국제학 석사학위논문

Oil Cross-Price Elasticity of Energy R&D Demand: A 12-Country Panel Analysis

에너지 R&D 수요에 대한 석유가격의 교차탄력성

- 12 개국에 대한 패널분석을 중심으로

2009 년 08 월

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Oil Cross-Price Elasticity of Energy R&D Demand:
A 12-Country Panel Analysis

A Thesis presented

by

Kevin P. Kane

to

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I dedicate this thesis to my wife, mother, father, brothers, friends, mentors, country, and God. I would not be here without each of them.

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Abstract

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This thesis investigates how oil cross-price elasticity of energy R&D demand undermines the pursuit of energy security. In 2008 when inflation-adjusted real oil prices reached as high as $120 per barrel, the debate on how to attain energy security dominated the minds of many experts and world leaders. Achieving effective national energy security, however, may require both reducing the influence of oil price changes on energy R&D investments and refocusing the discourse on energy security from the national to international level.

Carbon dioxide emissions could increase 60% by 2030 as global economic expansion propels energy demand upward. Therefore, new advancements in technology are required to increase energy supply, diversify inputs, and improve the quality of our environment. Deployment of energy technology with marginal costs currently above the price of oil, natural gas, and coal, however, may partly depend on governments pursuing more consistent and coordinated energy R&D strategies.

Following a literary review, this research first investigates recent shifts in oil supply and demand, which establishes the importance of hydrocarbon substitutes. Second, this research investigates energy consumption patterns and the rate of energy supply diversification. Third, with annual data from 1975 to 2007 for energy consumption and energy R&D investments for 12 IEA-member countries, this thesis analyzes the differences between past and present oil price influences on Total, Nuclear, Renewable,

Fossil Fuel, Energy Efficiency, and Power and Energy Storage Technology R&D. Fourth, this research analyzes time series regression results for eight of the twelve observed IEA-member nations. Fifth, this research infers if governments are reducing oil cross-price elasticity of R&D by analyzing changes in regression result coefficients. Sixth, this research concludes by proposing a global energy security strategy that captures the need for consistent energy R&D investments as well as the inescapable linkages inherent with increasing global economic interdependence.

Investigation results reveal that a positive relationship exists between oil prices and energy R&D investment. Research results also reveal that oil-cross price elasticity of energy R&D demand appears to be increasing over time for three of the six observed dependent variables. Time-series regression results for seven of the twelve observed nations suggest that oil price may affect different types of energy R&D within a country; moreover, the degree of oil cross-price elasticity of R&D demand varies between countries.

Governments may appear to behave rationally in the short term as their demand for energy R&D investment reflects changes in oil prices. On the other hand, allowing erratic investment changes in energy R&D to undermine long-term energy security strategies should appear equally as irrational. Even though many governments recognize the importance of decreasing CO2 emissions and increasing energy security through the diversification of energy inputs, uncoordinated, inconsistent, and ill-planned R&D investments continue to undermine the pursuit of these goals.

Key Words: Cross-Price Elasticity of Energy R&D Demand, Oil Prices, Natural Gas, Hydrocarbons, Energy R&D, Fossil Fuels, Renewable Energy, Nuclear Energy, Power and Energy Storage Technology, Energy Efficiency, Energy Diversification, Energy Security, International Energy Agency (IEA), Organization for Development and Co-Operation (OECD) Organization of the Petroleum Exporting Countries (OPEC)

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Abbreviations

AI: Actual Stocks of Oil

API: American Petroleum Institute

BTU: British Thermal Unit

CO2: Carbon Dioxide

DI: Desired Stocks of Oil

DV: Dependent Variable

DOE EIA: Department of Energy, Energy Information Agency

FBR: Fast Breeder Reactor

IEA: International Energy Agency

kW: Kilowatt

kWh: Kilowatt Hour

Mb/d: Million Barrels of Oil Per Day

MOTE: Million Tonnes of Oil Equivalent

OECD: Organization for Development and Co-Operation

OPEC: Organization of the Petroleum Exporting Countries

OTEC: Ocean Thermal Energy Conversion

WESO: World Energy Security Organization

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Chapter 1: Introduction

This chapter presents the primary focus of this research by describing the research subject, questions, and method. First, this chapter outlines the historical relationship between oil prices and energy R&D investment. Second, this chapter proposes new research questions in light of changes that have taken place in world energy markets over the past 10 years. Third and finally, this research describes the data and statistical methods used to analyze this relationship.

1. Research Subject

Due to the Arab Oil Embargo on Organization for Development and Co-Operation (OECD) members and the Organization of the Petroleum Exporting Countries (OPEC) oil price hikes, the global economy experienced its first major sustained oil price increases in the mid-1970s as annual average oil prices increased from inflation adjusted $44 per barrel to $93 per barrel.[1] [2] Simultaneously, total International Energy Agency (IEA)-member energy research and development (R&D) increased from 12.5 billion to 20.1 billion dollars. When oil prices decreased to an approximate average of $18 per barrel in the 1990s, IEA-member total energy R&D correspondingly decreased to an average value of 11.5 billion dollars.[3]

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[1] All references of dollar values reflect U.S. inflation adjusted real 2007 values.

[2] Energy Information Administration, "*Annual Oil Market Chronology,* 1970s," http://www. eia.doe.gov/cabs/ AOMC /7 079.html (accessed February 2, 2009).

[3] International Energy Agency, " R&D Budgets," http://wds.iea.org/WDS/Common/Login /login.aspx (accessed April 3, 2009).

From 1989 to 1998, government R&D investments followed oil prices and remained relatively low. From 1998 to 2008, the global economy—now more interdependent—experienced its second major upward shift in oil prices: increasing from an average 1998 price of $16 per barrel to an average 2008 price just short of $100 per barrel.[4] Total IEA-member energy R&D correspondingly increased from approximately 9.2 to 12 billion dollars.[5] [6] However, IEA-member energy R&D increases from 1998 to 2007 were lower than the increases from 1975 to 1980.

In 1980, IEA-member Total, Nuclear Energy, Renewable Energy, Fossil Fuel, Efficiency Energy, and Storage Technology R&D reached approximately 20.1 billion, 10.9 billion, 2.4 billion, 3.2 billion, 611 million, and 1.3 billion dollars, respectively.[7] Unlike the oil price increases from 1975 to 1980, price movements from 1998 to 2008 resulted in IEA-member total R&D values reaching 12 billion, 4.5 billion, 1.4 billion, 1.3 billion, 1.5 billion, and 502 million dollars by 2007, respectively.[8] Total energy R&D investment in 2007 appears almost 50% below its 1980 real inflation-adjusted levels.[9] Despite world energy consumption nearly doubling from 5784.1 million tons of oil equivalent (MTOE) in 1975 to 10557.6 MTOE in 2007, total energy R&D investment

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[4] British Petroleum, "Statistical Review of World Energy 2008," http://www.bp.com/liveassets/bp_internet /glob albp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2008.xls (accessed August 5, 2008)

[5] Ibid.

[6] International Energy Agency, "R&D Budgets," http://wds.iea.org/WDS/Common/Login/log in.aspx (accessed April 3, 2009).

[7] Ibid.

[8] Ibid.

[9] Ibid.

failed to increase correspondingly. In fact, changes in long-term energy R&D continue to reflect erratic changes in short-term oil price movements.[10]

2. Research Questions

The world currently consumes 85 million barrels of oil per day (mb/d). With oil consumption expected to reach 106 mb/d and CO2 emissions expected to increase 60% by 2030, the world needs technological shifts—facilitated by returns from R&D—to both increase aggregate energy supply and reduce CO2 emissions.[11] [12] Energy R&D will assist in increasing the marginal rate of fossil fuel substitution as well as overcoming the learning curve necessary to reduce marginal costs for expensive oil recovery methods.[13] [14] [15] Total IEA-member energy investment currently resides almost 50% below its 1980 levels. Total IEA-member energy R&D does not appear to increase with upward shifts in

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[10] British Petroleum, "Statistical Review of World Energy 2008," http://www.bp.com/liveassets /bp_internet/glob albp/globalbp_uk_english/reports_and_publications/statistical_energy_review _2008/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_ 2008.xls (accessed August 5, 2008)

[11] Energy Information Agency, "World Energy-Related Carbon Dioxide Emissions by Region, 2003-2030" http://www.eia.doe.gov/oiaf/archive/ieo07/excel/figure_77data.xls (accessed May 1, 2009)

[12] Energy Information Agency, "World Carbon Dioxide Emissions from Coal Combustion by Region, 1990-2030" http://www.eia.doe.gov/oiaf/archive/ieo07/excel/figure_83data.xls (accessed May 1, 2009)

[13] International Energy Agency, "New Energy Realities - WEO Calls for Global Energy Revolution Despite Economic Crisis" *International Agency on the Web*, November 12, 2008. http://www.iea.org/textbase/press /pressdetail.asp?press_rel_id=275 (accessed December 2, 2008).

[14] Glenn R. Hubbard, Anthony Patrick O'Brien, *Economics*, (Upper Saddle River: Pearson Education, Inc., 2006,) 71-77.

[15] In "Economics," Glenn R. Hubbard and Anthony O'Brien define marginal rate of substitution as the rate at which a consumer will be willing to trade off one good for another. This paper applies to represent the marginal rate of oil or fossil fuel substitution with another input of energy.

consumption demand and accelerating environmental negative externalities. Since international public discourse suggests that nations will try to diversify their energy supplies while also decreasing CO2 emissions, current R&D investment levels appear counterintuitive. This author presents the following three hypotheses to uncover the source of this counterintuitive reality:

(1) When the ratio of variable inputs for oil production to long run fixed inputs increases to the point where firms experience diminishing returns, *ceteris paribus*, marginal costs increase along with oil prices.

(2) When oil prices increase or decrease, government energy R&D investment correspondingly increases or decreases.

(3) As new globalization-related problems emerge and as energy strategies improve, governments will seek to reduce oil cross-price elasticity of energy R&D demand over time.

Although many previous studies identified a highly elastic relationship between the oil price hikes in the 1970s, no new studies analyze if governments have adjusted their energy security strategies in order to reduce energy cross-price elasticity of demand for energy R&D. What is more, with post-1998 oil price increases reflecting changes in supply and demand, the world needs newer surveys on the relationship between oil prices and energy R&D. Therefore, this research seeks to answer if governments are pursuing energy security strategies that reflect their clear knowledge that future demand for energy primary consumption may test the limits of sustaining affordable energy supply.

3. Research Method

To establish the importance of this research, this investigation includes an analysis of oil production's increasing marginal costs as well as a review of historical trends in primary energy consumption by energy type. After establishing the importance of future technology shifts in hydrocarbon substitute supply through R&D, this research uses six separate panel regressions to analyze oil cross-price elasticity of energy R&D demand. All observations represent first differences between logarithmic values using the equation, $\Delta Y = Yt - Y_{t-1}$. The first difference equation method controls for autocorrelation. Dependent variables include Total R&D, Nuclear R&D, Renewable R &D, Fossil Fuel R&D, Energy Efficiency R&D, and Power and Energy Storage Technology R&D. Independent variables include Gross Domestic Product Per Capita (GDP Per Capita), million tonnes of oil (MTOE) consumption by energy type, oil price and oil price (t-1). MTOE consumption independent variables include coal, oil, natural gas (NG), hydroelectric power (Hydro), and Nuclear power (Nuc). Dollar values are inflation-adjusted real 2007 prices.

The panel includes the periods 1975 to 2007 and 12 cross sections (countries) including Canada, Denmark, Germany, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States of America. Although the sample includes relatively developed countries, these countries prove to be the least bias for the following three reasons:

(1) Developed countries reflect the most important contributors to capital-intensive energy technology due to their relatively large share of investment.

(2) Each country in the sample relies on diverse energy policies and radically different percentage shares of energy primary production inputs.[16]

(3) Energy input diversity, high consumption rates inherent with developed countries, and energy resource endowment more relevantly determine demand for energy R&D as oppose to GDP.

The sample included in this research appears most relevant and least bias when considering the drivers behind energy R&D demand as well as each country's world share of financial contribution to energy technology.

This research controlled for structural breaks and changes in cross-price elasticity over time by analyzing four and under certain circumstances five, separate observable time-periods. The consistently observed four time-periods include 1975 to 2007, 1985 to 2001, 1975 to 1991, and 1991 to 2007. The fifth time-period includes observations after 2000; these additional time-periods observed vary depending on visible trends in the independent variable. Every regression includes the first four time-periods. The period 1985 to 2001 represents a time series without any significant increases or decreases in oil prices. Periods 1975 to 1991 and 1991 to 2007 serve to measure if governments reacted to the oil price increases from 1991 to 2007 differently from the oil price increase and decreases from 1975 to 1991. Observations after 1991 also represent the end of the Cold War and the beginning of economic globalization.

By applying time-series regression for twelve individual countries, this research analyzes differences in oil cross-price elasticity of energy R&D demand. This section of the research complements, but does not empirically substitute, results from the panel

[16] See Table Two in the appendix for a representation of energy input diversity within each sampled country.

tests. This section tests the same independent and dependent variables, albeit consumption data availability varies between each sampled country: each country in the sample meets their country's consumption demand with different electricity generation inputs depending on natural resource endowment as well as national energy strategy. This section of the research proves to be the least externally valid and generalizable due to limited sample sizes and missing consumption data between countries; therefore, the time-series results serve more of a complimentary role than as an empirical reference for conclusions about changes in relationship between energy R&D and oil prices over time.

4. Research Sequence

This research begins in Chapter 2 with a literary review followed in Chapter 3 with a review of supply and demand trends in the oil market as well as national efforts to diversify from fossil fuels. Chapters 4 and 5 interpret and analyze each panel and time-series regression results. Chapter 6 proposes policy options that reflect the implications of regression results for energy R&D policies as well as exogenous factors associated with economic globalization that complicated the pursuit of energy diversification and security. Chapter 7 closes by connecting lessons learned from this research to the most realistic method to achieving future energy security.

