DISSERTATION

THREE ESSAYS ON ENERGY AND ECONOMIC GROWTH

Submitted by

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ABSTRACT

THREE ESSAYS ON ENERGY AND ECONOMIC GROWTH

This dissertation explores the relationship between energy and economic growth. Chapter Two, Three, and Four examine the interaction of energy-related measures and economic outcomes by applying different methodologies across various spatial dimensions. Chapter Two shows that increases in energy consumption are necessary for increases in state level economic growth to occur. Chapter Three estimates a simultaneous supply and demand energy market at the state level. This system allows for estimates of structural elasticities to be obtained. Findings indicate that energy supply is considerably more elastic than energy demand. Energy demand is found to be determined by responses to short run shocks rather than long run processes. Chapter Four estimates the impact of changes in various elements of governance and institutional quality impact genuine investment within an economy. Increases in democracy are predicted to decrease genuine investment in energy-rich nations. The dissertation concludes with Chapter Five.

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TABLE OF CONTENTS

CHAPTER ONE

INTRODUCTION

This dissertation explores the relationship between energy and economic growth. Three essays consider the interaction of these variables both across a variety of spatial dimensions and over time. Energy is fundamental for economic processes. Despite the profound importance of energy in economies there is still much that is not understood about the energy-economy relationship.

Are increases in energy consumption a *necessary condition* for economic growth? Or have the observed efficiency gains in service based economies managed to decouple energy consumption from economic growth? Is increased energy consumption a byproduct of growth rather than a requirement for it to occur? The literature devoted to these questions does not provide conclusive answers. These questions motivate the studies presented in Chapters Two and Three.

Chapter Four investigates the energy-economy relationship by applying a test of sustainability. The depletion of non-renewable resources (energy resource being a subset) involves the drawing down of an economy's natural endowment. Investment is the mechanism by which depletion of non-renewable resources can be offset by increasing other forms of capital. The net change in a nation's productive base has important long run growth implications.

The scope of analysis within the dissertation includes economies at the state and macroeconomic level. The motivation for addressing a spectrum of geographic scales extends from policy activity addressing energy related issues. Energy related concerns are addressed at every level of governance. States and regions specifically have been proactive in formulating energy policies. Renewable portfolio standards, tax initiatives to attract energy companies, and a regional cap and trade program are but a few examples of sub-national policies. State and region-specific analysis facilitates a more accurate understanding of how energy concerns are predicted to impact economic growth at the sub-national level.

Economic growth is at the core of many policy decisions. Many view economic growth as a necessary condition for increased well-being. Often the terms "economic growth" and "economic development" are used interchangeably. While distinctions between the two terms are not addressed in this dissertation an appreciation of the impact of economic growth on well-being in both the short and long term is central to the work.

Chapter Two "Energy Consumption & Economic Growth: A State-Level Analysis" explores the relationship between energy consumption and economic growth for specific states in the Western United States. States studied are Arizona, California, and Wyoming. The existing literature is extended by applying a supply and demand theoretical foundation to the estimated relationships. The theoretical foundation yields a more detailed portrayal of the causality channels by which energy consumption impacts economic growth. The results from the partial equilibrium analysis are believed to be superior to those from a demand side only specification. Results indicate that while energy consumption is an important determinant of economic growth both demand and supply side influences are important. The causality channels are found to be unique across states within the sample.

The second extension to the literature made by Chapter Two is in regards to the scope of the analysis. The interaction of energy consumption and economic growth has been analyzed extensively at the macroeconomic level. The author is aware of only one state specific study which applies a similar methodology. Macroeconomic studies are not capable of capturing these unique attributes of states' economies.

Chapter Three "Elasticities of Energy Supply and Demand in the Western United States" estimates numerous elasticities of energy consumption. States within the Census' Western region of the United States are the focus of the analysis. The study makes two important contributions to the existing literature. First, an aggregate measure of energy consumption is used rather than market-specific consumption. Because energy demand is a derived demand aggregate measures yield insight into aggregate changes rather than market-specific outcomes. Second, a simultaneous supply and demand system is estimated. This system is capable of taking into account the endogenous nature of price and quantity in energy markets. The dominant approach within the literature is to consider only the demand side of energy markets.

Findings from the simultaneous system indicate that supply is much more elastic than demand. This indicates that when taxes are imposed on energy markets that a larger share of the burden is borne by consumers (not accounting for externalities). Estimated parameters also indicate that long run energy demand estimates from other studies may be misleading; structural parameters of the system are closer to short run elasticities found in the literature.

Chapter Four “What is the Impact of Governance on Genuine Investment in Energy-Rich Nations?” explores the role of governance in sustainable growth measures. Numerous studies have estimated genuine savings rates. Genuine investment levels represent a holistic interpretation of changes in a nations’ capital stock. They include changes in traditional measures of capital as well as resource capital (including energy sources). When genuine savings is non-negative, the nation’s capital stock is not declining over time indicating it is on a sustainable growth path.

The Hartwick rule is applied to determine if energy-rich economies are reinvesting a sufficient portion of the rents from the depletion of resource capital to meet the weak sustainability criterion. The study extends previous studies by explicitly accounting for the role of governance in reinvestment. Findings indicate increases in the level of democracy lead to declines in genuine investment.

Each chapter within the dissertation constitutes a self-contained study. Each study has a separate introduction, literature review, and so on. Relevant references and appendices can be found at the conclusion of each chapter. Chapter Five “Conclusion” will summarize the work. Chapter Five will also briefly highlight the author’s intended future research agenda including specific extensions and elaborations to be undertaken in the near future.

CHAPTER TWO

ENERGY CONSUMPTION AND ECONOMIC GROWTH: A STATE-LEVEL ANALYSIS

Section 1 Introduction

The study explores the link between energy consumption and economic activity at the state level. The motivating question being: Does economic growth require increased energy consumption? If so, energy conservation measures can be expected to have adverse impacts on economic growth. If not, reductions in aggregate energy consumption could be used to address a variety of energy related issues while being growth neutral. Without an expected decline in growth, policies aimed at addressing various energy related issues such as climate change, energy security, and so on would be more readily adopted.

Payne (2009) outlines several hypotheses which have emerged within the literature testing the relationship between energy consumption and economic growth. These are the ‘growth hypothesis’, the ‘conservation hypothesis’, the ‘feedback hypothesis,’ and the ‘neutrality hypothesis.’ The growth hypothesis asserts that energy consumption leads economic growth. Increases in energy consumption result in increased economic growth. In an economy categorized by this hypothesis energy conservation measures would be expected to hinder growth. In contrast, the conservation hypothesis is found when economic growth leads energy consumption. This scenario occurs when increases in economic growth are predicted to lead to increases in energy consumption.

Because causality does not run from energy to growth conservation efforts are not expected to adversely impact economic growth.

The feedback and neutrality hypotheses are extensions of the growth and conservation hypotheses. A feedback relationship is found when bi-directional Granger causality exists between energy consumption and growth. The policy implications of the feedback hypothesis are the same as the growth hypothesis. In both scenarios energy consumption leads output indicating that energy conservation is expected to decrease economic growth. In contrast, when the neutrality hypothesis holds no Granger causality is found. The policy implications for the conservation and neutrality hypotheses are the same. Whether no causality is found, or causality runs from output to energy consumption conservation will not hinder economic growth.

The study categorizes states' economies according to which of the preceding hypotheses are predicted to hold. The expected growth consequences of energy policies can be determined by this categorization. A better understanding of the growth consequences of energy conservation will aid stakeholders in the decision process. In instances where energy conservation is expected to be growth neutral policies aimed at reducing energy consumption are more likely to be adopted.

Within the literature Granger causality tests are used to determine the direction of causality between energy consumption and economic growth. These tests are based on Granger (1969). Much of the existing literature use bi or trivariate analysis to categorize economies according to the energy output hypotheses. The study extends the existing literature by applying a state-specific partial equilibrium model of the market for energy as the theoretical foundation. A partial equilibrium approach allows for important transmission channels to be accounted for. Supply and demand side factors are isolated to capture their influence on how energy consumption impacts states' economic growth.

The second extension is in regards to the level of analysis. Macroeconomic studies may overlook important sub-national differences. This is one plausible explanation for the lack of consensus within the literature regarding directions of causality. States are unique in their natural endowment of energy sources, the relative contribution of specific industries to gross state product (GSP), and their energy related policies and institutions. Metcalf (2008) finds that across states energy intensity is declining but the variation of intensity is increasing. Differences in intensity at the state level are becoming more pronounced. Different intensities imply that it is likely that energy consumption will impact states' growth differently.

A sample of states in the Western United States is the focus of the study. Arizona was chosen because of its low per capita energy consumption. The state has also experienced tremendous economic growth over the data set, 1970 to 2007. Real output has roughly quadrupled during this time period. Its energy intensity ranking across all states in 2007 was 12th (Energy Information Agency [EIA], 2010). Energy intensity is calculated as total energy consumption divided by real gross state product (GSP). California's economy has approximately doubled in real terms from 1970 to 2007. California is the largest state economy and ranked 5th in terms of energy intensity in 2007 (EIA). At the same time energy intensive sectors such as chemical, forest products, and petroleum refining industries are important to the state (EIA). California is also aggressive in its use of policy to manage its energy. Wyoming is chosen due to its prominent role in energy markets. Forty percent of all coal mined in the United States comes from the Powder River Basin in Wyoming (EIA). The state is an important exporter of natural gas as well. In 2007 Wyoming was ranked 48th in energy intensity making it one of the least efficient states (EIA). The contribution of energy intensive industries such as fossil fuel extraction and processing are likely determining this ranking.

The states presented in this study were chosen primarily for the aforementioned reasons. The study was not extended to other states due to two factors. Preliminary research did not result in theoretically consistent supply and demand curves for some states in the Western Region. For example, Colorado was found to have a positively sloped demand curve. It is not uncommon for energy related state-specific estimations to suffer from this problem (Maddala, Trost, Li, and Joutz, 1997). Even when theoretically sound curves were estimated the magnitude of extending the methodology to more and more states within a single study would have caused the study to become more expansive than the author originally intended. Rather than consider multiple states the author focused on a cross-section of unique states.

Section 2 Literature & Background

At the macroeconomic level numerous studies can be found supporting each of the aforementioned hypotheses. Kraft and Kraft's (1978) study of the United State began the literature. Their study explores the link between energy consumption and GNP. By applying Sims' (1972) causality test they find unidirectional causality from income to energy consumption but not vice versa. The authors assert "energy conservation programs are a feasible policy tool without impairing economic activity" (p. 403). As econometric methods evolved to address issues regarding the nonstationary properties of data subsequent studies have both supported and refuted their findings.

Yu and Jin (1992) is the first study to apply cointegration analysis to the United States. No evidence is found for a cointegrating relationship within the data supporting the conclusion of Kraft & Kraft (1978). Cointegration analysis has become the dominant methodology to test for the presence of the energy output hypotheses. Soytas and Sari (2003) examine the G-7 and selected emerging economies. They confirm the finding of no causality from energy consumption to income in the United States.

Lee (2006) using per capita GSP and aggregate energy consumption find bidirectional causality in the United States. Lee (2005) and Keppler (2007) are excellent summaries of other economies. This small sample of the literature suggests a consensus has not emerged from the empirical tests of this issue.

These studies and many others within the literature rely on bi and trivariate estimations to test for Granger causality. Trivariate studies are often used in the context of estimating the demand side of a market. In many cases data availability dictates the choice of estimating only a demand curve rather than a supply and demand system. When only the demand side of a market is estimated there is potential that the model is misspecified. Specifically, changes in quantity and price which occur due to supply side shocks may be incorrectly attributed to shifts in the demand curve. In a fully specified supply and demand system shifts in the respective curves are controlled for.

There are a few circumstances when estimation of both curves may be unnecessary. In the cases of a perfectly elastic supply curve any short run changes within the market would be due to demand shocks. Second, if the estimated demand curve accounts for the most important demand determinants and the curve is fully specified, then results from the estimation will not suffer from omitted variable bias. A fully specified curve will appropriately attribute market changes to the correct demand factors. Whether the estimated demand curve is fully specified will likely be determined by such factors such as the geographic scope of analysis, time frame considered within the data, and energy sources represented by the data.

Stern (2000) and Zachariadis (2007) assert that important transmission mechanisms are not accounted for in these types of specifications. Zachariadis advocates for the use of partial equilibrium, general equilibrium, or production function based approaches to address this shortcoming. Stern and others have estimated production function for various economies. Stern's estimation is for the United States and finds evidence for the growth hypothesis. Estimating a production function does not guarantee finding the growth hypothesis. Bartlett and Gounder (2010) is an example study which applies a production function methodology and supports the conservation hypothesis. It is interesting to note that their demand only specification confirms this result. Few studies in the literature have pursued this type of analysis simultaneously. Whether the added complexity of a production function approach is superior or not remains an open question.

Payne (2009) is the only study the author is aware of that has analyzed a specific state economy. Payne tests for the direction of causality in Illinois by using employment and energy consumption data finding evidence of the growth hypothesis. Aggregate United States employment is also included as a control variable. In preliminary work the author confirmed Payne's findings.

Section 3 Data

Energy consumption (E_Con), price of energy (E_Price), gross state product (GSP), and manufacturing employment (Mfg) are used in each state. A price index of primary energies will be used as well. The price of primary energy (Prim) is used for California and Wyoming and the price of coal (Coal) for Arizona. Data are from 1970 to 2007. Data are reported in natural logs though the notation is suppressed. Nominal values (GSP and prices) have been converted to 2000 dollars via a CPI calculated from the Bureau of Labor Statistics (BLS).

GSP and Mfg are collected from the Bureau of Economic Analysis (BEA). GSP is the state-level equivalent of GDP and expressed in million 2000 dollars. The conversion from the SIC to the NAICS industry classification system impacts the time series. Due to the reclassification a seamless time series is not created. NAICS measures of both GSP and Mfg are applied from 1997 onwards. Due to confidentiality reasons no observation of manufacturing employment in Wyoming is available for 2002. Manufacturing is a relatively small sector in Wyoming. Based on the author's calculations, real manufacturing output divided by real GSP, manufacturing output compromised an average of 5% of real GSP from 1997 to 2007. An average of 2001 and 2003 employment in the sector is used as a proxy for the missing observation.

Energy related data are from the Energy Information Agency (EIA). Energy consumption is reported in billion BTU and is calculated as the consumption of primary energy within a state for a given year. The EIA defines primary energy consumption as consumption of energy directly from the source. Examples include a utility's consumption of coal to generate electricity or a household using natural gas for heating.

Consumption of electricity would not be considered primary consumption because the electricity was generated from another source of energy. This is done to avoid double counting. Consumption measures are estimated via data regarding sales and distribution for each state. Net imports of electricity are also included in consumption data. For renewable sources such as hydro or solar consumption is assumed to be equal to net production. Consumption of renewable sources is then the gross amount of electricity generated minus any electricity used in its production.

Price of energy is measured as the average price of total energy. The study converts nominal measures into 2000 dollars per billion BTU. The price includes taxes whenever possible. In general, excise and per-gallon taxes are included but local sales taxes are not. Input prices used are proxies for input costs in energy production. Prim is a price of index of primary energies such as coal, natural gas, and so on. A coal price index is used in the case of Arizona. Coal data produces a theoretically consistent model. This may be due to its importance in the electricity sector, 40% of electricity consumed in the state was generated from coal in 2008. Prices are state-level so they do not capture in-state differences but aggregate trends over time.

The differences between E_Price and Prim will be influenced by the types and amounts of energies consumed within the state. The price paid for motor gasoline within the state will be a key difference between the price variables. Motor gasoline consumption represents a key element of aggregate energy consumption. The price paid will deviate from the price of petroleum based due to taxes, cost of refining, and so on. The nature of how buildings are heated is a second difference between the variables. As more heating needs are met with electricity the difference between the absolute value of the variables will increase. The price variables would be closer to one another if heating needs are met with primary forms of energy.

Section 4 Model & Methodology

4.1 Model

The equilibrium price and quantity resulting from the interaction of supply and demand for energy can inform what is occurring in the output energy relationship. The market for energy can be considered a factor market just as capital or labor. First, consider the demand relationship in isolation. An increase in price results in a decrease in quantity demanded. Ceteris paribus, the expected result of this scenario is a decline in output.

The demand for energy within a state takes the following general form:

(4.1.1) $Q_D = \beta_0 + \beta_1 P_E + \beta' X$

where Q_D is the quantity of energy demanded, P_E is the price of energy, and X is a vector of demand-side variables. X includes factors such as income, climate, urbanization of the states' population, and states' industrial structure. Supply is a function of price and other variables:

(4.1.2) $Q_S = \alpha_0 + \alpha_1 P_E + \alpha' Y$

where Q_S is the quantity of energy supplied, P_E is the price of energy, and Y is a vector of other influences. Included in Y would be input costs, natural endowment, and technology. In equilibrium, equations (4.1.1) and (4.1.2) are equal.

Energy consumption and the real price of energy have both increased from 1970 to 2007. Demand or supply and demand shifts would cause this outcome. Simultaneously states' real output has increased. Are the increases in energy consumption necessary for economic growth to occur or rather are they a byproduct of growth? If a byproduct, can growth occur without increases in energy consumption?

A standard neoclassical production function portrays the theoretical relationship between energy and output. Consider the following:

(4.1.3) $Y = f(A, K, L, E)$

where A is technological progress, K capital, L labor, and E energy. Theory predicts that energy will have a diminishing marginal product; increases in consumption cause increases in output at a decreasing rate. Specifically:

(4.1.4) $\frac{dY}{dE} > 0 \text{ and } \frac{d^2Y}{dE^2} < 0$,

where Y is output and E is energy. The study seeks to determine whether the first derivative is positive in a statistically significant manner. This is done in an implicit rather than explicit manner. Traditionally, the derivatives represented in (4.1.4) are usually estimated from a production function. The study uses Granger causality tests in a comparable manner. If energy Granger causes output the first derivative would be positive. An instance of energy not Granger causing output would be comparable to the first derivative being equal to zero.

4.2 Methodology

The estimation of supply and demand curves motivates the use of cointegration techniques in the analysis. Cointegrated variables do not deviate from each other for extended periods of time indicating the presence of an equilibrating process between them. This process may arise from an atheoretic econometric relationship or one suggested by economic theory. For nonstationary variables evidence of cointegration indicates that data's stochastic trends are related. Enders (2004) states "Equilibrium theories involving nonstationary variables require the existence of a combination of the variables that is stationary" (p. 320). This property allows for the cointegrated variables to be estimated as if they are stationary.

Engle and Granger (1987) developed the preliminary cointegration test. Over time the Johansen technique based upon Johansen (1988) replaced Engle and Granger's. The Johansen technique has been applied across numerous literatures. Johansen's technique involves estimation of a vector autocorrection model (VECM) after performing preliminary tests of the data. A VECM is a vector autoregression model (VAR) which includes any cointegrating relationships (also referred to as cointegrating equations) in the data. The cointegrating equations represent the long run relationship between the variables considered.

Sims (1980) began the VAR literature. Sims' critique of macroeconomic models at the time was that the distinctions between exogenous and endogenous variables were arbitrary. His VAR technique allows all the variables within a system to be treated as endogenous. Kennedy (2003) discusses many of the issues associated with VAR's mixed acceptance. Critics of the technique, such as Cooley and LeRoy (1985), believe that VARs do have their place in analysis. Cooley and LeRoy believe hypothesis-testing is a relative strength of this modeling approach. Because the estimation of a VECM involves estimating a VAR VECMs can be an effective statistical tool for categorizing states according to the energy growth hypotheses.

