Factors Affecting the Rise of Renewable Energy in the U.S.: Concern over Environmental Quality or Rising Unemployment?

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ABSTRACT

This paper studies the development of renewable energy (RE) in the U.S. by examining the capacity to generate electricity from renewable sources. RE capacity exhibits a U-shaped relationship with per capita income, similar to other metrics for environmental quality (EQ). To explain this phenomenon, I consider several of the environmental Kuznets curve theories that describe the relationship between income and environmental quality (Y-EQ), including evolving property rights, increased demand for improved EQ, and changing economic composition. The results fail to provide support for the Y-EQ theories. I further consider the alternative hypothesis that increases in unemployment lead to increases in relative RE capacity, suggesting that promoting RE projects as a potential job creator is one of the main drivers of RE projects. The results imply that lagged unemployment is a significant predictor of relative RE capacity, particularly for states with a large manufacturing share of GDP.

Keywords: Renewable energy, Environmental quality, Environmental Kuznets curve, Electricity mix, Transition, Unemployment

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1. INTRODUCTION

This paper analyzes the transition between renewable and nonrenewable energy sources by empirically examining the relationship between per capita income and the relative use of RE sources. Schmalensee, Stoker, and Judson (1998) stress that examining this relationship is important to understanding whether energy transitions are due to fundamental economic trends or environmental policy. Using 1990–2008 state level panel data from the U.S. electricity market, I examine two measures of relative RE use: the percent of capacity that utilizes RE sources and the development of RE capacity, defined as the change in the percent of RE capacity. The basic regression results report a U-shaped relationship between income and RE capacity.

Literature on the empirical relationship between renewable energy (RE) and income typically finds a positive relationship. Research on an individual's willingness-to-pay (WTP) for RE suggests that demand for RE increases with income. Bollino (2009) shows that high income individuals are willing to pay more for electricity from RE, and Long (1993) presents results that suggest high-income individuals spend more on RE investments. Oliver, Volschenk, and Smit (2011) study the developing country of South Africa and also find a positive link between household income and WTP for green electricity. On a more aggregate level, Carley (2009) finds evidence that the percentage of RE generation increases with a state's Gross State Product, and Burke (2010) finds that the share of electricity generation from wind, and biomass electricity increases with per capita

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GDP. Finally, several papers concerning the causality between RE consumption and GDP growth find a positive bidirectional causality relationship (Apergis and Payne, 2010, 2012, 2011; Sadorsky, 2009). These results suggest that income is an important factor impacting RE development, but fail to consider a possible quadratic relationship.

To understand the U-shaped empirical findings, I consider and test several theories presented in the literature. First, environmental quality (EQ) is often stressed in the promotion of RE (Ellis, 1996; Fischer and Preonas, 2010), and several theories have been presented to explain the U-shaped relationship between income and environmental quality (Y-EQ).[1] Explanations include: a) economies and diseconomies of scale of production for pollution, b) a changing economic composition from agrarian to manufacturing to service oriented industries, c) a change in demand for EQ at higher income levels, and d) an evolving property rights structure such that a common resource evolves into a well-defined private property structure (Andreoni and Levinson, 2001; Bhattacharya and Lueck, 2009; Cropper and Griffiths, 1994; Dinda, 2004; Stern, 2004; Panayotou, 1999). This paper contributes to the environmental literature by classify RE generating capacity as a new metric for EQ. Increases in relative RE use imply increases in EQ in terms of improved CO_2, methane, nitrous oxide, and sulfur dioxide emissions. Much of the environmental literature measures EQ using CO_2 emissions, water pollutants, deforestation, risk to hazardous waste exposure, or environmental actions. To date, the Y-EQ literature has not explicitly measured EQ through the relative use of RE.

Applying the Y-EQ theories to the U.S. electricity market from 1990–2008, I note several changes that potentially impact the use and development of RE. The four applications of the theories for the electricity markets include a) electricity market deregulation, which fundamentally changed the market and property rights structure, b) the implementation of the Clean Air Act Amendments of 1990, which developed air pollution markets for SO_2 and changed the property rights for pollution c) the transition of the U.S. economy from a manufacturing based economy toward a service oriented economy, and d) the increase in renewable portfolio standards (RPS), which increase the demand for RE electricity generation. The empirical results for these control variables fail to provide support to the Y-EQ theories. Additionally, states with a large manufacturing share of GDP typically have more RE capacity than states with a small share.

Alternatively, I consider possible economic factors that impact RE capacity rather than focusing on EQ. For example, Tahvonen and Salo (2001) propose a model where economies transition from renewables, to non-renewables, and back to renewables as the economy develops, fossil fuels become scarce, and consumption and production costs change. Because advocates for RE typically promote the development of wind and solar projects as a means of job creation, I consider the hypothesis that unemployment rates impact RE capacity (Wei, Patadia, and Kammen, 2010). Sari, Ewing, and Soytas (2008) support this hypothesis, finding a long run relationship between energy measures, industrial output and employment. I extend the model to examine the impact of lagged unemployment on RE. The results support Sari et al. (2008) and provide evidence that a high unemployment rate promotes RE development, but the impact decreases as a state's per capita

1. According to the Energy Information Administration (EIA) in 2009, coal generated 44.5% of the electricity in the U.S. and emitted 1,877 million tons of CO_2, but renewable sources, including hydropower, wind, and solar, generated 10.4% of the electricity and produced only 12 million tons of CO_2. Thus, in terms of carbon emissions, renewable sources provide cleaner electricity generation. Methane, nitrous oxide, and sulfur dioxide emission are also more prevalent in electricity generated from nonrenewable sources.

income increases, explaining the U-shaped relationship. These results suggest that economic factors, such as unemployment and manufacturing GDP, are better predictors of RE development than environmental policies, supporting the existence of an electricity ladder (Burke, 2010; Tahvonen and Salo, 2001). These results suggest that improvements in EQ can occur without an increase in income, when EQ projects are presented as a means of job creation.

The paper proceeds by examining the basic empirical relationship between income and RE in section 2. Section 3 examines three possible Y-EQ theories that explain the relationship between income and environmental quality. I apply the theories to the electricity industry to include controls in the empirical model. Results from the fixed-effects model are presented. Section 4 examines the alternative hypothesis that the unemployment rate impacts the use of RE. Section 5 concludes.