Chapter 2: Literary Review

In 1932, J.R. Hicks introduced the theory of induced innovation, which argued that changes in relative factor prices should catalyze the development of innovations that may offset the costs of increases in prices.[17] This theory proves to be important in explaining the role of oil prices and R&D. According to this theory, an increase in oil prices should lead to innovation in the energy sector, presumably through R&D. After the oil shocks in the 1970s, many scholars tested this hypothesis in relation to energy prices and market and government demand for new technology, as well as in R&D. The relationship between energy prices and innovation continues to be debatable. Most of the previous studies include a sample that primarily covers energy prices during oil price shocks while other research focuses on micro-level deployment of new technology developed during times of increasing energy prices. All of the previous studies fail to observe for changes in oil cross-price elasticity over time. They also fail to accumulate enough empirical evidence to make a broad generalization and capture oil-specific negative externalities associated with energy security and strategic R&D investments.[18]

In "An Empirical Analysis of National Energy R&D Expenditures," Jiu-Tian Zhang, Yin Fan, and Yi-Ming Wei attempt to analyze the relationship between oil shocks and energy R&D through scatter plots and entropy analysis.[19] The authors found that

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[17] John R. Hicks, *The Theory of Wages, (London: MacMillan, 1932)* Quoted in David Popp, "Induced Innovation and Energy Prices," *American Economic Review* 92 (2002): 1-2, http: //ideas.repec.org/p/nbr/nberwo/8284.html (accessed June 25, 2009)

[18] See works by David Popp (1999) and Jiu-Tian Zhang, Yin Fan, and Yi-Ming Wei (2006)

[19] Jiu-Tian Zhang and others, "An Empirical Analysis for National Energy R&D Expenditures," International Journal Global Energy Issues 25 (2006): 141-159, http://www.environmental-expert.com/resultEachArticlePDF.aspx?cid=6471&codi=23831 (accessed June 25, 2009)

countries continue to diversify energy R&D while the amount of investment adjusts with changes in oil prices. Their research however applies nominal values instead of inflation-adjusted real dollar values. Their research does not include observations for the second major oil prices increases from 1998 to 2008. Most importantly, their research does not control for other variables such as Gross Domestic Product (GPD) per capita and national consumption by energy type, which are all independent variables that include linkages to oil prices.

In "Induced Innovation and Energy Prices," David Popp established that energy prices, the supply of existing ideas, and productivity from research investment, affect energy R&D levels inside the U.S.[20] David Popp proves that diminishing returns in R&D cause investment to decline. However, the research focuses on peak oil price-periods as oppose to isolated time-periods where oil prices remain relatively steady. Unlike David Popp's work, this research will include consumption and government energy R&D for 12 countries while substituting British Thermal Unit (BTU) price value with world oil prices. By utilizing oil prices instead of domestic energy prices, this research captures the exogenous affect of oil dependence on energy R&D and IEA-member energy diversification efforts. Moreover, unlike Popp's study, this research analyzes oil cross-price elasticity of energy R&D demand in both peak and steady-price periods. Robert M. Margoils and Daniel M. Kammen found that R&D investments and patents are highly correlated.[21] Therefore, when energy price increase in a given country, energy R&D

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[20] David Popp, "Induced Innovation and Energy Prices," *American Economic Review* 92 (2002): 1-2, http://ideas.repec.org/p/nbr/nberwo/8284.html (accessed June 25, 2009)

[21] Robert M. Margoils, Daniel M. Kammen, "Underinvestment: The Energy Technology And R&D Challenge," Science 285 (1999): 690-691., http://www.sciencemag.org/cgi/content/abstract/285/5428/690 (accessed June 25, 2009)

consequently increases, which results in an increase in patents. Thus, *a prior*, R&D remains important to future energy security.

None of the reviewed literature includes surveys of data with the second oil price increases from 1998 to 2008. Including the second period of oil price increases controls for the possibility that R&D increases in the past could have represented the political choices associated with oil shocks in the 1970s rather than *en passant* economic fundamentals associated with changes in demand. Including the new data proves to be particularly important since the fundamentals of supply and demand coupled with increasing firm marginal costs explain most of the increases in oil prices from 1998 to 2008, juxtaposing the political and non-market related factors behind the price peaks in the 1970s. Moreover, by including new data and testing the energy-R&D relationship in a panel regression across 12 countries, this thesis will produce a more relevant and generalizable conclusion.

Chapter 3: Demand and Diversification

This chapter establishes the importance of stabilizing R&D investments by detailing how oil demand and supply shifts primarily explain recent increases oil prices. This chapter then underscores the significance of diversifying energy inputs away from fossil fuels through government energy R&D as a vehicle for substitute technology shifts. If supply and demand shifts explain most of the recent oil price increases from 1998 to 2008, then *ceteris paribus*, prices should increase again once the demand rebounds following recovery from the 2008 Financial Crisis.

1. Oil and Gas Supply and Demand

The International Energy Agency estimated in 2004 that world oil demand would reach 121 mb/d; present oil consumption resides around 85 mb/d.[22] After declining oil prices from over $120 per barrel to less than $50 per barrel, the IEA announced new expected demand estimates. The IEA currently estimates that oil demand will reach 106 mb/d by 2030.[23] The IEA reduced expected demand because of the negative "impact of much higher [oil prices] and slightly lower [expected world] GDP growth."[24] While the 2008 Financial Crisis dampened global oil demand, developing countries like China and

[22] International Energy Agency, "Call for Urgent and Decisive Policy Responses," *International Agency on the Web*, October 26, 2008. http://www.iea.org/textbase/press/pressdetail.asp?PRESS_REL_ID=137 (accessed May 1, 2009)

[23]International Energy Agency "IEA Forecasts Energy Demand to Increase 1.6 percent a Year Through 2030," *International Agency on the Web*, November 13, 2008. http://www.prlog.org/10141086-iea-forecasts-energy-demand-to-increase-16-percent-year-through-2030.html (accessed November 14, 2008) Quoted in PRLog *Free Press Release on the web*

[24] Ibid.

India will emerge as major forces relentlessly pushing demand upwards.[25] What is more, according to the IEA, the 2008 Financial Crisis could delay completing oil and gas projects that would otherwise provide additional and long-term supplies.[26] In November 2008, OPEC also warned that necessary investment in refining and distribution would cease if oil prices remained low.[27] This suggests that should energy demand rebound quickly and continue to increase without new inventory additions, *ceteris paribus*, the world could experience even higher prices than those experienced between 2007 and 2008.

IEA estimates and OPEC concerns suggest that lower oil prices will result in decreasing investment and reduced additions of oil and gas supply stocks. Moreover, the cumulative discovery of oil continues to decline with 1960, 1970, 1980, and 1990 discoveries reaching 360, 275, 150, and less than an estimated amount of 40 billion barrels, respectively.[28] Every decade, energy companies discover dramatically less oil than the previous decade, albeit improvements in recovery methods continue to expand commercially recoverable amounts of oil while increases in refinery efficiency expand the value of a given barrel of oil. Additionally, near and perhaps mid-term marginal costs are also substantially increasing as “more than 60% of all new oil being discovered is offshore; ” moreover, API (American Petroleum Institute) values continue to decrease—a measure of specific gravity—and sulfur content continues to increase. Both decreasing

[25] Ibid.

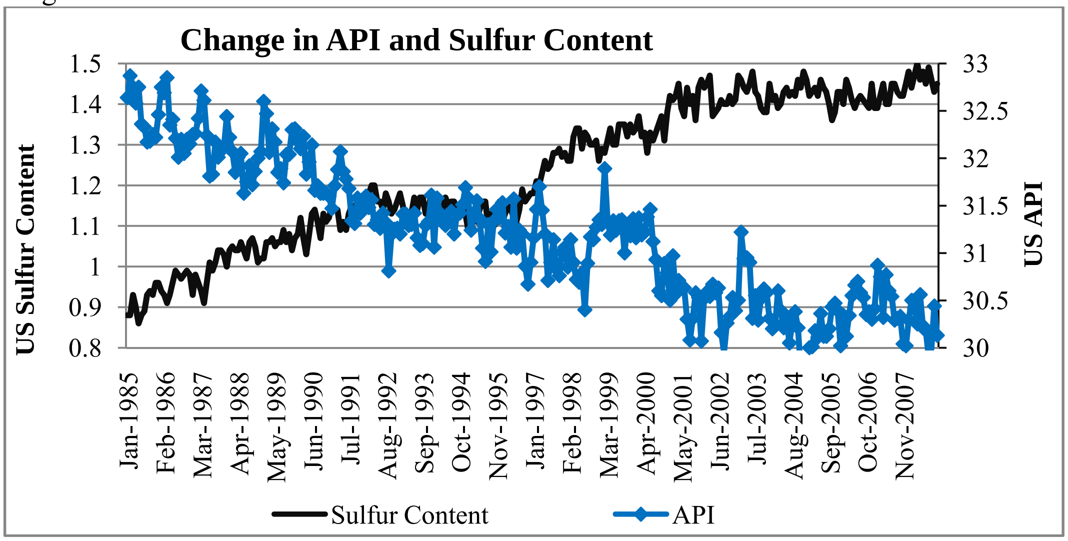
[26] Ibid.

[27] Ibid.

[28] Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, (Singapore: World Scientific Publishing Co., 2007), 36.

API and increasing sulfur content increase marginal costs for refineries.[29] For a review of unfavorable changes in sulfur content and API for U.S oil imports—see the figure 1 below:

<Figure 1>[30] [31]



Increasing marginal costs and unwavering outward shifts in demand suggests that without equal outward shifts in supply from potential technology changes, prices may continue to move upward. From 1975 to 2007, oil consumption, measured in million tonnes, increased almost 50% with demand jumping over 12% from 2000 to 2007.[32] On the other hand *proved reserves* increased also by 12% from 2000 to 2007.[33] Increases in

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[29] Ibid.,103.

[30] U.S. Department of Energy, Energy Information Administration, "*Crude Oil Input Qualities,"* http://tonto.eia.doe.gov/dnav/pet/pet_pnp_crq_dcu_nus_m.htm (accessed April 10, 2009).

[31] Changes in API and sulfur content for U.S. imports should be generalizable to represent world imports.

[32] British Petroleum, "Statistical Review of World Energy 2008," http://www.bp.com/liveassets /bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2 008/STAGING/lLocal_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2 008.xls (accessed August 5, 2008)

[33] Ibid.

reserves, however, do not necessarily lower short-run oil prices since they are not actual stocks (AI).[34] *Proved reserves* are generally defined as commercially recoverable hydrocarbons (oil and gas) with anywhere from 80 to 90% or greater probably of being recovered with profit, depending on the classification system applied; Reserves are further broken down into *proved*, *probable*, and *possible* with greater than 50% and less than 50% probability of commercially recoverable quantities of hydrocarbons, respectively.[35]

Oil reserves do not affect short-term oil and supply equilibrium; in fact, short run prices are not determined by the long term availability of oil (reserves). Oil prices primarily reflect the relationship between AI and desired stocks (DI).[36] Thus, AI and DI determine oil prices in the short run, particularly since reserves are not immediately movable inventories, or stocks (AI). Oil reserves are not immediately movable supplies of oil since hydrocarbon recovery rates depend more on geology and less on *fixed* and *variable* inputs.[37] [38] Since oil comes out of the ground at a natural rate that varies between oil fields—depending on geological factors including the type of *reservoir* and

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[34] Ferdinand Banks, *Economic Theory and Oil: A Modern Survey*, (2008) 22
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[35] Chapman Cronquist, *Estimation and Classification of Reserves of Crude Oil, Natural Gas, and Condensate. (*Houston: Society of Petroleum Engineers, 2001) 1 – 29.

[36] Ibid.

[37] Ibid.

[38] Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*(Tulsa: Penn Well Corporation, 2001)., 431-449.

drive mechanism—changes in variable inputs may play a limited role in increasing short to mid-term inventories.[39]

As firms seek to increase their *proved reserves* and add new inventories (AI), marginal costs are increasing as they search in less conventional locations for oil and gas. Consequently, offshore exploration now accounts for over 60% of all new oil discoveries.[40] These capital-intensive offshore rigs take several, and sometimes many, years to construct, leaving little room for increasing fixed inputs when DI increases or AI shrinks. According to the law of diminishing returns, at some point after adding more of a variable input to the same amount of fixed input (rigs), this will cause marginal product of the variable to decline, which pushes prices upward.[41]

If AI and DI explain oil prices, rigs should shut down whenever prices drop below marginal costs. In fact, with oil price (Y) being a function of oil production demand (P_o) divided by total oil and gas rigs in operation (Rt), the following equation demonstrates the AI-DI marginal cost relationship: $Y = P_o / R_t$.[42] This research uses total rig values since oil and gas (hydrocarbons) are often recovered from the same reservoir.[43] By applying this formula to monthly observations for oil price, world rigs in operation, and world production levels in 1000 barrels per month (b/m) units for production, correlation

[40] Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, (Singapore: World Scientific Publishing Co., 2007), 36.

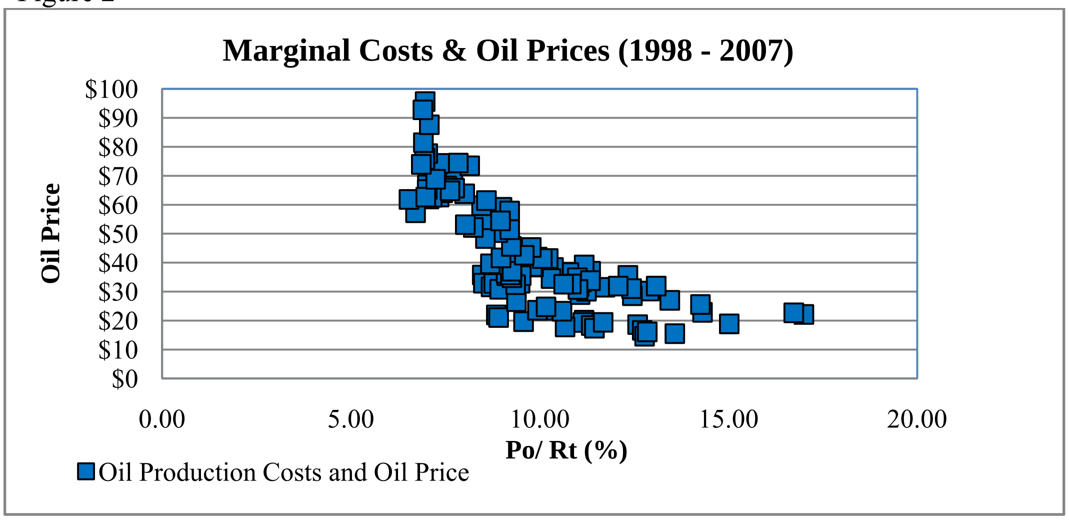
[41] Robert S. Pindyck, Daniel L. Rubinfeld, *Microeconomics* (Upper Saddle River: Pearson Education), 209.

