.150)
PENALTY	--	-1.134	-0.611	1.558
	--	(0.771)	(0.794)	(0.992)
RECATEGORY	--	0.0728*	0.0752*	0.0132
	--	(0.042)	(0.042)	(0.035)
PBF	--	0.594*	0.0374	0.035
	--	(0.313)	(0.374)	(0.350)
NM	--	-0.533**	-0.124	0.0542
	--	(0.242)	(0.203)	(0.175)
MGPO	--	2.09***	0.937**	0.676**
	--	(0.617)	(0.430)	(0.330)

Table 6.2 (cont'd)				
DEMOCARTIC	0.180	0.0791	0.0645	0.072
	(0.153)	(0.134)	(0.115)	(0.088)
OTHERPARTIES	1.311	1.122	0.794	-0.00149
	(0.990)	(0.890)	(1.088)	(0.911)
INPUTPRICE	-0.0679	-0.0427	-0.0751	-0.054
	(0.049)	(0.045)	(0.055)	(0.047)
IMPORT	0.0304*	0.033**	0.046**	0.041**
	(0.014)	(0.013)	(0.020)	(0.017)
ESALE	-0.00175	0.00604	-0.0249	-0.0273*
	(0.012)	(0.009)	(0.019)	(0.014)
POPDENSITY	-0.0164*	-0.015**	-0.0347	-0.0387
	(0.009)	(0.007)	(0.022)	(0.025)
UNEMPLOY	0.081	0.124	-0.106	-0.0573
	(0.124)	(0.099)	(0.107)	(0.075)
INCOMELEVEL	-0.0101	0.00934	-0.093	-0.133
	(0.081)	(0.067)	(0.091)	(0.094)
*SOLAR*REC*	--	--	--	4.19
	--	--	--	(3.880)
*BIOMASS*REC*	--	--	--	0.524
	--	--	--	(0.602)
*WIND*REC*	--	--	--	0.119
	--	--	--	(0.277)
Y' SOLAR*	--	--	--	yes
Y' BIOMASS*	--	--	--	yes
Y' WIND*	--	--	--	yes
*T*state dummies*	--	--	yes	yes
year fixed effects	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes
*cons_*	1.948	0.405	7.973*	8.843**
	(2.892)	(2.373)	(3.555)	(3.569)
R-square	0.9330	0.9416	0.9602	0.9712
No. of Obs.	912	912	912	912

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

Table 6.3 OLS regression results of the price equations for all the 48 states

Column #	(1)	(2)	(3)	(4)
Equation #	4	4*	4**	7*
RPS	0.0053*	0.00226	0.00055	0.0264***
	(0.003)	(0.003)	(0.003)	(0.008)
*RPS*feSOLAR*	--	--	--	-0.00545
	--	--	--	(0.061)
*RPS*feBIOMASS*	--	--	--	0.0045
	--	--	--	(0.014)
*RPS*feWIND*	--	--	--	-0.0147**
	--	--	--	(0.007)
*RPS*feREGION2*	--	--	--	0.036
	--	--	--	(0.034)
*RPS*feREGION3*	--	--	--	0.0856***
	--	--	--	(0.015)
*RPS*feREGION4*	--	--	--	-0.0139
	--	--	--	(0.013)
*RPS*feTIME1*	--	--	--	0.0015
	--	--	--	(0.002)
*RPS*feREC*	--	--	--	0.00127
	--	--	--	(0.007)
*RPS*fePENALTY*	--	--	--	-0.0017
	--	--	--	(0.006)
REC	--	0.00449	0.05	-0.481*
	--	(0.056)	(0.040)	(0.285)
PENALTY	--	0.0391	-0.0312	0.0345
	--	(0.062)	(0.047)	(0.058)
RECATEGORY	--	0.0043*	-0.00004	-0.00126
	--	(0.002)	(0.004)	(0.002)
PBF	--	-0.011	-0.051**	-0.061***
	--	(0.031)	(0.024)	(0.019)
NM	--	0.0189	-0.00968	0.00219
	--	(0.018)	(0.014)	(0.012)
MGPO	--	0.0732	-0.0207	0.047
	--	(0.060)	(0.020)	(0.030)

Table 6.3 (cont'd)				
DEMOCARTIC	-0.0149	-0.0176	-0.00012	0.00197
	(0.013)	(0.012)	(0.006)	(0.006)
OTHERPARTIES	0.00905	0.00983	0.0335*	0.0117
	(0.023)	(0.021)	(0.019)	(0.020)
INPUTPRICE	-0.00102	0.00084	0.0043*	0.00346*
	(0.004)	(0.003)	(0.002)	(0.002)
IMPORT	-0.001**	-0.001**	-0.0002	-0.00011
	(0.000)	(0.000)	(0.000)	(0.000)
ESALE	-0.0009	-0.0008	-0.01***	-0.005***
	(0.002)	(0.001)	(0.002)	(0.001)
POPDENSITY	0.00076	0.00038	-0.00155	-0.00144
	(0.001)	(0.001)	(0.001)	(0.001)
UNEMPLOY	0.00808	0.0097	0.00796	0.0128*
	(0.009)	(0.008)	(0.007)	(0.007)
INCOMELEVEL	0.00418	0.00302	0.00454	0.000953
	(0.004)	(0.004)	(0.004)	(0.004)
*SOLAR*REC*	--	--	--	0.406*
	--	--	--	(0.218)
*BIOMASS*REC*	--	--	--	0.0654*
	--	--	--	(0.036)
*WIND*REC*	--	--	--	-0.0157
	--	--	--	(0.021)
Y' SOLAR*	--	--	--	yes
Y' BIOMASS*	--	--	--	yes
Y' WIND*	--	--	--	yes
*T*state dummies*	--	--	yes	yes
year fixed effects	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes
*cons_*	2.27***	2.29***	2.70***	2.752***
	(0.180)	(0.154)	(0.151)	(0.160)
R-square	0.9361	0.9398	0.9753	0.9821
No. of Obs.	912	912	912	912

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

Table 6.1 shows the effect of RPS on renewable energy share in capacity when using the panel data. Column 1 and column 2 both indicate insignificantly negative effects of RPS on renewable energy share in capacity for equation (2) and equation (2*) which adds other RPS features and other renewable energy policies. However, column 3 predicts an insignificant positive effect of RPS on renewable energy share in capacity with different trends concern in equation (2**). Finally, column 4 estimates that RPS is a positive incentive of renewable energy share in capacity in states on average when interaction effect concern is also included in equation (5*). The estimation result predicts a significant 0.390 percentage increase in renewable energy share in capacity if the adjusted RPS annual target increased by 1 percentage.

Table 6.2 shows the relation between RPS and renewable energy share in generation. Without interaction effect concern and different trend concern, Column 1 and 2 both indicate significantly negative effects of RPS on renewable energy share in generation for equation (3) and equation (3*) which adds other RPS features and other renewable energy policies. But the estimation becomes insignificant when adding the interactions between each of the state dummies and the linear year number in column 3. However, after dealing with all the potential problems, column 4 indicates 1 percentage increase in RPS annual target would significantly lead to a 0.289 percentage growth in actual share of renewable energy generated electricity.

Table 6.3 focuses on the effect on electricity price when a state deploys a RPS, which leads to a change in consumer surplus. Column 1 predicts a significant positive effect of RPS on electricity price. Column 2 and 3 give insignificant effect of RPS on price when adding other RPS features and other renewable energy policies as well as different trends concern. After controlling the interactions and other independent variables, the estimated average effect on electricity price becomes significant again in column 4. Therefore, this paper predicts a 2.64 percent price increase when strengthening the policy by 1 percentage in RPS.

This article is "reweighting" the effect of RPS to be representative of all states in the last column of Table 6.1, Table 6.2, and Table 6.3, not just states that implemented RPS, which is what this paper gets without the interactions in the first three columns in those three tables. Thus, the results in the last column of Table 6.1, Table 6.2, and Table 6.3 in theory are good for evaluating the effects of a national RPS but very different with the estimation of the first three columns in each of the three tables. It's important to realize that these estimates reflect an "out of sample" prediction for the effect of RPS in states that did not actually implement RPS.

The analysis above verifies the assumption of RPS impacts predicted in the conceptual model. The three hypotheses about RPS impacts in the conceptual model are all valid. This article has assumed that 1 percentage increase in RPS annual target can: 1) increase the renewable energy share in capacity by $\boldsymbol{\alpha}$ percentages; 2) increase the renewable energy share in generation by $\boldsymbol{\beta}$ percentages; 3) increase the electricity price by $\boldsymbol{\gamma}$ percent at the end of Section 4.1. Therefore, the estimated $\widehat{\boldsymbol{\alpha}}$, $\widehat{\boldsymbol{\beta}}$, and $\widehat{\boldsymbol{\gamma}}$ are 0.390, 0.289, and 0.0264×100=2.64, respectively. To sum up, all the estimation results imply that RPS policies are effective since $\widehat{\boldsymbol{\alpha}}$ and $\widehat{\boldsymbol{\beta}}$ are significantly positive but will increase the electricity price because of the significant positive $\widehat{\boldsymbol{\gamma}}$. This article uses the estimated $\widehat{\boldsymbol{\alpha}}$, $\widehat{\boldsymbol{\beta}}$, and $\widehat{\boldsymbol{\gamma}}$ in latter analysis that are discussed in Section 4.2.

6.1.2 Estimations for Each of the Four Regions

Table 6.4 and Table 6.5 give the estimated effect of RPS on renewable energy share and electricity price for each of the four regions as discussed in Section 4.1.3. Each three-column is the estimations for each region. The "*fe(* X_{IT} *)*" refers to the variable X minus its mean ($X_{IT} - \bar{X}_{IT}$) of: 1) $9 \times 19 = 171$ observations for the 9 states in Northeast in the first three columns of Table 6.4; 2) $12 \times 19 = 228$ observations for the 12 states in Midwest in the second three columns of Table 6.4; 3) $16 \times 19 = 304$ observations for the 16 states in South in the first three columns of Table 6.5; and 4) $11 \times 19 = 209$ observations for the 11 states in West in the second three columns of Table 6.5.

Table 6.4 and Table 6.5 give the estimated average effects of RPS for each region on renewable energy share in capacity, renewable energy share in generation, and electricity price. When RPS increase by 1 percentage, 1) renewable energy share in capacity on average will increase 0.140 percentage and electricity price on average will increase 0.478 percent for states in Northeast; 2) renewable energy share in capacity on average will increase 0.694 percentage and renewable energy share in generation on average will increase 0.703 percentage for states in Midwest; 3) electricity price on average will increase 8.72 percent for states in South; and 4) renewable energy share in capacity on average will increase 0.608 percentage, renewable energy share in generation on average will increase 0.280 percentage, and electricity price will decrease 2.21 percent for states in West.

Table 6.4 OLS regression results for Northeast and for Midwest

Region	***Northeast***			***Midwest***		
Column #	(1)	(2)	(3)	(4)	(5)	(6)
Equation #	5*	6*	7*	5*	6*	7*
RPS	0.14***	-0.012	0.00478*	0.694***	0.703***	0.0059
	(0.040)	(0.052)	(0.003)	(0.140)	(0.183)	(0.009)
*RPS*feSOLAR*	-1.9***	-1.79***	-0.00545	-1.9***	-1.79***	-0.00545
	(0.486)	(0.633)	(0.032)	(0.486)	(0.633)	(0.032)
*RPS*feBIOMASS*	0.125	0.249*	0.0045	0.125	0.249*	0.0045
	(0.113)	(0.147)	(0.008)	(0.113)	(0.147)	(0.008)
*RPS*feWIND*	0.19***	0.01	-0.01***	0.19***	0.01	-0.01***
	(0.064)	(0.080)	(0.004)	(0.064)	(0.080)	(0.004)
*RPS*feREGION2*	-0.141	0.421	0.036***	-0.141	0.421	0.036***
	(0.199)	(0.260)	(0.013)	(0.199)	(0.260)	(0.013)
*RPS*feREGION3*	-0.0332	0.154	0.09***	-0.0332	0.154	0.09***
	(0.151)	(0.193)	(0.010)	(0.151)	(0.193)	(0.010)
*RPS*feREGION4*	0.62***	0.65***	-0.0139*	0.62***	0.65***	-0.0139*
	(0.117)	(0.152)	(0.008)	(0.117)	(0.152)	(0.008)
*RPS*feTIME1*	0.0288	0.00992	0.0015	0.0288	0.00992	0.0015
	(0.019)	(0.025)	(0.001)	(0.019)	(0.025)	(0.001)
*RPS*feREC*	-0.0887	-0.0696	0.00127	-0.0887	-0.0696	0.00127
	(0.061)	(0.079)	(0.004)	(0.061)	(0.079)	(0.004)
*RPS*fePENALTY*	-0.39***	-0.25***	-0.0017	-0.39***	-0.25***	-0.0017
	(0.062)	(0.080)	(0.004)	(0.062)	(0.080)	(0.004)