2. RENEWABLE ENERGY AND INCOME

Energy Information Administration (EIA) provides information for the 50 states on the capacity of electricity generation by source.[2] To measure RE relative to non-RE use, I calculate the percent of RE capacity excluding hydroelectric power, and the development of RE capacity, defined as the change in the percent of RE capacity. Table 1 provides summary statistics for both measures. The metric for relative RE capacity captures the level of investment in environmentally friendly, cleaner technologies, whereas the change in relative RE capacity captures the growth in investment towards environmentally friendly capital. Note that investment in more wind capacity does not necessarily imply more electricity generation from wind; I highlight the notion that relative RE capacity is a measure for the appearance of environmental-friendliness, and not necessarily the production of cleaner goods.[3]

For comparison, Figure 1 plots per capita income with the percent of RE capacity. Six states with high renewable potential and/or development are represented: Arizona, California, Iowa, Illinois, New York, and Texas. The figures illustrate that between 1990–2008, these six states experienced a growth in capacity dedicated to RE. The rise in real income for these same six states exhibits an overall upward trend in income with dips around 2000 and 2007. These illustrations suggest that higher income levels are correlated with a higher percent of RE capacity; however, the correlation is not perfect, as building large-scale capacity may result in a step-change increase in the percent of renewable capacity. Most notably in California around 2000 the Calpine Corporation acquired The Geysers for geothermal electricity production, increasing renewable capacity from under 2.1% to over 2.6%. Thus, the variation in relative RE capacity may be due to other factors such as the increased demand for environmental quality, or changes in economic composition. I consider these factors in section 3.

2. Data collected from EIA-860. I examine the total electric industry, which includes electric generators, electric utilities, independent power producers, and industrial and commercial power producers.

3. By using relative RE capacity as a measure of EQ, I make the assumption that renewable generation is replacing nonrenewable generation, rather than increasing the demand for it, and that renewable generation is more environmentally friendly than nonrenewable generation. There is some evidence from the Department of Energy that renewable sources are intermittent and increase the need for combustion turbine natural gas capacity to maintain electric system reliability. Additionally, renewable sources typically replace natural gas generation rather than coal generation implying that the environmental benefits from renewable sources are not as large as once presumed.

Table 1: Descriptive Statistics

Variable	Mean	St. Dev.	Min	Max	Description
Percent of Renewable Capacity	2.344	3.436	0	27.58	Renewable capacity includes geothermal, other biomass, pumped storage, solar thermal and photovoltaic, wind, wood, and wood derived fuels
RE Development (Δ.Percent of RE Capacity)	0.141	0.809	−10.657	9.179	Current percent of RE capacity minus the previous year's relative RE capacity
Income per Capita	20982.74	3588.462	13117	35621.62	Income per capita in 1990 dollars
Restructure	0.2937	0.4557	0	1	Dichotomous variable with 1 indicating a year when the state was restructured
Restructure Score	8.6032	18.6076	0	79	Average of Com., Ind., and Resid. ABACCUS scores for successful market restructuring. The variable is 0 for years when the state has not begun restructuring
SO_2	249.528	311.022	1	2046	Electric Power Industry Emissions Estimates (Thousand Metric Tons)
Manufacturing GDP	0.1480	0.0645	0.01782	0.3085	Manufacturing share of GDP including both SIC and NAIC
RPS	0.0027	0.01558	−0.0280	0.1547	Continuous index variable that accounts for a state with a renewable portfolio standard and its strength, constructed following Yin and Powers (2010)
Wind Potential	7.99	1.3330	5.5	10	Wind potential measured in meters per second at a height of 80 meters
Solar Potential	4.1	0.9649	3	6	Solar potential measured in kilowatt hours per meter squared per day
Bio Potential	323	152.4646	50	500	Biomass potential measured in thousands of tons per year
Unemployment	5.099	1.377	2.3	11.2	Seasonally adjusted monthly unemployment rate averaged by year

First, to examine the relationship between income and RE, consider the following fixed effect model common in the Y-EQ literature