Section 5 Estimation & Results

5.1 Estimation

The general VECM takes the following form:

(5.1.1) $\Delta y_t = \alpha_i + \delta_j CE_{j.t-1} + \sum_{l=1}^{p} \Gamma_l \, \Delta y_{t-l} + \varepsilon_{i,t}$

where Δ is the difference operator; y_t is a vector of the variables of interest; α_i a constant; δ_i is the speed of adjustment parameter; CE_i is the cointegrating equation, j will equal 1 or 2; $\Gamma_l \Delta y_{t-l}$ represents stationary variation in the variables; and $\varepsilon_{i,t}$ is a vector of the independent disturbances. The speed of adjustment parameters represent how the dependent variable responds to disequilibrium in the cointegrating equation. Two versions of the VECM are estimated. The first version has one cointegrating equation, j=1. This representation corresponds to the demand only specification. Results from this estimation are compared to the full supply and demand estimation. Under the supply and demand specification there are two cointegrating equations, j = 2. The demand curve is estimated using E_Con, GSP, and Mfg. The supply curve estimated with E_Con, the price of an energy input, and Mfg. In the case of California and Wyoming, Prim (price of primary energy) is used. The price of Coal is applied in Arizona. During preliminary work Coal was found to provide a theoretically consistent system for all three states. Prim did not provide a robust system for Arizona motivating the use of Coal.

Theory predicts Mfg will act as a positive shifter in the demand curve. Mfg is not typically included as a supply side variable; its inclusion in the supply curve is to enable the system of equations to be solved. There are reasons that Mfg may act as a positive or negative shifter of the supply curve in this market. An increase in Mfg corresponds to increased employment in this sector. Such an increase may result in a reduction of the supply of energy if the increases in employment in this sector come at the expense of energy related industries. An increase in Mfg could increase the supply of energy if this increase corresponds to energy related industries becoming more productive. The third possibility is that Mfg does not impact the supply curve in a significant manner.

Applying the general notation of equation (4.1.1) the demand curve in the demand only specification:

(5.1.2) $E\_Con = \beta_0 - \beta_1 * E\_Price + \beta_2 * GSP$.

When estimated the cointegrated equation 5.1.2 becomes:

(5.1.3) CE: $GSP_{t-1} - b_1 * E\_Con_{t-1} - b_2 * E\_Price_{t-1} + c = v_{t-1}$

where c is an intercept term and v is an independent disturbance. The cointegrating vector is normalized on GSP. The same process is used in the supply and demand framework. Via equations (4.1.1) and (4.1.2) the demand and supply curves are:

(5.1.4) $E\_Con = \beta_0 - \beta_1 * E\_Price + \beta_2 * GSP + \beta_3 * Mfg$

(5.1.5) $E\_Con = \alpha_0 + \alpha_1 * E\_Price - \alpha_2 * IC + \alpha_3 * Mfg$.

Because quantity demanded, supplied, and curve specific prices are not observed E_Con and E_Price serve as proxies for equilibrium quantity and price. Estimated within the VECM equations (5.1.4) and (5.1.5) become:

(5.1.6) $CE_1 : GSP_{t-1} - \beta_1 * E\_Price_{t-1} - \beta_2 * E\_Con_{t-1} - \beta_3 * Mfg_{t-1} + d = u_{t-1}$

(5.1.7) $CE_2 : IC_{t-1} - \beta_4 * E\_Price_{t-1} - \beta_5 * E\_Con_{t-1} - \beta_6 * Mfg_{t-1} + h = v_{t-1}$,

where d and h are intercept terms and u and v are independent disturbances. The beta coefficients are referred to as the cointegrating vector. They do not represent the beta from previous equations. IC refers to energy input costs. Cointegrating equations 1 and 2 represents the demand and supply curves respectively. In the estimation the equations are normalized on GSP and IC. Prim will be used for California and Wyoming and Coal in the case of Arizona.

The supply and demand system accounts for many ways in which energy consumption impacts growth. The energy output combinations reported by the time series capture past efficiency gains. In this way the time series embodies efficiency gains in capital. Due to this the conservation hypothesis becomes a relatively stronger classification of an economy than the growth hypothesis. The conservation hypothesis will continue to hold for an economy unless capital becomes less efficient or technological regress occurs in the future.

The time series also captures the combinations of capital, labor, and energy used to produce states' output. Manufacturing employment data embodies the impact this sector has on the supply and demand of energy in the state. It also embodies long run employment trends in the sector. As such the relative composition of manufacturing to output is accounted for. Ceteris paribus, a manufacturing based economy is expected to use more energy to produce $1 of output than a service based on. Granger causality tests establish directions of intertemporal causality. Often they are used in forecasting applications. As a forecasting tool the tests account for past relationships to inform expected future outcomes.

The methodology applied explicitly constructs a state-level energy market. This theoretical construction is appropriate for capturing state-level changes but is limited by the geographical market it represents. Energy markets exist along a spectrum of geographical scale from the local to global. For instance, the price of electricity is largely determined at the state (or sub-state) level, while the price of petroleum in international markets. The geographic market the theoretical model represents lies between the extremes of local and global markets. As such the model is unable to explicitly account for sub-state or global market changes. This does not mean that these changes are completely ignored but rather they impact the data in an implicit manner.

The primary way in which changes in global energy markets impact the model is via the price variables used. Changes in global demand for energy which result in changes in the final price of energy are captured in E_Price observations. E_Price serves as a proxy for the market equilibrium price. The input price proxy (IC) captures changes in the price of primary fuels such as coal, natural gas, and petroleum. Increases in petroleum prices (or another primary energy) would result in state supply curves shifting leftwards. For example, as China's demand for petroleum increases, ceteris paribus, the resulting increase in the price of petroleum would result in a decrease in the supply of energy at the state level. Conversely, decreasing natural gas prices due to increased extraction rates in the United States would result in an increase in the supply of energy.

5.2 Results

Prior to estimation the order of integration in the data must be determined. To do so the augmented Dickey-Fuller (ADF) test is applied. The ADF takes the form:

(5.2.1) $$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \alpha_i \sum_{i=2}^{m} \Delta Y_{t-i+1} + \varepsilon_t,$$

where: Δ indicates a lagged variable, t is a deterministic time trend, δ is the coefficient on the lagged dependent variable, α_i is the coefficient on the lagged differenced dependant variable, and ε_t is the random error term. The null hypothesis of the test is that the series is nonstationary. The author is not aware of a study where the economic and energy variables are not $I(1)$. State-level data should not be any different.

For GSP and energy consumption the ADF was estimated with a drift and drift with a time trend. Price variables were estimated with a drift and as a random walk. In general, the series are found to be $I(1)$ at the 5% level with both specifications confirming one another. Table 2.1 presents the results. Table 2.1 can be found in the Appendix. GSP is $I(1)$ in Arizona and Wyoming with drift but under drift and trend the results are inconclusive. The price variables are found to be $I(1)$ under both specifications.

The Schwarz and Akaike information criteria (SC and AIC respectively) are applied to determine the optimal lag length for the system of equations. Both measure the overall fit of a regression while controlling for the number of observations. The SC and AIC indicate one or two lags for each state. Two lags are used in order to insure sufficient interaction between the variables.

Once the data is determined to be $I(1)$ and the number of lags for the system determined the next step is to perform the Johansen tests. These tests are more conclusive in the supply and demand framework versus the demand only. In demand only there is evidence of one cointegrating equation at the 5% level for Arizona, one at the 10% from the trace test for California, and no evidence from either test for Wyoming. See Table 2.2 in the Appendix. In the supply and demand framework for Arizona the trace and max tests indicate four cointegrating equations. Both tests indicate three equations for California and two for Wyoming. Because a supply and demand framework is being estimated two cointegrating equations will be estimated for each state.

Table 2.3 lists the estimated cointegrating vector (estimated coefficients within the cointegrating equation) for the GSP equation. Only results from the supply and demand framework are presented. The cointegrating vectors represent theoretically consistent supply and demand curves. Within the cointegrating equations a few parameters are not significant. These are Mfg in California's supply equation and Wyoming's demand equation. Increases in Mfg act as a positive demand shifter in California and positive supply shifter in Wyoming. In the case of Arizona, Mfg is a negative shifter of demand and positive shifter of the supply curve. This could be due to efficiency improvements in the manufacturing sector.

Table 2.3 Estimated Cointegrating Vectors

	GSP(-1)	IC(-1)	E_PRICE(-1)		E_CON(-1)		MFG(-1)	
AZ	1	0	-0.196	***	-1.384	***	-0.151	*
			[-3.581]		[-21.462]		[-1.959]	
	0	1	-0.702	***	2.543	***	-3.152	***
			[-2.413]		[7.441]		[-7.697]	
CA	1	0	-0.296	***	-1.799	***	0.531	***
			[-4.156]		[-13.702]		[3.719]	
	0	1	-1.338	***	0.582	***	0.078	
			[-34.861]		[8.238]		[1.012]	
WY	1	0	-0.441	***	-1.920	***	0.133	
			[-5.022]		[-8.329]		[0.477]	
	0	1	-1.434	***	2.639	***	-1.621	***
			[-12.773]		[8.950]		[-4.552]	

Note: Tables presents the estimated cointegrating vectors. IC refers to input costs and C a constant term. IC is the price of primary energy in California and Wyoming and coal in the case of Arizona. CE^D refers to the demand curve and CE^S the supply curve. T-statistics are in brackets. The levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively.

The cointegrating vector can solved to represent (4.1.1) and (4.1.2). These representations are in Table 2.4. Data are in natural logs which mean coefficients represent elasticities. For example, the price elasticities of demand are -0.14, -0.16, and -0.23 for Arizona, California, and Wyoming respectively. All are inelastic. The price elasticity of supply vary widely across the states 0.28, 2.3, and 0.54 (same order). California's supply curve is the most elastic. Additional tests need to be conducted to ensure the accuracy of the estimates. Chapter Two applies a panel data based-approach to calculate demand side elasticities.

Table 2.4

Estimated Supply & Demand Curves

AZ	Q^D : E_Con = -0.142*E_Price + 0.723*GSP - 0.109*Mfg
	Q^S : E_Con = 0.276*E_Price – 0.393*IC + 1.24*Mfg
CA	Q^D : E_Con = -0.165*E_Price + 0.556*GSP + 0.295*Mfg
	Q^S : E_Con = 2.299*E_Price – 1.718*IC
WY	Q^D : E_Con = -0.23*E_Price + 0.521*GSP
	Q^S : E_Con = 0.543*E_Price – 0.379*IC + 0.614*Mfg

Note: Curves are based upon the general form represented in equations 4.1.1 and 4.1.2. All data are in natural logs so coefficients are interpreted as elasticities. Variables are excluded when not significant.

Speed of adjustment parameters represent how strongly the left hand side variable responds to disequilibrium within the cointegrating equation. Results are presented in Tables 2.5 and 2.6. Estimated coefficients capture whether disequilibrium within the cointegrating equation impacts GSP in a statistically significant manner. The signs indicate whether the change in GSP increases or decreases in response to positive disequilibrium in the cointegrating equation.

To illustrate the process behind disequilibrium occurring in the cointegrating equation consider positive disequilibrium in the demand curve. Two scenarios could cause positive disequilibrium: GSP and/or Mfg being too large relative to E_Price and

E_con or E_Price and/or E_Con too small relative to GSP and/or Mfg. Too large or too small refer to the values which create the stationary long run series. In supply and demand specification for Wyoming the result of positive disequilibrium in the demand curve is that GSP accelerates. In Arizona and California the preceding scenario would result in GSP decelerating. In the case of negative disequilibrium GSP responds opposite. Wyoming’s GSP also accelerates in response to positive disequilibrium in the supply curve relationship.

Table 2.5 Granger Causality Tests, Demand Side Only

	Wald F-Tests & CE T-test				
	d(E_Con)	d(E_Price)	CE	CE & d(E_Con)	CE & d(E_Price)
AZ					
GSP	1.505	1.236	-0.134	1.852	1.247
			[-0.761]		
CA					
GSP	1.141	0.026	0.173*	4.542	5.602
			[1.992]		
WY					
GSP	1.227	2.358	-0.245**	9.19**	8.187**
			[-2.651]		

Note: Table represent Granger causality to GSP. T-tests are performed on the speed of adjustment parameter. The levels of significance are 1, 5, and 10% denoted ***, **, and * respectively.

Table 2.6 Granger Causality Tests Supply and Demand Specification

State	d(IC)	d(E_Price)	d(E_Con)	d(Mfg)	CE^D	CE^S
	Wald *F*-Tests & CE *T*-test					
AZ						
GSP	2.472	0.655	0.797	6.797**	-0.432*	-0.024
					[-2.015]	[-0.612]
CA						
GSP	3.974	6.924**	1.069	6.028**	-0.189***	-0.007
					[-2.927]	[-0.047]
WY						
GSP	1.507	0.717	1.495	0.237	0.291**	0.278**
					[2.402]	[2.189]

Note: Tables represent Granger causality to GSP. IC refers to input costs. It is the price of primary energy in California and Wyoming and coal in the case of Arizona. In the supply and demand specification CE^D is the demand curve which is CE1 in the estimation. CE^S is the supply curve and is CE2. T-tests are performed on the speed of adjustment parameters. The levels of significance are 1, 5, and 10% denoted ***, **, and * respectively.

Tables 2.5, 2. 6, and 2.7 present the focus of the study, Granger causality tests. Table 2.5 lists the full results from the demand only specification, Table 2.6 short run Granger causality tests and *t*-tests of the speed of adjustment parameters, and Table 2.7 the interacted terms from the supply and demand framework. The differenced terms represent short run causality while the cointegrating equations long run. Tests on the interacted terms have been referred to as ‘strong Granger causality’ by Oh and Lee (2004 a and b) because they capture both the short and long run impacts of a variable on the left hand side variable. Asafu-Adjaye (2000) applies the strong Granger causality test in his study of developing economies in Asia.

Table 2.7 Granger Causality Tests, Supply and Demand Interaction Terms

Wald *F*-Tests

	CE^D & d(E_Price)	CE^D & d(E_Con)	CE^D & d(Mfg)	CE^S & d(IC)	CE^S & d(E_Price)	CE^S & d(E_Con)
AZ						
GSP	4.272	5.632	6.949*	2.763	1.161	2.080
CA						
GSP	9.364**	9.173**	9.505**	4.641	6.959*	1.324
WY						
GSP	6.122	7.159*	5.967	8.178**	7.071*	8.579**

Note: Tables represent Granger causality to GSP. IC refers to input costs. It is the price of primary energy in California and Wyoming and coal in the case of Arizona. In the supply and demand specification CE^D is the demand curve which is CE1 in the estimation. CE^S is the supply curve and is CE2. *T*-tests are performed on the speed of adjustment parameters. The levels of significance are 1, 5, and 10% denoted ***, **, and * respectively.

The classification of economies by the Granger causes of GSP is the focus of the analysis. In the demand only specification Arizona is classified by the neutral hypothesis. There is no evidence of Granger causality from E_Con or E_Price to GSP from the various tests. California and Wyoming are found to be classified by the growth hypothesis. In both states the cointegrating equation is significant. The Granger tests of E_Price and E_Con interacted with the cointegrating equation confirms this for Wyoming.

In the supply and demand framework tests are performed on the various determinants of supply and demand. This allows for the impacts of the individual curves as well as the components of supply and demand to be captured. In contrast to the demand only specification Arizona is no longer neutral. Granger causality is not found from any of the variables to GSP but is found when Mfg is interacted with the demand curve. This suggests that it is manufacturing's consumption of energy which is leading growth. In terms of the supply curve there is no evidence of Granger or strong Granger causality from any of its components to growth.

California is found to be classified by the growth hypothesis but it is primarily through the demand relationship that this occurs. On the demand side we see that E_Price, E_Con, and Mfg all interact with the demand curve to lead GSP. Each of the individual components of the demand curve Granger causes GSP. Manufacturing leads GSP in the short run and interacts with the demand curve to lead growth in the long run. Manufacturing's consumption of energy has played a role in California's growth. Decreases in E_Price and increase in E_Con will also lead economic growth in the state.

The speed of adjustment coefficient on the supply curve for California is not significant within the GSP equation. The supply curve interacted with price does Granger causes GSP. Additionally, the short run Granger tests indicate E_Price leads GSP. Thus it is not the individual components of the supply curve leading growth in California but rather their collective impact on E_Price. The demand curve findings reinforce this conclusion. Supply shocks which increase E_Price will lead to decreases in GSP via the demand relationship. On the other hand increases in supply which decrease price will contribute to economic growth for the state. Given the importance of energy intensive sectors and the amount of energy consumed by the transportation sector this makes sense.

For Wyoming both the supply and demand curve are significant in the GSP equation. In the short run, none of the variables lead growth. On the demand side we see that the level of consumption is more important than price in leading growth. When price is interacted with the demand curve it does not Granger cause growth while consumption interacted with demand does. The EIA classifies Wyoming's economy as being very energy intensive. Consumption of energy is more important than energy's price in leading growth. Manufacturing does not play the role in energy demand that it does in Arizona and California. Given the importance of natural resources in Wyoming's economy and the small contribution of manufacturing this is not surprising. From 1997 to 2007 mining's share of GSP averaged 20% and manufacturing's share 5%.

The supply side variables of input costs, E_Price, and E_Con all interact with supply to lead growth in Wyoming. The supply side relationship captures important leaders of growth that are omitted from the demand only specification. Wyoming is categorized by the growth hypothesis. In terms of policy implication increasing the supply of energy will lead to increases in growth for the state. One scenario in which this would occur would be a decrease in the price of energy inputs and the resulting supply shift.

Table 2.8 compiles diagnostic tests for the GSP equations from the two specifications. In all the states the null hypothesis of the *F*-test, that all the estimated coefficients are simultaneously equal to zero, is rejected. In addition to the R^2, adjusted R^2, and *F*-tests two other diagnostic tests are applied. Normality of residuals is tested via the Jarque-Bera test. Normality of residuals is necessary to ensure that statistical tests are accurate. Because a system of equations has been estimated the multivariate version of this test rather than the individual equation test will be presented and discussed. The null hypothesis of this test is that the errors are normally distributed. A high *p*-value implies that we cannot reject the null hypothesis and the errors are normally distributed. The multivariate statistic is reported in Table 2.8. In calculating these statistics EViews (the program used in the analysis) corrects for small samples based on Doornik and Hansen (1994). For all states the test indicates failure to reject the null hypothesis.

Table 2.8 Diagnostic Tests of GSP Equation

GSP – LHS

Demand Only

State	R^2	adj. R^2	F-Stat.	
AZ	0.385477	0.226156	2.419501	**
CA	0.476552	0.340844	3.511584	***
WY	0.506383	0.378408	3.956899	***

Supply & Demand

State	R^2	adj. R^2	F-Stat.	
AZ	0.566217	0.329608	2.393048	**
CA	0.590545	0.367206	2.644162	**
WY	0.560545	0.320842	2.338499	**

Note: The levels of significance are 1, 5, and 10% are denoted ***, **, and * respectively. All tests presented are for the GSP equation.

The final diagnostic test applied is the autoregressive heteroscedasticity (ARCH(1)) test. The null hypothesis of the ARCH(1) test is that there is no autoregressive heteroscedasticity. Large *p*-values indicate that the null cannot be rejected. Just as with the Jarque – Bera multivariate statistics are reported in Table 2.9 below.

Table 2.9 Jarque-Bera and ARCH Tests

Demand Only

State	Jarque-Bera Stat.	Jarque-Bera *P*-Value	ARCH(1) Stat.	ARCH(1) *P*-Value
AZ	2.4119	0.8782	3.3546	0.9486
CA	2.7702	0.8371	6.5172	0.6872
WY	6.3579	0.3843	9.6695	0.3779

Supply & Demand

State	Jarque-Bera Stat.	Jarque-Bera *P*-Value	ARCH(1) Stat.	ARCH(1) *P*-Value
AZ	5.2239	0.8757	22.4672	0.6086
CA	5.9819	0.8168	22.6560	0.5976
WY	13.0925	0.2185	31.3211	0.1786

Note: The table reports the multivariate Jarque-Bera test which is $\chi^2(6)$ for the demand only specification and $\chi^2(10)$ in the supply and demand. ARCH(1) which is $\chi^2(9)$ in the demand specification and $\chi^2(25)$ for supply and demand. Statistic reported is for the third lag. See the appendix for a comprehensive list of all estimated statistics.

Section 5.3 Potential Limitations of Results

One caveat regarding the results from the estimations should be noted. For California, the pair-wise correlation between the market equilibrium and input price proxies are quite high, 0.94. Table 2.10 lists the price pair-wise correlations for each state. The correlation between price variables is not very high for Arizona and Wyoming.