Table 6.4 (cont'd)						
REC	1.671	-5.459	-0.481**	1.671	-5.459	-0.481**
	(2.881)	(3.739)	(0.195)	(2.881)	(3.739)	(0.195)
PENALTY	0.018	1.558**	0.0345	0.018	1.558**	0.0345
	(0.600)	(0.708)	(0.037)	(0.600)	(0.708)	(0.037)
RECATEGORY	-0.0325*	0.0132	-0.00126	-0.0325*	0.0132	-0.00126
	(0.019)	(0.025)	(0.001)	(0.019)	(0.025)	(0.001)
PBF	-0.0986	0.035	-0.06***	-0.0986	0.035	-0.06***
	(0.152)	(0.194)	(0.010)	(0.152)	(0.194)	(0.010)
NM	0.142	0.0542	0.00219	0.142	0.0542	0.00219
	(0.106)	(0.139)	(0.007)	(0.106)	(0.139)	(0.007)
MGPO	0.9***	0.676**	0.047***	0.9***	0.676**	0.047***
	(0.244)	(0.317)	(0.016)	(0.244)	(0.317)	(0.016)
DEMOCARTIC	0.19***	0.072	0.00197	0.19***	0.072	0.00197
	(0.064)	(0.084)	(0.004)	(0.064)	(0.084)	(0.004)
OTHERPARTIES	-0.114	-0.00149	0.0117	-0.114	-0.00149	0.0117
	(0.197)	(0.149)	(0.013)	(0.197)	(0.149)	(0.013)
INPUTPRICE	-0.07***	-0.054*	0.003**	-0.07***	-0.054*	0.003**
	(0.023)	(0.030)	(0.002)	(0.023)	(0.030)	(0.002)
IMPORT	-0.00027	0.04***	-0.0001	-0.00027	0.04***	-0.0001
	(0.002)	(0.003)	(0.000)	(0.002)	(0.003)	(0.000)
ESALE	0.0107	-0.0273*	-0.005***	0.0107	-0.0273*	-0.005***
	(0.012)	(0.015)	(0.001)	(0.012)	(0.015)	(0.001)
POPDENSITY	-0.00553	-0.04***	-0.001***	-0.00553	-0.04***	-0.001***
	(0.006)	(0.008)	(0.000)	(0.006)	(0.008)	(0.000)

Table 6.4 (cont'd)						
UNEMPLOY	-0.0188	-0.0573	0.01***	-0.0188	-0.0573	0.01***
	(0.049)	(0.065)	(0.003)	(0.049)	(0.065)	(0.003)
INCOMELEVEL	-0.00701	-0.13***	0.001	-0.00701	-0.13***	0.001
	(0.039)	(0.050)	(0.003)	(0.039)	(0.050)	(0.003)
*SOLAR*REC*	0.186	4.19	0.406***	0.186	4.19	0.406***
	(2.325)	(2.972)	(0.154)	(2.325)	(2.972)	(0.154)
*BIOMASS*REC*	-0.867**	0.524	0.0654**	-0.867**	0.524	0.0654**
	(0.423)	(0.552)	(0.029)	(0.423)	(0.552)	(0.029)
*WIND*REC*	-0.23	0.119	-0.0157	-0.23	0.119	-0.0157
	(0.167)	(0.216)	(0.011)	(0.167)	(0.216)	(0.011)
Y' SOLAR*	yes	yes	yes	yes	yes	yes
Y' BIOMASS*	yes	yes	yes	yes	yes	yes
Y' WIND*	yes	yes	yes	yes	yes	yes
*T*state dummies*	yes	yes	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes	yes	yes
_cons	0.189	8.84***	2.752***	0.189	8.84***	2.752***
	(1.323)	(1.723)	(0.089)	(1.323)	(1.723)	(0.089)
R-square	0.9746	0.9712	0.9821	0.9746	0.9712	0.9821
No. of Obs.	912	912	912	912	912	912

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

Table 6.5 OLS regression results for South and for West

Region	*South*			*West*		
Column #	(1)	(2)	(3)	(4)	(5)	(6)
Equation #	5*	6*	7*	5*	6*	7*
RPS	0.153	0.155	0.0872***	0.6078***	0.280***	-0.022***
	(0.153)	(0.199)	(0.010)	(0.081)	(0.105)	(0.005)
*RPS*feSOLAR*	-1.9***	-1.79***	-0.00545	-1.9***	-1.79***	-0.00545
	(0.486)	(0.633)	(0.032)	(0.486)	(0.633)	(0.032)
*RPS*feBIOMASS*	0.125	0.249*	0.0045	0.125	0.249*	0.0045
	(0.113)	(0.147)	(0.008)	(0.113)	(0.147)	(0.008)
*RPS*feWIND*	0.19***	0.01	-0.01***	0.19***	0.01	-0.01***
	(0.064)	(0.080)	(0.004)	(0.064)	(0.080)	(0.004)
*RPS*feREGION2*	-0.141	0.421	0.036***	-0.141	0.421	0.036***
	(0.199)	(0.260)	(0.013)	(0.199)	(0.260)	(0.013)
*RPS*feREGION3*	-0.0332	0.154	0.09***	-0.0332	0.154	0.09***
	(0.151)	(0.193)	(0.010)	(0.151)	(0.193)	(0.010)
*RPS*feREGION4*	0.62***	0.65***	-0.0139*	0.62***	0.65***	-0.0139*
	(0.117)	(0.152)	(0.008)	(0.117)	(0.152)	(0.008)
*RPS*feTIME1*	0.0288	0.00992	0.0015	0.0288	0.00992	0.0015
	(0.019)	(0.025)	(0.001)	(0.019)	(0.025)	(0.001)
*RPS*feREC*	-0.0887	-0.0696	0.00127	-0.0887	-0.0696	0.00127
	(0.061)	(0.079)	(0.004)	(0.061)	(0.079)	(0.004)
*RPS*fePENALTY*	-0.39***	-0.25***	-0.0017	-0.39***	-0.25***	-0.0017
	(0.062)	(0.080)	(0.004)	(0.062)	(0.080)	(0.004)

Table 6.5 (cont'd)						
REC	1.671	-5.459	-0.481**	1.671	-5.459	-0.481**
	(2.881)	(3.739)	(0.195)	(2.881)	(3.739)	(0.195)
PENALTY	0.018	1.558**	0.0345	0.018	1.558**	0.0345
	(0.600)	(0.708)	(0.037)	(0.600)	(0.708)	(0.037)
RECATEGORY	-0.0325*	0.0132	-0.00126	-0.0325*	0.0132	-0.00126
	(0.019)	(0.025)	(0.001)	(0.019)	(0.025)	(0.001)
PBF	-0.0986	0.035	-0.06***	-0.0986	0.035	-0.06***
	(0.152)	(0.194)	(0.010)	(0.152)	(0.194)	(0.010)
NM	0.142	0.0542	0.00219	0.142	0.0542	0.00219
	(0.106)	(0.139)	(0.007)	(0.106)	(0.139)	(0.007)
MGPO	0.9***	0.676**	0.047***	0.9***	0.676**	0.047***
	(0.244)	(0.317)	(0.016)	(0.244)	(0.317)	(0.016)
DEMOCARTIC	0.19***	0.072	0.00197	0.19***	0.072	0.00197
	(0.064)	(0.084)	(0.004)	(0.064)	(0.084)	(0.004)
OTHERPARTIES	-0.114	-0.00149	0.0117	-0.114	-0.00149	0.0117
	(0.197)	(0.149)	(0.013)	(0.197)	(0.149)	(0.013)
INPUTPRICE	-0.07***	-0.054*	0.003**	-0.07***	-0.054*	0.003**
	(0.023)	(0.030)	(0.002)	(0.023)	(0.030)	(0.002)
IMPORT	-0.00027	0.04***	-0.0001	-0.00027	0.04***	-0.0001
	(0.002)	(0.003)	(0.000)	(0.002)	(0.003)	(0.000)
ESALE	0.0107	-0.0273*	-0.005***	0.0107	-0.0273*	-0.005***
	(0.012)	(0.015)	(0.001)	(0.012)	(0.015)	(0.001)
POPDENSITY	-0.00553	-0.04***	-0.001***	-0.00553	-0.04***	-0.001***
	(0.006)	(0.008)	(0.000)	(0.006)	(0.008)	(0.000)

Table 6.5 (cont'd)						
UNEMPLOY	-0.0188	-0.0573	0.01***	-0.0188	-0.0573	0.01***
	(0.049)	(0.065)	(0.003)	(0.049)	(0.065)	(0.003)
INCOMELEVEL	-0.00701	-0.13***	0.001	-0.00701	-0.13***	0.001
	(0.039)	(0.050)	(0.003)	(0.039)	(0.050)	(0.003)
*SOLAR*REC*	0.186	4.19	0.406***	0.186	4.19	0.406***
	(2.325)	(2.972)	(0.154)	(2.325)	(2.972)	(0.154)
*BIOMASS*REC*	-0.867**	0.524	0.0654**	-0.867**	0.524	0.0654**
	(0.423)	(0.552)	(0.029)	(0.423)	(0.552)	(0.029)
*WIND*REC*	-0.23	0.119	-0.0157	-0.23	0.119	-0.0157
	(0.167)	(0.216)	(0.011)	(0.167)	(0.216)	(0.011)
Y' SOLAR*	yes	yes	yes	yes	yes	yes
Y' BIOMASS*	yes	yes	yes	yes	yes	yes
Y' WIND*	yes	yes	yes	yes	yes	yes
*T*state dummies*	yes	yes	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes	yes	yes
_cons	0.189	8.84***	2.752***	0.189	8.84***	2.752***
	(1.323)	(1.723)	(0.089)	(1.323)	(1.723)	(0.089)
R-square	0.9746	0.9712	0.9821	0.9746	0.9712	0.9821
No. of Obs.	912	912	912	912	912	912

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

6.1.3 Conclusion

Table 6.6 gives the conclusion of the RPS impacts for each state and all the 48 lower states. The predicted direction of the consumer surplus, emissions, and consumer welfare are also listed in the table.

Table 6.6 Conclusion of the OLS estimators

Effect on / Subjects	Capacity	Generation	Price	Consumer Surplus	Emissions	Consumer Welfare
Northeast	(+)	(×)	(+)	(-)	(-)	?
Midwest	(+)	(+)	(×)	(×)	(-)	(+)
South	(×)	(×)	(+)	(-)	(-)	?
West	(+)	(+)	(-)	(+)	?	?
All 48 states	(+)	(+)	(+)	(-)	(-)	?

Notes: (+) refers to significantly positive effect; (-) refers to significantly negative effect; and (×) refers to insignificantly effect.

In the Northeast, RPS on average could increase electricity price but no significant effect on renewable energy share in generation, which will lead to consumer surplus loss and reduce carbon and other emissions according to the analysis in Section 3.3. But it is hard to predict the change in consumer welfare since it depends on the magnitude of consumer surplus loss and the value of reduced carbon and other emissions. This is the same situation for South region.

In the Midwest, RPS on average could increase renewable energy share in generation but no significant effect on electricity price, which will lead to no change in consumer surplus and reduce carbon and other emissions according to the analysis in Section 3.3. Therefore, consumer welfare on average will increase when states in Midwest strengthen RPS by 1 percentage, which implies that RPS on average is efficient with emission concern in Midwest.

Compared with the situation in Midwest, RPS on average also increases renewable energy share in generation, which can reduce carbon and other emissions. On the other hand, the decreased electricity price will increase consumer surplus but at the same time increase carbon and other emissions. Therefore, whether the total carbon and other emissions will increase or decrease depends on the relative magnitude of the increase in renewable energy share in generation and the decrease in electricity price. As a result, the direction of consumer welfare change is also hard to predict at this point.

For all the 48 lower states, RPS on average could increase electricity price which cause consumer surplus loss. The carbon and other emissions will decrease since the renewable energy share increase and price increase. Therefore, the change in consumer welfare depends on the magnitude of consumer surplus loss and the value of reduced carbon and other emissions.

To sum up, this article can only predict that RPS in Midwest can lead to consumer welfare increase and hence an efficient policy. The direction of effects on consumer welfare for each of the other three regions and for all the 48 lower states is not clear at this point. This paper first estimates the average effects for all the 48 lower states by the rest of the Section 6 and predicts the average effects for each of the other three regions using the same method.

6.2 Prediction on Consumer Surplus Loss

6.2.1 Demand Elasticity for Electricity Market

Table 6.7 provides estimates of demand for elasticity - that is, the percentage change in quantity demanded in response to a percentage change in price - first using ordinary least squares and then using instrumental variables with adjusted RPS annual target as an instrument based on a total balanced panel of 48 states $\times$ 19 years = 912 observations. Logically, a negative coefficient with the absolute value less than 1 is expected because former studies and reports noted an inelastic demand for US electricity market in this period. This table provides OLS estimators in the first pair of columns, TSLS estimators in the second pair of columns, and the estimation results about the first stage of the TSLS approaches when using RPS as instrument of electricity price in the last pair of columns. In each pair of columns, the first column is the estimation of demand equation (9) and the second column is the estimation when adding some other control variables into equation (9). This paper uses the demand elasticity estimated in the table for the following calculation in the rest of the section but also gives the final estimation results when demand elasticity is assumed to be 0 at the end of the section in Table 6.9.

Table 6.7 OLS and TSLS estimates for demand function with RPS annual target as an IV

Depend. Variable	log *Q*		log *Q*		log *P*	
	OLS		**TSLS**		**First Stage**	
Column #	(1)	(2)	(3)	(4)	(5)	(6)
log P	-0.4***	-0.3***	-0.81***	-0.558***		
	(0.025)	(0.024)	(0.148)	(0.133)		
RPS					0.01***	0.01***
					(0.001)	(0.001)
DEMOCARTIC		-0.02***		-0.02***		-0.01**
		(0.004)		(0.004)		(0.006)
OTHERPARTIES		-0.00101		0.00201		0.0072
		(0.013)		(0.013)		(0.018)
INPUTPRICE		0.000399		0.000093		-0.0021
		(0.002)		(0.002)		(0.002)
IMPORT		0.001***		0.001***		-0.001***
		(0.000)		(0.000)		(0.000)
POPDENSITY		0.0003		0.0004**		0.001***
		(0.000)		(0.000)		(0.000)
UNEMPLOY		0.01***		0.01***		0.01*
		(0.003)		(0.003)		(0.004)
year fixed effects	yes	yes	yes	yes	yes	yes
state fixed effects	yes	yes	yes	yes	yes	yes
_cons	4.74***	4.68***	5.82***	5.22***	2.45***	2.35***
	(0.063)	(0.060)	(0.361)	(0.315)	(0.199)	(0.031)
R-square	0.9971	0.9975				
No. of Obs.	912	912	912	912	912	912

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

In the first column, an ordinary least squares regression has been given with log electricity quantity as the explained variable and log electricity price as explanatory variable holding the year fixed effects and state fixed effects. The second column shows that the coefficient of log price is almost unchanged by adding more controls including governor's political party, natural gas price, electricity import ratio, population density, and unemployment rate.