[42] Oil production levels generally reflect the same amount of consumption levels, also known as demand, and so therefore, this formula focuses on production instead of consumption

[43] Ibid., 7.

results between price and the marginal costs function equal -82. Since the development of new rigs depends on discoveries from exploration, firms are only able to add variable inputs to increase short run production, which pushes up marginal costs. When oil prices fall below marginal costs, a rig may shut down until prices again equal marginal costs. Figure 2 captures this association in a smooth linear relationship between oil price and P_o/R_t. However, once prices reach $70 and $80 per barrel, the linear relationship ceases as prices shoot directly upward, thus limiting the explanatory power of this scatter plot.

<Figure 2> [44] [45] [46] [47] [48]



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[45] Energy Information Administration, "*Selected OECD Countries, Total OECD, and World Total, Years 1970-2007 (Million Barrels per Day),*" http://www.eia.doe.gov/emeu/ipsr/t46.xls (accessed February 2, 2009).

[46] Baker Hughes Incorporated, "Worldwide Rig Count: Current and Historical," http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm (accessed January 02, 2009)

[47] Federal Reserve Bank of St. Louis, "Series: Oil Price, Spot Price, West Texas Intermediate," http://research.stlouisfed.org/fred2/series/OILPRICE (accessed February 2, 2009)

[48] Federal Reserve Bank of St. Louis, "Series: CPIAUCNS, Consumer Price Index for All Urban Consumers: All Items" http://research.stlouisfed.org/fred2/series/CPIAUCNS (accessed February 2, 2009)

Oil production marginal costs increase when output increases on a fixed input (rig) for two primary reasons:

(1) Oil comes out of the ground at a natural rate dependent on geological formations, the type and design the hydrocarbon reservoir, and the type of natural *drive mechanism*, which means to increase the *recovery factor* (production output) firms need to add variable inputs through *enhanced recovery methods,* thereby increasing marginal costs.[49] [50] [51]

(2) Oil undergoes a *natural decline* rate where after a certain critical point of production, output declines every year, which then requires additional equipment and cost-intensive methods to sustain production without experiencing a decline.[52]

Applying the same formula represented in figure 2, figure 3 on the next page presents this trend in a line graph beginning in 1982 and ending in mid-2008.

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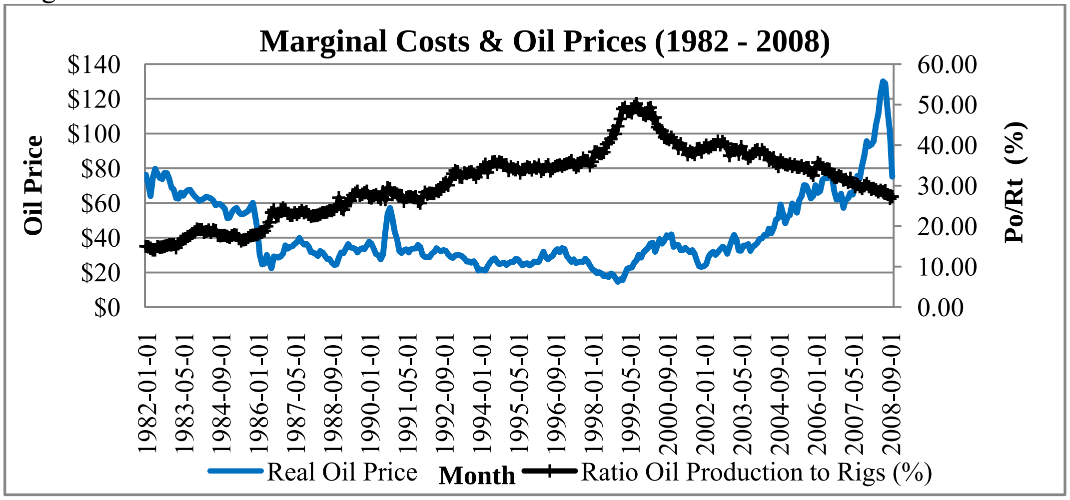
[49] Ibid., Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*(Tulsa: Penn Well Corporation, 2001)., 431-449.

[51] Chapman Cronquist, *Estimation and Classification of Reserves of Crude Oil, Natural Gas, and Condensate. (*Houston: Society of Petroleum Engineers, 2001) 1 – 29.

[52] Ferdinand Banks, *Economic Theory and Oil: A Modern Survey*, (2008) 12

<Figure 3>[53]



These results suggest that when the ratio of variable inputs for oil production to long-run fixed inputs increases to the point where firms experience diminishing returns, *ceteris paribus*, marginal costs increase along with oil prices.

Although firms will increase fixed inputs as they improve technology and increase discoveries from exploration, governments continue to place their future energy supplies on the assumption that firms can offer both low oil prices and capital-intensive technology changes. Although firms are able to develop highly capital-intensive oil fields, they have little incentives to produce hydrocarbons from these discoveries until prices equal marginal costs.[54] *A priori*, even though an oil company may have evidence from a seismic survey that suggests oil exists in the ground, they may withhold pursuing the subsurface tests necessary to convert the discovery from *probable* to *proven* reserves until prices increase.[55] What is more, Wood-Mackenzie, a leading energy-consulting firm,

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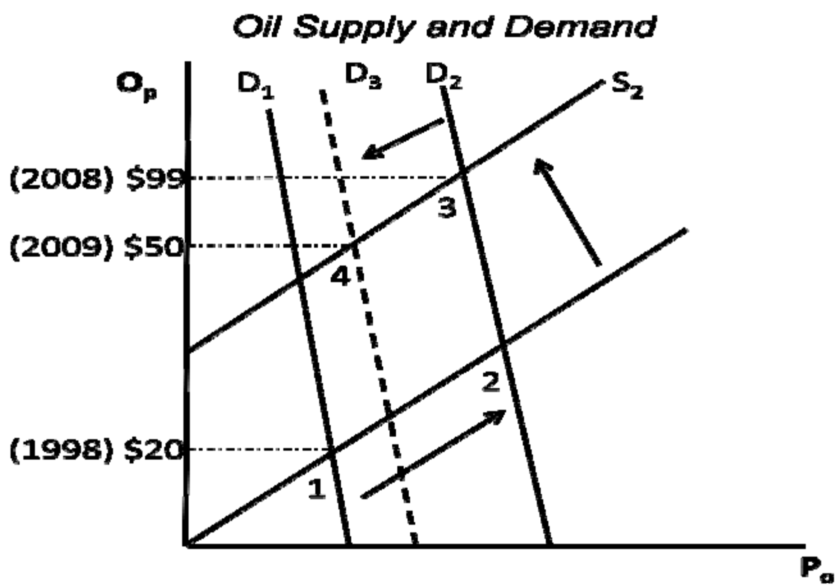
[53] See Figure 2 citations for data source.
[54] Chapman Cronquist, *Estimation and Classification of Reserves of Crude Oil, Natural Gas, and Condensate. (*Houston: Society of Petroleum Engineers, 2001) 1 – 29.

[55] Ibid. 1-29.

argues that oil companies presently need a price of $70 per barrel of oil in order to obtain the same profit that they would have realized several years ago with a price of $30 per barrel.[56]

When marginal costs increase, the "costs of producing goods rise," and demand curves shift to the right when "additional consumers result in greater quantity demanded at every price."[57] Moreover, supply may continue to shift to the left in the short to mid-term while the demand curve will continue to shift to the right, at least until technology changes reduce marginal costs, and substitutes decrease oil demand. Considering these facts, this research describes the 1998 to 2008, and perhaps future, oil supply and demand shifts with Figure 4.

<Figure 4>



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[56] Ferdinand Banks, *Economic Theory and Oil: A Modern Survey*, (2008) 16.

[57] R. Glenn Hubbard, Anthony Patrick O'Brien*, Economics*. (Upper Saddle River: Pearson Education, Inc., 2006,) 71-77.

Starting at Point 1, demand shifts to the right to Point 2 due to global economic growth and new emerging economies like China and India. Simultaneously, supply shifts to Point 3 as exploration and offshore marginal costs increase, marginal profits decrease, and commercially recoverable—*proved*—oil reserves continue to decline in the long-run. Finally, the graph ends with a temporary shift to point 4 following the drop off in demand after the 2008 Financial Crisis.[58]

This research does not suggest that a shortage of oil should be expected in the future, but that increasing marginal costs and low oil prices reduce firm incentives to pursue exploration and production (E&P), at least until prices equal the marginal costs involved with developing new wells. With increasing marginal costs and unwavering future energy demand on the horizon, unless future shifts in technology lower E&P costs, increasing energy R&D for substitutes may be necessary to diversify energy inputs and reduce oil demand. Unlike the 1970 oil price peaks that reflect market interventions and negative externalities such as conflict in the Middle East, the 1998 to 2008 oil price increases are supply and demand driven, which makes them distinctly different. Without the knowledge that supply and demand shifts explain the recent steady increase in oil prices, one would expect governments to plan R&D around ambitious energy security strategies that seek to diversify their energy input sources.

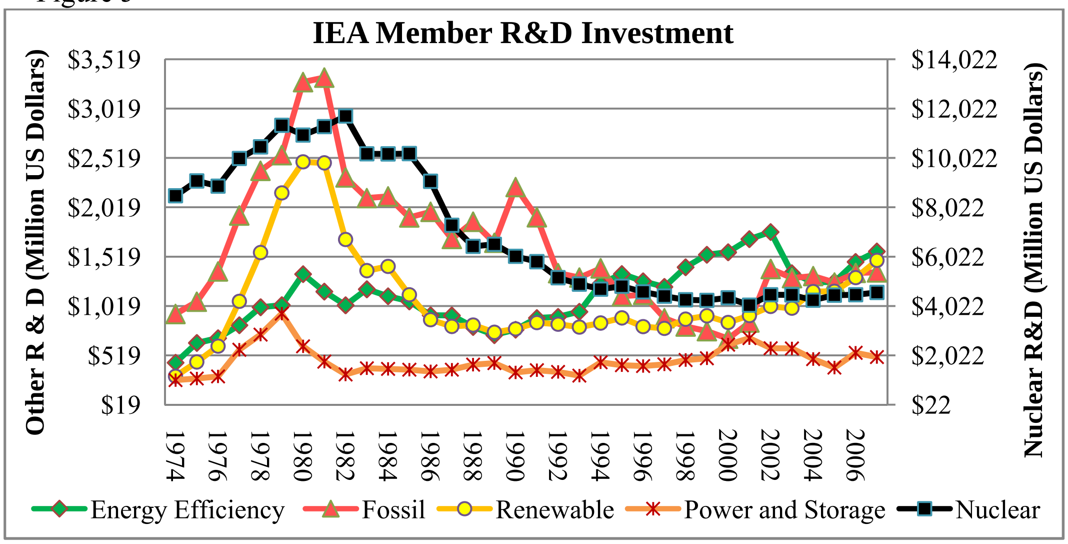
2. Energy Diversification

Investments in nuclear and renewable energy coupled with improvements in efficiency and power storage will help to offset some of the expected stresses on future

[58] Point 4 represents an average oil price estimate for 2009.

energy supply. Whether a government plans to decrease C02, increase national savings with efficient use of energy, or reduce demand for oil, *a priori*, long-term investments in energy R&D would appear to be the ideal solution, but do governments plan for the long-term despite the knowledge that oil prices in the future could continue to increase? If governments plan for long-term energy security, their R&D budgets will reflect this strategy. Figure 5 illustrates the historical trend of IEA-member government cumulative R&D investment by energy type.

<Figure 5>[59]



Each energy R&D type analyzed represents sum values of subcategories of individual types of energy R&D. See Table 1 in the Appendix for an explanation of what types of energy R&D subcategories are included the sum value.

The right axis in Figure 4 includes Nuclear Energy R&D values while the left axis accounts for remaining energy R&D values. Nuclear Energy R&D represents a much larger share of total R&D investment, which peaked close to 11.3 billion dollars in 1979

[59] International Energy Agency, "R&D Budgets," http://wds.iea.org/WDS/Common/Login /login.aspx (accessed April 3, 2009).

and continues to relatively decline through the present. Following the oil price peaks in the late 1970s, R&D investment in every energy sector increased, but then decreased after 1980, never returning to its previous levels in all types of R&D except for Energy Efficiency. Of all the energy types, fossil fuels continue to be most dominant supplier, accounting for 88% of the total share of primary consumption. Nuclear and hydroelectric power only account for, 5.6%, and 6.4% of the total respectively.[60] According to the IEA, as of 2006, combustible renewable as well as alternative energy forms such as wind and solar account for 5.8% of world total final consumption, up only 2.1% from 1973.[61] This 5.8% figure would fit somewhere in with the 100% that includes the 88%, 5.6%, and 6.4% from fossil, nuclear, and hydroelectric energy.

While a decline in energy R&D may have reflected diminishing returns or a correction in over-investment resulting from the 1970 oil shocks, government energy R&D does not necessarily reflect long-term plans for increasing consumption demand. If R&D reflected long-term planning, investments would increase ahead of expected supply stresses resulting from future energy consumption-demand. Figure 6 details the world's historical trend in energy consumption diversification.

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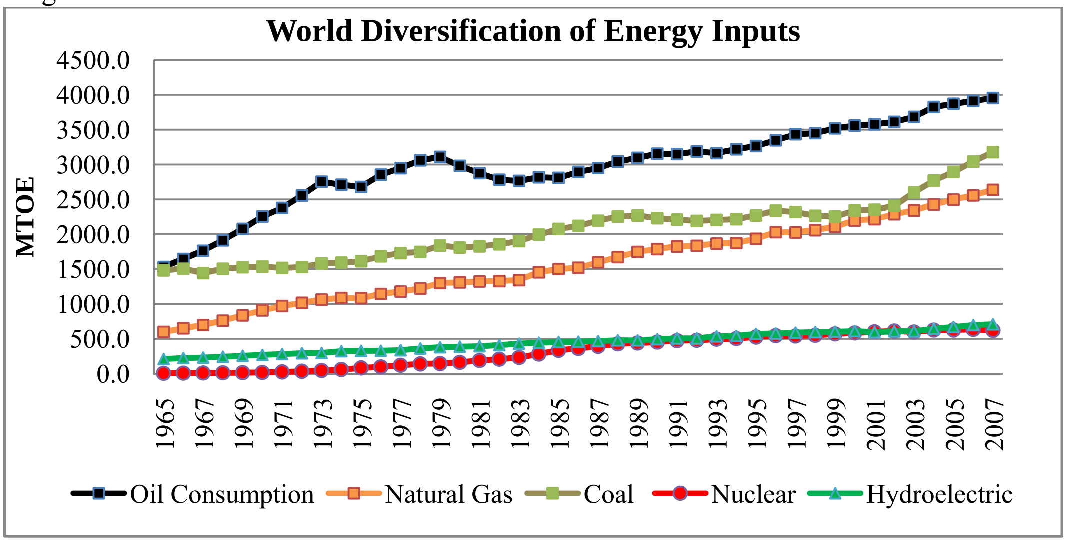
60 British Petroleum, "Statistical Review of World Energy 2008," http://www.bp.com/liveassets /bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2 008/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_20 08.xls (accessed August 5, 2008)

61 International Energy Agency, "Key World Energy Statistics," *International Agency on the Web*, 2008. http://www.iea.org/textbase/nppdf/free/2008 /key_stats_2008.pdf (Accessed May 1, 2009).