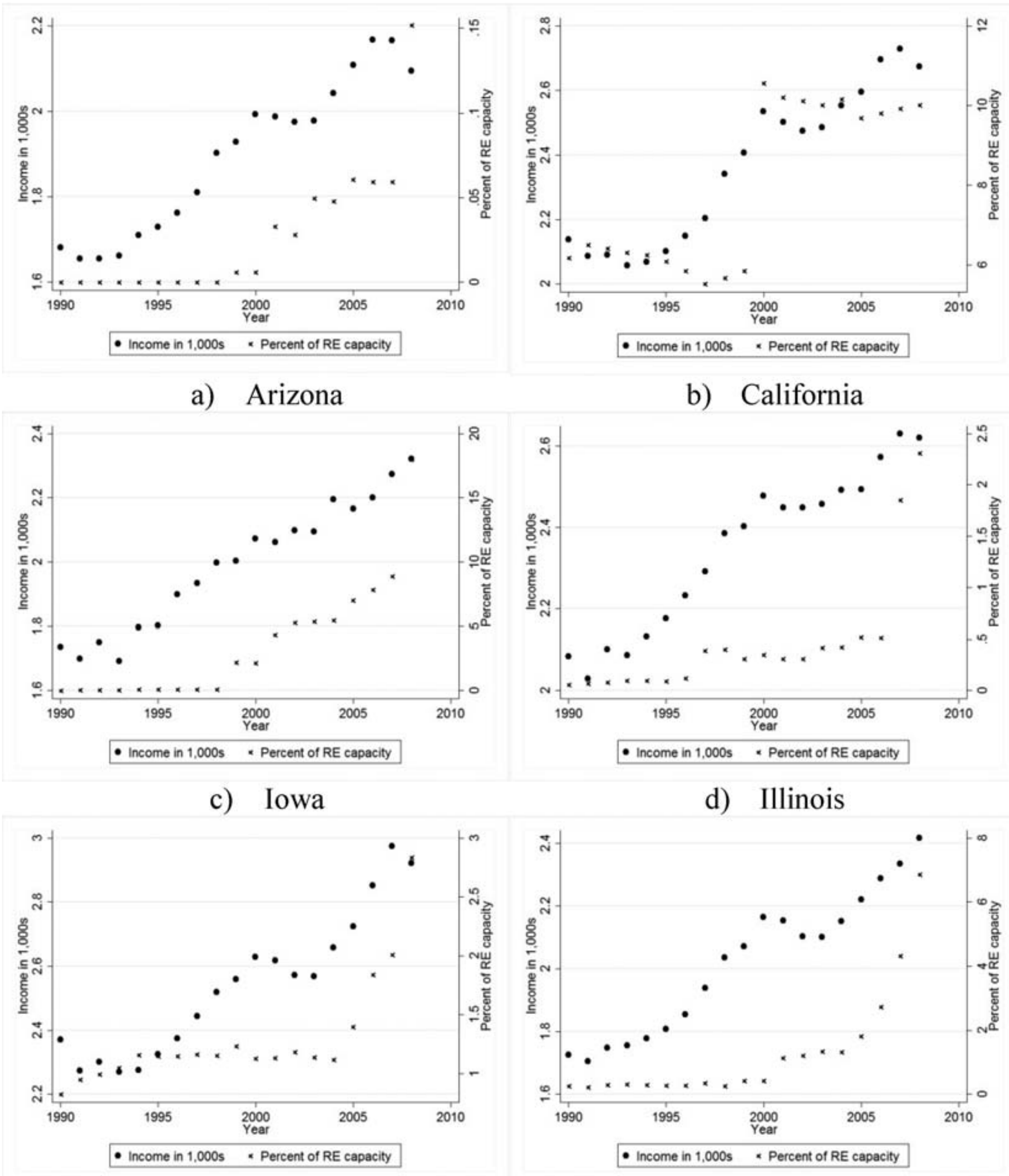
$$RE_{i,t} = \beta_{0,i} + \beta_1 Log(Income_{i,t}) + \beta_2 Log(Income_{i,t})^2 + \beta_3 t + \varepsilon_{i,t} \quad (1)$$

where i represents a state in time period t. I examine a fixed effects model with a time trend to account for technological change, following Aslanidis and Iranzo (2009); Cole, Rayner, and Bates (1997); Stern and Common (2001).[4] $RE_{i,t}$ is measured using relative RE capacity or RE development.

Table 2 summarizes the basic fixed-effects regression results with standard errors that control for heteroskedasticity and autocorrelation and a time trend. Columns 1 and 2 provide results for the percent of RE capacity, and columns 3 and 4 provide results for RE development. The estimated coefficients provide evidence of a quadratic relationship between income and relative RE capacity. *LogIncome* and *LogIncome*^{2} are jointly statistically significant for both RE capacity and RE capacity development. The estimated income turning point (ITP) for models 2 and 4 are $19,205 and $17,510. States that continually fall below $19,205 include Alabama, Arkansas, Idaho, Ken-

4. Similar results were found using a model with state-specific time trends.

Figure 1: Per Capita income and Percent of RE Capacity over Time



a) Arizona

b) California

c) Iowa

d) Illinois

e) New York

f) Texas

tucky, Louisiana, Mississippi, Montana, New Mexico, Oklahoma, South Carolina, Utah, and West Virginia. Most of these states are not known for renewable energy production. Idaho utilizes mostly hydropower which I exclude. Montana and Oklahoma have only recently begun developing wind when their per capita income levels were above $19,205. States above this estimated ITP averaged 2.65% RE capacity and a 0.185% increase. States below the ITP averaged 1.74% RE capacity and a 0.048% increase.

Table 2: The Percent of Renewable Energy and Per Capita Income[a]

	Percent of RE Capacity		RE Development (Δ.Percent of RE Capacity)	
	(1)	(2)	(3)	(4)
Log Income	0.1875	−63.4857***	0.3623	−25.8645***
	(0.342)	(16.021)	(0.317)	(8.612)
Log Income^2		3.2184***		1.3236***
		(0.810)		(0.435)
N	950	950	900	900
Wald χ^2	1442	1588	94.21	105.55
Prob. > χ^2	0.0000	0.0000	0.0002	0.0000

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

Thus, the results suggest a U-shaped relationship for both income and relative RE capacity in model 2 and income and RE capacity development in model 4. In the next section, I examine three theories from the literature on income and EQ.

3. RENEWABLE ENERGY, INCOME, AND Y-EQ THEORIES

To examine the Y-EQ relationship further, consider the following extension of the model:

$$RE_{i,t} = \beta_{0,i} + \beta_1 Log(Income_{i,t}) + \beta_2 Log(Income_{i,t})^2 + \beta_3 t + \boldsymbol{\beta_4 X} + \varepsilon_{i,t} \tag{2}$$

where **X** represents a vector of variables that control for each of the Y-EQ theories and $\boldsymbol{\beta_4}$ a vector of associated coefficients. Due to multi-collinearity between variables, I examine each theory in a separate model. The results for each model are presented in Table 3. Models for the percent of RE capacity are presented in Table 3A and models for RE capacity development in Table 3B. Models 1, 3, 5, and 7 present results with a linear income relationship, and models 2, 4, 6, and 8 include a quadratic term.

Several theories have been proposed to explain the Y-EQ relationship. Table 4 describes the different models considered, and explains which theories are tested in Tables 3A and 3B. Three main theories consistent in the literature include improving property rights, increasing demand, and changing economic composition. Each theory is applied to the electricity industry to determine the impact on RE capacity and development.