Table 2.10 Pair-Wise Correlation between Price Variables

AZ

	NATGAS	PRIM	COAL	E_PRICE
NATGAS	1	0.5057	0.6592	0.8714
PRIM	0.5057	1	0.0623	0.7309
COAL	0.6592	0.0623	1	0.5931
E_PRICE	0.8714	0.7309	0.5931	1

CA

	NATGAS	PRIM	COAL	E_PRICE
NATGAS	1	0.8118	0.1004	0.9147
PRIM	0.8118	1	0.3960	0.9437
COAL	0.1004	0.3960	1	0.2755
E_PRICE	0.9147	0.9437	0.2755	1

WY

	NATGAS	PRIM	COAL	E_PRICE
NATGAS	1	0.0910	-0.0116	0.7690
PRIM	0.0910	1	0.6679	0.6611
COAL	-0.0116	0.6679	1	0.4025
E_PRICE	0.7690	0.6611	0.4025	1

The presence of high correlation between right hand side variables in the estimations poses the possibility that estimations may suffer from multicollinearity. High pair-wise correlation between regressors does not guarantee the presence of multicollinearity. Gujarati (2003) notes “pair-wise correlations may be a sufficient but not necessary condition for the existence of multicollinearity" (p. 372). Gujarati (2003) outlines many of the potential consequences which may arise in the presence of multicollinearity. Particularly relevant to this study is the impact on estimated coefficients. Variances and covariances tend to be larger causing *t* ratios to be statistically insignificant. This outcome is often coupled with very high R^2. A second potential consequence is that estimated coefficients from OLS can be sensitive to subtle data changes (Gujarati, 2003, p. 350).

In order to see if California's results were robust to the use of other input price proxies, the coal series was applied. It is worth noting that a small percentage of California's electricity comes from coal. In 2008 coal represented roughly 0.7% of the total energy consumed in the state (author's calculation). For Arizona, it was approximately 30%. When coal is used as the input price proxy the speed of adjustment parameter for both supply and demand are insignificant in the GSP equation. See Table 2.11. Granger tests of short-run causality indicate that none of the changes in the energy variables Granger cause growth in the state, Table 2.11. In addition the adjusted R^2 and F-statistic are quite low, 0.2284 and 1.8387 respectively. See Table 2.12. The model is explaining very little of changes in economic growth for the state.

Table 2.11 Alternative Input Price Proxy for California

State	d(IC)	d(E_Price)	d(E_Con)	d(Mfg)	CE^D	CE^S
	Granger Causality Tests					
	Wald *F*-Tests & CE *T*-Test					
CA						
GSP	0.8357	2.2187	0.6233	0.1646	0.0084	-0.0077
					[0.0646]	[-0.7380]

Note: Coal is used as the input price proxy rather than the primary energy price index reported in Section s. Table represent Granger causality to GSP. T-tests are performed on the speed of adjustment parameter. The levels of significance are 1, 5, and 10% denoted ***, **, and * respectively.

Table 2.12 Diagnostic Tests of CA GSP Equation with Alternative Input Price Proxy

State	R^2	adj. R^2	*F*-Stat.
	GSP – LHS		
	Supply & Demand		
CA	0.5007	0.2284	1.8397

Note: The levels of significance are 1, 5, and 10% are denoted ***, **, and * respectively. All tests presented are for the GSP equation.

The author believes that Prim provides better interpretation of the relationship between energy consumption and economic growth in California. Despite the high positive correlation between Prim and E_Price the variables have the theoretically expected negative relationship in California's supply curve. The estimations for California with Prim do not exhibit high R^2 that is common in the presence of multicollinearity. When Coal is used no Granger causality is found in the short run. It seems unlikely that none of the variables in the model lead economic growth in the state in the short run. Even so the reader is advised caution in interpreting the results for California.

Section 6 Conclusion

The study has extended the existing literature in two important directions. First, by applying a supply and demand framework to test for a causal relationship between energy consumption and economic growth a more robust set of transmission channels are accounted for. The second extension is in regards to the scope of analysis. Important state-level differences have been found that would be overlooked from a macroeconomic or regional perspective.

The classification of economies according to the various energy growth hypotheses are not robust between the two specifications estimated. Specifically, the demand only specification classifies Arizona's economy according to the conservation hypothesis suggesting energy conservation will not impact economic growth. The demand only specification was used to allow results to be directly comparable to much of the existing literature. In the supply and demand framework Arizona is found to be classified by the growth hypothesis. This highlights the important of applying a more fully specified demand equation when researching the relationship between energy and growth. In Arizona is primarily manufacturing's consumption of energy that energy leads growth. This finding suggests that energy consumption in other areas of the economy such as transportation or household does not impact the state's growth. As a result policies which decrease energy consumption in these sectors are predicted to be growth neutral. The classification of Arizona's economy also suggests that the state's economy is not as responsive to energy shocks as California and Wyoming's. This relationship could be potentially exploited to meet various energy concerns for Arizona.

In both specifications California is classified by the growth hypothesis. Increases in energy consumption are predicted to lead economic growth primarily through demand side factors. In contrast to Arizona energy prices, aggregate energy consumption, and manufacturing's consumption of energy all lead growth. Increased energy prices will then decrease growth in the state. California could relax growth constraints associated with energy consumption via increases in energy supply. Increase in the supply of energy lead economic growth in the state. This is likely due to the resulting increase in quantity demanded. Efforts to increase energy consumption to trigger economic growth need not be solely focused on manufacturing's consumption.

Wyoming is unique in that supply-side influences are more influential in the growth process. This is likely due to the state's important role in energy markets. Demand-side factors lead growth via demand curve it is likely market interaction and the importance of supply factors causing this result. Increases in supply are predicted to impact economic growth in the state. Decreased input costs, increase energy prices, or increases quantity supplied strongly Granger cause economic growth. Wyoming is situated to benefit from increased scarcity in non-renewable energy sources. Technology improvements which increase supply or decrease input costs in turn will also lead.

This study has uncovered important state-level differences. These differences suggest important areas of future inquiry. For example, energy consumption equations have low R^2 and *F*-stats suggesting many of the important drivers of energy consumption have not been captured. Future work will seek to uncover these. With a better understanding of the determinants of energy consumption the policy implications from this study could become more focused. A second question the study's results raise is: Do different energy sources impact growth differently? Application of disaggregated energy measures may highlight important source differences. If growth responds to consumption of different fuels in distinct ways policy makers will have more specific tools at their disposal. This paper has set the foundation for a research agenda devoted to exploring the relationship between energy consumption and economic growth.

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Appendix

Table 2.1: Augmented Dickey Fuller Tests

		Intercept	Intercept & Trend	Random Walk			
State	Variable	ADF Test Stat	P Value	ADF Test Stat	P Value	ADF Test Stat	P Value
AZ	GSP	0.2054	0.9690	-5.1795	0.0009	-	-
	d(GSP)	-5.7393	0.0000	-5.6533	0.0003	-	-
	E_Con	-1.0701	0.7173	-3.0444	0.1345	-	-
	d(E_Con)	-5.2958	0.0001	-5.2270	0.0008	-	-
	E_Price	-2.4123	0.1456	-	-	1.0557	0.9206
	d(E_Price)	-4.1783	0.0024	-	-	-4.0180	0.0002
	Mfg	-2.3587	0.1602	-1.7012	0.7301	-	-
	d(Mfg)	-3.6804	0.0087	-5.4772	0.0004	-	-
	Coal	-2.1701	0.2201	-	-	0.2146	0.7430
	d(Coal)	-4.4583	0.0012	-	-	-6.2386	0.0000

State	Variable	ADF Test Stat	P Value	ADF Test Stat	P Value	ADF Test Stat	P Value
CA	GSP	-0.4867	0.8821	-3.3844	0.0694	-	-
	d(GSP)	-4.3516	0.0015	-4.2790	0.0092	-	-
	E_Con	-1.2295	0.6513	-2.9500	0.1595	-	-
	d(E_Con)	-5.4258	0.0001	-5.3397	0.0006	-	-
	E_Price	-2.3174	0.1722	-	-	1.5580	0.9684
	d(E_Price)	-4.2288	0.0021	-	-	-4.0673	0.0002
	Mfg	-1.9114	0.3235	-1.9593	0.6030	-	-
	d(Mfg)	-4.0161	0.0036	-5.0958	0.0011	-	-
	Prim	-1.9594	0.3027	-	-	1.1241	0.9294
	d(Prim)	-4.5832	0.0008	-	-	-4.4714	0.0000
WY	GSP	-2.5467	0.1134	-2.8148	0.2020	-	-
	d(GSP)	-3.0712	0.0379	-3.0934	0.1231	-	-

Variable	ADF Test Stat	P Value	ADF Test Stat	P Value	ADF Test Stat	P Value
d(E_Con)	-6.5686	0.0000	-6.5114	0.0000	-	-
E_Price	-1.6142	0.4646	-	-	0.5215	0.8234
d(E_Price)	-4.3594	0.0015	-	-	-4.1119	0.0002
Mfg	-2.1567	0.2249	-3.0525	0.1332	-	-
d(Mfg)	-5.9756	0.0000	-5.9989	0.0001	-	-
Prim	-1.6187	0.4610	-	-	0.5267	0.8247
d(Prim)	-4.3224	0.0016	-	-	-4.0764	0.0002

Note: *P* values reported in EViews from MacKinnon (1996). L_ indicates the log of a variable and d(L_) indicates the first difference. Failure to reject the null on levels and rejecting the null on differenced data indicates *I*(1).

Table 2.2: Johansen Tests

Demand Only Specification

	No. of CE(s)	EValue	Trace Stat	Crit Value 5%	Prob.	No. of CE(s)	EValue	Max Stat.	Crit Value 5%	Prob.
AZ:										
L(2)	None *	0.4566	32.4738	29.7971	0.0240	None *	0.4566	21.3491	21.1316	0.0466
	At most 1	0.2717	11.1247	15.4947	0.2040	At most 1	0.2717	11.0946	14.2646	0.1495
CA:										
L(2)	None	0.4039	27.6611	29.7971	0.0865	None	0.4039	18.1050	21.1316	0.1260
	At most 1	0.2182	9.5561	15.4947	0.3164	At most 1	0.2182	8.6168	14.2646	0.3194
WY:										
L(2)	None	0.2610	14.4673	29.7971	0.8134	None	0.2610	10.5845	21.1316	0.6885
	At most 1	0.0927	3.8828	15.4947	0.9128	At most 1	0.0927	3.4048	14.2646	0.9162

Note: An * indicates 1 more cointegrating equation at the 5% level. For example, both tests indicate one cointegrating equation for Arizona. EValue refers to eigenvalue. L(i) refers to the number of lags included in the test.

Johansen Tests: Supply & Demand Specification

	No. of CE(s)	EValue	Trace Stat	Crit Value 5%	Prob.	No. of CE(s)	EValue	Max Stat.	Crit Value 5%	Prob.
AZ:										
L(2)	None *	0.6778	113.3744	69.8189	0.0000	None *	0.6778	39.6394	33.8769	0.0092
	At most 1 *	0.5818	73.7350	47.8561	0.0000	At most 1 *	0.5818	30.5091	27.5843	0.0205
	At most 2 *	0.5392	43.2259	29.7971	0.0008	At most 2 *	0.5392	27.1163	21.1316	0.0064
	At most 3 *	0.3673	16.1096	15.4947	0.0404	At most 3 *	0.3673	16.0204	14.2646	0.0261
	At most 4	0.0025	0.0892	3.8415	0.7652	At most 4	0.0025	0.0892	3.8415	0.7652
CA:										
L(2)	None *	0.6692	107.2915	69.8189	0.0000	None *	0.6692	38.7148	33.8769	0.0122
	At most 1 *	0.5912	68.5767	47.8561	0.0002	At most 1 *	0.5912	31.3102	27.5843	0.0158
	At most 2 *	0.4854	37.2665	29.7971	0.0057	At most 2 *	0.4854	23.2556	21.1316	0.0248
	At most 3	0.2779	14.0109	15.4947	0.0826	At most 3	0.2779	11.3972	14.2646	0.1354
WY:										
L(2)	None *	0.7820	115.2905	69.8189	0.0000	None *	0.7820	53.3098	33.8769	0.0001
	At most 1 *	0.6191	61.9806	47.8561	0.0014	At most 1 *	0.6191	33.7784	27.5843	0.0070
	At most 2	0.4403	28.2022	29.7971	0.0755	At most 2	0.4403	20.3140	21.1316	0.0647

Note: An * indicates 1 more cointegrating equation at the 5% level. For example, Wyoming's supply and demand test indicates two cointegrating equations. EValue refers to eigenvalue. L(i) refers to the number of lags included in the test.

CHAPTER THREE

ELASTICITIES OF ENERGY SUPPLY AND DEMAND IN THE WESTERN UNITED STATES

Section 1 Introduction

In the near future energy markets will likely be impacted in a number of significant ways. The Energy Information Agency's *Annual Energy Outlook 2011* predicts energy prices to increase in both the short and long term due to a variety of factors. Among the contributors to increasing prices is the increased consumption of emerging markets such as China and India. *Ceteris paribus*, increased global demand will lead to increases in energy prices. Because energy consumption is an important determinant of economic growth in the United States (Payne 2009; Peach Chapter Two; Stern 1993 and 2000) increased prices which lead to decreased consumption are expected to in turn decrease economic growth.

A second factor which may profoundly impact energy markets in the United States is the notion of "energy security." Proponents of energy security are fundamentally arguing for increased domestic supplies. *Ceteris paribus*, increased domestic supplies would lead to increases in the amount of energy consumed.

In addition to these factors climate change is expected to have profound impacts on energy consumption and production. Significant uncertainty exists regarding the possibility and nature of climate change legislation within the United States.

Comprehensive climate change legislation could significantly impact the composition of energy consumption within the country.

Beyond the impacts of climate change legislation, climate change itself will impact energy consumption in important ways. Climate change is expected to result in a general increase in average temperatures in United States. Temperature change in turn results in changes to the heating and cooling requirements for buildings. This change provides researchers a first step at calculating the impact of climate change on energy needs.

Hadley, Erickson III, and Hernandez (2004) show that in the Western region the net impact of climate change on primary energy needs for heating and cooling of buildings is a net increase in energy consumed. This is due to a larger increase in cooling degree days relative to heating degree days. The increase in primary energy needed to cool buildings causes an increase in the energy required to produce the additional electricity.

The purpose of this study is to estimate a state-level energy markets in the Western United States. A fully specified supply and demand system will allow for the estimation of behavioral parameters. The general trend of continued increases in the energy efficiency of the United States' economy may make previous elasticity estimates out of date. In light of the findings of Essay One the state-specific estimated elasticities will allow for more accurate predictions of behavioral responses to state energy policy. This will aid attempts to manage negative externalities, increase supply, and so on.

Regions and states have also been proactive in formulating energy policy. The Northeast's Regional Greenhouse Initiative (RGGI) is one example, the plethora of renewable portfolio standards (RPS) at the state-level another. State-specific elasticity estimates will capture the idiosyncrasies of states' economies within the Western region.

Hamilton has extensively researched the impact of energy price shocks on the macroeconomy. He has shown that one of the primary means by which energy price shocks impact economic performance is the initial reaction of consumers' adjusting their expenditures on other goods. See Hamilton (2011 and 2008) for recent studies. If taxes or other price modifications are used by policy makers it is important to understand that given the relative inelastic price elasticity of energy demand consumption of other goods will likely be impacted. While the study addresses aggregate energy consumption its estimates can be used by general equilibrium research of the Western United States.

Metcalf (2008) shows that price increases are effective triggers of gains in energy efficiency at the state level. Popp (2002) and Bessec and Méritet (2007) are studies which confirm Metcalf's findings of the important role price plays in technological improvement. Given Hamilton's research, the technological advances which occur due to increased prices will simultaneously put downward pressure on economic growth.

The findings presented in this chapter suggest that changes in income impact energy demand more than the other components of demand. The conflicting pressure of increased incomes and prices highlight the multifaceted challenges inherent in many energy issues.

The study extends the literature on energy related elasticities by estimating both the supply and demand side of state energy markets. A simultaneous system will allow for the interaction of supply and demand to be controlled for. The econometric issues that emerge from estimating a reduced-form specification of one side of the market are presented by Gujarti (2003). One fundamental issue is the fact that price and quantity are jointly determined by supply and demand; both are endogenous. Because reduced-form estimations do not take into account the interaction of supply and demand in determining market prices reduced-form estimations may not yield accurate estimations of elasticities. Without adequately controlling for the supply and demand curve attributing price and quantity changes to a particular side of the market becomes tenuous.

A second extension is the application of an aggregate measure of energy consumption. The majority of studies within the literature estimate elasticities for a particular energy market or source. The practice within the literature is to use the estimated elasticity for a particular form of energy as a synonym for energy elasticity. For example, the price elasticity of demand for residential electricity may be discussed as simply the price elasticity of demand for energy. It is more appropriate to think of specific energy sources as a subset of overall energy consumption. These estimates are necessary for a robust understanding of energy markets but do not accurately convey aggregate energy changes. As energy sources continue to evolve elasticities from aggregate measures will capture the importance of shocks to final energy consumption. Because energy consumption is a derived demand, energy is consumed to deliver a service not for its intrinsic value, aggregate energy consumption elasticities will inform policy independent of substitution between energy sources.

Data applied in the study represent states in the Census' Western region with the exclusion of Hawaii and Alaska. These states were excluded due to their location outside of the continuous United States. Data cover a relatively long time span, from 1970 to 2007. This allows the data to capture important changes in the energy economy relationship. These changes include increased energy efficiency over time (for most states in the sample), increased real incomes and prices, as well as numerous energy price shocks.

The study proceeds as follows. Section 2 will discuss the relevant literature. Due to the abundance of studies estimating energy elasticities the discussion will be focused on a representative sample. Studies discussed will frame this study within the existing literature and motivate the use of the data set and estimation technique applied. Section 3 presents the underlying theoretical methodology. Data is presented in Section 4. Section 5 outlines the estimator used, results, and forecasts of changes in energy consumption arising from numerous shocks to demand determinants. The study concludes with Section 6.

Section 2 Literature & Extensions

2.1 Literature

A substantial literature devoted to estimating various elasticities associated with energy consumption exists. Elasticities have been estimated for a variety energy sources and geographic markets. Data applied in studies range from city-level to global aggregates. Filippini (2010) is a city-level example. Data from Swiss cities to estimate peak and off-peak price elasticity of electricity demand. He, Wang, and Lai (2010) is a study at the other end of the spectrum, the global long run price elasticity of oil demand is estimated to be -0.89.

In this section, studies will be presented that provide a foundation for the methodology applied. Readily comparable results to the findings of this study are also presented. Energy elasticities have been estimated for decades. In order to frame the study's results in a more contemporary context more attention will be paid to studies from the mid-90s onward. Contemporary studies are able to employ longer time series as well as updated econometric techniques. Literature surveys will also be highlighted for those interested in more resources.

Taylor's (1975) survey of electricity demand is the starting point for a review of modern energy elasticity estimates. Taylor provides an outline of numerous earlier studies devoted to estimating demand elasticities in the residential, commercial, and industrial markets. Those interested in the literature prior to the 1970s will benefit from the vast references provided. It is interesting to note that many of Taylor's recommendations for future research have been pursued. These recommendations include modeling peak versus off-peak residential consumption, seasonal demand, and an increased examination of industrial energy consumption. Data availability and advances in econometric techniques have allowed for many of these extensions to occur.

Pindyck (1979) is an important study due to the scope of analysis. Citing inconsistencies in the literature Pindyck seeks to establish whether energy and the other factors of production are substitutes or complements in industrialized nations. Energy and labor are found to be complements while energy and capital are substitutes. In addition to addressing the relationship between energy and other factors of production Pindyck estimates short and long run elasticities for individual fuels, the impact of industrial growth on energy demand, and the impact of increased energy costs on the cost of output. A panel data approach is applied using data from 1959 to 1973 for 10 industrialized nations. Most relevant to this study is the estimated own price elasticity of energy use which is found to be -0.8. This is a measure of how industrial energy consumption responds to prices in energy.