<Figure 6> [62]



Many factors including economic, geologic, and political issues beyond the scope of this research explain why supply inputs such as nuclear, hydroelectric, and renewable sources have not increased their share of energy consumption. However, increasing oil company marginal costs, global shifts in oil supply and demand, and well-established hydrocarbon negative environmental externalities make supply input diversification an urgent matter. Achieving lasting energy security through supply input diversification requires changing existing national energy strategies. These changes should include, but not be limited to, reducing oil cross-price elasticity of energy R&D demand.

[62] Ibid.

Chapter 4: Energy R&D Panel Regression Results

This chapter analyzes oil cross-price elasticity of energy R&D demand. This research studies this relationship by measuring the affects of changes in oil price on the following dependent variables: Total, Nuclear Energy, Renewable Energy, Fossil Fuel, Efficiency Energy, and Storage Technology R&D. Each analysis includes a time series graph supported by corresponding panel regression results. Panel regressions include 12 IEA-member country cross-sections observed over 33 annual periods from 1975 to 2007. Time series graph data represents IEA-member R&D total investment values with generalizable trends that represent the 12 member's observed in each panel regression.

As previously stated in Chapter 1 under the Methods section, this research analyzes four separate time-periods in order to observe coefficient (cross-price elasticity of demand) changes and control for structural breaks. Within each dependent variable analyzed, this research observes the sample periods 1975 to 2007, 1985 to 2001, 1975 to 1991, and 1991 to 2007 with the same independent variables. This research observes additional time-periods if individual energy-type specific data trends warrant further investigation. This research selected these four primary sample periods based on their logical significance.

The 1975 to 2007 period represents the entire sample. The sample from 1985 to 2001 represents a period with no major oil price peaks and an average oil price below $30 per barrel.[63] The 1975 to 1991 and 1991 to 2007 samples include two uniquely different sources behind each oil peak: the first peak represents non-market factors and the second peak represents supply and demand shifts. Moreover, both samples divide the 33 years

[63] See Panel Regression Tables 3 through 8 for each period's oil price average and range

observed into two groups with the sample after 1991 representing the beginning of globalization following the end of the Cold War. This research observes changes in oil cross-price elasticity of energy R&D demand through changes in regression result coefficients. Should coefficients decrease after 1991, elasticity will have decreased, and should the coefficients increase, elasticity will have increased.

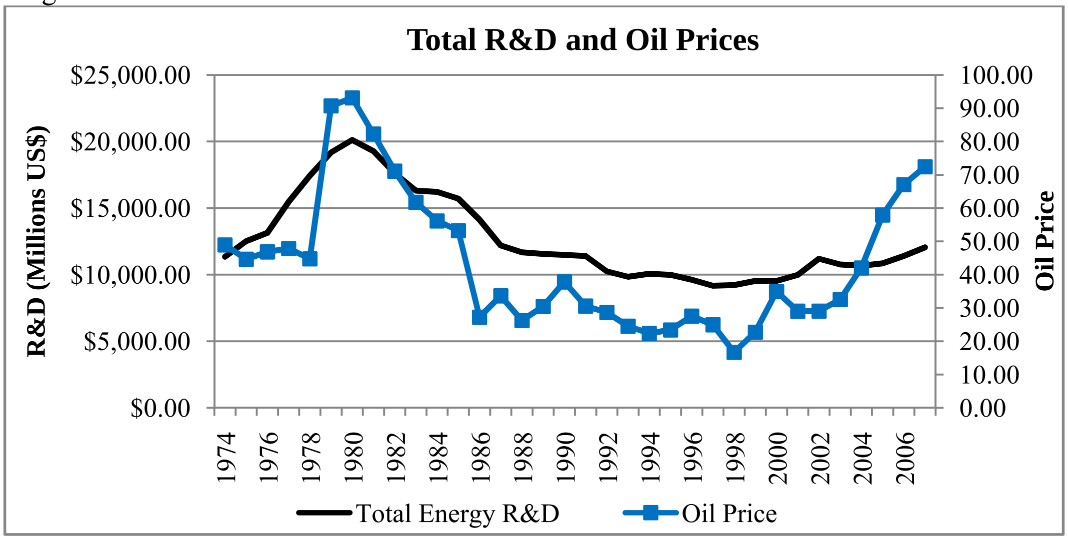
All results found that the independent variable Oil Price (t-1) appeared more significant than the independent variable Oil Price (t-0) and so this research refers to Oil Price (t-1) as "oil price" from this point forward. Oil Price (t-1) also appears to be the more logical choice to observe since *a priori* governments may take one year to adjust their energy R&D budgets in response to an oil price change. The 12 countries in the sample represent dramatically different consumption patterns as well as relatively different GDP Per Capita levels. For a comparison of GDP Per Capita as well as consumption patterns as a percentage of total use by energy type, see Table 2 in the Appendix.

1. Total Energy R&D Results

Total energy R&D represents the cumulative value of all types of energy R&D.[64] Figure 7 presents a time series representation of annual IEA-member Total Energy R&D.

[64] See Table 1 for a breakdown of what types of energy are included in the sum R&D value.

<Figure 7>



Panel regression results for total energy R&D are included in Table 3 of the Appendix. Results over all observed-periods show that a change in oil price leads to a change in government Total Energy R&D the following year. In periods 1975 to 2007, 1985 to 2001, 1975 to 1991, and 1991 to 2007, T-Statistic values include 4.25, 2.34, 3.05, and 3.06 respectively. All of the results are at the 1% significance level.

Coefficient changes show that oil cross-price elasticity of Total Energy R&D demand increased from 0.169 to 0.184 for the 1975 to 1991 and 1991 to 2007 periods, respectively. Elasticity appears lowest for the 1985 to 2001 period, which suggests that governments react more sensitively to constantly increasing or decreasing oil prices. Statistical significance during the 1985 to 2001 period suggests that oil-cross price elasticity of energy R&D demand exists even during periods without dramatic changes in oil prices. Regression results and *a priori* observations suggest the following two conclusions about Total Energy R&D:

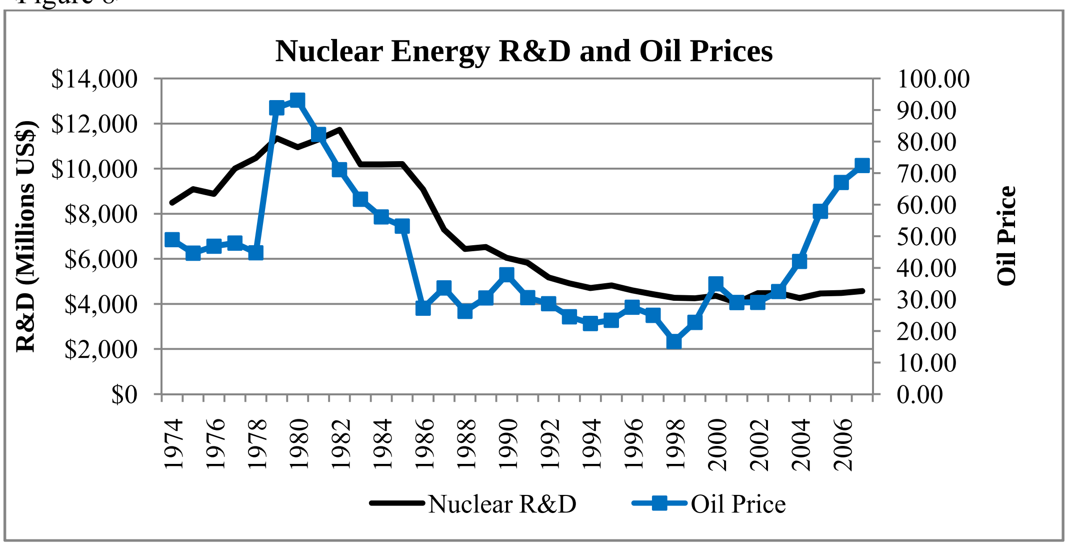
(3) Results suggest that a change in oil price causes a change in Total Energy R&D during periods of both stable and changing oil prices.

(4) Increasing elasticity after 1991 implies that governments have not sought to reduce oil cross-price elasticity of R&D demand; this suggests that governments lack well-planned energy security strategies

2. Nuclear Energy R&D Results

Nuclear Energy R&D represents the sum value of all types of nuclear energy, including fission and fusion. [65] Figure 8 presents a time series representation of cumulative IEA-member Nuclear Energy R&D

<Figure 8>

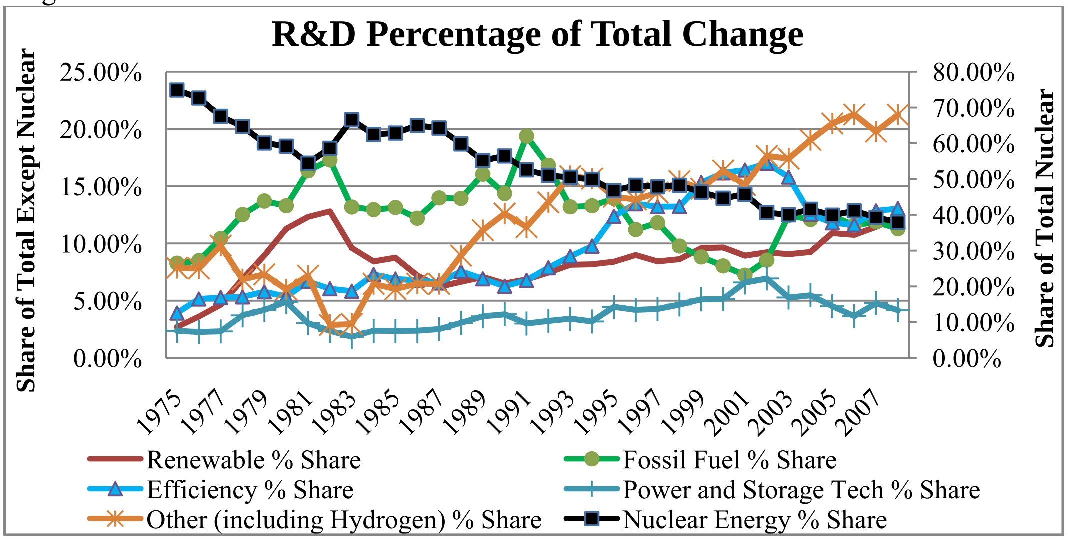


Panel regression results for Nuclear Energy R&D are included in Table 4 of the Appendix. Panel regression results suggest that a change in oil price results in a change in Nuclear Energy R&D, but with conditions. Although periods 1975 to 1991 and 1991 to 2007 independently share no significance, 1975 to 2007 T-Statistic values of 2.08 for oil price are above the 5% significance level.

[65] See Table 1 for a breakdown of what types of energy are included in the sum nuclear R&D value.

This research cannot measure Nuclear R&D coefficient changes since T-statistics were only significant for the 1975 to 2007 time-period. Insignificant statistical results within individual time-periods may reflect continuing disinvestment in nuclear energy. See figure 9 for a review of change in share of total R&D investment by energy type.

<Figure 9>



It appears unreasonable for diminishing returns to explain 26 years of Nuclear R&D disinvestment. It appears more likely that political discourse, public fear, and misinformation on nuclear safety explains continuing disinvestment in nuclear energy R&D.

Declining Nuclear R&D appears counterintuitive where energy security, CO2 reduction goals, and marginal costs may be concerned, particularly since nuclear reactors are now able to last up to 60 years while operating cost are 1.8 cents per kilowatt-hour (kWh). The operating costs for Coal on the other hand equal 2.1 cents per kWh.[66] For nuclear energy to become economical, however, capital costs need to fall from

[66] Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, (Singapore: World Scientific Publishing Co., 2007), 21.

\$2,000/Kilowatt (kW) to \$1,000/kW.[67] To put these costs in perspective, coal's capital costs total \$1,200/kW while combined cycle gas equipment costs equal \$500/kW.[68] Through investment in energy R&D, it may be possible to extend the life of a reactor, lower marginal costs, and lesson *periodic capital costs*, which could bring nuclear reactors close to the \$1,000/Kw range.[69]

Although concerns over storage of nuclear wastes exist, new-generation Fast Breeder Reactors (FBR) are able to exploit about 80% of the energy from their inputs while also including a variety of fuel sources such as depleted uranium.[70] Moreover, new generation graphite moderated and gas-cooled reactors such as the Pebble Bed Reactor are "absolutely safe." [71] Regression results and *a priori* observations suggest the following four conclusions about nuclear energy R&D:

(1) The 1975 to 2007 time-period results suggest a change in oil price causes a change in Nuclear Energy R&D; however, these results are questionable due to the lack of significance in all other regression time-periods.

(2) Disinvestment likely explains the loss of statistical significance for results in all other time-periods except for 1975 to 2007.

(3) Misinformation and public fears that do not represent changes in nuclear safety may be distorting investment in nuclear R&D.

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[67] Ibid., 21.

[68] Ibid., 21.

[69] Ibid., 263 – 264.