3.1 Better Defined Property Rights

Well-defined property rights of exclusivity, transferability, and enforceability impact EQ. As income increases, institutions develop better property rights and EQ improves. Several papers suggest that reducing environmental damage requires proactive policies, and such policies may incorporate the redefining of property rights, and improving the transferability and enforceability of such rights (Dinda, 2004; Rothman, 1998). Bhattacharya and Lueck (2009) present a model that examines the role of property rights in forming a relationship between resource stock and resource

Table 3A: Models for the Percent of Renewable Capacity and RE Development with Y-EQ Controls[a]

Dependent Variable: Percent RE Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Income	0.3128	−71.4083***	0.1870	−62.5575***	0.1048	−49.8486***	0.1602	−81.7683***
	(0.376)	(16.655)	(0.342)	(16.069)	(0.350)	(18.435)	(0.397)	(18.197)
Log Income^2		3.6424***		3.1711***		2.5359***		4.1430***
		(0.844)		(0.813)		(0.933)		(0.920)
Restructure	−0.0556	−0.0872						
	(0.062)	(0.073)						
Restructure Score	0.0007	−0.0008						
	(0.002)	(0.002)						
SO_2 Resid.			0.0054	0.0110				
			(0.028)	(0.034)				
RPS					0.5313	0.3671		
					(1.768)	(2.261)		
Manufact. GDP							0.6688	1.0751
							(0.700)	(0.758)
N	950	950	950	950	950	950	950	950
Wald χ^2	1735	1784	1440	1594	1414	1596	1575	1536
Prob. $> \chi^2$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

Table 3B: Models for the Percent of Renewable Capacity and RE Development with Y-EQ Controls[a]

Dependent Variable: RE Development (Δ.Percent of RE Capacity)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Income	0.5167*	−35.1917***	0.3623	−25.6159***	0.2602	−27.5002***	0.3910	−29.2768***
	(0.303)	(8.437)	(0.317)	(8.862)	(0.326)	(9.737)	(0.300)	(7.315)
Log Income^2		1.8044***		1.3108***		1.4022***		1.4943***
		(0.426)		(0.447)		(0.492)		(0.370)
Restructure	−0.0649	−0.0384						
	(0.048)	(0.044)						
Restructure Score	−0.0010	−0.0026**						
	(0.001)	(0.001)						
SO_2 Resid.			−0.0220	−0.0127				
			(0.027)	(0.028)				
RPS					−0.0270	−0.4830		
					(1.254)	(1.398)		
Manufact. GDP							1.1840**	1.3392***
							(0.480)	(0.455)
N	900	900	900	900	900	900	900	900
Wald χ^2	115	140	93.92	103.86	89.86	103.81	117	139
Prob. $> \chi^2$	0.000	0.000	0.0003	0.0009	0.0006	0.0007	0.000	0.000

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

Table 4: Qualitative Explanation of Models

	Dependent Variable			
	Percent of Capacity		Δ.Percent of RE Capacity	
	Income		Income	
	Linear	Non-linear	Linear	Non-linear
Better Defined Property Rights	Top Panel Table 3 (1, 3)	Top Panel Table 3 (2, 4)	Bottom Panel Table 3 (1, 3)	Bottom Panel Table 3 (2, 4)
Increasing Demand for EQ	Top Panel Table 3 (5)	Top Panel Table 3 (6)	Bottom Panel Table 3 (5)	Bottom Panel Table 3 (6)
Changing Economic Composition	Top Panel Table 3 (7)	Top Panel Table 3 (8)	Bottom Panel Table 3 (7)	Bottom Panel Table 3 (8)

In parenthesis is the model that corresponds to the theory tested.

rents, which they define as the Y-EQ relationship. In their model, a state transitions from open access to a more efficient property rights regime. Consequently, the Y-EQ relationship can be positive or quadratic depending on the agents' characteristics and ability to extract resources.

In the electricity industry, two factors are noteworthy of evolving property rights that impact the use of RE: market restructuring for wholesale generation, and emerging pollution markets.

3.1.1 Market Restructuring

The change in market structure for electricity generation is a fundamental change in the property rights regime, and much of the electricity industry in the U.S. has begun deregulating the generation sector, also commonly called restructuring. In the late 1990s and early 2000s, twenty-two states attempted to restructure their electricity market to some degree, and in doing so, their electricity markets began the process of transforming from a regulated vertical monopoly industry to a horizontally restructured market. The horizontal market was then segmented into generation, transmission, and distribution sectors. The main idea was that the incumbent monopolist would retain operation of transmission and distribution facilities, but utility commissions would require the monopolist to divest generating assets. Electricity generation would become competitive, while transmission and distribution remain as regulated monopolies. Then, generating companies could compete and sell electricity wholesale to the distributing utility through an independent power operator or power exchange.

Theoretically, the movement to a more competitive market structure improves the efficiency of property rights by removing the constraint of regulation, and allows for the differentiation between the use of renewable and nonrenewable sources by the consumer (Madlener and Stagl, 2005). Moreover, restructuring brings new attention to RE for consumers and policy advocates and allows for electricity suppliers to differentiate between clean goods and dirty goods (Wiser, Porter, and Clemmer, 2000). Thus, restructuring may increase relative RE use by allowing firms to offer different products, increasing transferability of clean goods, and increasing consumer awareness.

In the empirical model, *Restructure* is a dichotomous variable that controls for the regulation status of a state, where a value of one indicates a state that has begun restructuring away from the traditional natural monopoly regulation.[5] Using a similar variable, Carley (2009) finds

5. The restructuring status of a state was determined using the EIA website title "Status of Electricity Restructuring by State," accessible at http://www.eia.doe.gov/cneaf/electricity/page/restructuring/restructure_elect.html

mixed results on the impact of restructuring, where deregulation decreased the share of RE generation but increased total RE generation.

The deregulation status also varies considerably from state to state due to politics and industry influence. I include the variable *Restructure Score* to control for the differences in restructuring policies and level of competition in the generation sector. States such as Illinois, New York, and Texas created competitive markets by encouraging customer choice, and forcing incumbent firms to divest generating assets. States on the other end of the spectrum include Arizona, California, Michigan, and Virginia. These states failed to have the incumbent firm divest generating assets and/or suspended consumer retail choice. The Distributed Energy Financial Group scores and ranks the status of restructuring for each state (Energy Retailer Research Consortium, 2008). *Restructure Score* is calculated using the average score between industrial, commercial, and residential sectors. A high score indicates a more competitive market with 100 being the highest possible score.

The results for *Restructure* and *Restructure Score* in models 1 and 2 in Table 3 implies that deregulation has not had a substantial impact on RE capacity. For relative RE capacity in Table 3A, these two variables are jointly insignificant in model 2 with a $\chi^2(2)$-statistic of 4.37. For RE capacity development in Table 3B, the estimates in model 2 are jointly significant with a $\chi^2(2)$-statistic of 18.10, but indicate that restructuring had a negative impact on relative RE development.