Bohi and Zimmerman (1984) survey studies related to energy demand before and after the energy price shocks of 1974 and 1979. Their review focuses on studies of specific industries and fuels types. For markets where a consensus emerges short run elasticities are consistently smaller in absolute value than their long run counterparts. For example, the consensus for the short run price elasticity of demand for residential electricity is equal to -0.2 while the long run estimate is -0.7. The same values are found in the gasoline market. Elasticities becoming more elastic in the long run are a consistent theme across the literature.

A few insights from Bohi and Zimmerman (1984) pertaining to this study should be mentioned. First, the authors show that studies across a wide range of energy forms including gasoline, residential electricity, and residential natural gas find that demand elasticities have been not impacted by the energy shocks of the 70s; elasticities tend to be stable over time. The authors do note that this is a tentative finding as the price shocks they examined were still quite recent. The United States economy has become more energy efficient since this study. Therefore, it is valuable to have an updated test of the relative stability of elasticities.

Bohi and Zimmerman (1984) note that the level of aggregation is an important determinant of estimated elasticities. Findings at one level of aggregation should not be perceived as being accurate for another level. For example, residential electricity demand within a state will behave differently than aggregate demand for electricity in the United States. Given Hamilton's work (see 2011 and 2008 for recent studies) regarding the role changes in energy prices play in economic activity policy makers should be equipped with measures at the appropriate geographic level. Estimates in this study are for aggregate state-level energy markets. These estimates are most appropriate for questions regarding broad energy issues such as externalities, responsiveness of state-level consumption to changes in supply and demand factors, and so on.

The majority of studies discussed in Bohi and Zimmerman (1984) find cross-price elasticities to be statistically insignificant. Studies of individual markets do not appear to be capturing shifts in consumption between fuels. This inability to capture shifting consumption patterns of energy sources should be a benefit of applying aggregated energy measures as done in this chapter.

Maddala, Trost, Li, and Joutz (1997) analyze electricity and natural gas for states within the United States. Their study is notable due to its application of Bayesian techniques. Data for all the states, with the exception of Hawaii, are from 1970 to 1990. Bayesian techniques are used due to a number of issues regarding preliminary estimations. Most pertinent to this study is that estimations using only a single state's data resulted in theoretically inconsistent signs. As a result the authors rely on panel based approaches.

Maddala et al. (1997) find the short run price elasticity of demand for electricity equals -0.158 and -0.263 in the long run. The long run estimate is less elastic than the consensus that Bohi and Zimmerman (1984) report. Income elasticities are 0.39 and 0.89 in the short and long run respectively. Price elasticity for natural gas is -0.099 in the short run and -0.28 in the long run. Income elasticities equal 0.28 in the short run and -0.068 in the long run. Results from numerous techniques are applied in the study to ensure robust results. All the techniques employed find the long run income elasticity to be negative or zero. The authors cite numerous reasons for the income elasticity for natural gas declining in the long run including households substituting away from natural gas towards electricity and declining usage of natural gas over the data set. This updated study contrasts with the stability of elasticities that Bohi and Zimmerman find. Over a longer time horizon elasticities are not as stable as Bohi and Zimmerman suspected.

Olatubi and Zhang (2003) employ a similar methodology and data set as this chapter. Data are for 16 states in the Southern United States from 1977 to 1999. Olatubi and Zhang also apply an aggregate energy consumption variable. The long run estimated price elasticity of demand is found to be -0.32 and income elasticity of 0.4 indicating changes in income have a larger impact on energy consumption. Olatubi and Zhang find that the income elasticity of demand is declining over time. This result is predicted by the Engel curve. As incomes rise energy will represent a smaller budget share resulting in a declining income elasticity of demand. Olatbui and Zhang's results will be discussed in greater detail in Section 5 when they are compared to estimates derived for states in the Western United States.

The short run, long run categorization of elasticities made by Olatubi and Zhang (2003) and aforementioned studies is result of the theoretical model they apply. Because structural parameters are estimated in this chapter neither time dimension is directly comparable. A comparison of the theoretical foundation of studies similar to Olatubi and Zhang's and this chapter will be presented in detail in Section 3.

Liu (2004) calculates price and income elasticity of demand for the residential and industrial sectors using panel techniques applied to OECD data from 1978 to 1999. The energy sources considered include electricity, natural gas, hard coal, gas oil, and motor gas. Short run price elasticities range from -0.17 to 0.16 while the long run estimates from -0.52 to 0.59. Not all estimates are statistically significant from zero. When statistically significant, estimates are negative. The author does not provide critical values or significance levels for estimated coefficients but does note that those that do not have theoretically consistent signs are not statistically significant from zero. In absolute value, price elasticities are larger than the respective income elasticity for source and sector pairings.

Bernstein and Griffin (2006) estimate demand elasticities for electricity and natural gas at various geographic levels. The authors want to determine the appropriate level of analysis for estimating price elasticities; national, regional, or state. This is pursued because most of the Energy Information Agency's (EIA) analysis is performed at the regional level. The EIA typically breaks up the Census' Western region into the Pacific and Mountain region. The Pacific region is composed of California, Oregon, and Washington. The Mountain region includes Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming. Bernstein and Griffin show that regional differences are larger than the variation between states within a region. Even if there is more variation inter-region versus intra-region state specific estimates will be more informative for state specific policy discussions. Also, a regional panel approach assumes that all states within the data set have the same parameters. Given the diversity of economies and energy sources within the Western region universal parameters may not be a completely accurate assumption.

An interesting finding of Bernstein and Griffin (2006) is that they find the price elasticity of demand to be constant over their data set, 1977 to 2004 for residential electricity and natural gas and 1977 to 1999 for commercial electricity. As studies are able to take advantage of longer time series this is an important finding. Efficiency gains seem to have impacted demand behavior via declines in income elasticity rather than changes in price elasticity. This insight could be useful for policy formulation. It suggests that as increases in income will result in smaller increases in energy consumption over time. Simultaneously a given change in price is expected to cause a constant change in quantity demanded.

Fell, Li, and Paul (2010) estimate the price elasticity of demand to be -0.898, income elasticity 0.09, CDD -0.032, and HDD -0.015. The negative sign on CDD and HDD is not expected. *A priori*, as the number of CDD or HDD days increases households are expected to increase their energy consumption. The estimated coefficients have their theoretically expected signs when CDD is interacted with an air condition dummy and HDD an electric heat dummy. A generalized method of moments (GMM) is applied for their estimations. The study applies a novel data set, the Consumer Expenditure Survey from 2004 – 2006. The West region they estimate is comprised of Arizona, California, Colorado, Oregon, and Washington. The Survey allows for a detailed analysis of household behavior that is not possible with more aggregated data. A limitation in applying their findings to the Western region is that not all states are represented.

Lee and Lee (2010) perform panel data analysis with data on 25 OECD nations from 1978 to 2004. Their estimated income elasticity of demand equals 0.52 and price elasticity of energy demand is -0.19. The authors perform analysis of both aggregate energy and electricity consumption. The interested reader can find a summary of estimated coefficients from similar studies on pages two and three.

2.2 Extensions

Numerous themes from the surveyed literature have influenced this study. First, panel based approaches dominate the literature. Panel data approaches have certain advantages and disadvantages that time series techniques do not. The primary advantage is the increased variability inherent in combing multiple cross-sections rather than relying on individual cross-sections. A limitation of panel techniques is the assumption that estimated parameters are accurate for all the cross-sections within the estimation. As discussed earlier the diversity of states' economies suggests this may not be an accurate assumption. For this reason, and to inform state-level policies estimations will be performed on a state-by-state basis.

The dominant methodology applied in the energy elasticity literature is to derive demand side estimates via reduced-form demand curves. In many cases data availability precludes the simultaneous estimation of a supply curve. Because reduced-form estimations do not take into account the interaction of supply and demand in determining market prices reduced-form estimations may not yield accurate estimations of elasticities. If only the demand curve is estimated changes in price and quantity will be attributed to demand parameters when in fact they could be due to supply changes. Without adequately estimating a supply and demand curve, attributing price and quantity changes to changes in only one side of the market becomes tenuous.

A detailed discussion of the econometric issues which may emerge from estimating a reduced-form specification when a simultaneous system is appropriate can be found in Gujarati (2003). In a supply and demand framework the explanatory variables are likely correlated with error terms. As Gujarati (2003) notes a reduced-form estimation of quantity on price violates “the assumption of no correlation between the explanatory variable(s) and the disturbance term” (p. 719). Observed price and quantity are jointly determined by supply and demand; both quantity and price are endogenous. *Ceteris paribus*, a positive demand shock results in an increase in the equilibrium price and quantity. Because price enters both supply and demand as an explanatory variable, if the shock is manifested in the demand curve’s error term, an explanatory variable will be correlated with an error term.

Under certain conditions estimations from a reduced-form demand only estimation are expected to be efficient. If price is assumed (or determined) to be exogenous than it will not be correlated with the error terms. Bernstein and Griffin (2006) apply this assumption in estimating state and regional demand elasticities. When price is exogenous it is more accurate to think of estimated parameters as what Gujarati (2003) refers to as “short-run multipliers” (p. 738). These coefficients are estimates of the immediate impact of a change in an exogenous variable rather than capturing the structural elements of the market which are estimated in a simultaneous system.

A third extension provided by this study is related to the continued observations of other studies that elasticities of energy markets are not directly comparable across different energy forms or levels of aggregation. Combining this with the importance of aggregate energy consumption in economic growth suggests that aggregate energy measures may provide important insights.

Given the lack of region or state-specific studies within the literature sub-national estimates will provide valuable information for many policy issues. Many energy policies are determined at the sub-national level. The estimates obtained in this study will aid policy makers which represent states in the Western United States.

Section 3 Model & Methodology

3.1 Theoretical Model

In this section the theoretical supply and demand model will be presented. The general expressions for supply and demand are:

(3.1.1) $Q_t^D = f(p_t; X_t)$,

(3.1.2) $Q_t^S = h(p_t; Y_t)$,

where t is a time index, p is the price of energy, X is a vector of demand-side influences and Y supply-side. In this study each side of the market corresponds to a particular state. Theory suggests a number of factors to include in X such as price, income, type of economic activity, and weather. Supply-side variables might include price of inputs, climate, and technology. The availability of appropriate proxies will ultimately determine which variables are included in estimations.

The energy market is in equilibrium when:

(3.1.3) $Q_t^D = Q_t^S = Q_t^*$,

where * refers to an equilibrium value. The energy price which equates the quantity demanded and supplied in time t is the equilibrium market price, p_t^*. The challenge inherent in estimating the supply and demand system is correctly attributing shocks to the energy market to the correct side of the market.

Many studies in the literature apply the flow-adjustment model developed by Houthakker, Verleger, and Sheehan (1974). See Bernstein and Griffin (2006); Girod (2007); and Olatubi and Zhang (2003) for recent examples. In the application of Houthakker et al.'s model equation (3.1.1) is modified to represent desired demand:

(3.1.4) $Q_{i,t}^{D*} = f(X)$,

where * represents the desired demand. The adjective "desired" reflects the stock versus flow nature of energy demand. Consider a household's consumption of gasoline. Via the law of demand an increase in price will lead to a decline in quantity demanded. This change in behavior represents the flow process of energy consumption. A household responds first to the price change by changing its consumption. In the long term it may adjust its stock of energy using goods based upon the price change. A price increase may lead to the purchase of a more fuel efficient car in the future. Given a sufficient amount of time the decision may adjust its capital stock in response. The application of this model is why many studies obtain short and long run estimates.

The flow-adjustment model is applied when only the demand side of the market is estimated. As a result rather than assume price and quantity represent market equilibrium the adjustment process is modeled. Because a supply curve is estimated in this model rather than short and long run estimates structural parameters are obtained.

This study follows Lin (2011) assumption of linear supply and demand functions:

(3.1.5) $Q_t^D = \alpha_1 * p_t + \alpha_i X_t$

(3.1.6) $Q_t^S = \beta_1 * p_t + \beta_i Y_t$.

Under the assumption of market equilibrium one could solve for the reduced-form system representations of p_t and Q_t. This approach is often applied when ordinary least squares (OLS) or two-stage least squares (2SLS) are applied as the estimator.

3.2 Econometric Considerations

Three-stage least squares (3SLS) is used to estimate the system. As discussed by Lin (2011) this approach is more consistent and efficient than an equation-by-equation estimations using OLS or 2SLS. Increased efficiency is a result of the application of instrumental variables which are not applied in OLS estimations. Consistency is improved over OLS and 2SLS because of the simultaneous nature of the estimation.

Estimation via 3SLS applies a key aspect of the seemingly unrelated regression estimation (SURE) approach. Specifically, it controls for correlation between error terms across equations. Instrument variables are also used to account for correlation between predetermined variables and error terms. 2SLS also applies instrument variables but it does not account for the simultaneous nature of the system in a way that the SURE methodology does. Kennedy (2003) presents a more thorough discussion of the ways in which 3SLS can be interpreted as the simultaneous or full information version of 2SLS.

Section 4 Data

4.1 Date Overview

Data used to estimate the demand curve are energy consumption (E_Con), price of energy (E_Price), gross state product (GSP), manufacturing employment (Mfg), and climate (Clim). Data are from 1970 to 2007. With the exception of Alaska and Hawaii states in the Census' Western region are considered. These states are excluded due to their location outside the continuous United States. Data are reported in natural logs though the notation is suppressed. Nominal values (GSP and price) have been converted to 2000 dollars via a CPI calculated from the Bureau of Labor Statistics (BLS).

GSP and Mfg are reported by the Bureau of Economic Analysis (BEA). GSP is the state-level equivalent of GDP and expressed in million 2000 dollars. The conversion from the SIC to the NAICS industry classification system impacts the Mfg time series. Due to the reclassification a seamless time series is not created. NAICS measures of both GSP and Mfg are applied from 1997 onwards. This is a limitation of the data but nevertheless the series allows for important trends in manufacturing output to be captured.

Energy related data are from the Energy Information Agency (EIA). Energy consumption is reported in billion BTU and is calculated as the consumption of primary energy within a state for a given year. The EIA defines primary energy consumption as the consumption of energy directly from the source. Examples include a utility's consumption of coal to generate electricity or a household's use of natural gas for heating. Consumption of electricity would not be considered primary consumption because the electricity was generated from another source. Consumption of electricity is considered as secondary consumption is not included to ensure there is not double counting. Consumption measures are estimated via data regarding sales and distribution for each state. Net imports of electricity are included in consumption to capture the state's total consumption. For renewable sources such as hydro or solar consumption is assumed to be equal to net production. Consumption of renewable sources is then the gross amount of electricity generated minus any electricity used in its production.

Price of energy (E_Price) is measured as the average price of total energy. The study converts nominal measures into 2000 dollars per billion BTU. The price includes taxes whenever possible. In general, excise and per-gallon taxes are included but local sales taxes are not. Prices are state-level so in-state differences are not captured but aggregate trends over time are.

There are two climate proxies applied, cooling degree days (CDD) and heating degree days (HDD). Data for each state is reported by the National Oceanic and Atmospheric Administration (NOAA). CDD and HDD represent daily average temperatures as a deviation from 65 degrees. The variable captures the cooling or heating requirements for a building when temperatures are above or below the baseline of 65 degrees. For example, if the daily average temperature was 30 degrees the CDD value for the day would be 35. To calculate state-level measures observations from individual weather stations are weighted according to population. As a robustness check estimations will be performed with CDD and HDD individually as well as summed for a given year.

Glaeser and Kahn (2008) show that urbanization is an important determinant of carbon dioxide emissions. Energy consumption per capita is lower in urban areas and subsequently states with higher urbanized populations. Urbanization of the state's population will impact energy demand. In preliminary estimations urbanization was highly correlated with the quantity demanded proxy and weather variable resulting in imprecise coefficient estimates. As a result it was dropped from the analysis.

4.2 Potential Issues with an Aggregate Energy Measure

Applying an aggregate measure of energy consumption limits the applicability of results from the study. Specifically, substitution between energy fuels is not captured, aggregate consumption changes are. A significant amount of energy policy is related to specific fuels. For instance, carbon regulation accounts for the carbon content of fuels. Aggregate based measures are not able to inform market (or fuel) specific elasticities. While fuel-specific elasticities are policy relevant, changes in aggregate energy consumption has important economic growth consequences (Peach Chapter One; Stern, 2000).

In one sense energy does not have a substitute; if I want to drive my automobile I need gasoline to do so. In the production process energy is possibly a complement (or substitute) for other factors of production. Pindyck (1979) found energy and to be a complement to labor and substitute for capital. Stern (2003) summarizes the literature on energy and economic growth by stating “it seems that capital and energy act more as substitutes in the long-run and more as complements in the short run, and that they may be gross substitutes but net complements (Apostolakis, 1990)” p. 22. Stern (1997) notes the sensitivity of results between the nature of the relationship between energy and capital based upon the functional form applied in the study. In many macro models which account for energy consumption it is often treated as a complement with capital (Kim and Loungani, 1992; Dhawan, Jeske, and Silos; 2008). Stern (2003) also notes that there is little consensus in the literature regarding the nature of the relationship between energy and labor.

The manufacturing employment variable (Mfg) will explicitly account for the relationship between energy and labor in a capital intensive sector. If the estimated manufacturing elasticity is positive it would indicate that manufacturing employment increases result in increases in energy consumption. Unfortunately, one is not able to infer into the energy capital relationship because capital is not held constant in the estimations. Readily available capital data does not exist for states. Because capital is not held constant the manufacturing elasticity of energy demand should be interpreted cautiously.

Section 5 Estimation & Results

5.1 Estimation

Equations (3.1.5) and (3.1.6) provide the basis for the estimations. The X vector includes proxies for income, output composition, and climate. The variables which serve as these proxies are GSP, Mfg, CDD, and HDD respectively. The supply vector, Y is composed of proxies for input costs and climate. Prim, CDD, and HDD compromise the Y vector in estimations. Equilibrium price and quantity are represented by E_Price and E_Con. The system to be estimated is:

$$(5.1.1)\quad E\_Con_t^D = \alpha_0 + \alpha_1 * E\_Price_t + \alpha_2 * GSP_t + \alpha_3 * Mfg_t + \alpha_4 * E\_Con_{t-1} + \alpha_5 * CDD_t + \alpha_6 * HDD + u_{1t}$$

$$(5.1.2)\quad E\_Con_t^S = \beta_0 + \beta_1 * E\_Price_t + \beta_2 * IC_t + \beta_3 * E\_Con_{t-1} + \beta_4 * CDD_t + \beta_5 * HDD_t + u_{2t}.$$

where u_{it} are the random error terms. These are estimated simultaneously for each individual state in the Western United States. Lagged energy consumption is included as an explanatory variable in order to control for potential autocorrelation. Predetermined variables are used as the instruments for the 3SLS estimations. Estimation via 3SLS will also account for the simultaneous nature of the system. Key results are presented in Tables 1 and 2 below. Full estimation output for each state can be found in the Appendix.

Table 1 presents the estimated demand elasticities. Price has the expected sign (when significant) in 6 out of 11 states; California, Colorado, Idaho, Nevada, Utah, and Wyoming. The price elasticity of demand is consistently inelastic. When significant, its range is between -0.23 for Idaho and -0.06 in California. These estimates are smaller in absolute value than Fell, Li, and Paul's (2010); -0.98. State-specific elasticities are comparable to the range estimated by Olatubi and Zhang (2003) in their panel study of the Southern United States. Their estimates of the price elasticity of demand have a range of -0.08 to -0.11 in the short run and -0.21 to -0.32 in the long run.