The third column then provides a two stage least square (TSLS) approach. That is, first a regression is run with log electricity price as the predicted variable while RPS annual target, time dummy variables and state dummy variables as the predictor variables. The purpose of the first stage is to calculate the variation in price that is attributable to RPS annual target. The predicted values of electricity could be calculated by the coefficients from the first stage regression. Finally, the predicted price values have been inserted into the original equation instead of actual price to do OLS regression the same as in the first column. This column estimates the impact of the predicted electricity price on electricity quantity sale, which is twice that of OLS approach in column 1, which has an absolute value still less than 1. This implies an inelastic demand curve in United States electricity market during the latest two decades.

Adding the controls into the regression the same as column 2, as is done in the fourth column, increases the coefficient of log price from -0.81 to -0.558, which also indicates an inelastic demand with a higher absolute value than the OLS estimators..

According to regression result, this paper suggests a 0.558 percent decrease in quantity demanded in response to 1 percent increase in electricity price.

6.2.2 Consumer's Surplus Loss

The same database has been used to estimate both the equilibrium price P and quantity Q in Figure 3.2. $\widehat{\boldsymbol{P}}$ has been defined as the estimated weighted average real electricity price for all sectors also based on the same database, which is 9.1809 (2008 cents/KWh) while $\widehat{\boldsymbol{Q}}$ has been defined as the estimated average annual electricity sale, which is 3.2475×10^9 (MWh). As annual target of RPS increased by 1 percentage, electricity price will increase by 2.64 percent to 9.4233 (2008 cents/KWh) based on the OLS estimators with interaction effects, which is $\widehat{\boldsymbol{P'}}$ in Figure 3.2.

Since the estimated demand elasticity is -0.558, $\widehat{\boldsymbol{Q'}}$ is 3.1997×10^{9} (MWh) using equation (8). Therefore, this article can predict the consumer surplus loss when annual RPS target increased by 1 percentage. Finally, 1 percentage increase in RPS for the contiguous United States can lead to 7.803 billion 2008 dollars consumer surplus loss on average through equation (11) when using the OLS estimators with interaction effect concern about the effect on renewable energy share in generation and electricity price.

6.3 Prediction on Reduced Emission and Its Value

6.3.1 Reduced Emissions Amount

According to equation (12), (13), and (14), the real share of different energy source in this package of electricity generation, and the per unit emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide by each energy source are needed to estimate the reduced amount of emission when RPS requirement changes.

EIA provides the annual generation from difference energy source as well as the total generation by states. Hence, the share of the six types of energy, X_1, X_2, X_3, X_4, X_5, and X_6, can be estimated through dividing the average annual generation from non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource by the average total generation, respectively. These estimations, $\hat{X}_1$, $\hat{X}_2$, $\hat{X}_3$, $\hat{X}_4$, $\hat{X}_5$, and $\hat{X}_6$ represent the estimated average share of non-hydro renewable energy, natural gas, other gas, coal, petroleum, and other resource, respectively. These estimations are shown in Figure 4.2 as well as Table 6.8.

On one hand, this paper assumes the increased amount of renewable-generated electricity (***β*** percentages increased renewable energy share) displaces the electricity generated by coal and petroleum in proportion (1.465:1), which is discussed in the assumption 1 in section 4.2.2, while the share of natural gas, other gas and other resource in the electricity package stays the same ($\hat{X}'_1 = \hat{X}_1 + \hat{\boldsymbol{\beta}}$, $\hat{X}'_2 = \hat{X}_2$, $\hat{X}'_3 = \hat{X}_3$, $\hat{X}'_4 = \hat{X}_4 - \hat{\boldsymbol{\beta}}*1.465/(1.465+1)$, $\hat{X}'_5 = \hat{X}_5 - \hat{\boldsymbol{\beta}}*1/(1.465+1)$, and $\hat{X}'_6 = \hat{X}_6$) when the adjusted RPS annual target increased by 1 percentage.

On the other hand, based on the assumption 2, the increased amount of renewable-generated electricity (***β*** percentages increased renewable energy share) displaces the electricity generated by natural gas while the share of other gas, coal, petroleum, other resource in the electricity package stays the same ($\hat{X}'_1 = \hat{X}_1 + \hat{\boldsymbol{\beta}}$, $\hat{X}'_2 = \hat{X}_2 - \hat{\boldsymbol{\beta}}$, $\hat{X}'_3 = \hat{X}_3$, $\hat{X}'_4 = \hat{X}_4$, $\hat{X}'_5 = \hat{X}_5$, and $\hat{X}'_6 = \hat{X}_6$) when the adjusted RPS annual target increased by 1 percentage.

The unit emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide are different depending on the energy source. This paper estimates the average unit emission from historical data on the quantity of energy of various types consumed and their emissions. For example, the carbon dioxide emission per MWh electricity generated by coal is estimated through dividing the summation of carbon dioxide emission produced by coal in electric power industry from 1990 to 2008 by the summation of the electricity generated by coal from 1990 to 2008. The sulfur dioxide emission per MWh electricity generated by non-hydro renewables is estimated through dividing the summation of sulfur dioxide emission produced by non-hydro renewables in electric power industry from 1990 to 2008 by the summation of the electricity generated by non-hydro renewables from 1990 to 2008. Both the data of annual electric power industry emissions estimates (including carbon dioxide, sulfur dioxide, and nitrogen oxide) by source for each state from 1990 to 2008 and the annual electric power industry generation by primary energy source for each state from 1990 to 2008 are available in Energy Information Administration (EIA). The detailed estimated per unit carbon dioxide emission of the six energy sources ($\hat{\delta}_1$, $\hat{\delta}_2$, $\hat{\delta}_3$, $\hat{\delta}_4$, $\hat{\delta}_5$, and $\hat{\delta}_6$), estimated per unit sulfur dioxide emission of the six energy sources ($\hat{\eta}_1$, $\hat{\eta}_2$, $\hat{\eta}_3$, $\hat{\eta}_4$, $\hat{\eta}_5$, and $\hat{\eta}_6$), and estimated per unit nitrogen oxide emission of the six energy sources ($\hat{\rho}_1$, $\hat{\rho}_2$, $\hat{\rho}_3$, $\hat{\rho}_4$, $\hat{\rho}_5$, and $\hat{\rho}_6$) are also listed in Table 6.8, which are needed to calculate the reduced emission by equation (12), (13), and (14). This table also gives the explanation and unit for every variable.

Table 6.8 Energy share and unit emission estimates in electricity industry by source

Variable	Mean	Explanation
Energy Share		Unit: percentage
$\widehat{X_1}$	2.2327	average share of non-hydro renewable energy
$\widehat{X_2}$	15.9339	average share of natural gas
$\widehat{X_3}$	0.3631	average share of other gas
$\widehat{X_4}$	51.1120	average share of coal
$\widehat{X_5}$	2.6065	average share of petroleum
$\widehat{X_6}$	27.7517	average share of other resource
Assumption 1		Unit: percentage
$\widehat{X'_1}$	2.5220	average share of non-hydro renewable energy
$\widehat{X'_2}$	15.9339	average share of natural gas
$\widehat{X'_3}$	0.3631	average share of other gas
$\widehat{X'_4}$	50.9401	average share of coal

Table 6.8 (cont'd)		
$\widehat{X'}_5$	2.4891	average share of petroleum
$\widehat{X'}_6$	27.7517	average share of other resource
Assumption 2		Unit: percentage
$\widehat{X'}_1$	2.5220	average share of non-hydro renewable energy
$\widehat{X'}_2$	15.6446	average share of natural gas
$\widehat{X'}_3$	0.3631	average share of other gas
$\widehat{X'}_4$	51.1120	average share of coal
$\widehat{X'}_5$	2.6065	average share of petroleum
$\widehat{X'}_6$	27.7517	average share of other resource
Unit Emission		Unit: KG/MWh
$\widehat{\delta_1}$	59.2758786	unit CO_2 emission by non-hydro renewable energy
$\widehat{\delta_2}$	556.8041128	unit CO_2 emission by natural gas
$\widehat{\delta_3}$	7.7500344[a]	unit CO_2 emission by other gas
$\widehat{\delta_4}$	998.0944135	unit CO_2 emission by coal
$\widehat{\delta_5}$	983.3754856	unit CO_2 emission by petroleum
$\widehat{\delta_6}$	7.7500344[a]	unit CO_2 emission by other resource
$\widehat{\eta_1}$	2.3622888	unit SO_2 emission by non-hydro renewable energy
$\widehat{\eta_2}$	0.0353504	unit SO_2 emission by natural gas
$\widehat{\eta_3}$	0.5350774	unit SO_2 emission by other gas
$\widehat{\eta_4}$	6.0532769	unit SO_2 emission by coal
$\widehat{\eta_5}$	8.1740150	unit SO_2 emission by petroleum
$\widehat{\eta_6}$	0.0440054	unit SO_2 emission by other resource
$\widehat{\rho_1}$	1.7502413	unit NO_X emission by non-hydro renewable energy
$\widehat{\rho_2}$	0.8830420	unit NO_X emission by natural gas
$\widehat{\rho_3}$	2.1039647	unit NO_X emission by other gas
$\widehat{\rho_4}$	2.6267364	unit NO_X emission by coal
$\widehat{\rho_5}$	2.4740300	unit NO_X emission by petroleum
$\widehat{\rho_6}$	0.0279337	unit NO_X emission by other resource

Notes: a. there is no a separate carbon emission data for other gases. This article includes it into other resource and derives the same unit carbon dioxide emission for other gas and other resource.

According to the estimates from Table 6.8 and equation (12), (13), and (14), this article predicts 1 percentage increase in RPS annual target can on average reduce: 1) 38.627 million tons of carbon dioxide; 2) 0.204 million tons of sulfur dioxide; and 3) 0.084 million tons of nitrogen dioxide under the assumption 1. Based on assumption 2, however, 1 percentage increase in RPS annual target can on average reduce: 1) 34.597 million tons of carbon dioxide; 2) 0.140 million tons of sulfur dioxide; and 3) 0.068 million tons of nitrogen dioxide.

6.3.2 The Value of Reduced Emissions

6.3.2.1 ARP Price of SO_2

This article uses inflation data to adjust the real currency price (2008$) of sulfur dioxide price based on the United States Environmental Protection Agency (EPA) average annual SO_2 emissions permit price[23] (also called SO_2 Allowance price SUS) from 1995 to 2008 in the Acid Rain Program (ARP). Established under Title IV of the 1990 CAAA, the ARP requires major emission reductions of SO_2 and NO_X, the primary precursors of acid rain, from the electric power industry. The weighted average SO_2 emission permit price is 320.967 (2008$/ Metric Tons). However, in contrast to the system established for SO_2 emissions, the ARP does not establish tradable emission allowances for NO_X emission reductions. Thus NO_X price cannot be estimated from this program.

[23] Prices are in nominal $US, and are the average EPA Acid Rain Program Permit price for a particular year weighted by the number of permits in each successful bid.

6.3.2.2 RTC Price of SO_2 and NO_X

Data from Southern California's Regional Clean Air Incentives Market (RECLAIM) has been used to estimate the price of nitrogen oxide. Each RECLAIM trading credit (RTC) represents one pound of NO_X emissions and is valid for one year. According to *Annual RECLAIM Audit Report*[24] from 1997 to 2008 Compliance Year, the Average Prices for Current-Years' NO_X RTCs from 1997 to 2008 is 12822.90 (2008$/ Metric Tons). What's more, California's South Coast Air Quality Management District (SCAQMD) initiated the Regional Clean Air Incentives Market (RECLAIM) to control not only nitrogen oxide (NO_X) but also sulfur oxide emissions (SOx)[25]. An average price of 3377.28 (2008$/ Metric Tons) for Current-Years' SO_X RTCs could be derived by the same approach, which is 10 times bigger than the price calculated by the Acid Rain Program data.

6.3.2.3 CER and ECX Price for CO_2

This paper uses the ECX CER Futures Contracts and ECX EUA Futures Contract in the Europe Market to estimate the trading price of carbon dioxide. As the leading global marketplace for trading carbon dioxide (CO_2) emissions, ICE Futures Europe currently offers derivative contracts on two types of carbon credit: ICE ECX EU allowances (EUAs) and ICE ECX Certified

---

[24] Available at California's South Coast Air Quality Management District website: http://www.aqmd.gov

[25] http://www.spectronenvironmental.com/california-reclaim/category552.html provides more information about RECLAIM.

Emission Reductions (CERs)[26], which are launched in 2005 and 2008, respectively.

The ICE ECX EUA Futures Contract is a deliverable contract where each Clearing Member with a position open at cessation of trading for a contract month is obliged to make or take delivery of emission allowances to or from National Registries in accordance with the ICE Futures Europe Regulations. This article takes the average of daily price for the nearest future contract from 04/22/2005 to 12/31/2008, which leads to a nominal price of $24.364 per Metric Tons or a real price of 28.507 (2008$/ Metric Tons).

An ECX CER futures contract gives the holder the right and the obligation to buy or sell a certain amount of a certain underlying instrument at a certain date in the future, at a pre-set price. In the case of ICE ECX CER Futures Contracts, the underlying units of trading are CER units. CERs are a tradable unit of greenhouse gas emission reductions by a project registered under the Clean Development Mechanism (CDM) of the Kyoto Protocol. One ICE ECX CER Futures Contract ("lot") represents 1,000 CER units. This article calculates the average of daily price for the nearest future contract from 03/14/2008 to 12/31/2008. The nominal price is equal to real price because all the price data is from 2008, which is $26.068 per Metric Tons.

Through the above two estimates, this article takes the average of CER and ECX price and get the trading emission price to be 27.288 (2008$/ Metric Tons).