Thus, the negative result suggests that states that restructured and restructured well experienced less RE development. This result provides little policy implication but rather imply that at the time restructuring happened few states increased RE capacity. Moreover, the insignificant result in model 2 suggests a lack of evidence that electricity restructuring has increased RE capacity, even when controlling for differences in state policies. The estimated ITPs in model 2 remains close to the previous estimates at \$18,077 for the percent of RE capacity and \$17,182 for RE capacity development.

3.1.2 Pollution Markets

The Clean Air Act of 1990 created pollution allowance markets, causing a fundamental change in property rights for air quality. Coal power plants, which emit a relatively large amount of SO_2, were forced to start internalizing the cost of emissions. The pollution allowance for each power plant was reduced annually, with the final goal of reducing emissions to 50% of 1980 levels. In the time period 1990–2008, most emissions reductions came from the use of scrubbers and switching to a different fuel for coal, such as low-sulfur coal (A. Denny Ellerman and Bailey, 1997). Both of these switches are expected to have the following impacts: an increase to production costs for electricity generation from coal, a decrease in the relative price for generation from RE, and an increase in RE use.

To examine the impact of reducing SO_2 permits, I include the variable *SO_2 Resid*. This variable instruments for SO_2 emissions, and removes potential endogeneity between reducing SO_2 emissions and building more RE capacity. To control for the endogeneity, I regress the log of SO_2 emissions against three variables that capture the wind, solar, and biomass potential of a state. Descriptions of these resource potential variables are included in Table 1. Because a state's physical resource potential does not vary over time, the residuals from the regression on SO_2 are then purged of the states' differences in renewable potential, positively correlated with SO_2 emission, and provide instruments for the change in property rights for clean air. Thus, I expect a negative relationship between *SO_2 Resid.*, and RE use, capturing the effect of the pollution markets.

Models 3 and 4 in Tables 3A and 3B present the results for the theory of evolving property rights in pollution markets. For both models and metrics, the estimated coefficients are insignificant.

The estimates are extremely close to zero, and sometimes positive, opposite of what we expect. Thus, the results fail to provide evidence that pollution markets have increased RE use or development. Furthermore, the estimated ITP in model 4 remains close to the previous estimates at $19,220 for the percent of RE capacity, and $17,520 for RE capacity development. The lack of significance may be due to the reduced form empirical model. An empirical analysis using a structural model may tease out the full effect of pollution markets. Such a model would examine more accurately how increases in SO_2 lead to increases in the capital and operating costs of coal-fired powerplants and additionally how those higher cost impact renewable energy development. This analysis is left for future research.

3.2 Changes in Consumer Demand

The Y-EQ relationship also depends on the demand for EQ. Dinda (2004) describes a relationship where in the beginning stages of industrialization, people are concerned about jobs and income more than EQ, such as clean air and water. As income rises, individuals begin to value the environment more, and clean air and safe drinking water become a greater concern (Dasgupta, Laplante, Wang, and Wheeler, 2002).

In the electricity industry, one policy that reflects a change in the demand for RE is the renewable portfolio standard (RPS).[6] The RPS is a proportional constraint that requires utility companies to generate a specified percentage of electricity from renewable sources. In total, 29 states have an RPS, and the constraint can be viewed as a regulation that forces a firm to adopt new technologies. An RPS is likely to be adopted when EQ demand is large, or when EQ concerns are large enough and parties affected by the damage from nonrenewable sources have created enough opposition. Supporting this theory of a change in consumer demand, Huang, Alavalapati, Carter, and Langholtz (2007) and Delmas and Montes-Sancho (2011) show that adoption rates of an RPS increase with gross state product and income per capita, respectively.

The continuous index variable *RPS* controls for changing RE demand through a renewable standard. Follow Yin and Powers (2010), I construct an *RPS* index to measure the stringency of an RPS policy, utilizing information provided by the Database for State Incentives for Renewable Electricity.[7] This construction captures the amount of existing renewable generation and the percent of electricity sales covered by the standard.[8] The variable takes a non-zero value when the states' policy becomes effective. A negative value implies the policy is not binding in a manner that would encourage new development. A positive value suggests the policy is binding. States that have a stringent RPS include California, Maine, and New York, and states with a negative RPS include Colorado, Iowa, and New Mexico.

6. I note the following papers examine the effect of RPS policy on capacity ratios using a fixed effects model: Shrimali and Kniefel (2011); Yin and Powers (2010). Delmas and Montes-Sancho (2011) provides a more thorough analysis by using a two-stage model, with the probability of adoption as an instrument for the RPS variable, finding a negative relationship with total RE capacity with the exception of investor-owned utilities.

7. $RPS = \frac{Nominal \times Coverage \times Sales - ExistingGen}{Sales}$. I note that the construction of the RPS differs from Yin and Powers (2010) through the measure of coverage and existing renewable generation. For these two metric, I utilize DSIRE data on coverage and EIA-906 state level data on existing renewable generation including biomass, geothermal, solar, wind, and wood. These differences in construction may account for the differences in results.

8. Yin and Powers (2010) show that an RPS has a positive and significant impact on the share of renewable capacity.

The estimated coefficients for the *RPS* variable are presented in models 5 and 6 of Table 3. Table 3A shows models with the percent of RE capacity as the dependent variable. The parameter is positive as expected, indicating that the renewable standard increases the demand for RE capacity.[9] However, the results are insignificant, and again the estimated turning points in model 6 are reasonable at $18,557 and $18,144. Additionally, I find negative and insignificant results for models of RE development in Table 3B.

3.3 Economic Composition

The composition effect is defined as the change in EQ caused by a change in the make-up of an economy (Dinda, 2004). The most common example of a changing economy is a country that moves from an economy based on agriculture to industry to a service focused economy. As the focal point of an economy changes between these three main sectors, income increases. However, the transition from an agricultural economy to an industrial based one is thought to decrease EQ. On the other hand, the transition from industrial to service oriented is thought to improve EQ. Theoretically, the compositional effect creates a U-shape between income and EQ.