Table 1

Demand Elasticities

State	Price	Inc	Mfg	CDD	HDD
AZ	-	0.3441	-0.0860	0.1250	-
		(0.0482)	(0.022)	(0.0694)	
CA	-0.0593	0.1743	-	0.0531	-
	(0.0303)	(0.0380)		(0.0304)	
CO	-0.0951	0.2270	-0.1343	-	-
	(0.0447)	(0.0658)	(0.416)		
ID	-0.2336	0.2743	-	-	*0.1375*
	(0.575)	(0.646)			*(0.850)*
MT	-	0.3493	0.3114	-	0.2337
		(0.0673)	(0.1045)		(0.1127)
NM	-	-	-	-	-
NV	-0.0889	0.3166	-	-	-
	(0.0378)	(0.0634)			
OR	-	0.2002	0.3116	-	-
		(0.0308)	(0.641)		
UT	-0.1432	0.1734	-	-	-
	(0.0648)	(0.0754)			
WA	-0.1119	0.1712	0.3982	-	-
	(0.0502)	(0.0415)	(0.0803)		
WY	-	-	0.2140	-	-
			(0.1033)		

Note: Full output can be found in the Appendix. Statistically significant coefficients are listed with standard errors in parenthesis. With the exception of ID's HDD, all reported coefficients are significant at the 10% level. Italics indicate significance at the 11% level.

As discussed in Section 2.2 the short run long run categorization of elasticities made by Olatubi and Zhang (2003) are a result of their theoretical model. It is notable that most states' price elasticity of demand lies within Olatubi and Zhang's range for the short run; Idaho and Utah being the exceptions. Utah's estimate is the only elasticity that falls within their long-run range and it is at the lower end of the range. The structural parameters estimated in this chapter being closer to the short-run estimates of Olatubi and

Zhang could be the result of regional differences, an updated data set, or the structural estimation.

Olatubi and Zhang's (2003) estimated coefficients come from demand-only reduced-form models. These estimates are most accurately interpreted as short-run multipliers. If one assumes that the difference in the price elasticity estimates found in this study versus Olatubi and Zhang's are not due different time horizons in the data set or regional differences than long-run price elasticities may not be an accurate representation of the behavioral characteristics of state energy markets. Rather, structural coefficients appear to be more short-run in nature. It may be that the time horizon necessary for the behavior response represented in a long-run elasticity to manifest itself does not occur. If this is the case than it is more accurate to conceptualize the movement towards equilibrium within energy markets as being dictated by short run shocks rather than a long run process. The methodology of this chapter could be applied to the region of analysis (Southern United States) to determine which of three hypotheses are driving the different outcomes.

The income elasticity of demand has the expected sign in 9 of 11 states. New Mexico and Wyoming are the two states where income is insignificant. Olatubi and Zhang's (2003) short run range is 0.08 to 0.1 and 0.29 to 0.44 in the long run. In general, state-by-state estimates are greater than Olatubi and Zhang's short run range but less than their largest long run estimate. This result seems to confirm that structural parameters are closer to the short run estimates found within the literature.

Elasticity of manufacturing (output composition) has mixed signs when significant. For Arizona and Colorado it is negative while for Montana, Oregon, Washington, and Wyoming it is positive. If state-level capital were controlled for than a positive sign would indicate a complementary relationship between labor and energy while a negative sign that they are substitutes. *A priori*, the author expected a complementary relationship. The inconsistencies of the qualitative results make a universal explanation difficult to hypothesize. The simplest explanation would be that there is not a universal relationship between manufacturing and energy at the state level. It could be the type of manufacturing which occurs within the state that determines the aggregate relationship. Within each state the industrial sector consumed similar percentages of total energy, roughly 30% (based upon the author's calculations) so it is unlikely that it is state-level differences in the relative percentage of total energy consumption within a state that is driving the result.

Climate proxies are significant in Arizona, California, Idaho (at the 11% level), and Montana. In other state-level studies the significance of climate is mixed. Climate proxies are significant in Bernstein and Griffin (2006); Fell, Li, and Paul (2011); and Maddala et al. (1997). Within the literature the treatment of climate is not universal. Bernstein and Griffin as well as Maddala et al. apply the sum of CDD and HDD in their studies while Fell, Li, and Paul keep CDD and HDD separate. At the end of this section results from estimations with CDD and HDD combined will be briefly discussed.

Fell, Li, and Paul (2011) find climate proxies to be negative demand shifters, a result which was not expected by the authors. In the other studies previously mentioned climate consistently is found to be a positive demand shifter. Olatubi and Zhang (2003) do not find climate to be significant in their estimations. For Arizona and California, increases in CDD increase energy demand. Given the large population and warm climates of Los Angeles and Phoenix this result is not surprising.

For Montana and Idaho (at the 11% level) HDD is significant. Given these states' location it is logical that heating needs would act to increase demand. What is surprising about the climate variables is the lack of significance in the majority of states. It may be that there is not enough climate variation within a state to accurately capture the impact of climate changes on energy demand.

The price elasticity of supply has the expected sign in 8 of 11 states. It is insignificant in Colorado, Washington, and Wyoming. Estimated price elasticities of supply are much more elastic than demand. The range of estimated elasticities is between 2.43 and 7.67. Due to the lack of supply and demand studies at the state or regional level there are not directly comparable supply-side elasticities. Krichene (2002) and Lin's (2011) studies of the world oil market both estimate the price elasticity of supply to be inelastic.

Table 2

Supply Elasticities				
State	Price	IC	CDD	HDD
AZ	7.3680	-2.9627	-	-
	(1.3978)	(0.5488)		
CA	4.1310	-1.6837	0.0526	0.0811
	(0.9407)	(0.3770)	(0.307)	(0.0442)
CO	-	-	-	-
ID	6.9926	-2.9089	-	*0.1335*
	(1.4365)	(0.5862)		*(0.0854)*
MT	6.3801	-2.5979	-	0.2807
	(1.6569)	(0.6684)		(0.1242)
NM	2.6569	-1.1211	-	-
	(1.3806)	(0.5760)		
NV	6.6627	-2.7154	-	-
	(1.4094)	(0.5637)		
OR	3.9372	-1.6343	-	-
	(0.9317)	(0.3793)		
UT	3.0885	-1.2928	-	-
	(1.4223)	(0.5685)		
WA	-	-	-	*-0.1906*
				(0.1196)
WY	-	-	-	-

Note: Full output can be found in the Appendix. Statistically significant coefficients are listed with standard errors in parenthesis. With the exception of HDD in ID and WA all reported coefficients are significant at the 10% level. The significance level for ID is 12% and WA 11%.

For states within the Western United States the price elasticity of supply is more elastic than its demand counterpart. This finding yields insight into potential tax burdens of energy-related policies. Consumers will likely bear a larger portion of the loss in surplus from a tax (or policy) which results in an increased price of energy. The methodology of the study is not capable of taking into account any negative externalities associated with energy consumption or production.

States with significant price elasticity of supply also have significant input price elasticities. All significant estimates have the theoretically predicted negative sign. The elasticity of input price is also elastic but consistently smaller in absolute value than the price elasticity of supply. For a given percentage price change in primary energy (coal, natural gas, and so on) the impact on the quantity supplied will be larger than the shock. In Arizona, *ceteris paribus*, a one percent increase in the price of primary energy results in a 3% decrease in the supply of energy.

Given the importance of energy consumption in the economic growth process increases in the supply of energy will result in increased growth (Payne, 2009; Peach Chapter Two; Stern, 2000). Supply increases provide a mechanism by which prices may decrease within the region. Technological improvements in extraction are one way by which increases may occur.

The continued promotion of renewable resources is a second way to increase the supply of energy. With the exception of energy from hydroelectric dams, the data is capturing the production and consumption of non-renewable energies. Renewable energies such as solar or wind have input costs equal to zero. Many renewable portfolio standards (RPS) within the region require significant increase in the percentage of renewables in total production. For example, Colorado requires 30% by 2020. If these percentage requirements are met than the input cost supply elasticity would likely not be accurate as it would not capture this markedly different composition of energy supply.

CDD is positive in California while HDD is positive in Montana and Idaho (12% significance level). At the 11% significance level HDD is negative in Washington. As in the case of demand it may be a lack of state-level variation which leads to these findings. Washington's negative sign is not expected but negative signs have been found in other studies (Fell, Li, and Paul; 2011). This could a result of the prominence of hydroelectric power in the state. In 2011, hydroelectric generation accounted for 75% of the electricity generation in the state (EIA, 2011). The supply of hydroelectric energy would increase in the spring months when snowmelt and thus river flows increase. HDD is a proxy for heating needs, which is likely correlated with winter months. In this case energy supply would decrease in the state when snow falls but increase when the snow melts.

Elasticities provide useful estimates of how energy markets will change from various shocks. On the demand side, for a given percentage change income shocks will cause the largest absolute changes in energy consumption. Table 3 presents forecasted increase in energy consumption if the states' income grows at its average over the data set. In the region Arizona and Nevada are predicted to have the largest increases in energy demand while California and Oregon the lowest.

Table 3

Forecasted Percentage Increase in Energy Demand from Increasing Incomes

AZ	1.5748
CA	0.5184
CO	0.8867
ID	0.8672
MT	0.7464
NM	-
NV	1.7140
OR	0.5991
UT	0.6986
WA	0.5592
WY	-

The *Annual Energy Outlook 2011* reference scenario provides forecast of price changes in the Western United States. Forecasts applied are the expected price changes from 2009 to 2035 for individual fuels. Aggregate energy price forecasts are not published. In the Western region motor gasoline is expected to increase by 3.7%, natural gas 3.1%, and electricity 1.8%. Applying the high and low estimates to create a range for potential increases in aggregate prices Table 4 present the respective changes in quantity demanded and supplied. For a given percentage change, price changes cause larger responses in the quantity of energy supplied than demanded.

Table 4 Forecasted Changes in Quantity Demanded & Supplied from Price Changes

	Demand		Supply	
	Percentage Increase		Percentage Increase	
	3.7%	1.8%	3.7%	1.8%
AZ	-	-	27.2615	13.2624
CA	-0.2193	-0.1067	15.2848	7.4358
CO	-0.3520	-0.1712	-	-
ID	-0.8642	-0.4204	25.8725	12.5866
MT	-	-	23.6063	11.4842
NM	-	-	9.8305	4.7824
NV	-0.3288	-0.1599	24.6521	11.9929
OR	-	-	14.5675	7.0869
UT	-0.5297	-0.2577	11.4274	5.5593
WA	-0.4142	-0.2015	-	-
WY	-	-	-	-

Considering the implications this study's findings the complicated future of energy consumption in the Western United States becomes evident. Expected increases in income lead to increases in energy demand while price increases will decrease the quantity demanded. On the supply side quantity supplied has a positive relationship with the market price but supply has a negative relationship with the price of primary energy. The magnitude of changes to the structural foundation of the supply and demand for energy within states will determine the net result of these conflicting pressures.

Equations (5.1.1) and (5.1.2) were estimated with CDD and HDD aggregated into a single variable. This variable would capture both cooling and heating needs throughout the year. This is the approach applied in Bernstein and Griffin (2006). Table t and t present the key results. The results are similar to the disaggregated variable so output has not been included.

Table 5 Significant Elasticities

		Demand		
State	Price	Inc	Mfg	Clim
AZ	-	0.3598	-0.0718	-
CA	-0.0550	0.1815	-	-
CO	-0.1005	0.2254	-0.1336	-
ID	-0.2318	0.2726	-	-
MT	-	0.3452	0.2695	0.2279
NM	-	-	-	-
NV	-0.0874	0.3154	-	-
OR	-	0.1832	0.3156	-
UT	-0.1403	0.1650	-	-
WA	-0.1118	0.1709	0.3977	-
WY	-	-	0.2115	-

Note: Full output can be found in the Appendix. All reported coefficients are significant at the 10% level.

Table 6 Significant Elasticities

	Supply Elasticities		
State	Price	IC	Clim
AZ	7.6760	-3.0861	-
CA	4.3186	-1.7575	0.1126
CO	-	-	-
ID	6.9037	-2.8721	-
MT	6.4077	-2.6084	0.2819
NM	2.4342	-1.0359	-
NV	6.6334	-2.7028	-
OR	3.4659	-1.4370	-
UT	2.9606	-1.2406	-
WA	-	-	-0.2145
WY	-	-	-

Note: Full output can be found in the Appendix. Statistically significant coefficients. All reported coefficients are significant at the 10% level.

Full output from state estimations with CDD and HDD separate can be found in the Appendix. Results from their combined series are not provided as they do not differ significantly from the estimations with CDD and HDD isolated. The estimations perform well with high *F*-statistics. In general Durbin-Watson statistics are close to 2 indicating that autocorrelation is not impacting results.

Section 6 Conclusion

The study has estimated various energy elasticities for states in the Western United States. The estimation of a supply and demand system rather than only a demand curve is another contribution to the literature. Results suggest that demand in energy markets responds more to short run shocks than long run responses. Supply side estimates provide insight into how quantity supplied responds to various shocks. The supply side of energy markets is typically not captured in elasticity studies.

A second extension of the study is the use of an aggregate energy consumption measure. Sources of energy will likely evolve in the future due to renewable sources becoming more prominent and changes in the relative prices of non-renewables. Aggregate measures allow for a more robust understanding of how changes in demand side variables impact final energy consumption. Energy demand being a derived demand and energy's integral role in the economic growth process indicates that estimations of changes to overall consumption provide a complement to estimates of changes within specific energy markets.

The study does suffer from a few limitations. In only 4 of the 11 states analyzed are price elasticities significant and theoretically consistent for both sides of the market. These states are California, Idaho, Nevada, and Utah. It may be that state-level energy markets are not the appropriate geographical scope. The impact of CDD and HDD on supply and demand is surprising. As discussed earlier this could be a manifestation of the limited variation of climate on a state-by-state analysis. Finally, as discussed in Section 4 applying an aggregate measure of energy consumption has both benefits and limitations.

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Appendix State Estimation Output

Within this Appendix relevant output statistics for each state are presented. Estimations were performed with three-stage least squares. All variables are reported in natural logs. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. See Section 4 for data definitions.

Arizona

Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	4.1455	0.9843	4.2115	***
E_Price	-0.0315	0.0354	-0.8911	-
GSP	0.3441	0.0482	7.1367	***
MFG	-0.0860	0.0223	-3.8571	***
E_Con(-1)	0.4553	0.0735	6.1906	***
CDD	0.1250	0.0694	1.8019	*
HDD	-0.0202	0.0412	-0.4905	-
Supply				
C	-58.1761	10.8226	-5.3754	***
E_Price	7.3680	1.3798	5.3399	***
IC	-2.9627	0.5488	-5.3988	***
E_Con(-1)	0.4809	0.0867	5.5450	***
CDD	0.1067	0.0819	1.3015	-
HDD	0.0206	0.0472	0.4369	-

Demand	R^2	0.9963
Curve	adj. R^2	0.9955
	S.E.	0.0193
	DW stat.	1.9817
Supply	R^2	0.9948
Curve	adj. R^2	0.9939
	S.E.	0.0225
	DW stat.	1.4572

California				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	5.2301	1.5179	3.44571	***
E_Price	-0.0593	0.0303	-1.9563	*
GSP	0.1743	0.0380	4.58253	***
MFG	-0.0242	0.0286	-0.8467	-
E_Con(-1)	0.5293	0.1013	5.22595	***
CDD	0.0531	0.0304	1.74476	*
HDD	0.0664	0.0471	1.41078	-
Supply				
C	-30.0978	6.7458	-4.4617	***
E_Price	4.1310	0.9407	4.39166	***
IC	-1.6837	0.3770	-4.4661	***
E_Con(-1)	0.5468	0.1001	5.46236	***
CDD	0.0526	0.0307	1.7127	*
HDD	0.0811	0.0442	1.83375	**

Demand	R^2	0.9763
Curve	adj. R^2	0.9716
	S.E.	0.0199
	DW stat.	1.5085
Supply	R^2	0.9759
Curve	adj. R^2	0.9720
	S.E.	0.0198
	DW stat.	1.4698

Demand	Colorado Coeffic	Std. Err	t-Stat	Sig
C	3.9336	1.5952	2.4659	**
E_Price	-0.0951	0.0447	-2.127	**
GSP	0.2270	0.0658	3.44973	***
MFG	-0.1343	0.0416	-3.2263	***
E_Con(-1)	0.6435	0.1151	5.59035	***
CDD	-0.0005	0.0162	-0.0299	-
HDD	0.1294	0.0949	1.36338	-
	Supply			
C	-12.5665	9.2092	-1.3646	-
E_Price	1.4764	1.1854	1.2455	-
IC	-0.6370	0.4740	-1.3438	-
E_Con(-1)	0.9148	0.0890	10.2824	***
CDD	0.0014	0.0183	0.07629	-
HDD	0.1365	0.1074	1.2708	-

Demand	R^2	0.9899
Curve	adj. R^2	0.9879
	S.E.	0.0235
	DW stat.	2.1616
Supply	R^2	0.9870
Curve	adj. R^2	0.9850
	S.E.	0.0262
	DW stat.	2.0555

Idaho				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	4.8467	1.5004	3.23021	***
E_Price	-0.2336	0.0575	-4.0635	***
GSP	0.2743	0.0646	4.24398	***
MFG	0.0435	0.0606	0.71729	-
E_Con(-1)	0.4948	0.0991	4.992	***
CDD	0.0086	0.0234	0.36925	-
HDD	0.1375	0.0850	1.61793	-
Supply				
C	-54.5600	11.2692	-4.8415	***
E_Price	6.9926	1.4365	4.86789	***
IC	-2.9089	0.5862	-4.9625	***
E_Con(-1)	0.4988	0.0996	5.00562	***
CDD	0.0038	0.0226	0.16931	-
HDD	0.1335	0.0854	1.56368	-

Demand	R^2	0.9728
Curve	adj. R^2	0.9674
	S.E.	0.0304
	DW stat.	1.7341
Supply	R^2	0.9724
Curve	adj. R^2	0.9680
	S.E.	0.0302
	DW stat.	1.7860

Montana				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	0.3857	1.9086	0.20208	-
E_Price	-0.0620	0.0555	-1.1182	-
GSP	0.3493	0.0673	5.19314	***
MFG	0.3114	0.1045	2.98041	***
E_Con(-1)	0.3329	0.1371	2.4282	**
CDD	0.0360	0.0221	1.62672	-
HDD	0.2337	0.1127	2.07403	**
Supply				
C	-50.9496	13.3616	-3.8131	***
E_Price	6.3801	1.6569	3.85063	***
IC	-2.5979	0.6684	-3.8865	***
E_Con(-1)	0.4767	0.1429	3.33614	***
CDD	0.0185	0.0238	0.77687	-
HDD	0.2807	0.1242	2.2594	**

Demand	R^2	0.7785
Curve	adj. R^2	0.7342
	S.E.	0.0410
	DW stat.	1.4204
Supply	R^2	0.7253
Curve	adj. R^2	0.6810
	S.E.	0.0449
	DW stat.	1.5471

New Mexico

Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	1.4521	2.5534	0.5687	-
E_Price	-0.1056	0.1048	-1.008	-
GSP	0.0817	0.0846	0.96562	-
MFG	0.0317	0.0620	0.51082	-
E_Con(-1)	0.8602	0.1099	7.82555	***
CDD	-0.0298	0.0614	-0.4864	-
HDD	0.0799	0.1605	0.49763	-
	Supply			
C	-21.0267	11.0812	-1.8975	*
E_Price	2.6569	1.3806	1.92441	*
IC	-1.1211	0.5760	-1.9463	*
E_Con(-1)	0.8357	0.0992	8.42222	***
CDD	-0.0276	0.0614	-0.4488	-
HDD	0.0856	0.1606	0.53266	-

Demand	R^2	0.9413
Curve	adj. R^2	0.9296
	S.E.	0.0409
	DW stat.	2.2103

Supply	R^2	0.9409
Curve	adj. R^2	0.9314
	S.E.	0.0404
	DW stat.	2.1675

	Nevada			
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	3.0510	0.9462	3.22448	***
E_Price	-0.0889	0.0378	-2.3479	**
GSP	0.3166	0.0634	4.99239	***
MFG	-0.0522	0.0377	-1.3845	-
E_Con(-1)	0.6194	0.0811	7.63287	***
CDD	-0.0074	0.0504	-0.147	-
HDD	0.0217	0.0659	0.3298	-
	Supply			
C	-53.0149	11.2799	-4.6999	***
E_Price	6.6627	1.4094	4.72746	***
IC	-2.7154	0.5637	-4.8172	***
E_Con(-1)	0.6197	0.0832	7.44633	***
CDD	-0.0035	0.0516	-0.0675	-
HDD	0.0393	0.0663	0.59265	-