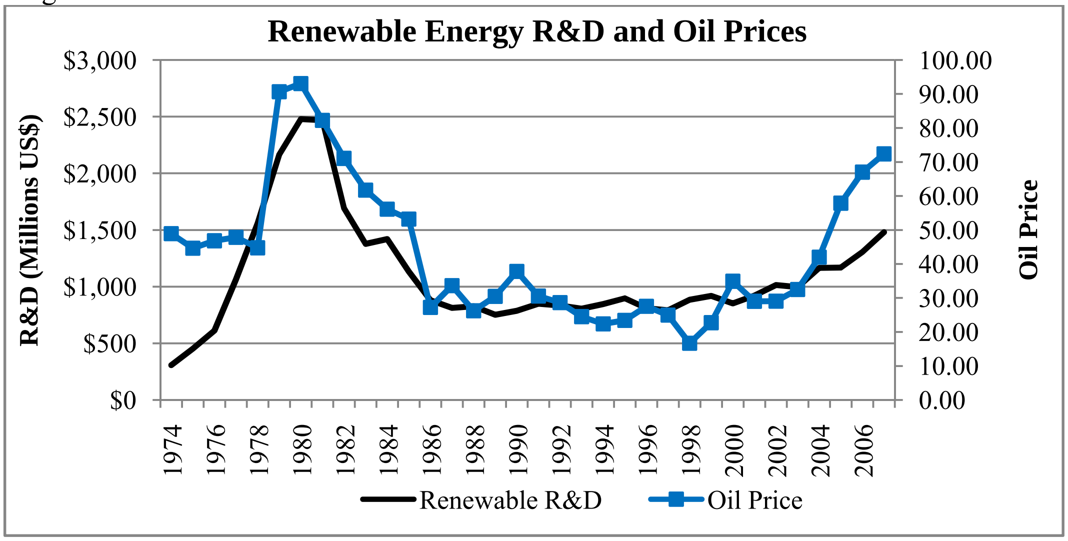
[70] Ibid., 273.

[71] Ibid., 267, 269.

3. Renewable Energy R&D Results

Renewable energy R&D represents the sum value of all forms of alternative energy.[72] Figure 10 presents a time series representation of cumulative IEA-member Renewable energy R&D.

<Figure 10>



Renewable Energy R&D panel regression results are included in Table 5 of the Appendix. Renewable Energy R&D results are similar to Total Energy R&D, albeit differences exist in the 1991 to 2007 sample. Regression results for the periods 1975 to 2007, 1985 to 2001, and 1975 to 1991, produce oil price T-Statistics of 6.62, 2.20, 6.54, and 1.93 respectively. Like Total Energy R&D, statistical significance for 1975 to 2007 equals 1% while the 1985 to 2001 sample significance equals 5%. Unlike total R&D however, the sample from 1991 to 2007 fails to meet 5% significance and instead resides just above the 10% significance level. Panel results as well as Figure 10 suggest that a general relationship between oil price and Renewable Energy R&D may exist, albeit this

[72] See Table 1 for a breakdown of what types of energy are included in the sum renewable R&D value.

relationship remains questionable due to decreasing significance revealed in the 1991 to 2007 sample.

Coefficient changes show that cross-price elasticity of Renewable Energy R&D demand decreased from 0.611 to 0.180 for the periods 1975 to 1991 and 1991 to 2007, respectively. High cross-price elasticity appears most counterintuitive considering that renewable energy faces many problems. While many leaders and environmental commentators appear to portray renewable energy as a key component to future energy security, physics and economics suggest otherwise. Although renewable energy may assist in reducing the use of oil in transportation, alternative energy inputs cannot sufficiently supply electricity to power grids. If the entire world switches to electric hybrid automobiles, this will put enormous stress on electricity generation facilities, which may result in increasing the use of fossil fuels. Therefore, real energy security resides in diversifying electricity generation input supplies.

Renewable energy such as solar and wind power cannot provide an electric gird *base load*—the constant minimum demand of electricity—and so therefore these inputs can only provide some of the *peak load*—the peak period of electricity demand.[73] Renewable energy supply inputs cannot sufficiently supply the *base load* because electricity cannot efficiently be stored with existing and near future technology. On the other hand, ocean power such as Ocean Thermal Energy Conversion (OTEC) could become more promising if it can eventually provide the *base load*.[74] Thus, electricity generation-related

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[73] Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, (Singapore: World Scientific Publishing Co., 2007), 53, 304.

[74] Lockheed Martin, "U.S. Department of Energy Awards Lockheed Martin Contract to Demonstrate Innovative Ocean Thermal Energy Conversion Subsystem," *Lockheed Martin on the*

R&D investments may more meaningfully for energy security. This research suggests the following three conclusions about renewable energy R&D:

(1) Results from the 1975 to 2007 sample suggest that in general, a change in oil price causes a change in Renewable Energy R&D; however the 10% level T-statistics for the 1991 to 2007 sample portend that this relationship may eventually cease.

(2) With the highest average elasticity of .466 for all energy R&D types during the period 1975 to 2007, renewable energy proves to be most sensitive to oil price changes.

(3) Declining oil cross-price elasticity of Renewable Energy R&D demand may suggest either that renewable energy marginal cost are declining or that governments are more carefully planning renewable R&D.

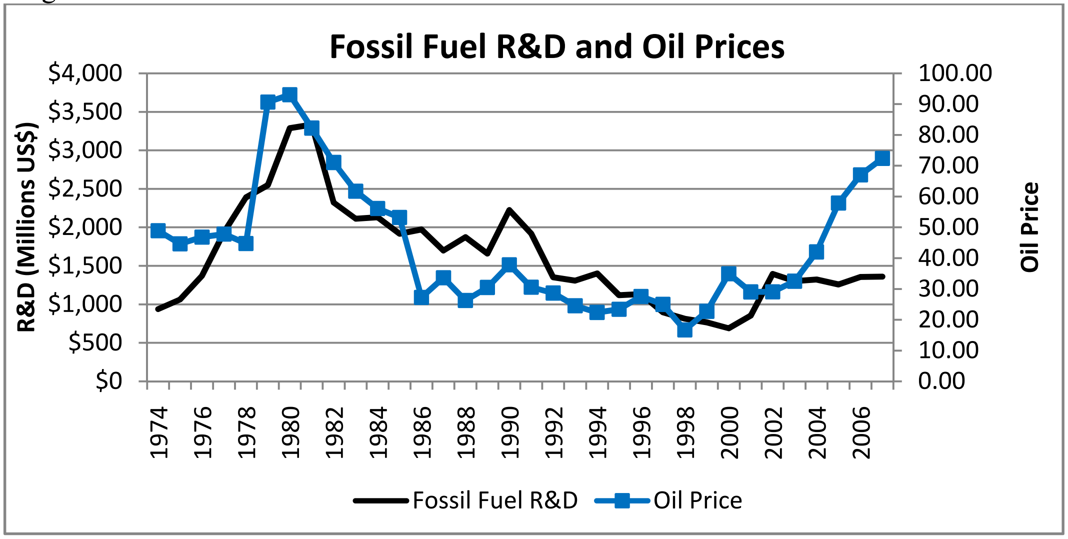
4. Fossil Fuel R&D

Fossil Fuel R&D represents the sum value of all types of fossil fuels, including but not limited to, unconventional hydrocarbons, coal, and oil and gas.[75] Figure 11 provides a time series representation of IEA-member fossil fuel R&D.

Web, October 8, 2008, http://www.lockheedmartin.com/news/press_releases/2008/100808_OTEC_Contract.html (accessed April 1, 2009)

[75] See Table 1 for a breakdown of what types of energy are included in the sum renewable R&D value.

<Figure 11>



Panel regression results for fossil fuel R&D are included in Table 6 of the Appendix. Panel regression results for Fossil Fuel R&D suggests that, *ceteris paribus*, a change in oil price causes a change in Fossil Fuel R&D, albeit this research found contradictory results with some of the sub-samples. For the significant periods 1975 to 2008 and 1975 to 1991, oil price T-statistics were over the 5% and 1% significance level, respectively. For the periods 1985 to 2001 and 1991 to 2007, T-statistics were not significant.

Figure 11 suggests that disinvestment may eventually break the statistical relationship between oil price and R&D. Among every type of energy source, Fossil Fuel R&D proves to be the most important to the world's future energy supply. Coal could account for 45% of world electricity generation by 2030 while oil will remain equally as inextricably linked to future energy security.[76] Therefore, Fossil Fuel related-R&D may continue to rely on public sector funding, particularly for CO2 reduction-technology.

[76] Klaus Brendow, *Global and regional coal demand perspectives to 2030 and beyond Quoted in* Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*. (Singapore: World Scientific Publishing Co., 2007) 232.

Even though coal emits twice as much CO2 as natural gas, global coal consumption increased approximately 36% from 2000 to 2007. [77] Oil, natural, gas, nuclear, and hydroelectric power consumption increased 11%, 19%., 6%, and 16% respectively.[78]

CO2 capture and storage cumulative IEA-member R&D investment increased over 3,600% from $4,000,000 in 2002 to $150,000,000 by 2007.[79] CO2 world total emissions in 2006 total 29,000,000 metric tons while the U.S. Department of Energy, Energy Information Agency (DOE EIA), estimates that emissions could reach 49,000,000 metric tons by 2030 with coal accounting for 40% of this estimate.[80] [81] [82] Although Fossil Fuel R&D investment leveled off after 2002, demand for CO2 capture and storage as well as other unconventional fossil fuel technology may require continued R&D investment in future. Moreover, if private companies include environmental costs from using fossil fuels, substitute energy sources will become more relatively cost-effective.

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[77] Energy Information Agency, "World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels (Million Metric Tons of Carbon Dioxide), 1980-2006" http://www.eia.doe.gov/pub/international/iealf/tab leh1co2.xls (accessed May 1, 2009)

[78] Ibid.

[79] International Energy Agency, "R&D Budgets," http://wds.iea.org/WDS/Common/Login /login.aspx (accessed April 3, 2009).

[80] British Petroleum, "Statistical Review of World Energy 2008," http://www.bp.com/liveassets/bp_internet/glob albp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/l ocal_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2008.xls (accessed August 5, 2008)

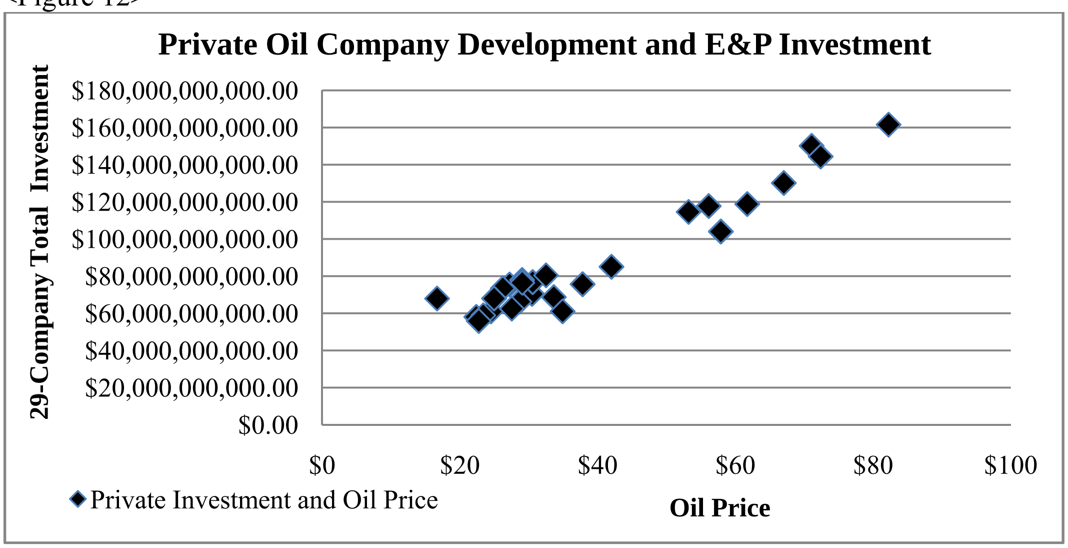
[81] Energy Information Agency, "World Energy-Related Carbon Dioxide Emissions by Region, 2003-2030" http://www.eia.doe.gov/oiaf/archive/ieo07/excel/figure_77data.xls (accessed May 1, 2009)

[82] Energy Information Agency, "World Carbon Dioxide Emissions from Coal Combustion by Region, 1990-2030" http://www.eia.doe.gov/oiaf/archive/ieo07/excel/figure_83data.xls (accessed May 1, 2009)

Unlike many other forms of investment for fuels such as nuclear and renewable energy, oil and gas technological developments primarily takes place in the private sector, which may explain the reduction in statistical significance for fossil fuels after 1991. In 2007, cumulative investment in production, development, and exploration for 29 oil companies surveyed by the DOE EIA totaled $130 billion dollars.[83] Cumulative Fossil Fuel R&D for the world's 28-member IEA totaled 1.3 billion dollars, an amount less than 1% of the total dollar value spending for oil and gas between these 29 companies.

To analyze the relationship between private sector oil company investment and oil price, this research collected data from the 29-company DOE EIA survey. The linear relationship that exists between private company investment and oil price appears tightly grouped enough to conclude that a change in oil price affects a change in private oil company investment. The scatter plot in Figure 12 represents the relationship between oil price and production, development, and exploration from 1981 to 2008.

<Figure 12>[84]



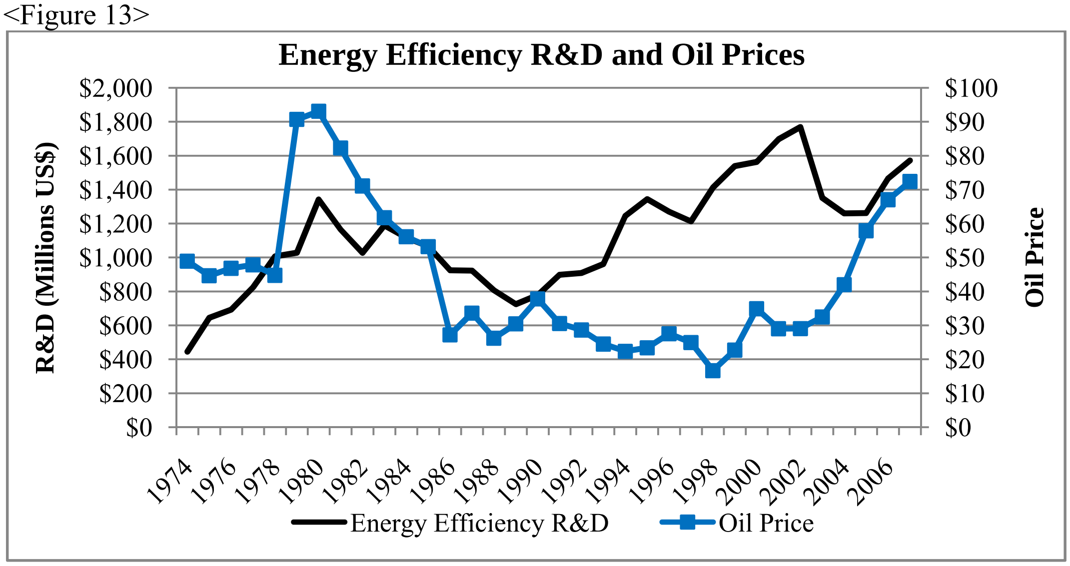
[83] Energy Information Administration, "*Performance Profiles of Major Energy Producers 2007,*" www.eia.doe.gov/emeu/perfpro/figuredata.xls (accessed February 2, 2009).
[84] Ibid.