For the electricity industry, the change in economic composition can have large impacts on energy use. For example, a manufacturing focused economy typically needs consistent and reliable sources of energy, such as coal and nuclear powerplants. On the other hand, a service oriented economy has fewer energy needs and may be better equipped to deal with intermittent energy sources. Services, such as advertising, entertainment, marketing, and insurance, have fewer consistency requirements for energy because of their relatively small demand. Thus, the transition of an economy from manufacturing to one based on service industries is correlated with an increase in income, and an increase in the demand for RE, creating an empirically positive relationship between income and relative RE use.[10]

Manufact. GDP represents the share of GDP for the manufacturing industry and controls for a change in a state's economic structure. States with a large manufacturing industry are expected to use less RE because of the need for consistent and reliable electricity. Models 7 and 8 in Table 3 present the estimated coefficients controlling for a changing economic composition through *Manufact. GDP.* The results are positive and statistically significant for RE development, in Table 3B. These result suggests that a large manufacturing industry increases relative RE capacity. For example, model 7 implies that a one percentage point increase in the manufacturing share of GDP will increase the percent of RE capacity by 0.0067 percentage points, ceteris paribus. The same change will result in a 0.0118 percentage point increase in RE capacity development.

These results oppose the theory that a large manufacturing economy will utilize less RE. Additionally, unemployment in the manufacturing sector has increased over the last two decades. In the next section, I consider the hypothesis that unemployment is an important factor in RE development, and that advocates for RE typically promote the development of wind and solar projects as a means of job creation.

9. Dong (2012) reports that the RPS has a negative and/or statistically insignificant impact on cumulative wind capacity. Shrimali and Kniefel (2011) find that the RPS has a negative impact on aggregate renewables, wind, and biomass, but a positive impact on solar and geothermal energy.

10. I note that the transition of the U.S. economy from manufacturing to a service-oriented one suggests an increase in outsourcing manufacturing industries and therefore outsourcing environmental degradation (Suri and Chapman, 1998).

Table 5: Unemployment's Impact on the Percent of Renewable Capacity[a]

Dependent Variable: Percent of RE Capacity

	(1)	(2)	(3)	(4)	(5)	(6)
Log Income	0.2773	1.6355***	−125.0233***	0.3985	1.6442***	−130.5359***
	(0.456)	(0.588)	(43.230)	(0.472)	(0.624)	(47.087)
Log Income^2			6.3723***			6.6946***
			(2.180)			(2.377)
L.Unemployment	−0.0253**	3.1759***	−50.5019	−0.0324**	2.8755***	−67.8560
	(0.012)	(0.792)	(39.612)	(0.013)	(0.835)	(44.536)
L.Unemployment × Log Income		−0.3230***	10.4496		−0.2934***	14.0323
		(0.080)	(8.006)		(0.084)	(9.009)
L.Unemployment × Log Income^2			−0.5404			−0.7253
			(0.405)			(0.456)
Restructure				−0.0808	−0.0985	−0.0867
				(0.074)	(0.071)	(0.071)
Restructure Score				0.0001	−0.0011	−0.0018
				(0.002)	(0.002)	(0.002)
SO_2 Resid.				0.0159	0.0038	−0.0046
				(0.030)	(0.030)	(0.034)
RPS				0.1587	0.8688	0.2949
				(1.687)	(2.049)	(2.485)
Manufact. GDP				0.2995	−0.1811	0.8689
				(0.721)	(0.773)	(0.818)
N	900	900	900	900	900	900
Wald χ^2	2216	2147	2229	2547	2170	2302
Prob. > χ^2	0.000	0.000	0.000	0.000	0.000	0.000

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

4. UNEMPLOYMENT AND RENEWABLE ENERGY

An alternative explanation for the increase in RE capacity is that of job creation (Bergmann, Colombo, and Hanley, 2008; Blazevic, 2009; Menegaki, 2011; Wei et al., 2010). Advocates for green jobs uphold the idea that the green policies can create both temporary and permanent jobs. Thus, states with a high unemployment rate are more likely to support RE development and legislation for RE standards or subsidization (Jenner, Chan, Frankenberger, and Gabel, 2012). States with low unemployment are less likely to be concerned with job creation and thus RE projects are likely to have fewer supporters.

Consider the model presented in equation 2. I examine 6 alterations to the model that include lagged unemployment as a control in the **X** vector. Model 1 regresses lagged unemployment, and per capita income on RE use. Model 2 includes an interaction, and model 3 includes an interaction and a quadratic for income. Models 4–6 are similar to 1–3 but include the Y-EQ control variables. The estimated results are presented in Table 5 for the percent of RE capacity and Table 6 for the development of relative RE capacity.

For the percent of RE capacity in Table 5, lagged unemployment appears to have a positive but diminishing impact on RE capacity. Most notably, in models 2 and 4, unemployment, income, and their interaction are all statistically significant. Models 1 and 3 present a negative and statistically significant effect for unemployment, but the lack of statistical significance for income high-

Table 6: Unemployment's Impact on the Development of Renewable Capacity[a]

Dependent Variable: RE Development (Δ.Percent of RE Capacity)

	(1)	(2)	(3)	(4)	(5)	(6)
Log Income	0.6466*	1.5825***	−27.3047	0.2652	1.1474**	−7.1755
	(0.348)	(0.457)	(29.495)	(0.362)	(0.463)	(28.309)
Log Income^2			1.4367			0.4050
			(1.483)			(1.424)
L.Unemployment	0.0136	1.9684***	−4.5887	0.0017	1.7330***	18.8613
	(0.010)	(0.622)	(26.158)	(0.010)	(0.612)	(24.005)
L.Unemployment × Log Income		−0.1968***	1.0404		−0.1744***	−3.7026
		(0.063)	(5.278)		(0.062)	(4.852)
L.Unemployment × Log Income^2			−0.0581			0.1815
			(0.266)			(0.245)
Restructure				−0.0609	−0.0628	−0.0632
				(0.049)	(0.054)	(0.049)
Restructure Score				−0.0007	−0.0006	−0.0012
				(0.001)	(0.002)	(0.002)
SO_2 Resid.				−0.0122	−0.0164	−0.0052
				(0.028)	(0.030)	(0.030)
RPS				−0.3735	0.0303	−0.4440
				(1.095)	(1.147)	(1.234)
Manufact. GDP				0.9167	1.1785*	1.2087**
				(0.623)	(0.605)	(0.591)
N	900	900	900	900	900	900
Wald χ^2	106	123	127	114	134	145
Prob. $> \chi^2$	0.000	0.000	0.000	0.000	0.000	0.000