Demand	R^2	0.9974
Curve	adj. R^2	0.9968
	S.E.	0.0229
	DW stat.	1.6778
Supply	R^2	0.9972
Curve	adj. R^2	0.9968
	S.E.	0.0231
	DW stat.	1.5376

Oregon				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	4.4140	1.2898	3.42235	***
E_Price	-0.0688	0.0443	-1.5518	-
GSP	0.2002	0.0308	6.50699	***
MFG	0.3116	0.0641	4.86227	***
E_Con(-1)	0.2686	0.0911	2.94775	***
CDD	-0.0194	0.0174	-1.1138	-
HDD	0.0632	0.0687	0.92023	-
Supply				
C	-27.1446	6.9671	-3.8961	***
E_Price	3.9372	0.9317	4.22563	***
IC	-1.6343	0.3793	-4.309	***
E_Con(-1)	0.5063	0.0984	5.14326	***
CDD	-0.0241	0.0222	-1.0827	-
HDD	0.0216	0.0872	0.24712	-

Demand	R^2	0.9620
Curve	adj. R^2	0.9544
	S.E.	0.0216
	DW stat.	2.0653
Supply	R^2	0.9377
Curve	adj. R^2	0.9276
	S.E.	0.0272
	DW stat.	1.7962

Utah				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	3.0824	1.9131	1.61117	-
E_Price	-0.1432	0.0648	-2.2107	**
GSP	0.1734	0.0754	2.30051	**
MFG	-0.0588	0.0678	-0.8663	-
E_Con(-1)	0.7310	0.1185	6.16747	***
CDD	-0.0145	0.0391	-0.3699	-
HDD	0.1288	0.1183	1.08902	-
Supply				
C	-24.4033	10.9356	-2.2315	**
E_Price	3.0885	1.4223	2.17145	**
IC	-1.2928	0.5685	-2.2742	**
E_Con(-1)	0.7513	0.1174	6.40066	***
CDD	-0.0100	0.0391	-0.2564	-
HDD	0.1509	0.1166	1.29384	-

Demand	R^2	0.9668
Curve	adj. R^2	0.9602
	S.E.	0.0386
	DW stat.	1.7448
Supply	R^2	0.9661
Curve	adj. R^2	0.9607
	S.E.	0.0384
	DW stat.	1.7188

Utah				
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	3.0824	1.9131	1.61117	-
E_Price	-0.1432	0.0648	-2.2107	**
GSP	0.1734	0.0754	2.30051	**
MFG	-0.0588	0.0678	-0.8663	-
E_Con(-1)	0.7310	0.1185	6.16747	***
CDD	-0.0145	0.0391	-0.3699	-
HDD	0.1288	0.1183	1.08902	-
Supply				
C	-24.4033	10.9356	-2.2315	**
E_Price	3.0885	1.4223	2.17145	**
IC	-1.2928	0.5685	-2.2742	**
E_Con(-1)	0.7513	0.1174	6.40066	***
CDD	-0.0100	0.0391	-0.2564	-
HDD	0.1509	0.1166	1.29384	-

Demand	R^2	0.9668
Curve	adj. R^2	0.9602
	S.E.	0.0386
	DW stat.	1.7448
Supply	R^2	0.9661
Curve	adj. R^2	0.9607
	S.E.	0.0384
	DW stat.	1.7188

	Wyoming			
Demand	Coeffic	Std. Err	*t*-Stat	Sig
C	3.2371	2.3447	1.38062	-
E_Price	-0.1481	0.1051	-1.4092	-
GSP	0.0941	0.0648	1.45042	-
MFG	0.2140	0.1033	2.07125	**
E_Con(-1)	0.6801	0.1101	6.17497	***
CDD	0.0109	0.0269	0.40518	-
HDD	-0.0375	0.1414	-0.2651	-
	Supply			
C	-14.8829	12.5254	-1.1882	-
E_Price	2.1316	1.5988	1.33323	-
IC	-0.9236	0.6787	-1.361	-
E_Con(-1)	0.8009	0.0987	8.11499	***
CDD	0.0071	0.0284	0.2519	-
HDD	-0.0604	0.1489	-0.4055	-

Demand	R^2	0.9474
Curve	adj. R^2	0.9368
	S.E.	0.0417
	DW stat.	1.8550
Supply	R^2	0.9413
Curve	adj. R^2	0.9318
	S.E.	0.0434
	DW stat.	1.9546

CHAPTER FOUR

WHAT IS THE IMPACT OF GOVERNANCE ON GENUINE INVESTMENT?

Section 1 Introduction

Savings and the level of investment are important determinants of an economy's output. Traditional measures of investment measure changes in manufactured capital. "Adjusted net or *genuine* saving measures the true level of saving in a country" (Hamilton, 2006, p. xv). This "true level" is indicative of changes in an economy's entire capital stock, or what Arrow et al. (2004) refer to as the "productive base." Arrow et al. (2004) describe the productive base as "consisting of society's capital assets and institutions" (p. 149). Arrow et al. (2004), Hamilton (2006), and Hamilton and Clemens (1999) are studies which have calculated genuine saving (investment) for numerous nations and regions finding important differences across the globe. Measures of investment saving convey important information regarding a nation's long term growth prospects.

The aforementioned studies do not account for the impact of institutions and governance on genuine investment. Instead they focus on the measurement of genuine savings' individual components. This focus includes both the theoretical underpinnings and the creation of the actual estimates. In this chapter, the impact of governance on genuine investment in energy-rich nations (defined in Section 4) will be estimated. Quantifying and accounting for changes in governance will provide a deeper understanding of what institutional characteristics influence genuine investment. To determine the relationship between governance and genuine investment numerous hypotheses will be tested. Hypotheses are motivated by a combination of economic theory and econometric concerns. The specific governance characteristics to be considered are democracy, stability, corruption, effectiveness, regulatory quality, and the promotion of the private sector. Measures of genuine investment which exclude environmental damages will also be considered. Regional and developmental differences will also be accounted for.

Genuine investment measures changes in produced, human, and natural capital as well as environmental damages (Hamilton, 2006, p. xv). *Ceteris paribus*, depletion of natural capital decreases a nation's level of genuine saving due to decreasing its capital assets. Investments in other forms of capital in turn increase genuine saving. Reinvesting a portion of economic rents from the depletion of non-renewable resources allows for the possibility of offsetting the decline in one component of genuine investment via increases in another. The possibility of increasing the productive base while depleting non-renewable resources has important implications for resource-based economies. It means that their economic performance need not be limited by declining non-renewable resources. By investing in other forms of capital, such as human, produced, and social forms, declines in non-renewable resources can be offset.

A priori, the expectation is that institutional quality is an important determinant of genuine investment and thus sustainable growth. Previous studies which measure the interaction of institutions and economic performance will be discussed in Section 4. Poor governance has the potential to hinder the sustainable management of an economy's resources. Weak institutions, ill-defined property rights, corruption, and so on may result in resource rents being used for nonproductive purposes.

The Hartwick rule provides the theoretical foundation for the sustainability criterion applied in the analysis. This rule is based upon Hartwick (1977) and Solow (1974 and 1986). The rule states that net investment must be greater than or equal to zero in order for an economy to be on a sustainable growth path. Energy-rich nations provide an interesting case study because of their divergent growth experiences. Within this sample casual observation indicates nations which seem to have succumbed to and eluded the resource curse. The resource curse is the notion that resource abundance deters economic growth.

The study will proceed as follows. Section 2 presents the findings of relevant literatures. Section 3 will presents the methodology. The theory applied relies on work by Arrow, Solow, and Hartwick. The empirical model will also be presented in Section 3. Data and its expected impact on genuine savings are addressed in Section 4. Results and how these results fit into the wider literature will be considered in Section 5. Numerous empirical specifications will be applied as a robustness check. The study concludes with Section 6.

Section 2 Literature and Background

2.1 Resource Curse

The motivation for exploring the impact of governance on genuine investment comes from multiple literatures devoted to analyzing the interaction of governance, environment, and economy. Elements from the resource curse and sustainability literatures will be presented in this section. By incorporating methodologies and findings from these literatures their relative strengths can be leveraged.

A priori, one would expect a large endowment of natural capital to be an economic blessing. The resource curse literature has found the opposite to be true. Numerous studies have found that an abundance of natural resources diminishes growth. Sachs and Warner (1995) is widely acknowledged as an important early study in the resource curse literature. The authors have since updated and extended their initial work on numerous occasions (Sachs and Warner; 1997, 1999, 2001). Subsequent studies have confirmed the initial finding that resource abundance is a drag on economic growth.

The majority of resource curse studies analyze the relationship between resources and growth from an income convergence perspective. Baumol (1986) and Barro and Sala-i-Martin (1992) are two early foundational studies in the income convergence literature. Income convergence studies often estimate income growth over a given time period as a function of various institutional and economic variables. The literature finds that in general, lower income economies grow at a faster rate than their higher income counterparts. This finding is conditional on numerous factors.

The income convergence methodology has become standard in the resource curse literature. For example, Sachs and Warner (2001) regress economic growth for a number of nations from 1970 to 1990 on proxies for natural resource abundance, trade openness, investment, rule of law, terms of trade, and economic growth from 1960 to 1969.

Papyrakis and Gerlagh's (2007) find that for states in the United States, natural resource abundance is a drag on income convergence. Resource abundance is found to decrease a state's openness, investment, and R&D spending while also increasing its corruption levels. This study is notable because of the institutional similarity between states. There are governance differences between states but they operate under the same federal system.

Numerous hypotheses have been put forth to explain the paradoxical resource curse. Gylfason (2006) offers an excellent summary of five channels by which dependence on resources may deter growth; the "Dutch disease," encouragement of rent seeking behavior, decreased incentives to invest in human capital, decreased demand for capital, and a lack of financial depth. The Dutch disease manifests itself via a nation's exchange rate. Volatile exchange rates potentially deter foreign investment and trade in other goods.

An economy dependent on the natural resource sector may also have a limited financial sector. A large percentage of a nation's investment being channeled to the natural resource sector may be to the detriment of growth in other sectors. As a result the economy's performance becomes increasingly reliant on the economic returns of the natural resource.

Rent seeking behavior is encouraged due to the many benefits associated with controlling resources. Gylfason (2006) suggests that the incentives to invest in education are diminished by natural resource abundance because they provide a source of non-wage income for the economy. Inadequate institutions, property rights, and rule of law may exacerbate individual (or all) of these channels. As a result over time the natural resource sector may come to dominate the domestic economy. Gylfason argues that an economy overly dependent on one sector decreases its long run growth potential.

Kalyuzhnova, Kutan, and Yigit (2009) uncover important transmission mechanisms by which energy-rich economies' can become more sustainable. They find that decreased business regulations and increases in democracy lead to lower levels of corruption. Corruption acts to reduce the growth rate and level of GDP per capita in these nations. One limitation of Kaluzhnova et al. is that their data set is limited in time series observation (averages from 1989 to 2006). Also, they use static measures of non-renewable resource production rather than changes in these forms of natural capital over time.

The resource curse is not universally agreed upon. Casual observation suggests counterexamples such as Norway and the United States. The economic growth of nations such as these does not appear to be adversely impacted by resource abundance. Brunnschweiler and Bulte (2008) assert that studies which support the notion of the resource curse do so because of model misspecification. Specifically, resource abundance measures used in estimations are more accurately measures of resource dependence. The distinction between resource abundance and dependence is important. Dependence suggests a more volatile economy-resource relationship. The economy's growth becomes intricately linked to the economic returns from the resource. Abundance suggests a relatively low opportunity cost of reaping the economic benefits from said resource. Controlling for resource dependence Brunnschweiler and Bulte do not find empirical support for the curse. Rather they find that resource dependence does not impact growth and resource abundance leads to better institutional quality and higher levels of growth.

Papyrakis and Gerlagh (2004) is another rejection of the resource curse. They find that when governance, terms of trade, and education are controlled for natural resources abundance positively impact growth. In both studies governance is an important control variable. These studies are outliers in the literature but suggest that there may be a weakness in the methodology or data applied in studies.

Neumayer (2004) investigated whether the resource curses exists when measured against measures of genuine income. Neumayer's study links the methodology of the resource curse with the concept of genuine investment which is sustainability-based measure. His findings confirm the presence of the resource curse.

Costantini and Monni (2008) combine the resource curse and environmental Kuznets curve methodologies finding that investments in human capital and good institutional development are necessary to achieve sustainable growth.

From the resource curse literature it is evident that democracy, institutional quality, and corruption are important determinants of long run growth. What is less clear is whether resources themselves deter growth or is it their impact on institutional development which leads to the resource curse. In order to address this ambiguity, important aspects of the sustainability literature will be applied in this study.

2.2 Sustainability

The sustainability literature provides a natural complement to the resource curse literature. The resource curse literature is inherently retrospective, asking what is the impact of resources on economic growth over a given period of time? In contrast, sustainability studies are forward looking, what are the impacts of decisions today on future growth? Before presenting the sustainability literature it is worth formally defining "sustainability" in this chapter.

Across disciplines sustainability is applied to a variety of issues. Even within the discipline of economics, sustainability is taken to mean a number of things. Application of sustainability criterions provide clarity to a term that is often used ambiguously. In the context of resource management the weak and strong sustainability criterions have drastically different implications. As Ayres (1998) notes, the fundamental premise of the strong sustainability criterion is a requirement that “minimum amounts of a number of different *types* of capital (economic, ecological, social) should be independently maintained” (p. 6). The weak sustainability criterion requires that net investment in an economy’s aggregate capital stock be non-negative.

A critical difference between the two criterions is the issue of substitutability between forms of capital. *Ecological Economics Volume 22* (1997) has numerous articles devoted to the issue of capital substitutability. Contributing authors include Herman Daly, Robert Solow, and Joseph Stiglitz. The strong criterion places stricter requirements on acceptable changes in capital stocks. Proponents of the strong criterion advocate precautionary management of ecosystems due to the irreversibility of many decisions. The strong criterion may be violated if a specific resource stock declines whereas the weak criterion allows for substitution between declining stocks given appropriate increases in another.

Consider a non-renewable resource such as oil. A nation may satisfy the weak sustainability criterion by drawing down its oil reserves while investing in education. The strong sustainability may require that a given amount of oil should not be extracted. In this study the weak sustainability criterion is applied. The study could be amended or expanded in the future to account for resource management issues from a strong sustainability criterion. Pearce, Hamilton, and Atkinson (1996) argue that genuine savings measures offer important information regarding the net change in an economy's assets regardless of whether the weak or strong sustainability criterion is applied.

The Hartwick rule has become a popular test of sustainability. Hartwick (1977) and Solow (1974 and 1986) have been influential in the formalization this rule. Dixit, Hammond, and Hoel (1980) and Farzin (2002, 2004, and 2006) are examples of extensions and clarifications of the Hartwick rule. Hamilton (2006) summarizes the rule and its implications stating "a constant level of consumption can be sustained if the value of (net) investment equals the value of rents on extracted resources at each point in time" (p. 49). The Hartwick rule requires that any declines in non-renewable forms of capital must be offset by increases in other forms of capital for sustainable growth to be met. When this occurs consumption need not decline.

Hamilton, Ruta, and Tajibaeva (2006) perform a counterfactual analysis to determine the capital stock that would exist on a per nation basis if nations applied the Hartwick rule. They find that in nations where resource rents make up more than 15% of GDP the Hartwick rule has not been followed. These nations are investment much less than the rule requires. This suggests that on average, resource rich nations are not on sustainable growth paths, as defined by the Hartwick rule. Additionally, the authors show that a constant positive level of genuine investment allows consumption to not be bounded. A formal expression of the Hartwick rule will be presented in Section 3.

In order to test for whether a nation's investment is meeting the Hartwick rule accurate measures of the various component of its productive base are necessary. Accurately measuring the productive base has many challenges, proper valuation of changes in natural capital being perhaps the biggest. Valuation of changes in natural capital is less established than its manufactured capital counterpart. Implicit in creating accurate values is the assessment of the economic rents which accrue from the extraction of natural resources. Kirk Hamilton at The World Bank has been a prominent researcher in creating measures of the net investment in natural capital. These estimates are used to create genuine savings measures. Genuine savings measures rely on adjusting national savings for changes in natural capital. Hamilton (2006) outlines the methodology behind the substantial amount of work which has been done in this area.

Hamilton and Clemens (1999) is an early publication of genuine savings estimates. They find genuine savings to be negative in Sub-Saharan Africa. This paper also outlines the theoretical foundation for estimating genuine savings measures. Arrow et al. (2004) show that genuine savings is negative for certain regions of the world, particularly Sub-Saharan Africa and the Middle East and North Africa regions. This paper will be addressed in greater detail in Section 3.

These studies show that genuine savings is negative for particular regions of the world. Once changes in various capital stocks are created the estimate of genuine savings measures is by and large an exercise in accounting. These studies do not formally decompose what is driving negative genuine savings. In this chapter the role of governance will be explicitly accounted for.

The resource curse literature suggests that poor governance increases the likelihood of natural resource management not increasing economic growth. If natural resource abundance (or dependence) is a drag on growth it extends that it may limit investment in the economy's productive base as well.

Section 3 Model and Methodology

3.1 Theoretical Model

The following social welfare function provides the theoretical foundation for the analysis:

$$(3.1.1) \qquad V(t) = \int_t^\infty e^{-\delta(s-t)}\, U(C(s))ds,$$

where t is time, δ is the discount rate, U(C) is the utility from consumption, C(t) is consumption, and V(t) represents intertemporal social welfare. Utility and thus social welfare are based upon society's consumption. Non-decreasing welfare, a common interpretation of sustainability criterion requires:

$$(3.1.2) \qquad \frac{\partial V(t)}{\partial t} \geq 0 \text{ ,}$$

or that the change in social welfare across time is non-negative. This interpretation does allow for the change in the value function to be zero which is the case if genuine investment is exactly enough to meet the Hartwick rule.

Arrow, Dasgupta, and Mäler (2003) apply a Ramsey-Solow model to explore several sustainability issues in imperfect economies. Critical to their analysis is the idea that a nation's wealth is a function of its capital assets. Expressing social welfare over time as a function of wealth it follows that the social welfare function V(·), can be expressed as a function of an economy's capital (Arrow, Dasgupta, and Mäler; 2003). An economy's aggregate capital stock can be divided into two forms of capital, non-resource and resource capital. Let **K**(t) be the vector of non-resource capital and **R**(t) the vector of resource capital. Non-resource capital includes manufacturing equipment, buildings, human capital, and so on. Let an individual form of resource capital be denoted R_j, $j = 1,$

…. , N and non-resource capital K_i, $i = 1, \ldots, M$. The social welfare function, V(t) becomes V(**K**, **R**).

Inequality (3.1.2) will be expanded to account for changes in an economy's productive base. The Hartwick rule provides the criterion to do so. Arrow (1986) defines the rule as "at each instant it invests in reproducible capital goods the competitive rents on its current use of the wasting resource," when the rule is met "society can maintain a constant stream of consumption" (p. 144). The rule links investment, consumption, and social welfare.

First, changes in capital assets (the entire capital stock) will be considered. In order to quantify the economic value of changes in capital stocks appropriate prices must be determined. Let shadow (or accounting) prices of non-resource and resource capital (K_i and R_j respectively) be represented by:

$$(3.1.3)\quad \frac{\partial V(\boldsymbol{K},\boldsymbol{R})}{\partial K_i} = \lambda_i \ \&$$

$$(3.1.4)\quad \frac{\partial V(\boldsymbol{K},\boldsymbol{R})}{\partial R_j} = \lambda_j \ .$$

Via the chain rule (3.1.2) becomes:

$$(3.1.5)\quad \sum_{i=1}^{M} \lambda_i(t)\,\dot{K}_i(t) + \sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t) \geq 0 \ .$$

where λs represent shadow prices and $\dot{K}_i(t)$ (or $\dot{R}_j(t)$) represents the time derivative of the respective capital stock, or investment. A negative time derivative on a particular stock implies a decrease in physical amount of the stock. The left hand side of (3.1.5) represents the net present value of the change in the economy's capital assets across time, also termed genuine investment. When genuine investment is positive the weak sustainability criterion has been satisfied.