---

[26] https://www.theice.com

6.3.2.4 Emission Value

This article evaluates the value of the reduced emissions using the estimated emission amount and the market prices of two different price portfolios.

Price Portfolio 1: when using ARP Price of sulfur dioxide, RTC Price of nitrogen oxide, and CER and ECX average Price of carbon dioxide, 1 percentage increase in RPS annual target will produce 2.197 billion (2008$) benefits through reducing the emissions under assumption 1, and 1.867 billion (2008$) benefits through reducing the emissions under assumption 2.

Price Portfolio 2: when using RTC Price of both sulfur dioxide and nitrogen oxide, and CER and ECX average Price of carbon dioxide, 1 percentage increase in RPS annual target will produce 2.819 billion (2008$) benefits through reducing the emissions under assumption 1, and 2.295 billion (2008$) benefits through reducing the emissions under assumption 2.

6.4 Total Welfare for Consumers

6.4.1 Estimations for All the 48 Lower States

The estimated reduced emission values when RPS are strengthened by 1 percentage is range from 1.8 billion (2008$) to 3 billion (2008$). The consumer surplus loses 7.803 billion (2008$) when RPS increased by the same percentage. Then, equation (16) gives a negative consumer welfare change, which indicates the estimated value of reduced emissions is too low to fully compensate the consumer surplus loss when RPS increases by 1 percentage.

As is mentioned in Section 4, Table 6.9 includes consumer surplus loss, reduced amount and estimated value of carbon dioxide, sulfur dioxide, and nitrogen oxide, consumer welfare, and breakeven price for carbon dioxide when RPS annual target increased by 1 percentage under different assumptions and price portfolios. This table also includes the estimations when demand elasticity is assumed to be 0 using the same method in section 6.2 and section 6.3.

The table shows that all the estimates of total change in consumer's welfare are negative. More specifically, 1 percentage increase in RPS annual target national wide can reduce consumer welfare by 4.9 to 8 billion 2008 dollars according to different estimating approaches. Therefore, strengthening RPS is no good to consumers even with an environmental concern.

Table 6.9 Consumer welfare change and breakeven price for carbon for all the states

	Demand Elasticity= -0.558		Demand Elasticity= 0		Unit
	assumption1	assumption2	assumption1	assumption2	
⊿CS	-7.803	-7.803	-7.861	-7.861	Billion 2008$
⊿CO_2	38.627	34.597	8.764	4.674	Million tons
⊿SO_2	0.204	0.140	0.043	-0.022	Million tons
⊿NO_X	0.084	0.068	0.008	-0.008	Million tons
⊿Emissions1	-2.197	-1.867	-0.351	-0.016	Billion 2008$
⊿Benefit1	-5.606	-5.936	-7.510	-7.845	Billion 2008$
⊿Emissions2	-2.819	-2.295	-0.482	0.051	Billion 2008$
⊿Benefit2	-4.984	-5.508	-7.379	-7.912	Billion 2008$
*$*$CO_2$	202.01	225.54	896.89	1681.64	2008$/Metric Ton

Notes: ⊿Emissions1 and ⊿Benefit1 uses the price in portfolio 1 including ARP Price of sulfur dioxide, RTC Price of nitrogen oxide, and CER and ECX average price of carbon dioxide; ⊿Emissions2 and ⊿Benefit2 uses the price in portfolio 2 including RTC Price of sulfur dioxide, RTC Price of nitrogen oxide, and CER and ECX average price of carbon dioxide.

However, the value of reduced emissions is dependent on the price of the emission. If the market prices of carbon dioxide, sulfur dioxide, and nitrogen oxide are underestimated, the real effect of RPS on consumer welfare might be less negative or even positive.

One the other hand, the breakeven price for carbon dioxide is about 200 dollars in real 2008 price, which is much higher than the average of CER and ECX price for carbon dioxide ($27.288) when demand elasticity is -0.558. When using zero demand elasticity, these breakeven prices of carbon dioxide are even higher.

6.4.2 Estimations for Each of the Four Regions

Table 6.10 provides the related estimation results for each of the four regions including original average electricity prices and sales, the consumer surplus change, reduced emission amount and value, consumer welfare change, and breakeven price for carbon dioxide under different assumptions of elasticity, renewable energy replaced sources, and price portfolios.

Table 6.10 shows that in the Northeast, 1 percentage increase in RPS can on average decrease the consumer welfare by 0.2-0.3 billion dollars which implies RPS is more likely to be inefficient policies in the Northeast. For the states in Midwest, 1 percentage increase in RPS can on average increase the consumer welfare by 0.09-0.3 billion dollars which implies RPS is an efficient policy in the Midwest. RPS is not that efficient in South since 1 percentage increase in RPS can on average decrease the consumer welfare by 6-11 billion dollars. 1 percentage increase in RPS can on average increase the consumer welfare by 0.7-1.2 billion dollars and hence an efficient policy in the states of West.

Table 6.10 Consumer welfare change and breakeven price for carbon for each region

	Elasticity= -0.558		Elasticity= 0		Unit
	assumption 1	assumption 2	assumption 1	assumption 2	
Northeast					
P	13.49	13.49	13.49	13.49	2008 cents/KWh
Q	0.457×10^9	0.457×10^9	0.457×10^9	0.457×10^9	MWh
ΔCS	-0.294	-0.294	-0.294	-0.294	Billion 2008$
ΔCO_2	0.764	0.764	0	0	Million tons
ΔSO_2	0.004	0.004	0	0	Million tons
ΔNO_X	0.002	0.002	0	0	Million tons
$\Delta Emissions1$	-0.047	-0.047	0	0	Billion 2008$
$\Delta Benefit1$	-0.247	-0.247	-0.294	-0.294	Billion 2008$
$\Delta Emissions2$	-0.060	-0.060	0	0	Billion 2008$
$\Delta Benefit2$	-0.234	-0.234	-0.294	-0.294	Billion 2008$
$\$CO_2$	384.61	384.61	--	--	2008$/Metric Ton
Midwest					
P	8.15	8.15	8.15	8.15	2008 cents/KWh
Q	0.780×10^9	0.780×10^9	0.780×10^9	0.780×10^9	MWh
ΔCS	0	0	0	0	Billion 2008$
ΔCO_2	-5.118	-2.730	-5.118	-2.730	Million tons
ΔSO_2	-0.025	-0.013	-0.025	-0.013	Million tons
ΔNO_X	-0.004	-0.005	-0.004	-0.005	Million tons
$\Delta Emissions1$	-0.205	-0.009	-0.205	-0.009	Billion 2008$
$\Delta Benefit1$	0.205	0.009	0.205	0.009	Billion 2008$
$\Delta Emissions2$	-0.281	-0.009	-0.281	-0.009	Billion 2008$
$\Delta Benefit2$	0.281	0.009	0.281	0.009	Billion 2008$
$\$CO_2$	--	--	--	--	2008$/Metric Ton
South					
P	8.26	8.26	8.26	8.26	2008 cents/KWh
Q	1.421×10^9	1.421×10^9	1.421×10^9	1.421×10^9	MWh

Table 6.10 (cont'd)					
ΔCS	-9.987	-9.987	-10.236	-10.236	Billion 2008$
ΔCO_2	43.412	43.412	0	0	Million tons
ΔSO_2	0.234	0.234	0	0	Million tons
ΔNO_X	0.111	0.111	0	0	Million tons
ΔEmissions1	-2.680	-2.680	0	0	Billion 2008$
ΔBenefit1	-7.307	-7.307	-10.236	-10.236	Billion 2008$
ΔEmissions2	-3.394	-3.394	0	0	Billion 2008$
ΔBenefit2	-6.593	-6.593	-10.236	-10.236	Billion 2008$
$\$CO_2$	230.05	230.05	--	--	2008$/Metric Ton
West					
P	8.12	8.12	8.12	8.12	2008 cents/KWh
Q	0.589×10^9	0.589×10^9	0.589×10^9	0.589×10^9	MWh
ΔCS	1.066	1.066	1.059	1.059	Billion 2008$
ΔCO_2	-3.012	-3.739	1.539	0.821	Million tons
ΔSO_2	-0.017	-0.028	0.008	-0.004	Million tons
ΔNO_X	-0.010	-0.013	0.001	-0.001	Million tons
ΔEmissions1	0.220	0.279	-0.062	-0.003	Billion 2008$
ΔBenefit1	0.846	0.787	1.121	1.062	Billion 2008$
ΔEmissions2	0.272	0.366	-0.085	0.009	Billion 2008$
ΔBenefit2	0.794	0.700	1.144	1.050	Billion 2008$
$\$CO_2$	353.88	285.07	--	--	2008$/Metric Ton

To sum up, although RPS on average is not that efficient with emission concern for all the 48 lower states, the conclusion is different when doing regional level analysis. Table 6.10 shows that RPS is efficient in Midwest and in West but is not likely to be efficient in Northeast and in South with emission concern. These findings are similar to the earlier prediction in section 2.5.1 which implies RPS policies functioned well in Midwest and West while Northeast and South are still struggling in how to make the policies on the track.

CHAPTER 7: CONCLUSION

Existing research on the effect of RPS policies in the United States assumes states have the same trends of outcomes in absence of RPS, which is a hypothesis that is unlikely to hold in the real world. What's more, no research estimates whether the value of reduced emissions from RPS could compensate the negative effect of price increases, which might lead to positive consumer welfare when enacts or strengthens RPS.

This article first uses Least Square Dummy Variable (LSDV) model to predict the effects of RPS on renewable energy share in capacity, renewable energy share in generation, and price of electricity. Then the basic model is advanced to control the effect of other RPS features and other renewable energy policies, the concerns of partial effect of RPS, different trends of outcomes in absence of RPS, and solve the serial correlation problem. The results imply RPS on average are effective policies by estimating both significantly positive coefficients of RPS annual target on renewable energy share in capacity and in generation but are not likely to be efficient policies since RPS would significantly increase the electricity price, which makes for a serious consumer surplus loss. Moreover, even with an emission concern, RPS still decrease total welfare for consumers since the positive benefit on saving emissions cannot fully compensate the consumer surplus loss in the electricity market if using the current market prices of carbon and other emissions. But this conclusion might change if different per unit value of emissions is applied. If the market prices used in this article underestimate the value of emissions to consumers, it is still possible for RPS on average to be efficient policies with environmental concern. The breakeven price for carbon dioxide is much higher than the market price, which also means the cost of reducing the emission using this policy is too high. Finally, the regional level analysis shows that RPS is efficient in Midwest and West but is not likely to be efficient in Northeast and South with emission concern.

However, there is still point for further exploration especially the analysis and evaluation of the emission value. This article uses the market trading price to evaluate the monetary value, which always underestimates the emission value. The unit trading prices for CO_2 in this article is the price in European market rather than U.S. market. What's more, they are the prices for future contracts and there is a gap between current price and futures even this article uses the nearest contract prices. Even if the unit price this paper estimated is close to the real price, the current price could be underestimated since there are other kinds of emissions reduced or increased due to RPS that this article overlooked. Future studies could also estimate the emission value by willingness to pay (WTP) approach, pollution capture cost approach or pollution damage approach.

Moreover, there are other benefits if more renewable energy can substitute fossil fuels which this paper doesn't take into account. For example, the reduced mercury emissions and their effects on human health are also the benefit from RPS when using less coal. Even if we consider all the costs and benefits of RPS and find they can increase consumer's welfare, it is still hard to predict that RPS are the best renewable energy policies since they might not as efficient as other policies.

APPENDIX

Appen dix 1: Equations for every column of Table 6.1, Table 6.2, and Table 6.3

Table A.1 Equations for every column of Table 6.1, Table 6.2, and Table 6.3

Equation #	Equation
(2)	$R_{IT} = \beta_{10} + \beta_{11} RPS_{IT} + \beta'_{12} W'_{IT} + \beta'_{13} Y' + \beta'_{14} I' + \varepsilon_{RIT}$
(2*)	$R_{IT} = \gamma_{10} + \gamma_{11} RPS_{IT} + \gamma'_{12} W'_{IT} + \gamma'_{13} Y' + \gamma'_{14} I' + \gamma'_{15} R'_{IT} + \lambda_{RIT}$
(2**)	$R_{IT} = \gamma_{10} + \gamma_{11} RPS_{IT} + \gamma'_{12} W'_{IT} + \gamma'_{13} Y' + \gamma'_{14} I' + \gamma'_{15} R'_{IT} + \gamma'_{18} I' * T + \lambda_{RIT}$
(5*)	$R_{IT} = \gamma_{10} + \gamma_{11} RPS_{IT} + \gamma'_{12} W'_{IT} + \gamma'_{13} Y' + \gamma'_{14} I' + \gamma'_{15} R'_{IT} + \gamma'_{16} RPS_{IT} * (E'_{IT} - \bar{E}'_{IT}) + \gamma'_{17} Z'_{IT} * M'_{IT} + \gamma'_{18} I' * T + \lambda_{RIT}$
(3)	$RR_{IT} = \beta_{20} + \beta_{21} RPS_{IT} + \beta'_{22} W'_{IT} + \beta'_{23} Y' + \beta'_{24} I' + \varepsilon_{RRIT}$
(3*)	$RR_{IT} = \gamma_{20} + \gamma_{21} RPS_{IT} + \gamma'_{22} W'_{IT} + \gamma'_{23} Y' + \gamma'_{24} I' + \gamma'_{25} R'_{IT} + \lambda_{RRIT}$
(3**)	$RR_{IT} = \gamma_{20} + \gamma_{21} RPS_{IT} + \gamma'_{22} W'_{IT} + \gamma'_{23} Y' + \gamma'_{24} I' + \gamma'_{25} R'_{IT} + \gamma'_{28} I' * T + \lambda_{RRIT}$
(6*)	$RR_{IT} = \gamma_{20} + \gamma_{21} RPS_{IT} + \gamma'_{22} W'_{IT} + \gamma'_{23} Y' + \gamma'_{24} I' + \gamma'_{25} R'_{IT} + \gamma'_{26} RPS_{IT} * (E'_{IT} - \bar{E}'_{IT}) + \gamma'_{27} Z'_{IT} * M'_{IT} + \gamma'_{28} I' * T + \lambda_{RRIT}$
(4)	$\log P_{IT} = \beta_{30} + \beta_{31} RPS_{IT} + \beta'_{32} W'_{IT} + \beta'_{33} Y' + \beta'_{34} I' + \varepsilon_{PIT}$
(4*)	$\log P_{IT} = \gamma_{30} + \gamma_{31} RPS_{IT} + \gamma'_{32} W'_{IT} + \gamma'_{33} Y' + \gamma'_{34} I' + \gamma'_{35} R'_{IT} + \lambda_{PIT}$
(4**)	$\log P_{IT} = \gamma_{30} + \gamma_{31} RPS_{IT} + \gamma'_{32} W'_{IT} + \gamma'_{33} Y' + \gamma'_{34} I' + \gamma'_{35} R'_{IT} + \gamma'_{38} I' * T + \lambda_{PIT}$
(7*)	$\log P_{IT} = \gamma_{30} + \gamma_{31} RPS_{IT} + \gamma'_{32} W'_{IT} + \gamma'_{33} Y' + \gamma'_{34} I' + \gamma'_{35} R'_{IT} + \gamma'_{36} RPS_{IT} * (E'_{IT} - \bar{E}'_{IT}) + \gamma'_{37} Z'_{IT} * M'_{IT} + \gamma'_{38} I' * T + \lambda_{PIT}$

Appendix 2: Testing for Serial Correlation of Equation (2) in Appendix 1

Step One: Run the OLS regression for equation (2) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.1.