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

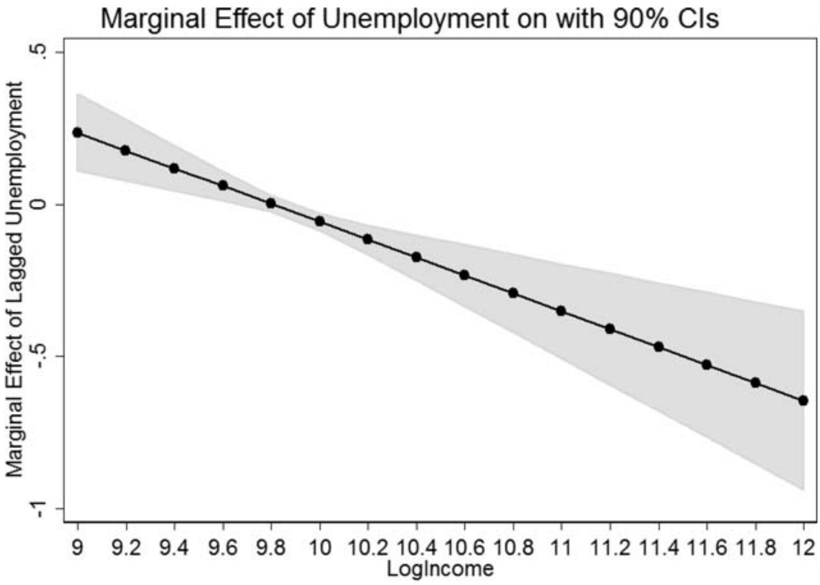
lights the importance of including the interaction between unemployment and income. Models 3 and 6 find the U-shaped relationship between per capita income and RE capacity, but the quadratic relationship may cause collinearity problems due to the correlation between unemployment and income, creating inflated standard errors and causing insignificance.

Consider that high unemployment is often experienced with low income levels. At high income levels, individuals are less worried about unemployment, and the creation of jobs from RE development. The estimated coefficient for the *Unemployment* × *LogIncome* interaction term is negative, supporting the hypothesis that as per capita income rises the impact of unemployment on relative RE capacity decreases. The estimated coefficients for *Unemployment* and *Unemployment* × *LogIncome* are jointly significant in models 2 and 5 with $\chi^2(2)$-statistic of 19.6 and 16.05.

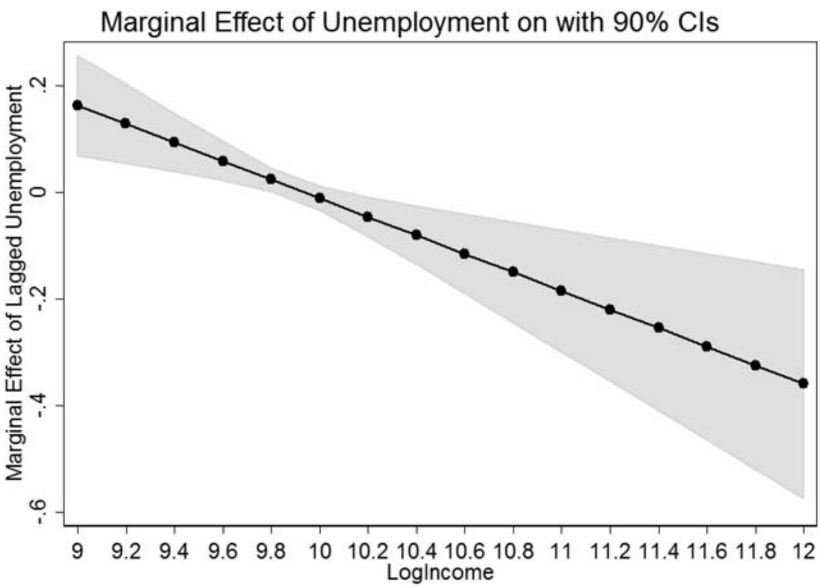
Figure 2(a) graphs the marginal effects of unemployment for model 5 over the relevant range of incomes. At low income levels, the marginal effect of lagged unemployment is positive and statistically significant. As income rises, the impact of unemployment decreases until it eventually becomes negative. The estimated income level of this transition is $18,045, similar to the estimated ITP for the quadratic models presented above.

The results for the development of RE capacity in Table 6 provide similar results. Lagged unemployment has a positive impact on RE development. As income rises, unemployment typically declines and its impact diminishes. Eventually, the income effect outweighs the unemployment effect and RE development begins to rises with income. Model 5 estimates that the marginal effect for unemployment is positive for income levels below $20,680 and negative above. This income

Figure 2: Marginal Effects of Unemployment



a) Percent of Renewable Capacity



b) Renewable Capacity Development

level is within a feasible range. Figure 2(b) further illustrates this trade-off between income and the marginal effect of unemployment. Thus, the relationship between income and RE is likely to be strictly positive with the unemployment rate explaining non-linearities.

Interestingly, the unemployment rate has a larger impact on RE use than any of the proposed Y-EQ control variables. The estimates for the Y-EQ control variables are again mostly sta-

Table 7: Unemployment's Impact by Manufacturing GDP[a]

	Dependent Variable	
	Percent RE Capacity	RE Development (Δ.Percent of RE Capacity)
L.Unemployment	1.8797*	0.4889
	(1.104)	(0.800)
Log Income	2.6154***	1.2314**
	(0.762)	(0.532)
L.Unemployment × Log Income	−0.1924*	−0.0484
	(0.111)	(0.081)
High Man. GDP × L.Unemployment	2.3668***	2.1956**
	(0.873)	(0.873)
High Man. GDP × Log Income	0.4547	1.0520*
	(0.582)	(0.611)
High Man. GDP × L.Unemployment × Log Income	−0.2426***	−0.2203**
	(0.089)	(0.088)
N	900	900
Wald χ^2	2308	141
Prob. > χ^2	0.0000	0.0000
Chow Test χ^2	23.46	15.26
Prob. > χ^2	0.000	0.001

[a] All models include state fixed-effects and a time trend. Standard errors control for panel heteroskedasticity and autocorrelation and are stated in the parenthesis. Significance levels: *0.10, **0.05, ***0.01.

tistically insignificant, and fail to provide support for the proposed theories. The results suggest that improvements in EQ can occur without an increase in income, when EQ projects are presented as a means of job creation.