R&D regression results and the Figure 12 scatter plot suggest that a change in oil price causes both a change in public and private sector investment in Fossil Fuel R&D, albeit this generalization may or may not apply to future R&D investments.

5. Energy Efficiency R&D

Energy Efficiency R&D represents the sum value of investment in improving efficiency and conservation in industry, residential, commercial, and transportation consumption sectors.[85] Figure 11 provides a time series representation of cumulative IEA-member fossil fuel R&D.

<Figure 13>



Panel regression results for energy efficiency R&D are included in Table 7 of the Appendix. Table 7 includes an additionally observed sample from 2002 to 2007. This research observed an additional time period due to the visually-identifiable post-2001 relationship between R&D and oil price represented in Figure 13. Panel regression

[85] See Table 1 for a breakdown of what types of energy are included in the sum renewable R&D value.

results for energy efficiency R&D suggests that a change in oil price results in a change in energy efficiency R&D, although the relationship may not always be consistent. For the sample periods 1975 to 2007 and 1975 to 1991, significance exceeded the 1% level with T-Statistics of 3.48 and 3.66, respectively. For sample periods 1985 to 2001 and 1991 to 2007, oil price appears statistically insignificant. For the sample period 2001 to 2007 however, the significance level reaches 5% with a T-Statistic value of 2.00.

Coefficient changes from .445 to 1.03 for the sample periods 1975 to 1991 and 2001 to 2007 suggest that oil cross-price elasticity of Energy Efficiency R&D demand increased over 50%. Despite the increased awareness on the importance of conservation of natural resources, government changes in Energy Efficiency R&D suggests that their demand for investment reflects short term market changes more than the negative externalities associated with energy inefficiency. The rapid increase in Energy Efficiency R&D after 2002 suggests that oil price changes rather than diminishing returns explains government Energy Efficiency R&D investment decisions.

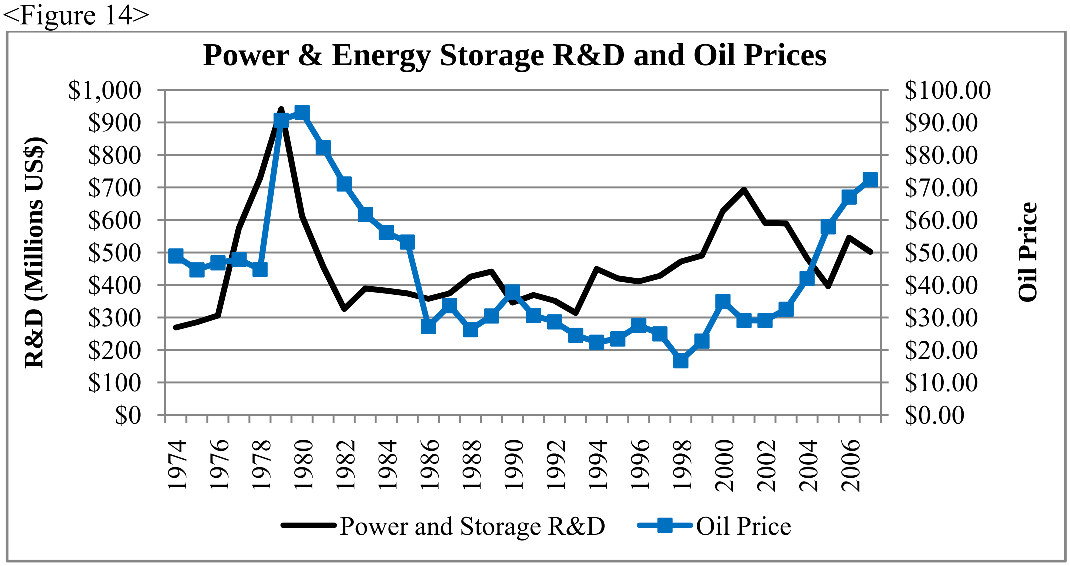
While a structural break may have occurred from 1985 to 2001, the relationship between oil price and Energy Efficiency R&D appears mostly consistent. Since the observed periods involve relatively persistent increases in oil prices, results may suggest that steady upward or downward trends in oil price lead to increasing or decreasing political interest in Energy Efficiency R&D. On the other hand, relatively stable oil prices may not influence Energy Efficiency R&D investment decisions. Figure 13 suggests that Energy Efficiency R&D continued to increase through the 1990s despite relatively low oil prices, but when R&D decreased at the start of the 21st Century, the trend reversed by 2002 as R&D followed oil price changes. As of 2007, Energy

Efficiency R&D accounts for 13% of Total Energy R&D. Energy Efficiency R&D investment proves to the most responsive to oil price changes. These results appear counterintuitive given the elevated awareness of the need to conserve energy through increased efficiency.

6. Power and Energy Storage Technology R&D

Power and Energy Storage Technology R&D represents the sum value of investment in electric power conversion, electricity transmission, electricity distribution, and energy storage.[86] Developing power and energy storage technology serves as the necessary link to making renewable energy useful to electricity generation. Figure 14 provides a time series representation of cumulative IEA-member Power and Energy Storage Technology R&D.

<Figure 14>



[86] See Table 1 for a breakdown of what types of energy are included in the sum renewable R&D value.

Panel regression results for Power and Energy Storage Technology R&D are included in Table 8 of the Appendix. With a T-Statistic Value of 2.54 at the 5% significance level for the period from 1975 to 2007, results suggest that a change in oil price results in a change in Power and Energy Storage Technology R&D.

Like Energy Efficiency R&D, during periods where oil prices are not consistently increase or decreasing, the oil cross-price elasticity of energy R&D demand ceases to exist. Due to a visually observable two-year lag in R&D during the 2000 to 2007 period, this research checked for statistical significance with oil price (t-2). This two-year oil price lag produced a T-Statistic of 2.47 at the 5% significance level. Increasing oil prices from 2001 to 2007 resulted in a rapid increase in Power and Energy Storage Technology R&D.

Coefficient values increased from .131 for the period 1975 to 1991 to .510 for the period sample 2000 to 2007. This suggests that oil cross-price elasticity of Power and Energy Storage Technology R&D demand increased over 380%. Power and energy storage technology, however, remains an indispensible key to making renewable energy applicable to reducing fossil fuel demand in primary consumption. Insofar, without power and electricity storage technology, most renewable energy inputs will never provide an electric grid *base load* since electricity presently cannot be stored.[87]

7. Panel Regression Method Limitations

With 12 developed countries observed across a panel regression for a 33-year period, generalizations from the results apply to a variety of developed countries with diverse

[87] Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, (Singapore: World Scientific Publishing Co., 2007), 304.

types of energy inputs, political systems, and demand needs. Research results may be limited to generalizations for developed countries since GDP Per Capita among the observed nations remain relatively high. Due to data limitations, major developing countries like China, India, Russia, and Brazil were not also included in the panel. On the other hand, T-statistic values remained consistent with 12 diverse countries that make up some of the largest shares of world energy consumption.

Chapter 5: Time Series Regression Analysis

This chapter briefly analyzes country-level time series results while applying the same dependent and independent variables in the panel regressions, albeit the sample sizes are naturally much smaller. Individual time-series regression results confirm the same conclusions drawn from panel regression results; albeit, this research found that what type of R&D investments change following oil price movements depends on the policy of a given country. This research also found that cross-price elasticity of energy R&D demand varies between countries.

Tables 10 through 17 in the Appendix include time-series regression results for Norway, Netherlands, U.S., Canada, Germany, Japan, Spain, and New Zealand. Denmark. Switzerland, Sweden, and the UK are not included due to a limited number of observations as well as inconsistent results. This research included all 12 countries in the panel regressions because results are from an unbalanced panel. With the exception of Norway, which maintains the highest GDP Per Capita of the sample, one or more energy R&D budget in every country appears sensitive to changes in oil prices.

1. Country Level Results

1.1 Cross Price Elasticity of Energy R&D Demand

This research analyzed T-statistic and coefficient results between countries in order to indentify varying degrees of oil cross-price elasticity of energy R&D demand; Table 18 in the Appendix sums up these comparisons. Only statistically significant results were included in the Figure. Results with 10% significance were marked with the standard single asterisk marking while 5% and 1% results were not marked in this table.

1.2 Analysis

Renewable Energy R&D proved to be the most frequently statistically significant with relatively high coefficients for seven of the eight individually observed countries. Total and Fossil Fuel R&D also appeared statistically significant and similarly elastic in the U.S., Germany, and New Zealand. Power and Energy Storage Technology R&D, Nuclear Energy R&D, and Energy Efficiency R&D each proved significant above the 5% level in only one country. Germany appears to be the only country to permit a change in oil price to influence investment in Nuclear Energy R&D. Germany and the Netherlands are the only countries that allow oil price changes to affect investment in Power and Energy Storage Technology R&D. Results suggest that only the Netherlands allows oil price changes to affect investment in Energy Efficiency, and with a very high cross-price elasticity of energy R&D demand represented by a coefficient value of 1.107.

Norway and Japan energy R&D investments appear to be the least sensitive to oil price changes. Sum values of coefficients for every energy R&D type may indicate the degree at which oil prices affect overall national energy R&D policies. Figure 15 below includes a ranking of sum coefficient totals for statistically significant observations where oil price (t-1) results in a change in energy R&D.

<Figure 15>[88]

Statistically Significant Sum Coefficients		Rank
Netherlands	3.001	8
New Zealand	1.677	7
Germany	1.123	6
U.S.	1.094	5
Spain	0.898	4
Canada	0.712	3
Japan	0.308	2
Norway	0	1

The rankings are in reverse order with Norway representing the lowest sum value of oil cross-price elasticity of energy R&D demand. If elasticity represents a failure to plan energy R&D around a long-term strategy, then the ranks above represent the consistency of a nation's energy security strategy. Significance and coefficient values may vary possibly depending on factors such as the country's degree of energy independence, political decision-making procedures, and endowment with natural resources. Although oil price does not affect every energy R&D type within every country evenly, panel regression results suggest that oil price changes should cause a change in a countries R&D investments.

2. Method Limitations

A limited number of observations and inconsistencies in data between countries make the imbalanced panel design analyzed in Chapter 4 more reliable for empirical conclusions than the individual time series analysis. A limited number of observations

[88] Sum values were calculated by adding the value of coefficient results for every statistically significant R&D energy type result within each country.

and differences in results between countries may constrain external validity. On the other hand, time series analysis serves to highlight differences in energy R&D strategies between the observed countries while also revealing the lack of bias in the sample since energy R&D investments are not all affected in the same way between each country.

Chapter 6: Research Implications for Energy Security

First, this chapter infers from regression results if IEA-member governments maintain coherent energy security strategies. Second, this chapter discusses the complexity of implementing an energy security strategy in an era of globalization. Third and finally, this chapter closes with policy recommendations.

1. Government Learning and Cross-Price Elasticity

When governments increased energy R&D rapidly in the 1970s as oil prices soared, their erratic investment responses reflected short-term market fluctuations rather than long-term energy security strategies. Global IEA-member energy R&D investment reductions during the 1980s suggest that governments prioritized reacting to short-term energy price changes over long-term negative externalities. Insofar, declining R&D investments in the 1980s suggest that governments based R&D investment levels on oil price changes rather than the costs associated with CO2 emissions, resource nationalism, and military conflict. As nations undergo complex learning through energy security trial and error experiences, *a priori*, modern governments should eventually develop long-term R&D strategy that prioritizes permanently diversifying their energy input sources.

Regression results and increasing coefficients after 1991 suggest that governments continue to base their long-term energy R&D funding on short-term changes in oil prices, albeit some countries are delinking oil from their long-term energy security strategies.[89] Moreover, increasingly stable Renewable Energy R&D investments juxtapose the

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[89] For lessons learned from energy and oil cross-price elasticity of energy R&D demand, see works by David Popp (1999), Jiu-Tian Zhang, Yin Fan, and Yi-Ming Wei (2006), and Richard G. Newell, Adam B. Jaffe and Robert N. Stavins (1998) Robert M. Margoils, Daniel M. Kammen (1999)

worsening oil cross-price elasticity of Power and Storage Energy Technology R&D demand. Due to the inherent connection between renewable energy and electricity storage, these counterintuitive results suggest that IEA-members lack a well-planned energy diversification strategy.

2. Changing National Energy R&D Strategies

With economic globalization and unrelenting increases in developed and developing country primary consumption demand, this research suggests that governments should reduce oil cross-price elasticity of energy R&D demand by resisting temptations to adjust R&D as oil prices erratically fluctuate. Energy R&D investment levels should instead reflect energy security goals. The IEA estimates global oil demand will increase from 85 mb/d to 106 mb/d while CO2 emissions are expect to increase at least 60% by 2030.[90] Global oil demand will continuously increase in the future, and energy security through technology, international coordination, and diversification will become increasingly important to plan for far in advance.

Countries have been at least superficially attempting to diversify their energy input sources since the late 1970s, but as Figure 6 reveals, diversification proves to be elusive despite investment in energy R&D. This may be the result of erratic developments in energy innovation due to oil cross-price elasticity of energy R&D demand. This may also reflect flawed energy security strategies that fail to capture the new complexities of globalization and economic integration. Nations should first recognize that a strategy

[90] Energy Information Agency, "World Energy-Related Carbon Dioxide Emissions by Region, 2003-2030" http://www.eia.doe.gov/oiaf/archive/ieo07/excel/figure_77data.xls (accessed May 1, 2009)

designed around individual national efforts does not reduce the effects of oil market insecurity on their economy. National goals such as the U.S. pursuit of energy import independence, or so-called "freedom from oil," falls short of a serving as a well-planned energy security strategy.[91]

3. Framing Global Energy Security

As the world develops into a financially integrated world economy, an energy crisis that influences one domestic economy will also ripple through another economy. Nations connected to other nations via trade and global financial markets are mutually vulnerable to energy insecurity regardless of their independent energy strategies. Thus, all developed nations are only as energy independent as their least energy secure economically integrated partner.