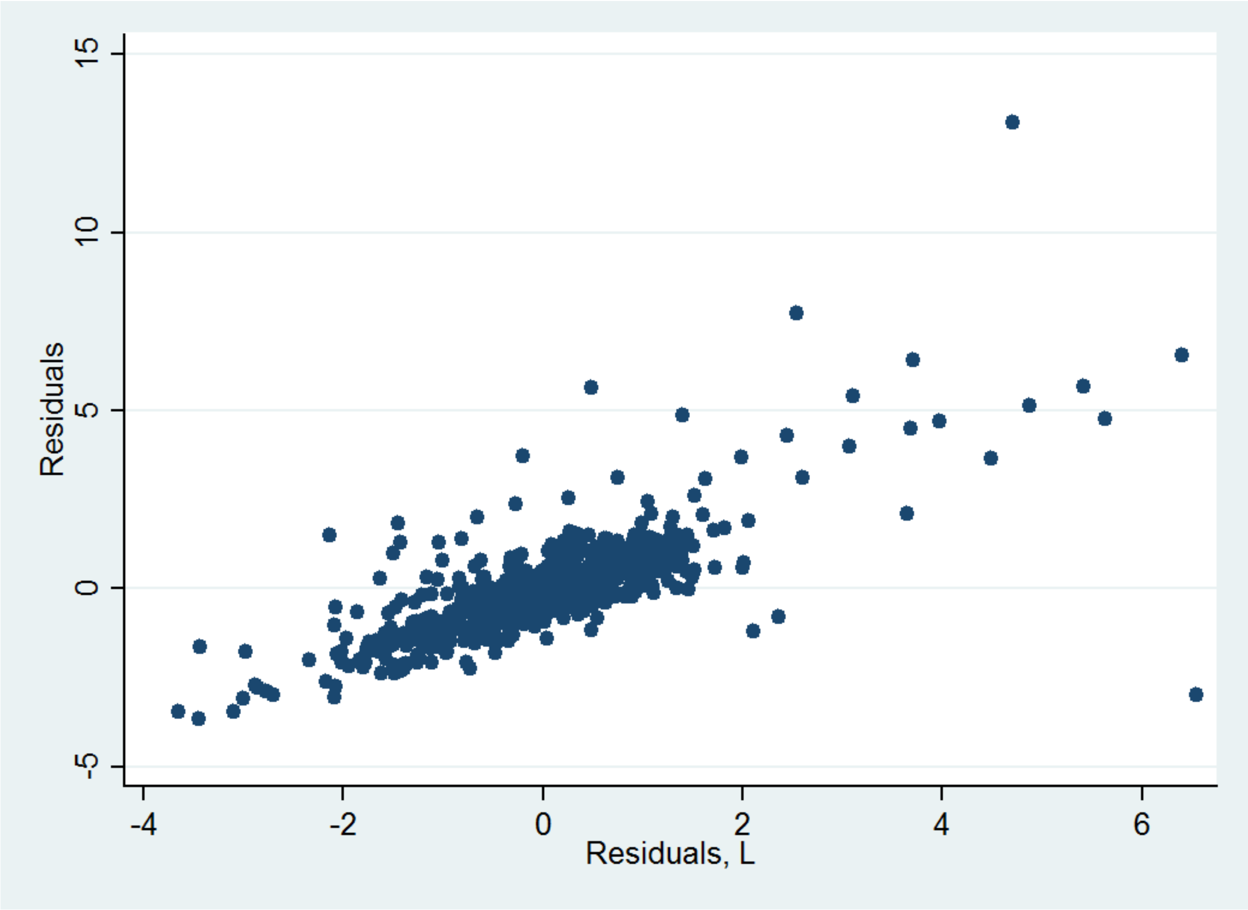

Figure A.1 The relation between residuals and their lagged values in equation (2)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 34.48 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (2).

Appendix 3: Testing for Serial Correlation of Equation (2*) in Appendix 1

Step One: Run the OLS regression for equation (2*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.2.

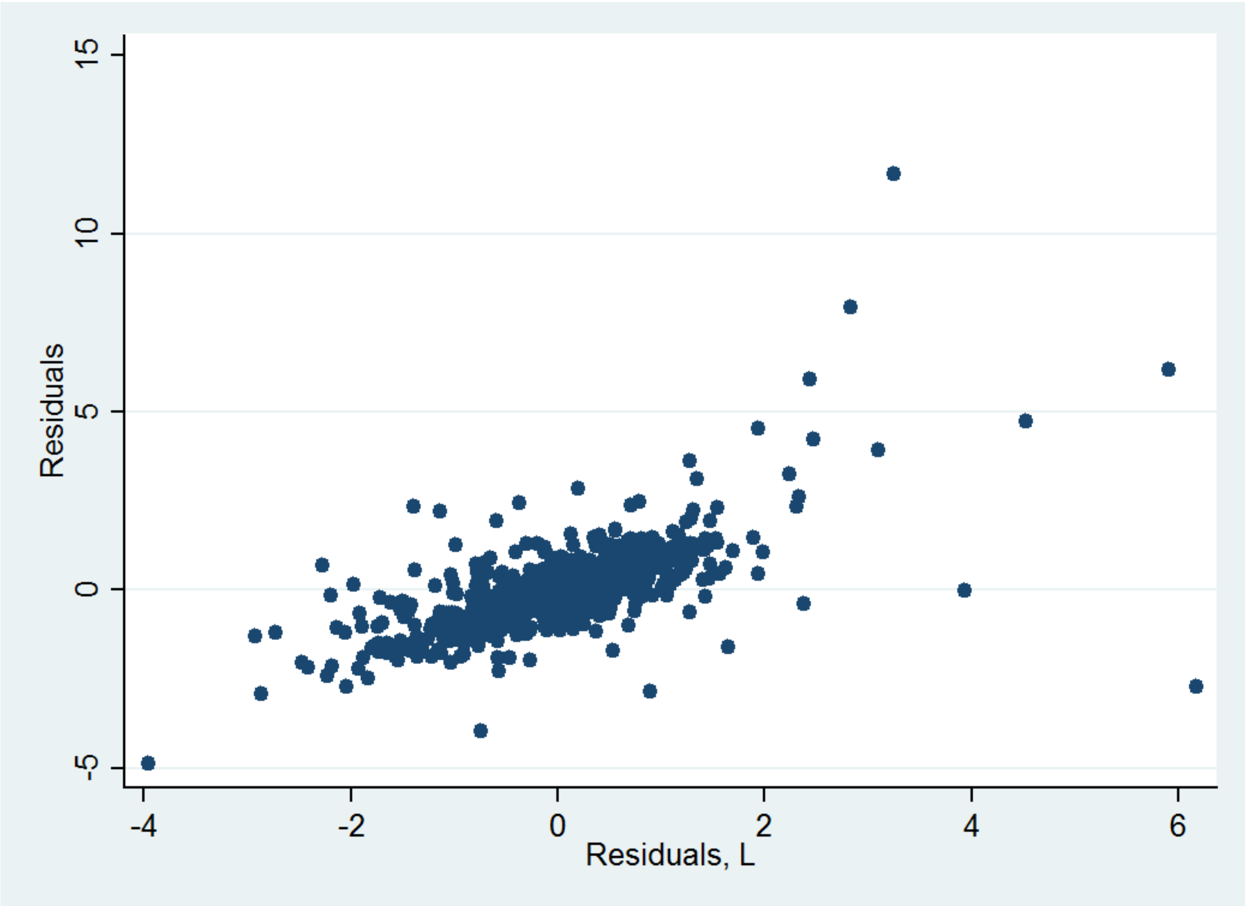

Figure A.2 The relation between residuals and their lagged values in equation (2*)

Step Three: Run the OLS regression of residuals on <u>their lagged values</u>, obtain the coefficient of lagged residual and its *t*-value= 26.65 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (2*).

Appendix 4: Testing for Serial Correlation of Equation (2**) in Appendix 1

Step One: Run the OLS regression for equation (2**) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.3.

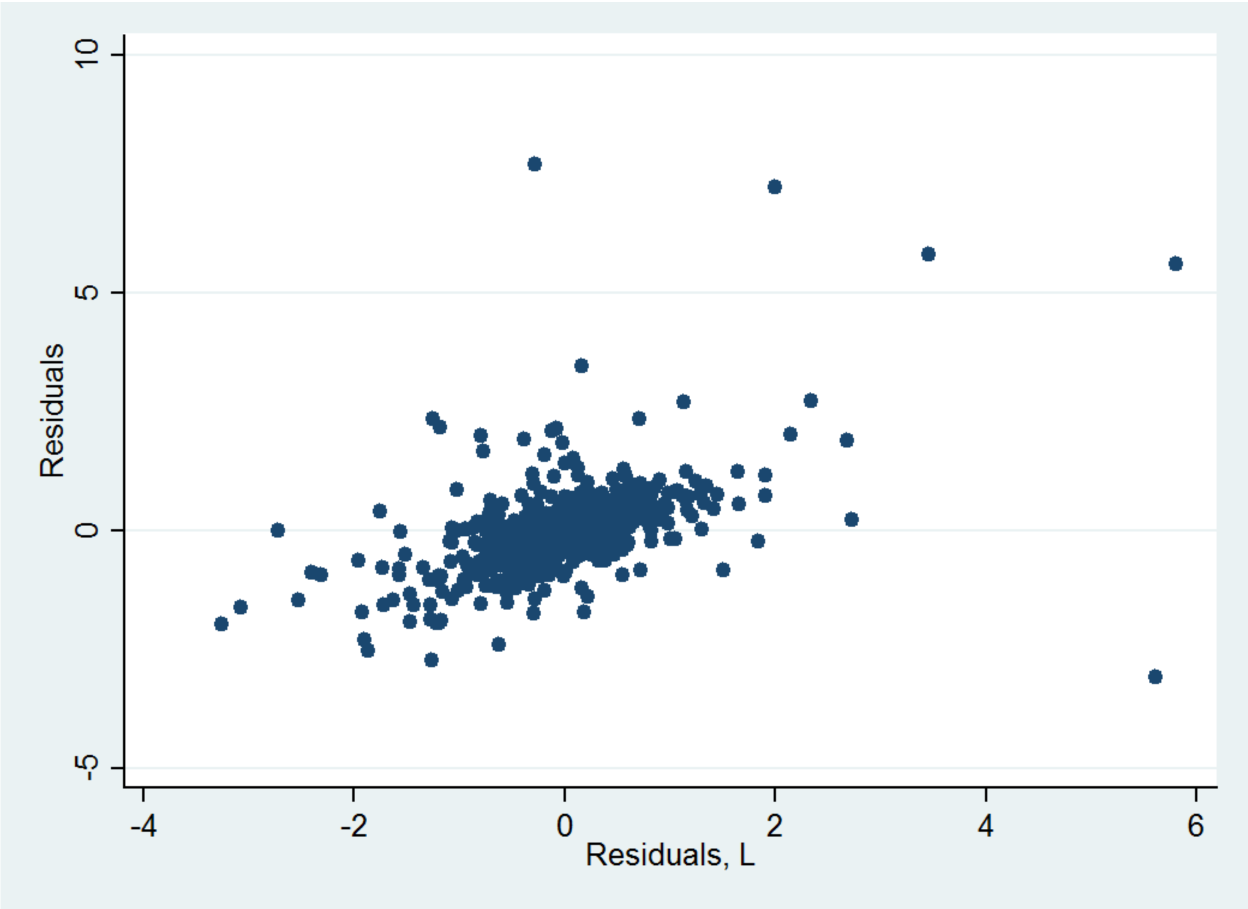

Figure A.3 The relation between residuals and their lagged values in equation (2**)

Step Three: Run the OLS regression of residuals on <u>their lagged values</u>, obtain the coefficient of lagged residual and its *t*-value= 17.57 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (2**).

Appendix 5: Testing for Serial Correlation of Equation (5*) in Appendix 1

Step One: Run the OLS regression for equation (5*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.4.