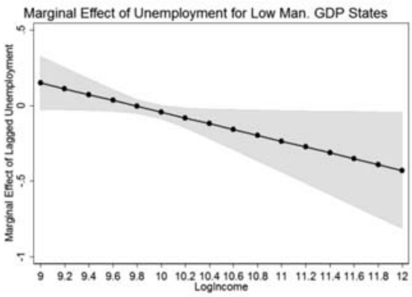
To further support the hypothesis that unemployment encourages RE use, I separate the states by their share of manufacturing GDP to examine where unemployment has the largest impact on RE development.[11] I regress model 5 with an interaction for low and high manufacturing GDP. The results presented in Table 7 show that manufacturing heavy states have a greater unemployment effect. The results show statistically different estimates for states with large and small shares of manufacturing GDP as noted by the Chow test results of 23.46 and 15.26.

For states with a large manufacturing GDP, the impact of a 1% increase in unemployment is a 4.25 percentage point increase in RE capacity, and a 2.68 increase in RE development. The interaction between unemployment and income, again suggests that the unemployment effect is diminishing as income increases, and the turning point for high manufacturing GDP states is estimated to be $17,363 and for low manufacturing states $17,496. For RE development, the estimates are higher at $21,822 for high manufacturing states and $24,373 for low manufacturing states.

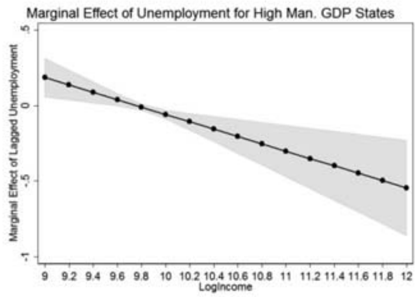
Unemployment particularly in the manufacturing industry can impact the investment in new, renewable technologies. Figure 3 illustrates the trade-off between the rising income and the effects of lagged unemployment for high and low manufacturing GDP states. Panels 3(b) and 3(d) show that the unemployment marginal effects exhibit a greater impact for large manufacturing states because the line is more steeply sloped than in panels 3(a) and 3(c) for small manufacturing states.

11. States are separately evenly such that the 25 states with the largest manufacturing share GDP are categorized as having a high manufacturing GDP.

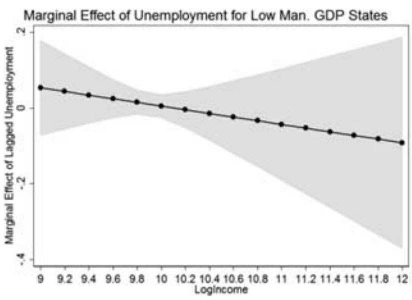
Figure 3: Marginal Effects of Unemployment by Manufacturing GDP



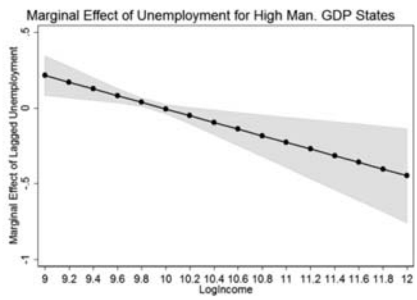
a) Percent Renewable Capacity for Low Manufacturing States



b) Percent Renewable Capacity for High Manufacturing States



c) Renewable Capacity Development for Low Manufacturing States



d) Renewable Capacity Development for High Manufacturing States

5. CONCLUSION

The relationship between income and environmental quality has been widely studied in the economics literature. Previous research has examined various measures of EQ, such as deforestation rates, air quality, and water pollution levels across countries. Carson (2010) suggests that identifying the factors that lead to improved EQ can help policymakers make better improvements in regulatory structures and incentive systems. This paper contributes to the literature by examining EQ in the U.S. electricity industry, and analyzing two new metrics: the percent of capacity for RE sources and the development of RE, measured as the change in the percent of RE capacity.

By using renewable capacity as a measure of EQ, I can examine the Y-EQ relationship controlling for several theories including evolving property rights, increased demand for EQ, and changing economic composition. The control variables fail to provide support for any of the theories. This supports the findings by Marques, Fuinhas, and Manso (2011) who finds that environmental concern has not yet significantly impacted the development of renewables.

Alternatively, I consider the theory that job creation is a major component in renewable energy development. To test the hypothesis, I examine the impact of changes in the unemployment rate. The results provide strong evidence that a higher unemployment rate has a positive impact on relative RE capacity, but this impact decreases as income increases. Furthermore, states with a large manufacturing industry also exhibit a positive correlation between the unemployment rate and relative RE capacity. These findings suggest that job creation is an important driver of RE projects rather than simply improved EQ, and that increases in income per capita or economic growth are not essential to promote improved EQ. Policies that promote RE development as a means of job creation can increase renewable energy use. This result conflicts with Shrimali and Kniefel (2011) by finding that some economic variables play a crucial role in increasing renewables. In fact, Delmas and Montes-Sancho (2011) finds that unemployment and income are statistically significant at predicting the adoption of RPSs. However, the types of policies passed can have differing effects on RE development as noted by Carley (2012); Green and Yatchew (2012); Marques and Fuinhas (2012); Menz and Vachon (2006).

Furthermore, the results in this paper support Burke (2010) and Tahvonen and Salo (2001), who illustrate that as an economy develops, energy demands increase with income, creating an electricity ladder where states transition between renewable and non-renewable sources. The findings suggest that fundamental economic trends have increased renewable energy development.

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