Achieving energy security not only requires decreasing oil cross-price elasticity of energy R&D demand, but it also for world leaders to abandon pre-globalization concepts such as national-level "energy independence" and "freedom from oil."[92] Reframing the focus to global energy security requires world leaders to make some major policy shifts on energy. Moreover, world leaders should recognize that if one nation were to improve its energy technology while not sharing that technology with other countries, it would not be increasing its energy security unless it were sharing that technology with all of the countries connected to the global economy. Thus, any national leader that pursues

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[91] David Sandalow*, Freedom From Oil: How the Next President Can End the United States Oil Addiction*, (New York: McGraw-Hill, 2008) 1- 216.

[92] Ibid.

"energy independence" or "freedom from oil" is instead pursuing pseudo-energy independence.

National leaders should present the energy security problem to their populations with the more appropriate concept of "global energy security." This diverges from the existing rhetoric that frames the problem as "energy security." The term "energy security" wrongly suggests that nations can independently isolate themselves from the negative externalities associated with foreign energy supply sources. "Global energy security" reflects the reality of our evolving interdependent global community where all nations are only as energy secure as their least secure global partner. Both increasing levels of oil cross-price elasticity of energy R&D demand and nationalistic rhetoric calling for "energy security" undermine the pursuit of the only viable energy security strategy: global energy security.

4. Policy Recommendations

Considering the reality of globalization and the importance of developing new energy technologies, this research proposes that governments should not only reduce oil cross-price elasticity of energy R&D demand, but also develop coordinated policies that reflect their mutual energy insecurity. If national leaders are serious about energy security, they will together pursue the following five "global energy security" objectives:

(1) Energy Trade Liberalization

(2) Global Cooperation

(3) Technology Sharing

(4) Government and Private Sector R&D Coordination

(5) Infrastructure Development and Technology Deployment

Nations will only achieve energy security when they reduce market distortions and increase energy trade liberalization, cooperation, and technology sharing. Through such a global strategy, it may be possible to secure permanent energy security for the world, particularly through such ambitious projects like nuclear fusion, which may require an international effort to mine the moon for Helium-3 (He-3).[93] Achieving lasting energy security strategy may require world leaders to form an inclusive World Energy Security Organization (WSEO). This organization would have to plan, coordinate, and manage executing international security initiatives. Although some nations will resist participating in this organization, accelerating energy demand around the world coupled with global integration makes it so that any independent effort to achieve permanent energy security will fail.

[93] Bryan Palaszewski, "Atmospheric Mining in the Outer Solar System," *National Aeronautics and Space Administration (NASA) on the web,* October 2006. http://gltrs.grc.nasa.gov/reports /2006/TM-2006-214122.pdf (accessed May 15, 2009)

Chapter 7: Conclusion

First, this research finds that oil supply and demand shifts should increase the importance both diversifying energy input sources and delinking energy R&D investments from oil price changes. Second, this research finds through panel regression results that oil prices continue to influence energy R&D budgets; therefore, governments allow short-term market changes to influence long-term R&D goals. Third, this research finds that oil cross-price of Total, Energy Efficiency, and Power and Storage Energy Technology R&D demand increased after 1991, which means that governments are not necessarily learning from previous over-reactions to oil shocks. Fourth, this research finds that governments like Norway are able to break the existing oil cross-price elasticity of energy R&D demand structure. Fifth and finally, this research proposes that if the purpose of energy R&D should be to increase energy security, global economic integration requires energy polices to become internationally coordinated.

Works Cited

Baker Hughes Incorporated. "International Rig Counts: Land/Offshore Split by Region and Country" http://files.shareholder.com/downloads/BHI/ 62492238x0x292732 /310C5A06-B2F6-471E-B7FF-EDAB46E0D957/International_Rig_Count_April_ 2009.xls" (accessed February 2, 2009)

Banks, Ferdinand. *Economic Theory and Oil: A Modern Survey. (*2009)

Banks, Ferdinand. *The Political Economy of World Energy: An Introductory Textbook.* Singapore: World Scientific Publishing Co., 2007.

Brendow, Klaus. *Global and regional coal demand perspectives to 2030 and beyond Quoted in* Ferdinand *Banks, The Political Economy of World Energy: An Introductory Textbook. Singapore: World Scientific* Publishing Co., 2007.

British Petroleum. "Statistical Review of World Energy 2008 http://www.bp.com /liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/ statistical_energy_review_2008/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2008.xls (accessed August 5, 2008)

Cronquist, Chapman. *Estimation and Classification of Reserves of Crude Oil, Natural Gas, and Condensate.* Houston: Society of Petroleum Engineers, 2001.

Federal Reserve Bank of St. Louis. "Series: Oil Price, Spot Price, West Texas Intermediate," http://research.stlouisfed.org/fred2/series/OILPRICE (accessed February 2, 2009)

Federal Reserve Bank of St. Louis. "Series: CPIAUCNS, Consumer Price Index for All Urban Consumers: All Items" http://research.stlouisfed.org/fred2/ series/CPIAUCNS (accessed February 2, 2009)

Hicks, John R. *The Theory of Wages, (London: MacMillan, 1932)* Quoted in David Popp, "Induced Innovation and Energy Prices," *American Economic Review* 92 (2002): 1-2, http://ideas.repec.org/p/nbr/nberwo/8284.html (accessed June 25, 2009)

Hubbard, Glenn R., Anthony Patrick O'Brien. *Economics*, Upper Saddle River: Pearson Education, Inc., 2006.

Hyne, Norman J. *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*. Tulsa: Penn Well Corporation, 2001.

International Energy Agency. "Call for Urgent and Decisive Policy Responses," *International Agency on the Web*, October 26, 2008. http://www.iea.org/textbase/press/pressdetail.asp?PRESS_REL_ID=137 (accessed May 1, 2009)

International Energy Agency. "IEA Forecasts Energy Demand to Increase 1.6 percent a Year Through 2030," *International Agency on the Web*, November 13, 2008. Quoted in *PRLog Free Press Release on the web.* http://www.prlog.org/10141086-iea-forecasts-energy-demand-to-increase-16-percent-year-through-2030.html, (accessed November 14, 2009)

International Energy Agency. "Key World Energy Statistics," *International Agency on the Web*, 2008. http://www.iea.org/textbase/nppdf/free/2008 /key_stats_2008.pdf (accessed May 1, 2009)

International Energy Agency. "New Energy Realities - WEO Calls for Global Energy Revolution Despite Economic Crisis" *International Agency on the Web*, November 12, 2008. http://www.iea.org /textbase/press /pressdetail.asp?press_rel_id=275 (accessed December 2, 2008).

International Energy Agency. "R&D Budgets," http://wds.iea.org/WDS/Common /Login/login.aspx (accessed April 3, 2009).

International Energy Agency. Quoted in Ferdinand Banks, *The Political Economy of World Energy: An Introductory Textbook*, Singapore: World Scientific Publishing Co., 2007.

Kalicki, Jan H., David L. Goldwun. *Energy Security: Toward a New Foreign Policy Strategy*, Washington D.C., Woodrow Wilson Center Press, 2005.

Lockheed Martin. "U.S. Department of Energy Awards Lockheed Martin Contract to Demonstrate Innovative Ocean Thermal Energy Conversion Subsystem," *Lockheed Martin on the Web*, October 8, 2008, http://www.lockheedmartin.com/news/press_releases/2008/100808_OTEC_Contract.html (accessed April 1, 2009)

Palaszewski, Bryan. "Atmospheric Mining in the Outer Solar System," *National Aeronautics and Space Administration (NASA) on the web,* October 2006. http://gltrs.grc.nasa.gov/reports /2006/TM-2006-214122.pdf (accessed May 15, 2009)

Robert M. Margoils, Daniel M. Kammen. "Underinvestment: The Energy Technology And R&D Challenge," Science 285 (1999): 690-691., http://www.sciencemag.org /cgi/content/ abstract/285/5428/690 (accessed June 25, 2009)

Sandalow,David, *Freedom From Oil: How the Next President Can End the United States Oil Addiction*: New York: McGraw-Hill, 2008.

U.S Department of Energy, Energy Information Administration, *Annual Oil Market Chronology,* 1970s, http://www.eia.doe.gov/cabs/AOMC/7 079.html (accessed , February 2, 2009).

U.S. Department of Energy, Energy Information Agency, "World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels (Million Metric Tons of Carbon Dioxide), 1980-2006" http://www.eia.doe.gov/pub/ international/iealf/tab leh1co2.xls (accessed May 1, 2009)

U.S. Department of Energy, Energy Information Agency, "World Carbon Dioxide Emissions from Coal Combustion by Region, 1990-2030" http://www.eia.doe.gov /oiaf/archive/ieo07/excel/figure_83dat a.xls (accessed May 1, 2009)

U.S. Department of Energy, Energy Information Administration, "*Crude Oil Input Qualities,"* http://tonto.eia.doe.gov/dnav/pet/pet_pnp_crq_dcu_nus _m.htm (accessed April 10, 2009).

U.S. Department of Energy, Energy Information Administration, *Performance Profiles of Major Energy Producers 2007,* www.eia.doe.gov/emeu/perfpro /figuredata.xls (accessed February 2, 2009).

U.S. Department of Energy, Energy Information Agency, "World Energy-Related Carbon Dioxide Emissions by Region, 2003-2030" http://www.eia.doe.gov /oiaf/archive/ieo07/excel/figure_77data.xls (accessed May 1, 2009)

U.S. Department of Energy, Energy Information Administration, "*Crude Oil Input Qualities,"* http://tonto.eia.doe.gov/dnav/pet/pet_pnp_crq_dcu_ nus_m.htm (accessed April 10, 2009).

Appendix

<Table 1>

Explanation of IEA R&D Data	
IEA Total	= Totals from Nuclear, Fossil Fuel, Renewable Energy, Energy Efficiency, Power and Energy Storage Technology, and Hydrogen Fuel
Total Nuclear Energy	= Total Nuclear Fission and Fusion technology, storage, et al.
Total Fossil Fuels	= Total Oil and Gas + Total Coal
Total Renewable Energy Sources	= Total Solar Energy + Wind Energy + Ocean Energy + Total Bio-Energy + Geothermal Energy+ Total Hydropower + Other Renewables
Energy Efficiency	Industry + Residential and Commercial + Transportation + Other Conservation
Power and Energy Storage Technology	= Electric Power Conversion+ Electricity Transmission & Distribution + Energy Storage

Table <2>[94]

Energy Consumption MTOE as a % of Total									
Country	GDP Per Capita	Renewable % of Total Rank	Total MTOE	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Renewable
Sweden	$49,873	1	65.83	25.53%	1.42%	3.36%	23.18%	22.76%	23.76%
Norway	$82,465	2	57.90	17.47%	6.64%	0.77%	NA	52.88%	22.24%
Denmark	$57,257	3	21.37	43.76%	19.19%	22.11%	NA	NA	14.94%
Switzerland	$56,579	4	33.98	33.28%	7.77%	1.17%	18.49%	24.46%	14.83%
New Zealand	$31,219	5	19.84	35.24%	17.01%	8.57%	NA	26.94%	12.23%
Germany	$40,162	6	339.13	33.17%	21.96%	25.37%	9.37%	1.83%	8.29%
Spain	$32,451	7	160.58	49.02%	19.68%	12.52%	7.76%	4.61%	6.41%
Netherlands	$46,669	8	94.26	51.48%	35.48%	9.39%	1.01%	NA	2.65%
Canada	$43,368	9	321.72	31.80%	26.28%	9.46%	6.56%	25.89%	1.00%
Japan	$34,225	10	517.46	44.23%	15.69%	24.22%	12.20%	3.66%	1.00%
U.K.	$45,549	11	216.38	36.15%	38.03%	18.10%	6.52%	0.99%	0.21%
U.S.	$45,047	12	2,361.53	39.94%	25.22%	24.29%	8.13%	2.40%	0.01%

[94] Percentage totals range from 80 to 102 percent due to inherent inconsistencies related with data from different sources. Except for renewable energy in Japan and Canada, all other forms of energy percentages were calculated with Million Tons of Oil Equivalent use. Total MTOE data represents sum values provided by the 2008 British Petroleum Statistical Review, which does not include renewable data, and thus accounts for percentage total inconsistencies.