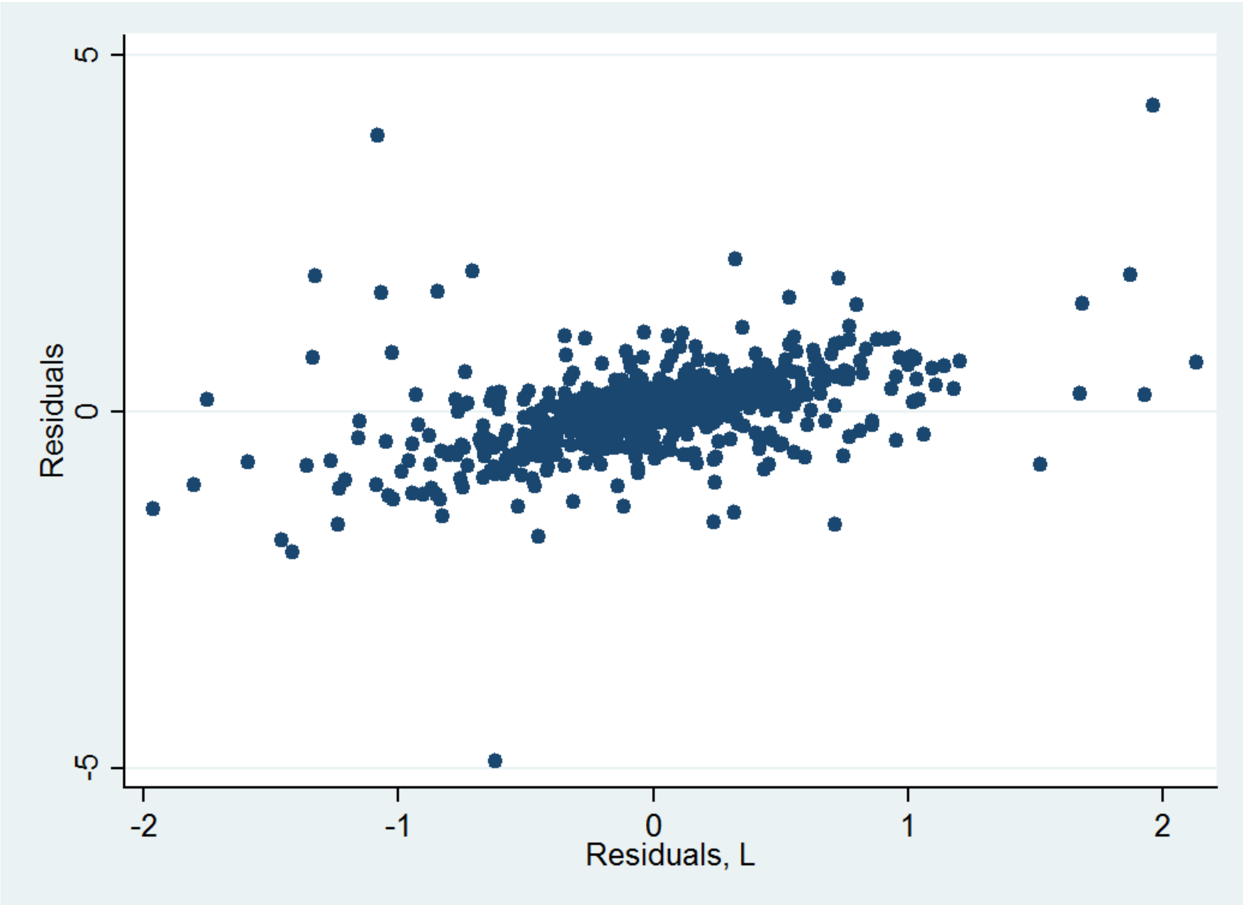

Figure A.4 The relation between residuals and their lagged values in equation (5*)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 15.52 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (5*).

Appendix 6: Testing for Serial Correlation of Equation (3) in Appendix 1

Step One: Run the OLS regression for equation (3) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.5.

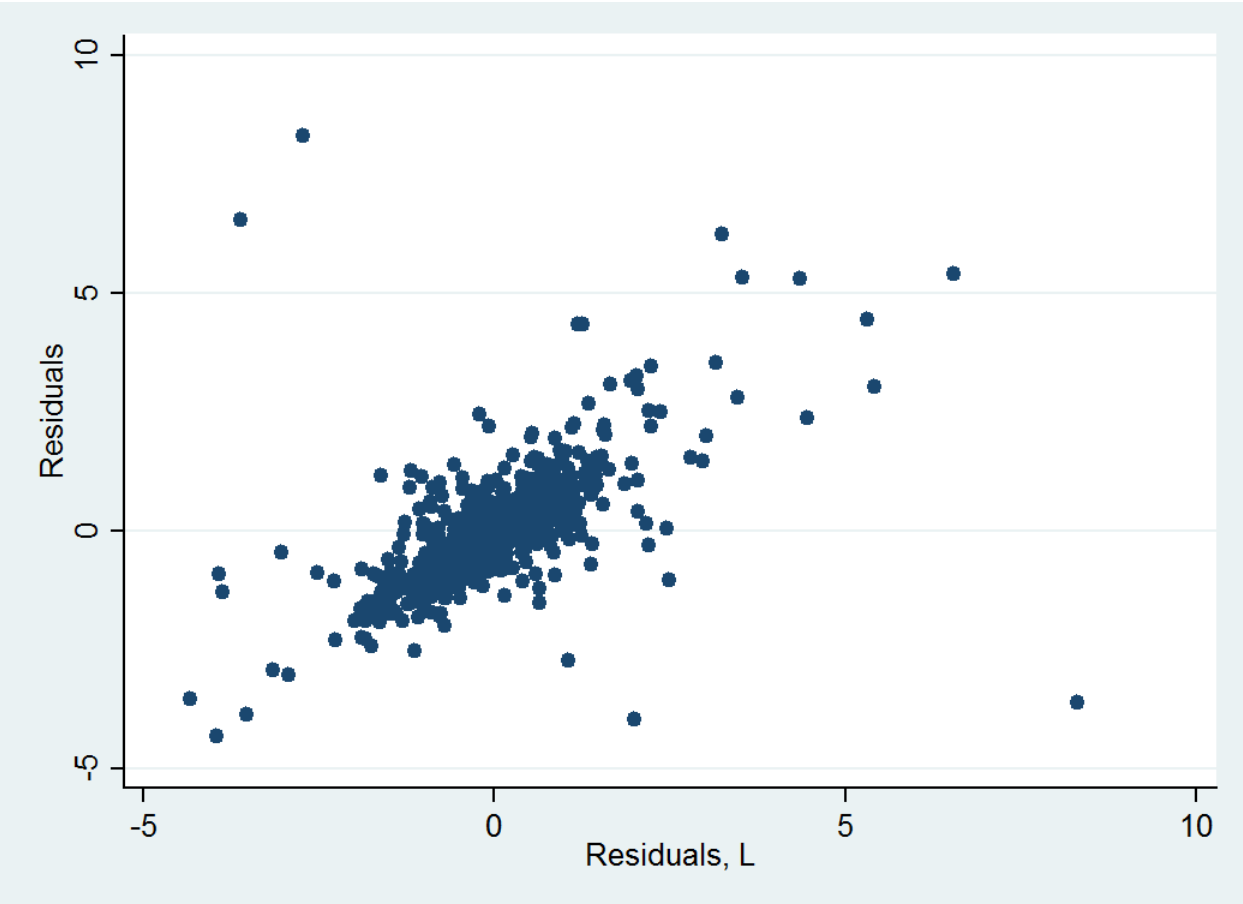

Figure A.5 The relation between residuals and their lagged values in equation (3)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 21.50 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (3).

Appendix 7: Testing for Serial Correlation of Equation (3*) in Appendix 1

Step One: Run the OLS regression for equation (3*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.6.

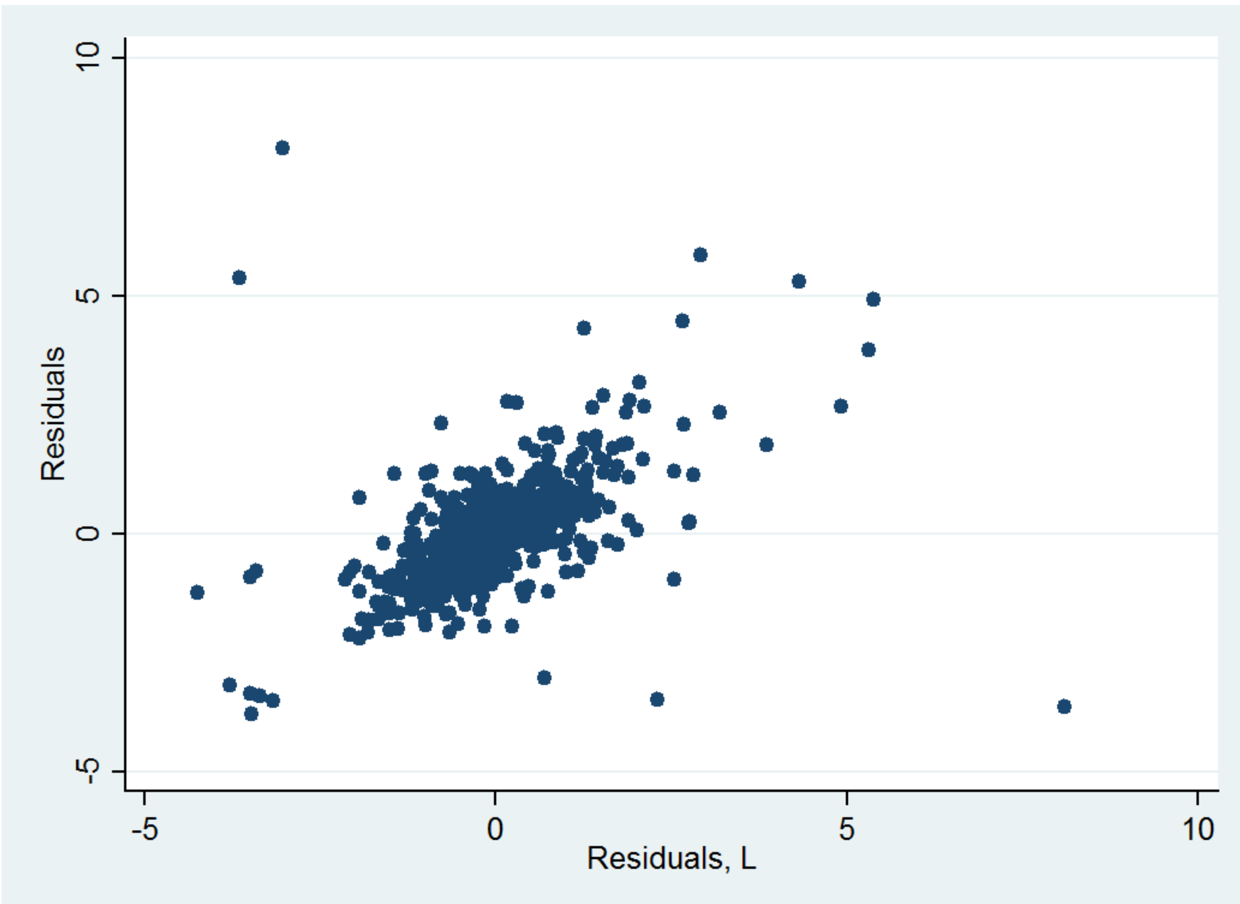

Figure A.6 The relation between residuals and their lagged values in equation (3*)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 18.40 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (3*).

Appendix 8: Testing for Serial Correlation of Equation (3**) in Appendix 1

Step One: Run the OLS regression for equation (3**) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.7.

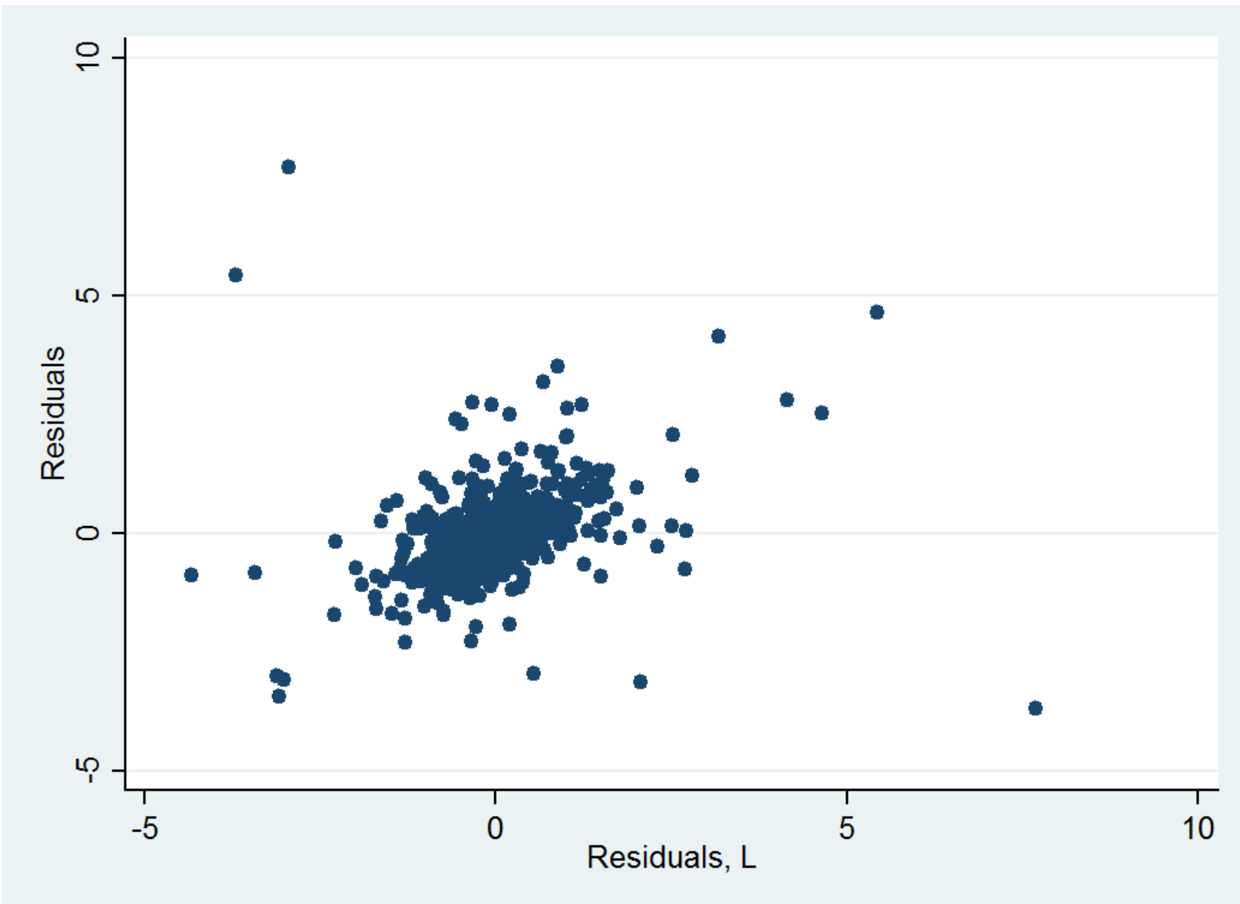

Figure A.7 The relation between residuals and their lagged values in equation (3**)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 10.54 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (3**).