Inequality (3.1.5) captures the wealth management aspect of the weak sustainability criterion and Hartwick rule. As Hamilton and Hartwick (2005) note "investing exhaustible resource rents in produced capital and its extension, 'zero net investment,' is an intrinsic part of Solow's (1974) original and generalized constant consumption model Hartwick (1977)" (p. 615). The net investment condition is evident in (3.5). When resource capital stocks decline, (3.1.5) can only be satisfied if investments in non-resource capital stocks are positive. Additionally, the value of the investment in non-resource capital must be greater than or equal to the value of the decline in resource capital. In the case of the declines and increases being equal 'zero net investment' exists. Inequality (3.1.5) could be expanded or amended to represent the strong sustainability criterion. For instance, $\dot{R}_j(t) \geq 0$ could embody constraint requiring that the change in a specific form of resource capital be non-negative across time.

3.2 Empirical Model & Estimation Strategy

Inequality (3.1.5) is amended to create an estimable test of sustainability:

$$(3.2.1)\quad \sum_{i=1}^{M} \lambda_i(t)\, \dot{K}_i(t) = (1+\alpha(t))\left[-\sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t)\right],$$

where α(t) is a parameter whose sign will indicate whether an economy's net investment is meeting the Hartwick rule at time t. Rearranging (3.2.1) to isolate genuine investment:

$$(3.2.2)\quad \sum_{i=1}^{M} \lambda_i(t)\, \dot{K}_i(t) + \sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t) = -\alpha(t)\left[\sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t)\right].$$

If the left hand side is positive, then α(t) > 0, assuming non-increasing investment in resource capital ($\dot{R}_j < 0$).

Genuine savings has been estimated to be negative for certain regions and nations (Arrow et al., 2004; Hamilton, 2006). But as Arrow et al. (2004) note an economy's productive base "consists of society's capital assets and institutions at time *t*" (p. 149). Measures of genuine savings are capturing the change in capital assets but do not account for institutions. A decomposition of α(t) has the potential to uncover the impact of institutions and other characteristics on genuine savings. That is, α(t) can be considered a function of social characteristics; α(t) = f(**Z**), where **Z** is a vector, **Z** = (1, Z_1, Z_2, … , Z_K). Substituting into (3.2.2) and assuming a linear functional form for f(**Z**) yields:

$$(3.2.3)\ \sum_{i=1}^{M} \lambda_i(t)\,\dot{K}_i(t) = (1 + Z'\alpha(t))\left[-\sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t)\right].$$

where α(t) is an estimable parameter vector. Equation (3.2.3) provides a richer treatment of genuine investment by considering more than changes in capital assets. Now, genuine investment is a function of social characteristics and the change in the value of resource capital.

Let $VR_t = \sum_{j=1}^{N} \lambda_j(t)\dot{R}_j(t)$ and $VK_t = \sum_{i=1}^{M} \lambda_i(t)\,\dot{K}_i(t)$. The data applied in the estimations (presented in Section 4) expresses declines in R_t as a positive value. Therefore (3.2.3) becomes:

$$(3.2.4)\ \ VK_t - VR_t = Z'\alpha(t)VR_t\ .$$

where VK_t – VR_t is genuine investment (GI_t) and the sign of Z'α(t) indicates the sign of genuine investment. Finally, (3.2.4) can be rewritten to explicitly detail the decomposition of α(t) by the various characteristics found in **Z**:

$$(3.2.5)\ GI_t = \alpha_0 + \alpha_1 Z_{1t}\,VR_t + \alpha_2 Z_{2t}\,VR_t + \ldots + \alpha_K Z_{Kt}\,VR_t\ .$$

With a few modifications (3.2.5) provides the basis for empirical estimations. First, an error term must be included; it will capture any unobservable characteristics within the data. A panel data approach is applied in estimations. Specific data used are presented in Section 4. In order to control for unobservable time-invariant cross-section characteristics the fixed effects (FE) estimator is applied. The estimator will capture the within variation, variation in the data within the cross-section unit of observation (nations). Time effects are also used to control for events which may have impacted the entire sample. The FE estimator of (3.2.5) is:

$$(3.2.6)\ GI_{it} = \gamma_i + \gamma_t + \alpha_0 + \alpha_1 Z_{1it} R_{it} + \alpha_2 Z_{2it} R_{it} + \ldots + \alpha_K Z_{Kit} R_{it} + \varepsilon_{it}$$

where i is the country index, t is a time index, GI_{it} is genuine investment, γ_i is the country fixed effect, γ_t are the time fixed effects, $Z_{1it}, \ldots, Z_{Kit}$ are the characteristics to be included in the estimation, R_{it} is the net present value of investment in resource capital, and ε_{it} is an unobservable mean-zero random variable.

Estimated coefficients will determine how country characteristics impact genuine investment (savings). For example, the marginal impact of Z_1:

$$(3.2.7)\ \frac{\partial GI}{\partial Z_1} = \alpha_1 R\ .$$

This indicates that the impact depends on the value of R as well as the estimated coefficient. In this way R acts as a scaling factor. In estimations **Z** will be compromised of various governance measures including the level of corruption. In the preceding example if Z_1 is the corruption proxy, (3.2.7) represents the marginal change in genuine investment given a change in corruption.

Section 4 Data

4.1 Overview

The data set applied in estimations represents energy-rich nations. The definition of energy-rich is based upon Kalyuzhnova, Kutan, and Yigit's (2009). To be considered “energy-rich” a nation must have at least 0.2% of proven world reserves in either oil or gas. These measures are taken from *The BP Statistical Review of World Energy* (2010).

Energy-rich nations offer an interesting sample because of the spectrum of development and economic growth they represent. The sample captures nations that appear to have succumbed to and eluded the resource curse. Within the data that measures changes in resource capital non-renewable energy sources are one of the most established components. The full list of nations analyzed can be found in Table 4.1 of the Appendix. A total of 55 nations are included in the data set. For many of the nations full data are not available. When results are presented the number of cross-section units applied in estimations will be listed.

Hamilton (2006) outlines the steps involved with estimating genuine investment and its various subcomponents. Genuine investment equals gross national savings minus consumption of fixed capital plus expenditures on education minus the value of resource depletion and environmental degradation damages (Hamilton, 2006, p. 36 – 37). Two measures of genuine investment are available, with and without particulate emission damages (denoted GI and GIX respectively).

Net national savings (NNS) and education expenditures (Educ) serve as proxies for the net present value of the change in non-resource capital, VK_{it}. Net national savings is gross national savings minus depreciation. It measures the change in manufactured capital for the economy in a given year. Education expenditures serve as a proxy for investment in human capital. Educ includes operating expenses as well as educator salaries. NNS and Educ and the other data capturing net investment in particular forms of capital are from the World Bank’s *World Development Indicators*. Quoted definitions of the series are presented in Table 4.2 of the Appendix. All data have been converted to 2000 US dollars via the United States GDP deflator.

Several variables are used to capture the change in the resource capital stock. Measures of energy and mineral depletion, net forest depletion, as well as carbon dioxide and particulate matter damages are used in the study. Energy depletion (Energy) estimates total rents from the extraction of crude oil, natural gas, and coal. Mineral depletion (Mineral) is an estimate of rents from mineral extraction including bauxite, copper, iron, lead, nickel, phosphate, tin, zinc, gold, and silver. In the creation of these measures new discoveries are not included in the stock of resource capital due to the total world supply being fixed (Arrow et al., 2004, p. 160). This means that measures only capture depletion. Net forest depletion (Forest) is a measure of rents that occur from harvesting timber above its natural growth rate. In the case when growth exceeds harvest the measure is set equal to zero (Hamilton, 2006, p. 37).

It is important to note that market prices are used to calculate rents. As such many of the resource specific prices may be artificially low due to not accounting for externalities. The extent to which this occurs will bias genuine investment measures upwards because an artificially low value of resource depletion is subtracted from savings.

Carbon dioxide damages (CO2) are calculated based upon the nation's CO_2 emissions for the year. Damages are calculated by applying a global average of marginal damages obtained from Fankhauser (1994) (Hamilton, 2006, p. 38). Particulate matter damage (PartDam) is a measure of willingness to pay to avoid death attributed to these types of emissions. Measures of willingness to pay are based upon Pandey et al. (2005)

(Hamilton, 2006, p. 38). In certain estimates only energy, mineral, and forest depletion will be considered. The measures of environmental damages are removed from the series.

Countries for which data does not exist for some or all the resource capital variables include Iraq, Libya, Myanmar, Nigeria, Qatar, Turkmenistan, and Yemen. When data exists for a nation, in general it is available from 1970 – 2008. This is not the case for particulate damage which is calculated from 1990 – 2008. Table 4.3 presents descriptive statistics of the genuine investment data.

Table 4.3 Descriptive Statistics of Genuine Investment Data

	GI	GIX	NNS	EDUC	ENERGY
Mean	513,347,252	470,537,955	387,600,338	187,595,588	105,048,495
Median	62,585,381	64,225,595	92,262,583	21,383,262	30,634,989
Max	13,557,903,611	13,850,159,394	15,990,532,489	5,634,486,760	2,748,854,841
Min	-317,861,420	-624,565,675	-1,128,452,285	23,375	0
Std. Dev.	1,443,577,878	1,364,210,979	1,003,535,379	640,083,458	229,203,189
Obs.	748	1,232	1,360	1,531	1,798

	FOREST	CO2	PARTDAM	MINERAL
Mean	2,265,110	18,348,667	14,510,721	4,860,184
Median	0	3,105,275	1,875,323	52,642
Max	86,204,604	413,014,539	347,968,013	302,689,590
Min	0	0	0	0
Std. Dev.	8,950,224	51,735,264	44,145,687	17,573,823
Obs.	1,722	1,798	949	1,798

Note: Genuine investment measures are from the World Bank's World Development Indicators. Gross national savings is used in the estimation of genuine investment but is not included in the table.

Several variables are used to serve as governance proxies. The *World Governance Indicators* (WGI) from the World Bank provide six governance metrics. These are Voice and Accountability (Account), Political Stability and Absence of Violence/Terrorism (Stable), Government Effectiveness (Effect), Regulatory Quality (Regqual), Rule of Law (Law), and Control of Corruption (Corrupt). Each indicator is calculated for 1996, 1998, 2000, and 2002 – 2009. These data are calculated from survey data. As such they capture respondents' perception of the various indicators. For more detailed description of how the measurements are calculated see Kaufmann, Kraay, and Mastruzzi (2010). These data will be considered individually in estimations. Section 4.3 outlines some of the limitations of the WGI data.

The second source of governance data are from the Integrated Network for Societal Conflict Research (INSCR). Their *Polity2* (Polity for the remainder of the paper) measure is used as a proxy for level of democracy within an economy. Marshall (2010) pages 14 – 15 provide a detailed description regarding the estimation of this variable. When Polity is used as a democracy proxy Brunei, Iraq, Libya, Myanmar, Nigeria, Qatar, Turkmenistan, United Arab Emirates, and Yemen are not included in the estimation. For most nations Polity measures are from 1970 – 2008. Table 4.4 lists descriptive statistics of governance data.

Table 4.4 Descriptive Statistics of Governance Measures

	Account	Corrupt	Effect	Law	RegQual	Stable	Polity
Mean	-0.4639	-0.1836	-0.0977	-0.2181	-0.1555	-0.3543	-0.6979
Median	-0.6738	-0.3806	-0.2589	-0.4502	-0.2307	-0.3017	-4
Max	1.8267	2.4359	2.2369	1.9640	3.3453	1.4548	10
Min	-2.1859	-1.8257	-2.1333	-2.0474	-2.8412	-3.0786	-10
Std. Dev.	1.0360	1.0423	0.9943	1.0061	1.0309	0.9893	7.7144
Obs.	550	549	549	550	550	550	2304

Note: Polity is published by Integrated Network for Societal Conflict Research. All other governance variables are from the World Bank's World Governance Indicators.

Dummy variables are applied to determine whether there are regional or development differences within the data set. A Middle East and North Africa (MENA) regional dummy variable will be applied. MENA nations included in the data set are Algeria, Bahrain, Egypt, Iran, Iraq, Kuwait, Libya, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen. For many of these nations there are data limitations so they will not be included in estimations. Genuine investment data is not available for Algeria, Iraq, Libya, Qatar, United Arab Emirates, and Yemen. OECD member nations within the data set include Australia, Canada, Denmark, Germany, Italy, Mexico, Norway, Poland, United Kingdom, and United States. With the exceptions of Mexico and Poland the OECD dummy will also control for high income nations.

4.2 Expected Relationships

The findings of numerous studies can be drawn upon to formulate expectations of the interaction between institutional quality and genuine investment. Stiglitz (2002) offers a compelling discussion of the importance of governance in long run development and sustainability. Political turmoil and instability have been shown to decrease economic growth (Alesina, Özler, Roubini, and Swagel; 1996). While the causes of political turmoil are multifaceted economic circumstances play a role.

Gylfason (2001) discusses the phenomenon that nations with higher levels of resource abundance typically have higher levels of corruption. If corruption exists within a political structure that emphasizes investment (public work projects) it is possible that increases in corruption increase genuine investment. On the other hand, Mo (2001) finds that corruption decreases private investment indicating increases in corruption would decrease genuine investment. Aidt, Dutta, and Sena (2008) show that the impact of corruption on growth depends on the institutional climate of a nation. In nations with low quality institutions an increase in corruption has a bigger negative impact on growth than in nations with high quality institutions.

Democracy is another important institutional consideration. As democracy increases members of society are be able to exercise their preference for the use of rents from resource depletion and for public investment. Preferences may be manifested in a number of ways ranging from the creation and management of sovereign wealth funds to education expenditures.

There are reasons to believe the level of democracy may impact genuine savings positively or negatively. Barro (1996) finds that when the level of democracy is low increases causes increases in economic growth while at high levels of democracy a marginal increase reduces growth. Farzin and Bond (2006) show that democracy provides a mechanism for society to express environmental preferences. Genuine saving captures environmental damages so the level of democracy will likely impact genuine savings given the extent to which social preferences can be manifested.

4.3 Data Limitations

One potential weakness of the study stems from the correlation among the institutional variables. It is possible that governance scores for a nation move together from year-to-year. As discussed in Section 4.1 these variables are created via surveys. In the case that the governance proxies are measuring overall quality of governance their scores may be highly correlated. Compounding this problem some of the proxies measure similar aspects of governance. For instance, ReqQual captures the perception of government's promotion of the private sector while Effect the quality of policy.

High correlation between governance variables may cause the estimations to suffer from multicollinearity. Gujarati (2003) outlines many of the potential consequences which may arise in the presence of multicollinearity. Particularly relevant to this study is the impact on estimated coefficients. Variances and covariances tend to be larger causing *t* ratios to be statistically insignificant. A second potential consequence is that estimated coefficients from OLS can be sensitive to subtle data changes (Gujarati, 2003, p. 350).

Gujarati (2003) notes "pair-wise correlations may be a sufficient but not necessary condition for the existence of multicollinearity" (p. 372). The pair-wise correlations among the institutional variables are presented in Table 4.5. The highest correlation is between Corrupt and Law, 0.95. The lowest correlation among the WGI is between Account and Stable, 0.58. The high correlation (0.86) between Account and Polity is not surprising, both are democracy measures. Polity is not as correlated with the other WGI as Account is. This will be addressed in the estimation of the full model.

Table 4.5 Pair-Wise Correlation Coefficients for Governance Variables

	Account	Effect	Law	Polity	RegQual	Stable	Corrupt
Account	1	0.8043	0.7671	0.8586	0.8224	0.5843	0.7769
Effect	0.8043	1	0.9536	0.5159	0.9267	0.7602	0.9529
Law	0.7671	0.9536	1	0.4285	0.9015	0.8143	0.9535
Polity	0.8586	0.5159	0.4285	1	0.5607	0.2546	0.4504
RegQual	0.8224	0.9267	0.9015	0.5607	1	0.7010	0.8898
Stable	0.5843	0.7602	0.8143	0.2546	0.7010	1	0.7555
Corrupt	0.7769	0.9529	0.9535	0.4504	0.8898	0.7555	1

In the future, the author intends on incorporating more data series into the analysis. The Index of Economic Freedom from the Heritage Foundation and Wall Street Journal provides one extension. This index measures freedom for a variety of areas including business, trade, and labor freedom. By expanding governance and institutional measures the multicollinearity issues presented in Section 5 may be alleviated. The application of different data series from a variety of sources should diminish pair-wise correlation allowing for a more accurate representation of the impact of **Z** genuine investment.

Section 5 Estimation and Results

In this section estimations which test the hypotheses presented in the Introduction will be presented. *A priori*, the expectation is that all of the governance variables should impact genuine investment. As discussed in Section 4.3 despite the intended uniqueness of WGI there is high pair-wise correlation between them. The likelihood that multicollinearity will impact results will be tested to determine if all the governance proxies can be included in estimations.

The first hypothesis to be tested is in regards to the relationship between resource capital and genuine investment. Given the definition of genuine investment it seems likely that there is a negative relationship. It is possible that investment levels in energy-rich nations are sufficient to offset the expected decline in genuine investment from increases in resource capital depletion.

The initial estimation prior to any inclusion of governance variables takes the form:

$$(5.1) \quad GI_{it} = \gamma_i + \gamma_t + \alpha_o + \alpha_1 R_{it} + u_{it} .$$

Results can be found in Table 4.6. In these estimations the R vector serves as the primary explanatory variable, none of the other country characteristics have been included. The significance of α_1 is sensitive to the inclusion of lags. A consensus does not emerge regarding the qualitative relationship between GI and R. This could be due to not accounting for other determinants of genuine investment.

Table 4.6 Estimation with Resource Capital

Dep Var GI

Variable	Coeffic	Std. Error	Coeffic	Std. Error	Coeffic	Std. Error
C	252598801***	34960877	-25932607***	16471591	12693254***	1.6E+07
R	1.4455***	0.1447	-0.1741**	0.0695	-0.0270	0.0646
GI(-1)	-		1.1613***	0.0215	1.6559***	0.0424
GI(-2)	-		-		-0.6582***	0.0505
R^2	0.8218		0.9687		0.9756	
adj. R^2	0.8057		0.9657		0.9731	
F-stat	50.9614		318.6626		389.2757	
DW stat.	0.2564		1.034406		1.8656	
N	748		701		655	
T	1990 - 2008		1991 - 2008		1992 - 2008	
M	44		44		43	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T, *M* denote number of observations, time period, and number of cross-section units applied.

The low Durbin-Watson statistic for the first estimation, 0.26 indicates positive autocorrelation may be impacting the results. Lagged GI terms are included to address potential autocorrelation. For this reason the remainder of estimations will also include GI lagged twice. The high explanatory power of these lagged terms causes the R^2 measure to be quite large. High R^2 are consistent across the estimations presented in this section.

The second hypothesis to be tested is in regards to the impact of location and development on GI. Two categories of dummy variables are applied in this estimation. A regional dummy is created for countries that are located in the Middle East and North Africa region (MENA). Nations within the data set that are members of the MENA region are Bahrain, Egypt, Iran, Kuwait, Oman, Saudi Arabia, Syria, and Tunisia. Other nations within the region that are categorized as energy-rich are not included due to a lack of data. The second dummy applied is for OECD membership. OECD member nations within the data set include Australia, Canada, Denmark, Germany, Italy, Mexico, Norway, Poland, United Kingdom, and United States. With the exceptions of Mexico and Poland the OECD dummy is also a control for high income nations.