Appendix 9: Testing for Serial Correlation of Equation (6*) in Appendix 1

Step One: Run the OLS regression for equation (6*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.8.

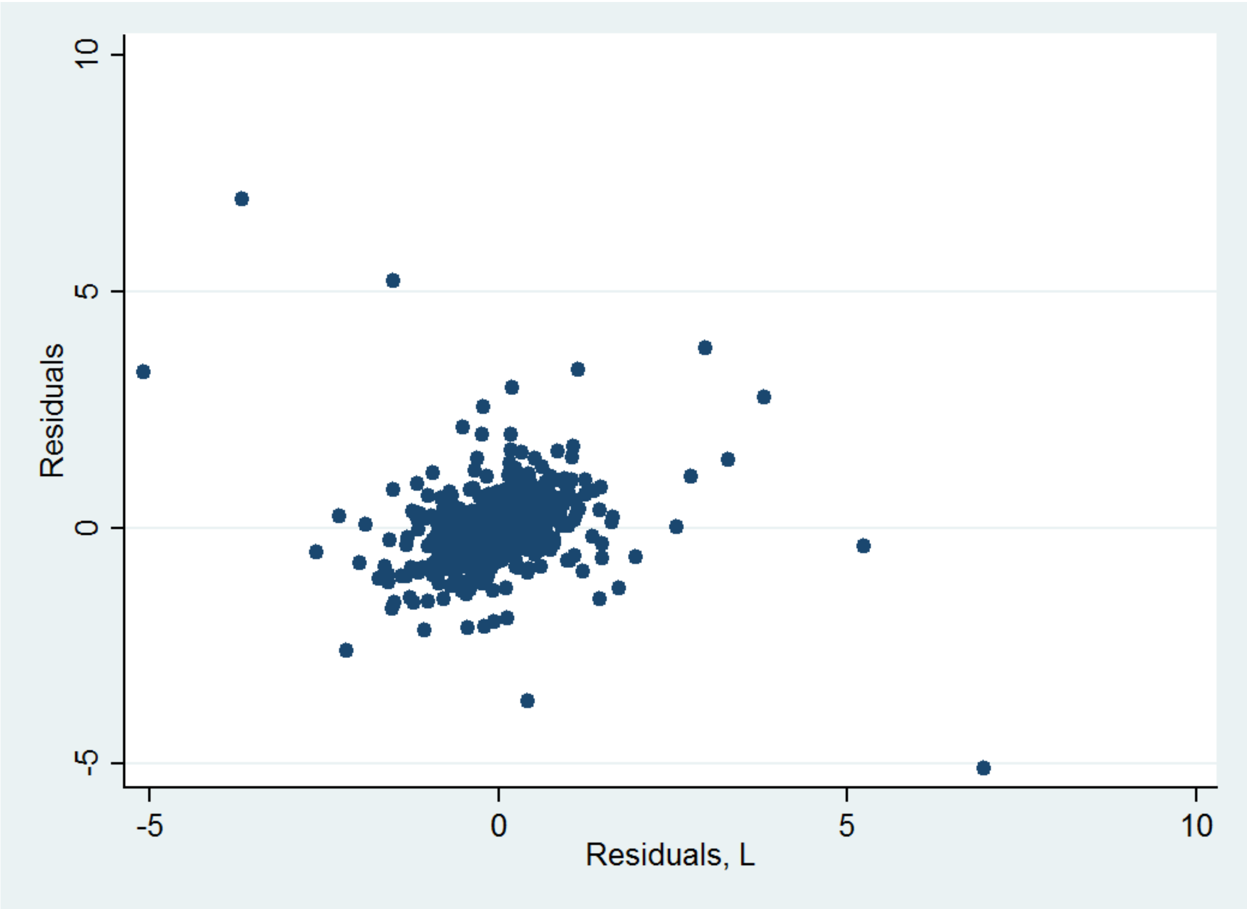

Figure A.8 The relation between residuals and their lagged values in equation (6*)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 2.95 (p-value=0.003).

Conclusion: Serial Correlation is a problem in equation (6*).

Appendix 10: Testing for Serial Correlation of Equation (4) in Appendix 1

Step One: Run the OLS regression for equation (4) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.9.

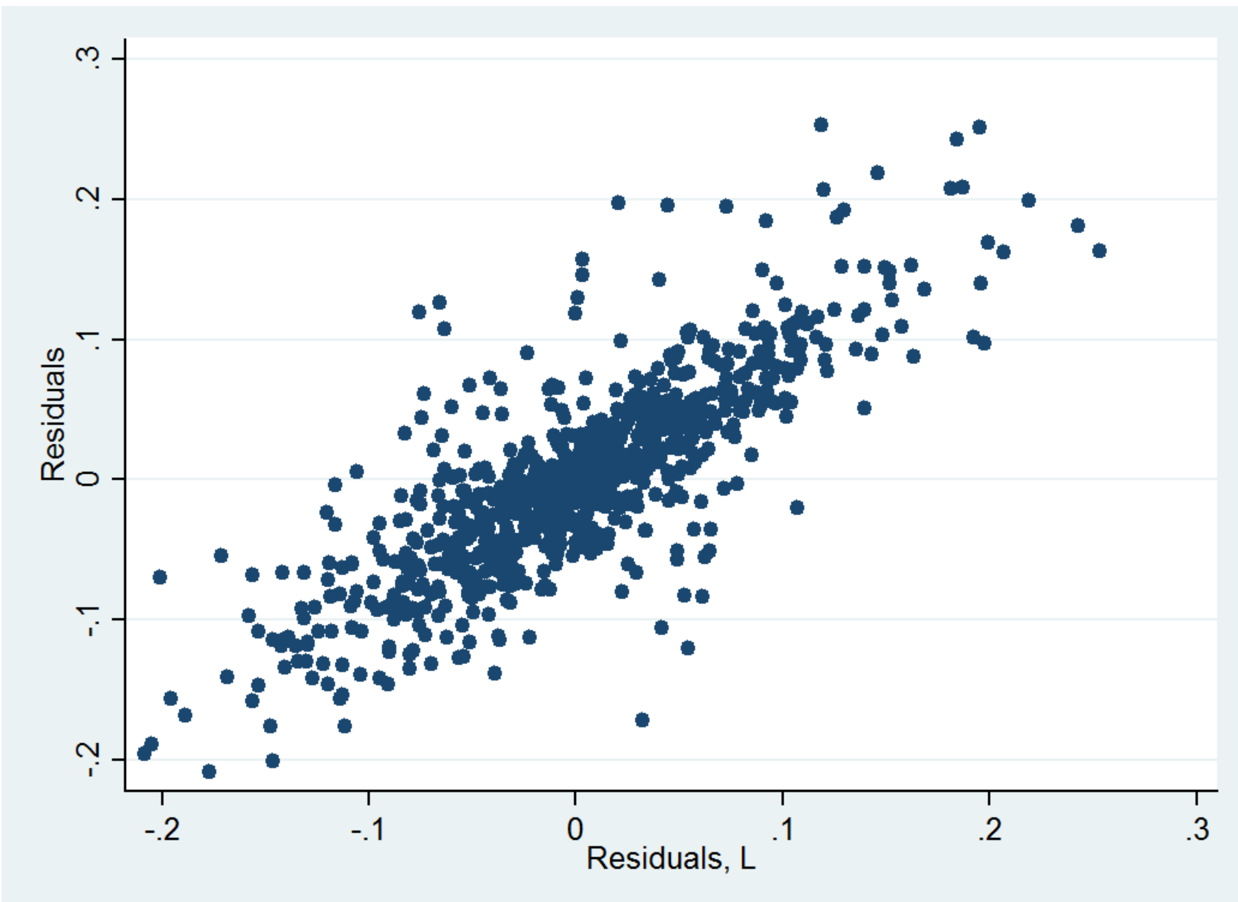

Figure A.9 The relation between residuals and their lagged values in equation (4)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 39.97 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (4).

Appendix 11: Testing for Serial Correlation of Equation (4*) in Appendix 1

Step One: Run the OLS regression for equation (4*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.10.

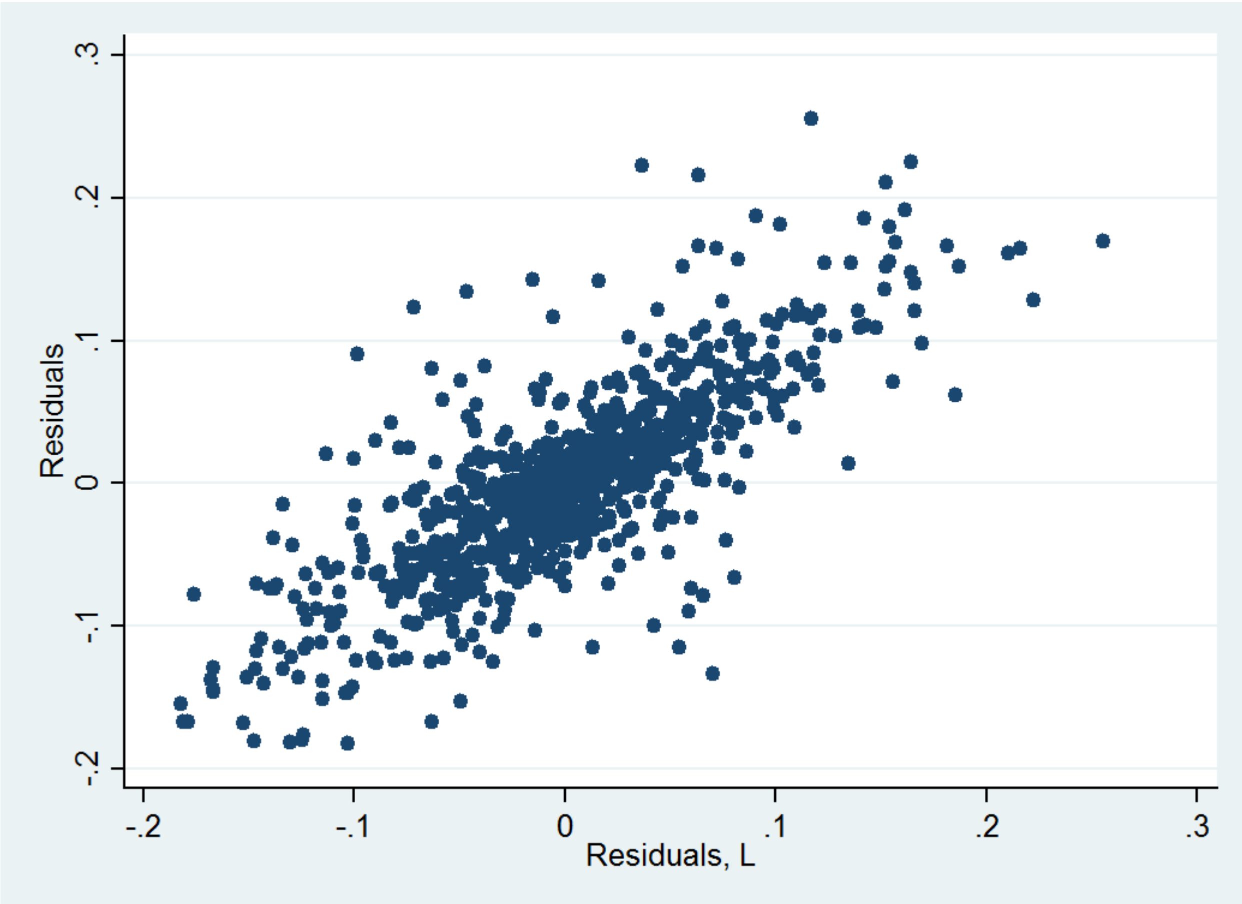

Figure A.10 The relation between residuals and their lagged values in equation (4*)

Step Three: Run the OLS regression of residuals on <u>their lagged values</u>, obtain the coefficient of lagged residual and its *t*-value= 37.43 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (4*).

Appendix 12: Testing for Serial Correlation of Equation (4**) in Appendix 1

Step One: Run the OLS regression for equation (4**) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.11.