The estimation takes the form:

$$(5.2)\quad GI_{it} = \gamma_i + \gamma_t + \alpha_o + \alpha_1 R_{it} + \alpha_2 R * MENA_{it} + \alpha_3 R * OECD_{it} + \alpha_4 GI_{it-1} + \alpha_5 GI_{it-2} + u_{it} \ .$$

In this specification all the coefficients of interest are statistically significant. If a nation is neither a member of the OECD or MENA region an increase in R causes an increase in GI. Both the MENA and OECD dummies have a negative relationship with GI. This suggests that regional or developmental differences across countries impact the relationship with GI. MENA's negative sign is not surprising OECD's is. The model predicts that OECD membership causes a larger decline in GI than MENA membership. Studies such as Hamilton (2006) find that for many developed nations GI is positive, their productive bases are increasing over time while many nations in the MENA region have negative GI levels.

Table 4.7 Regional & Development Categories

Dep Var: GI

Variable	Coeffic	Std. Err
C	65947987***	16006829
R	0.3111***	0.0731
R*MENA	-0.3452**	0.1460
R*OECD	-1.1400***	0.1207
GI(-1)	1.4929***	0.0433
GI(-2)	-0.5356***	0.0489

R^2	0.9788
adj. R^2	0.9766
F-stat	433.8432
DW stat.	1.9754
N	655
T	1992 - 2008
M	43

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T, *M* denote number of observations, time period, and number of cross-section units applied.

The next set of estimations seeks to capture the impact of governance on GI. Results can be found in Table 4.8. Due to the high pair-wise correlation between WGI the model will be estimated with each indicator individually as well as Polity. In four of the seven estimations R's estimated coefficient is significant and negative. This contrasts with the findings of the previous estimations. When governance is controlled for an increase in resource depletion causes a decline in GI.

Table 4.8 Estimation with Individual Governance Indicators

Dep Var: GI

	Account		Polity		Corrupt		Effect	
Variable	Coeffic	Std. Err	Coeffic	Std. Err	Coeffic	Std. Err	Coeffic	Std. Err
C	128750015	29474341	78025809***	16219333	42821272	26537948	-406913	25217597
R	-0.5210***	0.0891	0.0834	0.0611	-0.2143***	0.0805	0.0010	0.0856
$R*Gov_i$	-0.5286***	0.0629	-0.0653***	0.0066	-0.4504***	0.0732	-0.4616***	0.0949
GI(-1)	1.4591***	0.0531	1.5085***	0.0422	1.4831*	0.0561	1.5616***	0.0539
GI(-2)	-0.4746***	0.0617	-0.5921***	0.0474	-0.4062*	0.0663	-0.4644***	0.0660
R^2	0.9793		0.9791		0.9775		0.9766	
adj. R^2	0.9760		0.9769		0.9740		0.9730	
F-stat	300		452		275		265	
DW stat.	2.0859		1.9383		1.9967		2.0150	
N	42		42		42		42	
T	1996 - 2008		1992 - 2008		1996 - 2008		1996 - 2008	
M	397		651		397		397	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Gov_i refers to the individual governance variable applied in the estimation. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. N, T, M denote number of observations, time period, and number of cross-section units applied.

Table 4.8 Continued

Dep Var: GI

	Law		Stable		RegQual	
	Coeffic	Std. Err	Coeffic	Std. Err	Coeffic	Std. Err
C	30438733	24964072	5296723	25457003	17412238	25476255
R	-0.1323*	0.0779	-0.3196***	0.0895	-0.0329	0.0819
R*Gov_i	-0.468***	0.0645	-0.5088***	0.1048	-0.4656***	0.0815
GI(-1)	1.5105***	0.0528	1.5742***	0.0535	1.5248***	0.0545
GI(-2)	-0.4465***	0.0635	-0.4598***	0.0662	-0.4584***	0.0652
R^2	0.9784		0.9766		0.9772	
adj. R^2	0.9749		0.9730		0.9736	
F-stat	286		265		272	
DW stat.	2.1301		2.1031		2.0984	
N	42		42		42	
T	1996 - 2008		1996 - 2008		1996 - 2008	
M	397		397		397	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Gov_i refers to the individual governance variable applied in the estimation. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T, *M* denote number of observations, time period, and number of cross-section units applied.

Each of the governance variables is found to be significant with a negative sign. The range of estimates of the WGI is between -0.53 and -0.45. The high correlation between the WGI and comparable coefficients suggests despite the intention to capture different aspects of governance the data are measuring the same thing.

Given the similarity of results between Account and Polity it may be that WGI are acting as democracy proxies. Account is highly correlated with many of the WGI while Polity has a pair-wise correlation of 0.51 or lower with each WGI. Both Polity's and Account's estimated coefficients are negative but differ in absolute value. This is due to the different scales used in the variables' calculation. Polity scores range from -10 to 10. As a point of reference in 2008 a one unit increase represents the difference between India ($Polity_{2008}$= 9) and United States ($Polity_{2008}$ = 10) or Oman ($Polity_{2008}$ =-8) and Syria ($Polity_{2008}$ = -7). WGI based measures are reported to range from -2.5 to 2.5. A one unit increase in Account roughly represents the difference between the United States ($Account_{2008}$ = 1.07) and Mexico ($Account_{2008}$ = 0.08) in 2008.

A key difference between when Account or Polity is applied is the statistical significance of R's coefficient. When Polity is applied R is no longer individually significant in the estimation. A longer data set exists for Polity. When Polity is used 254 more observations are included in the estimation. It may be that over a longer time horizon changes in democracy dictate changes in GI rather than changes in resource capital.

Increases in the level of democracy reflect increases in the ability for citizens to express their preferences in governmental decisions. Estimates suggest that increases in democracy decrease genuine investment. This finding confirms those of Barro (1996). He finds that increases in democracy decrease economic growth in nations with a moderate level of democracy. Barro and this study's finding contradicts much of the resource curse literature. Gylfason (2006) offers discussion of the ways that increases in democracy can contribute to a nation avoiding the negative growth consequences of the resource curse. A non-linear specification is used in order to test for whether Barro's finding is confirmed. Table 4.9 presents the results.

Table 4.9 Non-linear Specification

Dep Var: GI

	Account		Polity	
Variable	Coeffic	Std. Err	Coeffic	Std. Err
C	157539487	29904011	96519386***	16047454
R	-0.8409***	0.1216	0.5401***	0.0961
$R*Gov_i$	-0.4074***	0.0696	-0.0637***	0.0064
$R*Gov_i^2$	0.2587***	0.0684	-0.008***	0.0013
GI(-1)	1.4247***	0.0529	1.4580***	0.0418
GI(-2)	-0.4965***	0.0608	-0.5421***	0.0467
R^2	0.9801		0.9803	
adj. R^2	0.9769		0.9782	
F-stat	306		472	
DW stat.	2.1340		2.0083	
N	42		42	
T	1996 - 2008		1992 - 2008	
M	397		651	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Gov_i refers to the individual governance variable applied in the estimation. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T, *M* denote number of observations, time period, and number of cross-section units applied.

The non-linear estimation both supports and contradicts the findings of the linear estimations of Account and Polity. The general representation of the second derivative is:

$$(5.3)\ \partial^2 GI \big/ \partial Gov_i^{\,2} = 2\alpha_4 R\ .$$

In both the linear and non-linear specifications both Account and Polity have a negative first derivative. In the non-linear specification the second derivative for Account is positive while Polity's is negative. The negative relationship between democracy and genuine investment is confirmed but the rate of a change in the two variables is qualitatively different.

The model consistently predicts that genuine investment declines as the level of democracy increases. To the extent that democracy allows for a nation's population to manifest its preferences in energy-rich nations the expectation is these preferences are not for increasing levels of genuine investment. Increases in democracy are predicted to move nations away from sustainable investment paths.

In the linear specification R's coefficient is negative with Account and not significant with Polity. In the non-linear specification the finding is confirmed for Account but now R's coefficient is positive for polity. The nature of the relationship between R and GI in these specifications is determined by the level of Account or Polity in a nation. The estimations are telling qualitatively different stories regarding marginal change in R.

The combination of multiple governance indicators is pursued to determine how multiple changes in governance impact GI. Table 4.10 outlines an estimation in which the qualitative findings are not robust. This is likely due to multicollinearity. Results are consistently sensitive to which WGI are included. Other estimations are not presented due to lack of robustness.

Table 4.10 Multiple Governance Measures

Dep Var: GI

Variable	Coeffic	Std. Err	Coeffic	Std. Err
C	80319323***	27570036	145236287***	30668465
R	0.0516	0.0821	-0.293***	0.1121
R*Polity	-0.0603***	0.0098	-0.0624***	0.0095
R*Effect	-0.2603***	0.0962	0.5172***	0.2006
R*Corrupt	-	-	-0.6774***	0.1545
GI (-1)	1.4678***	0.0537	1.3556***	0.0582
GI (-2)	-0.4842***	0.0631	-0.4046***	0.0641
R^2	0.9790		0.9801	
adj. R^2	0.9756		0.9769	
F-stat	292		302	
DW stat.	2.0703		2.0337	
N	41		41	
T	1996 -2008		1996 -2008	
M	393		393	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T*, M* denote number of observations, time period, and number of cross-section units applied.

In order to determine if resource depletion in and of itself has an impact on genuine investment a variant of the investment data is applied. Specifically, environmental damages were removed from the genuine investment and resource capital data. In the data two series capture environmental damages; particulate emission and carbon dioxide damages. A selection of results from estimations with environmental damages removed from the data series are found in Table 4.11. The qualitative findings of the model are robust to the exclusion of environmental damages.

Table 4.11

Dep Var: GI R

Variable	Coeffic	Std. Err	Coeffic	Std. Err	Coeffic	Std. Err	Coeffic	Std. Err
C	2398356	20645634	88989702***	26526281	54783248***	21220826	71923856***	21474778
Res	-0.0989	0.0711	-0.4676***	0.0844	0.25***	0.0862	0.0773	0.0706
Res*ACCT	-	-	-0.4973***	0.0624	-	-	-	-
Res*POLITY	-	-	-	-	-	-	-0.0669***	0.0085
Res*MENA	-	-	-	-	-0.2944*	0.1746	-	-
Res*OECD	-	-	-	-	-1.0369***	0.1439	-	-
GI R(-1)	1.6482***	0.0477	1.4703***	0.0528	1.5151***	0.0490	1.5226	0.0477
GI R(-2)	-0.62***	0.0600	-0.4804***	0.0618	-0.5626***	0.0576	-0.6094***	0.0566
R^2	0.9747		0.9783		0.9773		0.9777	
adj. R^2	0.9717		0.9749		0.9744		0.9750	
F-stat	318		287		341		358	
DW stat.	1.8772		2.1185		1.9823		1.9492	
N	42		42		42		41	
T	96 -08		96 -08		96 -08		96 -08	
M	398		398		518		514	

Notes: The overall regression intercept is denoted C. Results are from a fixed-effects estimations with both cross-section and period effects. GI_R refers to GI with environmental damages removed. Res refers to the change in resource capital with environmental damages removed. Levels of significance are 1, 5, and 10% and denoted ***, **, and * respectively. *N*, T, *M* denote number of observations, time period, and number of cross-section units applied.

5.1 Potential Weaknesses

The data applied in this study warrants numerous caveats regarding the strength of the results. The high pair-wise correlation between governance variables has been noted. Research such as this which considers long run development and growth issues would ideally apply a longer time series. A longer time series would presumably capture more variation in the data. Also, it would capture more of the economic development process. Currently, the time series is limited by the availability of governance proxies. The WGI are only available from 1996 onwards. A longer span of data would likely result in a clearer picture of the impact of governance on genuine investment.

In the theoretical model the productive base accounts for all forms of capital. Data availability necessitates the exclusion of many important forms of capital. For example, social capital is not accounted for. Investments in human capital are represented by education expenditures. Education expenditures are a standard proxy for investments in human capital but the true benefit of investment in human capital is the increases in labor's skills. Changes in skills are not captured by education expenditures.

Resource capital measures change in energy, mineral, and forests. Fisheries represent a notable exclusion. Environmental damages are represented by particulate emission damages and the expected impact of climate change. Measures of climate change impacts are associated with a high degree of uncertainty. Water and soil quality are not accounted for in the environmental damages data. The data applied represents an important portion of an economy's productive base but do not capture its changes entirely.

Section 6 Conclusion

The impact of governance on genuine investment has been analyzed in a variety of ways. Data capturing numerous aspects of governance were applied with limited effectiveness. WGI are intended to capture six different aspects of governance; democracy, corruption, effectiveness, stability, regulation quality, and the promotion of the private sector. Despite this intention, the high pair-wise correlation between the indicators suggests that the indicators are measuring one aspect of governance. The robustness of results pertaining to democracy suggests that individual WGI may be measuring democracy.

The qualitative findings of estimations are similar when two different democracy proxies are applied; the Integrated Network for Societal Conflict Research's Polity and the World Bank's Account. Increases in democracy are predicted to decrease genuine investment in energy-rich nations. This finding is robust to the exclusion of environmental damages from genuine investment and resource capital depletion measures. These estimations are not consistent regarding the fundamental relationship between resource depletion and genuine investment. This inconsistency may be due to a longer time series and more observations being available for Polity.

Estimations which control for both regional location and the level of development find that resource depletion and genuine investment have a negative relationship in energy-rich OECD nations. The finding is confirmed for members of the MENA region but the absolute value of the relationship is smaller. Given the relationship between democracy and genuine investment it may be that OECD membership is acting as a democracy proxy. The findings related to the MENA region have been confirmed by other studies such as Arrow et al. (2004) and Hamilton (2006).

In the future the author plans on expanding the governance characteristics considered in the study by incorporating other data sets. For instance, the *Index of Economic Freedom* from the Heritage Foundation and Wall Street Journal will be applied. This data set may provide insight into what aspects of democracy are driving its negative relationship with genuine investment.

A second possible extension involves analyzing the individual components of genuine investment. Genuine investment includes measures of public and private investment, environmental damages, and resource depletion. The impact of governance on these individual elements could be estimated to gain a better understanding of the causality channels by which governance impacts genuine investment.

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Appendix

Table 4.1 Energy-Rich Nations

Algeria (DZA)	Germany (EDU)	Poland (POL)
Angola (AGO)	India (IND)	Qatar (QAT)
Argentina (ARG)	Indonesia (IDN)	Romania (ROM)
Australia (AUS)	Iran (IRN)	Russian Federation (RUS)
Azerbaijan (AZE)	Iraq (IRQ)	Saudi Arabia (SAU)
Bahrain (BHR)	Italy (ITA)	Sudan (SDN)
Bangladesh (BGD)	Kazakhstan (KAZ)	Syria (SYR)
Brazil (BRA)	Kuwait (KWT)	Thailand (THA)
Brunei (BRN)	Libya (LBY)	Trinidad & Tobago (TTO)
Canada (CAN)	Malaysia (MYS)	Tunisia (TUN)
Chad (TCD)	Mexico (MEX)	Turkmenistan (TKM)
China (CHN)	Myanmar (MMR)	United Arab Emirates (ARE)
Colombia (COL)	Nigeria (NGA)	United Kingdom (GBR)
Congo, Rep. (COG)	Norway (NOR)	United States (USA)
Denmark (DNK)	Oman (OMN)	Uzbekistan (UZB)
Ecuador (ECU)	Pakistan (PAK)	Venezuela (VEN)
Egypt (EGY)	Papua New Guinea (PNG)	Vietnam (VNM)
Equatorial Guinea (GNQ)	Peru (PER)	Yemen (YEM)
Gabon (GAB)		

Notes: To be considered energy-rich a nation must have at least 0.2% of proven world reserves in either oil or gas according to data from *The BP Statistical Review of World Energy* (2010). Country abbreviations are in parenthesis.

Table 4.2: Genuine Investment Component Definitions (quoted from source)

Variable	Definition
Net national savings	Gross national savings minus consumption of fixed capital plus transfers
Education Expenditure	Current operating expenditures in education, including wages and salaries and *excluding* capital investments in buildings and equipment
Energy Depletion	The product of unit resource rents and the physical quantities of energy extracted. It covers crude oil, natural gas, and coal
Mineral Depletion	The product of unit resource rents and the physical quantities of minerals extracted. It refers to bauxite, copper, iron, lead, nickel, phosphate, tin, zinc, gold, and silver.
Net Forest Depletion	The product of unit resource rents and the excess of roundwood harvest over natural growth
Carbon Dioxide Damages	Carbon dioxide damage estimated to be $20 per ton of carbon (the unit damage in 1995 U.S. dollars) times the number of tons of carbon emitted.
Particulate Emissions Damage	Calculated as the willingness to pay to avoid mortality attributable to particulate emissions.

Source: All definitions quoted from the World Development Indicators; http://data.worldbank.org/ .

Table 4.3 World Governance Indicators Definitions (quoted from source)

Variable	Definition
Voice & Accountability (Account)	Capturing perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.
Political Stability and Absence of Violence/Terrorism (Stable)	Capturing perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.
Government Effectiveness (Effect)	Capturing perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.
Regulatory Quality (RegQual)	Capturing perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
Rule of Law (Law)	Capturing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.
Control of Corruption (Corrupt)	Capturing perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests

Source: All definitions are quoted from Kaufmann, Kraay, and Mastruzzi (2010) p. 4.

CHAPTER FIVE

CONCLUSION

This dissertation has explored the relationship between energy and economic growth. This relationship was considered across a variety of spatial dimensions. Chapters Two and Three both pursued state-level analyses considering both short run and long run questions. Chapter Four analyzed macro-level genuine investment measures. The level of genuine investment contains information on the expected long run sustainability of an economy.

Chapter Two "Energy Consumption and Economic Growth: A State-Level Analysis" has shown that the relationship between energy consumption and economic growth is unique across states. A supply and demand framework has been applied to capture the interaction of energy consumption and economic growth. This specification adds a more tractable theoretical foundation to the existing literature. Additionally, it is capable of identifying supply and demand side channels of causality. By doing so the expected growth impacts of market interventions which seek to alter energy consumption are determined.

In the future the author intends on applying the methodology of Chapter Three to other states. The expectation is that as more states are analyzed patterns across states may be uncovered. This work will inform policy formation in the states analyzed. If there is a pattern of state characteristics which determine the causality channels between energy consumption and economic growth this will further aid understanding of the energy economy relationship. Chapter Three has shown that policy may have unintended consequences if state-specific characteristics are not considered.

In Chapter Three “Elasticities of Energy Supply and Demand in the Western United States” estimates for individual states are presented. An aggregate measure of energy consumption is used rather than consumption of a particular form of energy. Application of an aggregate measure is unique in the energy elasticity literature; it is applied to estimate elasticities associated with aggregate responses. The literature is also extended by the application of a simultaneous system in order to capture the behavioral responses of both sides of energy markets.

Chapters Two and Three have created a foundation to continue to build upon to continue explore the interaction of energy consumption and economic growth within the United States. Future studies will seek to determine whether the consumption of electricity, natural gas, or petroleum impacts growth differently. Another area of potential research is whether the energy source used to generate electricity has growth consequences. Are there differential impacts on growth from the consumption of electricity from renewable on non-renewable sources? By disaggregating energy measures a deeper appreciation of the role of energy in economic growth will be facilitated.

A second area of research extending from Chapters Two and Three is related to determining the causality channels by which efficiency gains occur at the state level. Improved efficiency allows the economy to become less reliant on energy consumption. In turn, decreased energy consumption also has the potential to decrease the negative externalities associated with consumption. Understanding the drivers of energy efficiency provides another key aspect of the energy economic growth relationship.

Chapter Four "What is the Impact of Governance on Genuine Investment in Energy-Rich Nations?" has shown that governance and institutional quality impacts the level of genuine investment within a nation. Findings indicate increases in the level of democracy lead to declines in genuine investment.

Chapter Four will likely evolve in a number of ways. Other measures of governance such as the *Index of Economic Freedom* from the Heritage Foundation and Wall Street Journal will be applied to ensure results are robust to different data sources. Genuine investment includes measures of public and private investment, environmental damages, and resource depletion. The impact of governance on these individual elements will also be estimated.

My hope is that this dissertation contributes to the overall understanding of the relationship between energy and economic growth. The importance of energy related economic concerns is not likely to diminish in the near future. During the research process I have come to realization that my dissertation marks the first step in a career long journey. Rather than ending the inquiry each question answered has led to multiple others.