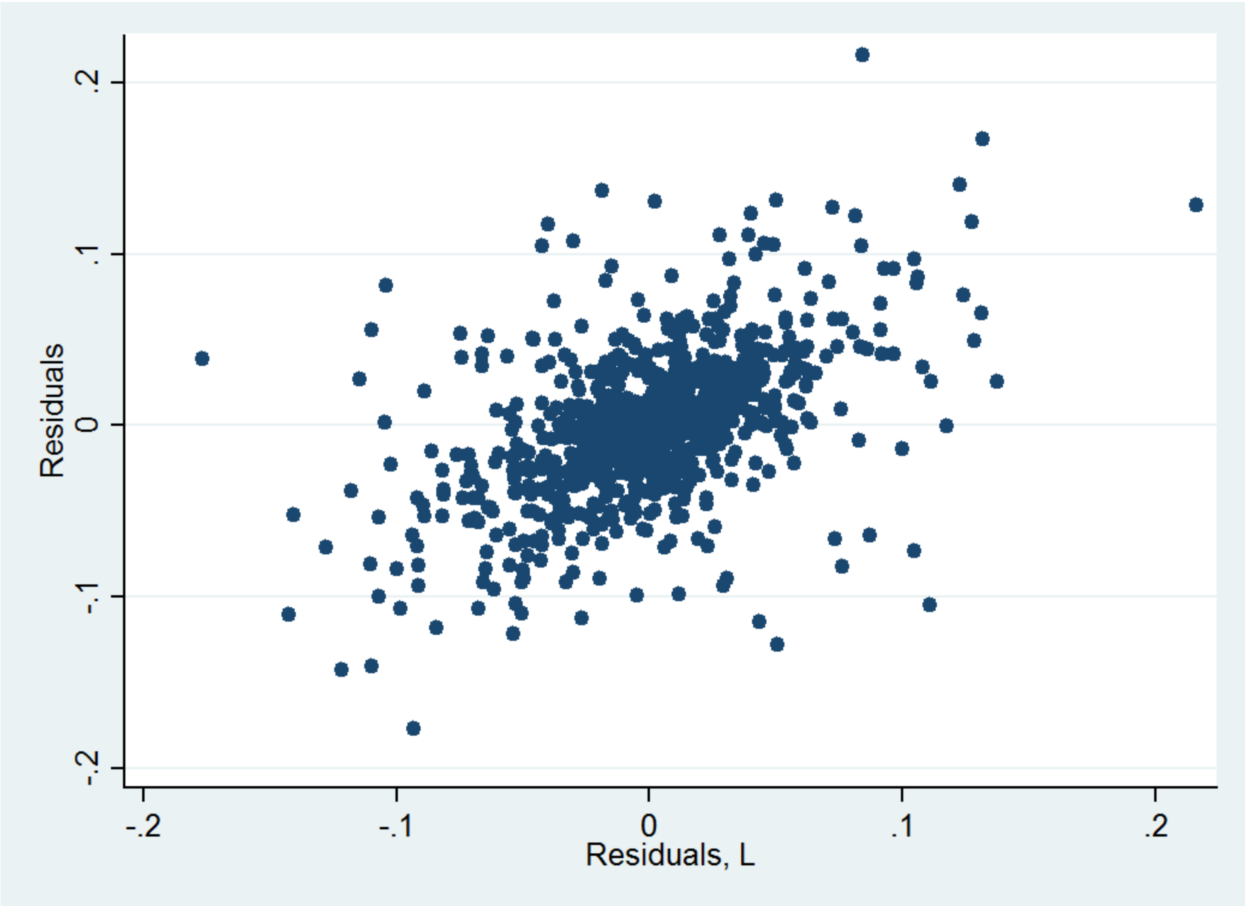

Figure A.11 The relation between residuals and their lagged values in equation (4**)

Step Three: Run the OLS regression of residuals on their lagged values, obtain the coefficient of lagged residual and its *t*-value= 17.19 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (4**)

Appendix 13 Testing for Serial Correlation of Equation (7*) in Advanced Model

Step One: Run the OLS regression for equation (7*) and obtain the OLS residuals.

Step Two: Scatter graph reflects the relation between residuals and their lagged values in Figure A.12.

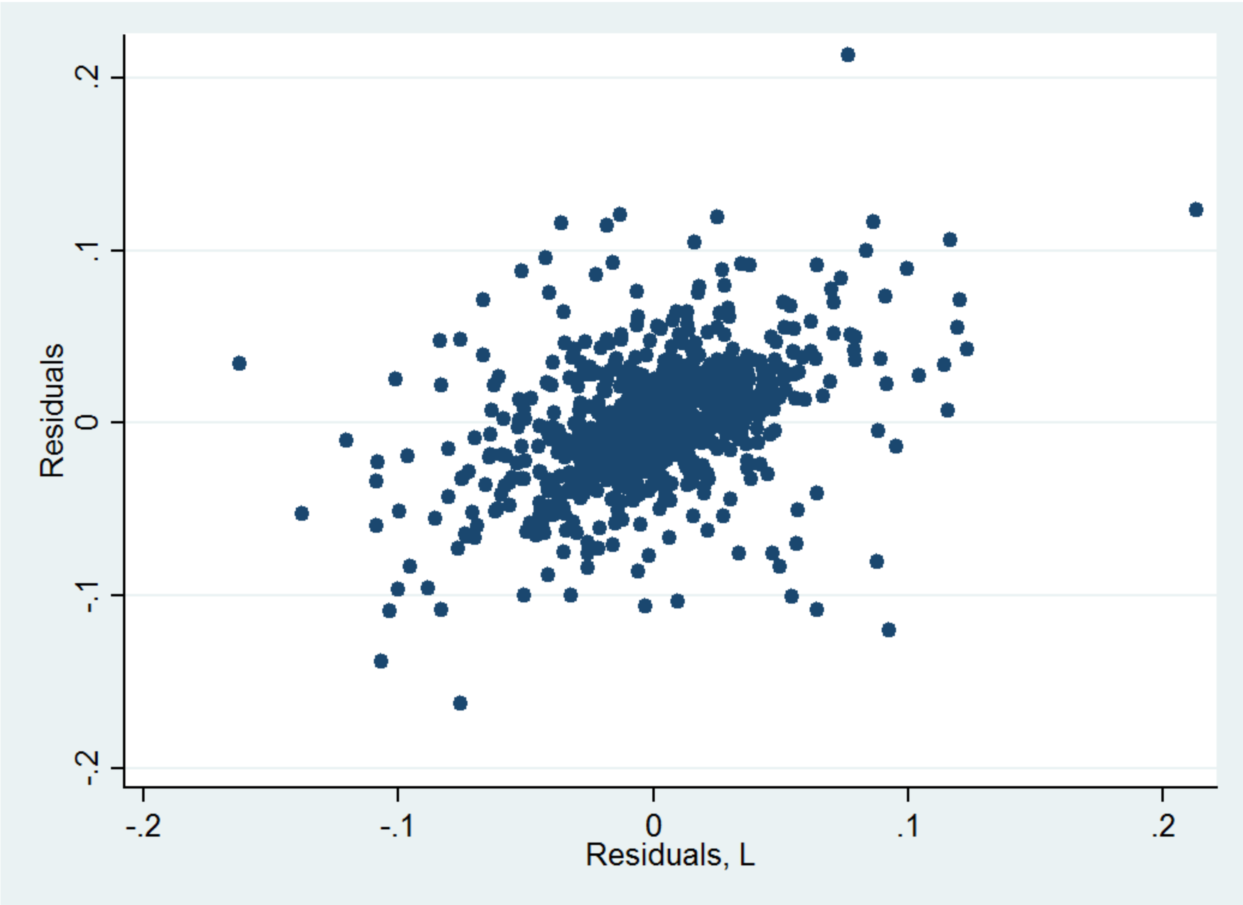

Figure A.12 The relation between residuals and their lagged values in equation (7*)

Step Three: Run the OLS regression of residuals on <u>their lagged values</u>, obtain the coefficient of lagged residual and its *t*-value= 13.64 (p-value=0.000).

Conclusion: Serial Correlation is a problem in equation (7*).

BIBLIOGRAPHY

Arthur, W. (1990). Positive Feedbacks in the Economy. *Scientific American*, February, 92–99.

Arthur, W. (1994). Path Dependence, Self-Reinforcement, and Human Learning. *Increasing Returns and Path Dependence in the Economy*, Ann Arbor: University of Michigan Press, 133–58.

Bernow, S., Dougherty, W., & Duckworth, M. (1997). Quantifying the Impacts of a National, Tradable Renewables Portfolio Standard. *The Electricity Journal*, 10 (4), 42-52

Burns, D. (2010). National Acid Precipitation Assessment Program Report to Congress: An Integrated Assessment. *Annual RECLAIM Audit Report for 2008 Compliance Year.*

Carley, S. (2009). State Renewable Energy Electricity Policies: An Empirical Evaluation of Effectiveness. *Energy Policy* 37(8), 3071-3081

Chen, C., Wider, R., Mills, A., & Bolinger, M. (2009). Weighing the Costs and Benefits of State Renewable Portfolio Standards in the United States: A comparative Analysis of State-level Policy Impact Projection, Renewable and Sustainable. *Energy Reviews*, 13, 552-566

Elliot, R., Anna M., Steven N., & Elizabeth B. (2003). Natural Gas Price Effects of Energy Efficiency and Renewable Energy Practices and Policies. Report E032. *Washington: American Council for an Energy-Efficient Economy.*

Elliott, D.L., Wendell, L.L., & Gower, G.L. (1991). An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States. *Technical Report,* 08

Espey, S. (2001). Renewable Portfolio Standard: a Means for Trade with Electricity from Renewable Energy Sources. *Energy Policy* 29 (7), 557–566.

Fischer, C. (2006). How Can Renewable Portfolio Standards Lower Electricity Prices? RFF Discussion Papers 06-20.

Gouchoe, S., Everette, V., & Haynes, R. (2002). Case Studies on the Effectiveness of State financial incentives for renewable energy. *NREL/SR-620-32819*, National Renewable Energy Laboratory, Raleigh, NC.

Hindman, D. (2009). Mass Media Flow and Differential Distribution of Politically Disputed Beliefs: The Belief Gap Hypothesis. J*ournalism and Mass Communication Quarterly* 86, 790-808.

Ho, D., Kosuke, I., Gary, K., & Elizabeth, S. (2007). Matching as Nonparametric Preprocessing for Reducing Model Dependence in Parametric Causal Inference. *Political Analysis*, 15 (3), 199-236.

Hodgson, G. (1998). The Approach of Institutional Economics. *Journal of Economic Literature*, 36(March), 166–192.

Iyengar, S, & Kyu, H. (2009). Red Media, Blue Media. *Journal of Communication* 59, 19-39.

Johnson, E. (2010). The Price Elasticity of Supply of Renewable Electricity Generation: Evidence from State Renewable Portfolio Standards. Dissertation and Job Market Paper. from http://www-personal.umich.edu/~johnsoep/docs/epjohnson_rps.pdf

Kneifel, J. (2008). Effects of State Government Policies on Electricity Capacity from Non-Hydropower Renewable Sources. Mimeo, University of Florida.

Lahsen, M. (2005). Technocracy, Democracy, and U. S. Climate Politics. *Science, Technology & Human Values* 30, 137-169.

Lahsen, M. (2008). Experiences of Modernity in the Greenhouse: A Cultural Analysis of a Physicist 'Trio' Supporting the Backlash against Global Warming. *Global Environmental Change*, 18, 204-19.

Langniss, O., & Wiser, R. (2003). The Renewable Portfolio Standard in Texas: An Early Assessment. *Energy Policy* 31 (6), 527–535.

Layzer, J. (2007). Deep Freeze: How Business Has Shaped the Global Warming Debate in Congress. *Business and Environmental Policy*, Cambridge, MA: MIT Press.

Lyon, T., & Yin, H. (2007). Why Do States Adopt Renewable Portfolio Standards? An Empirical Investigation. Available at SSRN: http://ssrn.com/abstract=1025513

McCright, A., & Riley, D. (2000). Challenging Global Warming as a Social Problem. *Social Problems*, 47, 499-522.

McCright, A., & Riley, D. (2003). Defeating Kyoto: The Conservative Movement's Impact on U.S. Climate Change Policy. *Social Problems*, 50(3), 348-73.

Mercuro, N., & Steven, M. (2006). Economics and the Law: From Posner to Post-Modernism and Beyond. Second Edition. Princeton, NJ: Princeton University Press.

Nielsen, R., & Sheffield, J. (2009). Matching with Time-Series Cross-Sectional Data. Conference on Political Methodology. from http://polmeth.wustl.edu/conferences/methods2009/resources/papers/Nielsen-PanelMatching2009-poster.pdf

Oreskes, N., & Erik, C. (2010). Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from to Bacco Smoke to Global Warming. New York: Bloomsbury Press.

Palmer, K., & Dallas, B. (2005). Cost-Effectiveness of Renewable Electricity Policies. *Energy Economics*, 27(6), 873-894.

Rabe, G. (2006). Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards. Prepared for the Pew Center on Global Climate Change.

Rader, N., & Norgaard, R. (1996). Efficiency and Sustainability in Restructured Electricity Markets: The Renewables Portfolio Standard. *The Electricity Journal*, July 1996. 37-49

Schmid, A. A. (1987). Property, Power and Public Choice: An Inquiry into Law and Economics. New York, Praeger.

Schmid, A. A. (2001). Institutional and Behavioral Economics. East Lansing, Walbridge Press.

Schmid, A. A. (2004). Conflict and Cooperation: Institutional and Behavioral Economics. Malden, MA: Blackwell.

U.S. National Academies of Science Panel on Advancing the Science of Climate Change. (2010). Advancing the Science of Climate Change. Washington, D.C., National Academies Press.

U.S. National Academies of Science Panel on Limiting the Magnitude of Future Climate Change. (2010). Limiting the Magnitude of Future Climate Change. Washington, D.C., National Academies Press.

Wiser, R., & Barbose, G. (2008). Renewable Portfolio Standards in United States: A Status Report with Data through 2007. Lawrence Berkeley National Laboratory.

Wiser, R., Namovicz, C., Gielecki, M., & Smith, R. (2007). The Experience with Renewable Portfolio Standards in the United States. *The Electricity Journal*, 20 (4).

Yin, H., & Powers, N. (2010). Do state renewable portfolio standards promote in-state renewable generation ? *Energy Policy*, 38(2), 1140-114.