<Table 3>

Regression Results: Panel Least Squares				
Method: Panel Least Squares		Cross Sections Included: 12 Countries		
Dependent Variable: Δ Total R&D.				
Period Average Oil Price	$43.45	$29.06	$51.66	$34.49
Period Oil Price Range	$76.39	$36.52	$66.84	$55.70
Observation Years (Periods)	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg 4.
Δ *Oil Price*	0.145 (3.03)***	0.032 (0.559)	0.193 (2.68)**	0.04 (0.65)
Δ *Oil Price(t-1)*	0.167 (4.25)***	0.137 (2.34**)	0.169 (3.05)***	0.184 (3.06)***
Δ *GDP Per Capita*	0.059 (0.49)	-0.194 (-1.31)	-0.084 (-0.44)	0.199 (1.25)
Δ *Consumption Coal*	-0.202 (-2.52)**	-0.144 (-1.129)	-0.342 (-2.60)***	-0.074 (-0.82)
Δ *Consumption Oil*	0.290 (1.10)	0.016 (0.177)	0.122 (1.18)	-0.175 (-0.867)
Δ *Consumption NG*	0.077 (0.95)	-0.355 (-0.904)	0.483 (1.30)	0.013 (0.033)
Δ *Consumption Hydro.*	0.139 (1.43)	000 (-0.00)	0.253 (1.45)	0.056 (0.558)
Δ *Consumption Nuc*	0.240 (3.06)***	-0.192 (-1.19)	0.316 (3.02)***	-0.202 (-1.322)
Observations	381	197	194	199
R-Squared	0.106939	0.075993	0.158752	0.078754
Adjusted R-Squared	0.087734	0.036673	0.122373	0.039964
Durbin-Watson stat	1.704681	1.669829	1.550397	2.156433

Significance Level: * 10%, **5%, ***1%

<Table 4>

Regression Results: Panel Least Squares				
Method: Panel Least Squares	Cross Sections Included: 12 Countries			
Dependent Variable: Δ Nuclear Energy R&D				
Period Average Oil Price	$43.45	$29.06	$51.66	$34.49
Period Oil Price Range	$76.39	$36.52	$66.84	$55.70
Observation Periods	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg 4.
Δ *Oil Price*	0.091 (1.43)	0.037 (0.41)	0.115 (1.41)	0.030 (0.28)
Δ *Oil Price(t-1)*	0.106 (2.08)**	0.088 (0.98)	0.080 (1.31)	0.167 (1.63)
Δ *GDP Per Capita*	0.076 (0.47)	-0.223 (-0.95)	0.237 (1.08)	-0.175 (-0.62)
Δ *Consumption Coal*	-0.051 (-0.46)	-0.414 (-2.05)**	-0.072 (-0.45)	-0.151 (-0.98)
Δ *Consumption Oil*	0.121 (0.34)	-0.315 (-0.51)	0.36 (0.85)	-1.18 (-1.68)*
Δ *Consumption NG*	0.027 (0.17)	0.097 (0.40)	0.066 (0.36)	0.007 (0.02)
Δ *Consumption Hydro.*	0.063 (0.50)	-0.161 (-0.85)	0.109 (0.56)	-0.084 (-0.5)
Δ *Consumption Nuc*	0.121 (1.21)	-0.106 (-0.43)	0.202 (1.77)*	-0.247 (-0.97)
Observations	354	183	181	184
R-Squared	0.02422	0.041868	0.05534	0.047264
Adjusted R-Squared	0.001593	-0.002184	0.011402	0.00371
Durbin-Watson stat	1.962765	2.103174	1.827695	2.037853

Significance Level: * 10%, **5%, ***1%

<Table 5>

Regression Results: Panel Least Squares				
Method: Panel Least Squares		Cross Sections Included: 12 Countries		
Dependent Variable: Δ Renewable Energy R&D				
Period Average Oil Price	$43.45	$29.06	$51.66	$34.49
Period Oil Price Range	$76.39	$36.52	$66.84	$55.70
Observation Periods	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg 4.
Δ *Oil Price*	0.292 (3.64)***	0.074 (0.93)	0.566 (4.79)***	-0.034 (-0.36)
Δ *Oil Price (t-1)*	0.446 (6.62)***	0.177 (2.20)**	0.611 (6.54)***	0.180 (1.93)*
Δ *GDP Per Capita*	0.324 (1.61)	-0.129 (-0.63)	0.027 (0.088)	0.325 (1.32)
Δ *Consumption Coal*	-0.235 (-1.75)*	-0.229 (-1.3)	-0.379 (-1.76)*	-0.099 (-0.71)
Δ *Consumption Oil*	0.131 (0.96)	0.036 (0.28)	0.134 (0.798)	0.0123 (0.01)
Δ *Consumption NG.*	0.724 (1.63)	-0.64 (-1.19)	1.304 (2.12)**	0.001 (0.00)
Δ *Consumption Hydro.*	0.079 (0.49)	-0.109 (-0.64)	0.067 (0.23)	0.019 (0.12)
Δ *Consumption Nuc*	0.391 (2.45)**	-0.576 (-2.59)***	0.367 (1.64)	-0.187 (-0.79)
Observations	379	197	192	199
R-Squared	0.152344	0.09364	0.265866	0.029347
Adjusted R-Squared	0.134016	0.055071	0.233772	-0.011522
Durbin-Watson stat	1.680599	1.874316	1.563470	2.424424

Significance Level: * 10%, **5%, ***1%

<Table 6>

Regression Results: Panel Least Squares				
Method: Panel Least Squares	Cross Sections Included: 12 Countries			
Dependent Variable: Δ Fossil Fuel R&D				
Period Average Oil Price	$43.45	$29.06	$51.66	$34.49
Period Oil Price Range	$76.39	$36.52	$66.84	$55.70
Observation Periods	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg 4.
Δ *Oil Price*	0.339 (3.44)***	0.167 (1.27)	0.489 (3.57)***	0.237 (1.64)
Δ *Oil Price(t-1)*	0.171 (2.08)**	0.0426 (0.31)	0.300 (2.75)***	-0.060 (-0.44)
Δ *GDP Per Capita*	0.137 (0.54)	-0.080 (-0.23)	-0.210 (-0.55)	0.070 (0.18)
Δ *Consumption Coal*	-0.055 (-0.311)	-0.220 (-0.75)	-0.113 (-0.39)	-0.020 (-0.1)
Δ *Consumption Oil*	-0.408 (-0.73)	0.040 (0.04)	0.234 (0.31)	-0.403 (-0.42)
Δ *Consumption NG*	-0.289 (-1.3)	-0.614 (-1.73)*	-0.241 (-0.88)	-0.500 (-1.06)
Δ *Consumption Hydro.*	0.080 (0.39)	0.220 (0.78)	0.249 (0.72)	0.050 (0.23)
Δ *Consumption Nuc*	0.293 (1.84)*	-0.260 (-0.71)	0.273 (1.39)	-0.420 (-1.19)
Observations	361	193	178	195
R-Squared	0.063548	0.045202	0.123049	0.036033
Adjusted R-Squared	0.042265	0.003689	0.081536	-0.005428
Durbin-Watson stat	1.932287	1.930234	1.914821	1.983001

Significance Level: * 10%, **5%, ***1%

<Table 7>

Regression Results: Panel Least Squares					
Method: Panel Least Squares			Cross Sections Included: 12 Countries		
Dependent Variable: Δ Energy Efficiency R&D					
Period Average Oil Price	$43.45	$29.06	$51.66	$34.49	$47.13
Period Oil Price Range	$76.39	$36.52	$66.84	$55.70	$43.36
Observation Years (Periods)	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)	01-07 (7)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg. 4.	Reg. 5
Δ *Oil Price*	0.144 (1.147)	0.223 (1.38)	0.18 (1.221)	0.124 (0.56)	-0.06 (-0.11)
Δ *Oil Price(t-1)*	0.384 (3.485)***	0.242 (1.51)	0.455 (3.66)***	0.198 (0.93)	1.03 (2.00)**
Δ *GDP Per Capita*	-0.336 (-1.076)	-0.61 (-1.49)	-0.043 (-0.11)	-0.632 (-1.13)	0.165 (0.11)
Δ *Consumption Coal*	-0.45 (-1.956)*	-0.405 (-1.19)	-0.453 (-1.7)	-0.328 (-0.81)	0.43 (0.54)
Δ *Consumption Oil*	0.15 (0.646)	1.308 (1.19)	1.646 (2.12)**	-0.269 (-0.18)	-2.13 (-0.73)
Δ *Consumption NG*	1.546 (2.219)**	0.197 (0.71)	0.045 (0.19)	1.074 (1.51)	1.79 (1.34)
Δ *Consumption Hydro.*	0.244 (0.95)	0.323 (1.01)	0.035 (0.09)	0.344 (0.94)	0.640 (1.03)
Δ *Consumption Nuc*	0.235 (1.124)	0.703 (1.55)	0.201 (0.92)	0.584 (1.07)	0.36 (0.30)
Observations	358	252	179	190	76
R-Squared	0.061003	0.046065	0.116096	0.039615	0.103021
Adjusted R-Squared	0.039478	0.01466	0.074501	-0.002833	-0.004081
Durbin-Watson stat	2.102955	2.098629	2.198717	2.10891	2.462489

Significance Level: * 10%, **5%, ***1%

<Table 8>

Regression Results: Panel Least Squares					
Method: Panel Least Squares	Cross Sections Included: 12 Countries				
Dependent Variable: Δ Power and Energy Storage Technology R&D					
Period Average Oil Price	\$43.45	\$29.06	\$51.66	\$34.49	\$47.13
Period Oil Price Range	\$76.39	\$36.52	\$66.84	\$55.70	\$43.36
Observation Periods	75 - 07 (33)	85-01 (17)	75-91 (17)	91-07 (17)	01-07 (7)
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg. 4.	Reg. 5
Δ *Oil Price*	0.05 (0.42)	0.105 (0.66)	0.170 (0.85)	0.014 (0.08)	0.061 (0.32)
Δ *Oil Price(t-1)*	0.25 (2.54)**	0.07 (0.46)	0.131 (3.04)***	-0.066 (-0.37)	0.204 (0.71)
Δ *GDP Per Capita*	0.105 (0.35)	0.33 (0.82)	0.439 (-0.68)	0.203 (0.43)	-0.82 (-1.56)
Δ *Consumption Coal*	-0.156 (-0.76)	-0.74 (-2.14)	0.335 (-0.98)	-0.363 (-1.41)	-0.23 (-1.18)
Δ *Consumption Oil*	-0.119 (-0.18)	-0.114 (-0.10)	0.843 (0.64)	-0.373 (-0.31)	-0.720 (-0.60)
Δ *Consumption NG*	0.099 (0.48)	-0.01 (-0.04)	0.247 (0.65)	-0.776 (-1.29)	-1.221 (-2.20)
Δ *Consumption Hydro.*	0.102 (0.41)	-0.308 (-0.87)	0.417 (0.5)	-0.13 (-0.43)	-0.096 (-0.38)
Δ *Consumption Nuc*	0.221 (1.06)	-0.484 (-1.06)	0.262 (0.83)	-0.624 (-1.30)	-0.435 (-0.78)
Oil Price (t-2) (2000-2007)	NA	NA	NA	NA	0.510 (2.47)**
Observations	355	191	181	185	84
R-Squared	0.025516	0.036549	0.0648	0.031692	0.180795
Adjusted R-Squared	0.002984	-0.005801	0.021302	-0.012322	0.081162
Durbin-Watson stat	2.167711	2.314597	1.923926	2.273647	2.406156

Significance Level: * 10%, **5%, ***1%

<Table 9>

Regression Results Compared: Panel Least Squares: Cross Sections Included: 12 Countries						
Observation Period	75 - 07 (33)	75 - 07 (33)	75 - 07 (33)	75 - 07 (33)	75 - 07 (33)	75 - 07 (33)
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg. 1	Reg. 2	Reg. 3	Reg 4.	Reg 4.	Reg 5.
Δ Oil Price	0.145 (3.03)***	0.292 (3.64)***	0.091 (1.43)	0.339 (3.44)***	0.05 (0.42)	0.144 (1.14)
Δ Oil Price (t-1)	0.167 (4.25)***	0.446 (6.62)***	0.106 (2.08)**	0.171 (2.08)**	0.25 (2.54)**	0.384 (3.485)***
Δ GDP Per Capita	0.059 (0.49)	0.324 (1.61)	0.076 (0.47)	0.137 (0.54)	0.105 (0.35)	-0.336 (-1.07)
Δ Consumption Coal	-0.202 (-2.52)**	-0.235 (-1.75)*	-0.051 (-0.46)	-0.055 (-0.311)	-0.156 (-0.76)	-0.45 (-1.95)*
Δ Consumption Oil	0.290 (1.10)	0.131 (0.96)	0.121 (0.34)	-0.408 (-0.73)	-0.119 (-0.18)	0.15 (0.64)
Δ Consumption NG	0.077 (0.95)	0.724 (1.63)	0.027 (0.17)	-0.289 (-1.3)	0.099 (0.48)	1.546 (2.21)**
Δ Consumption Hydro	0.139 (1.43)	0.079 (0.49)	0.063 (0.50)	0.080 (0.39)	0.102 (0.41)	0.244 (0.95)
Δ Consumption Nuc	0.240 (3.06)***	0.391 (2.45)**	0.121 (1.21)	0.293 (1.84)*	0.221 (1.06)	0.235 (1.12)
Observations	381	379	354	361	355	358
R-Squared	0.106939	0.152344	0.02422	0.063548	0.025516	0.061003
Adjusted R-Squared	0.087734	0.134016	0.001593	0.042265	0.002984	0.039478
Durbin-Watson stat	1.704681	1.680599	1.962765	1.932287	2.167711	2.102955

Significance Level: * 10%, **5%, ***1%

<Table 10>

Regression Results	Country: Norway					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.100 (0.55)	0.329 (1.147)	0.020 (0.10)	0.009 (0.06)	-0.059 (-0.55)	-0.587 (-0.84)
Δ Oil Price(t-1)	0.032 (0.18)	0.356 (1.259)	-0.111 (-0.58)	-0.283 (-1.93)*	-0.068 (-0.64)	-0.347 (-0.50)
Δ GDP Per Capita	-0.130 (-0.21)	-0.359 (-0.371)	0.070 (0.10)	1.041 (2.06)**	0.309 (0.84)	0.640 (0.27)
Δ Consumption Coal	-0.895 (-3.33)***	-0.788 (-1.83)*	-0.684 (-1.86)	0.468 (1.66)*	0.358 (1.75)*	-0.974 (-0.93)
Δ Consumption Oil	2.078 (1.59)	2.687 (1.29)	-1.652 (-1.07)	-0.368 (-0.311)	0.720 (0.83)	-0.156 (-0.03)
Δ Consumption NG	1.513 (3.32)***	2.402 (3.30)***	0.159 (0.22)	-0.889 (-1.61)	-0.528 (-1.32)	-1.335 (-0.75)
Δ Consumption Hydro	0.356 (0.73)	0.729 (0.94)	-0.727 (-1.37)	-0.620 (-1.52)	-0.168 (-0.57)	-1.09 (-0.58)
Δ Consumption Nuc	NA	NA	NA	NA	NA	NA
Observations	30	30	29	29	29	30
R-Squared	0.718040	0.617519	0.256473	0.403808	0.302140	0.134664
Adjusted R-Squared	0.628325	0.495820	0.008630	0.205077	0.069521	-0.140671
Durbin-Watson stat	2.222460	1.544321	1.837359	2.020543	1.631866	1.909360

Significance Level: * 10%, **5%, ***1%

<Table 11>

Regression Results	Country: Netherlands					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.135	0.326	0.201	0.296	0.160	-0.208
	(1.07)	(1.00)	(0.95)	(0.80)	(0.63)	(-0.76)
Δ Oil Price(t-1)	0.110	0.530	0.093	0.563	0.801	1.107
	(1.20)	(2.23)**	(0.60)	(2.10)**	(4.10)***	(5.29)***
Δ GDP Per Capita	-0.538	-0.491	-0.313	-0.611	0.896	0.645
	(-1.74)*	(-0.61)	(-0.60)	(-0.68)	(1.38)	(0.93)
Δ Consumption Coal	-0.159	0.057	-0.627	-0.526	-1.257	-1.012
	(-0.56)	(0.07)	(-1.32)	(-0.63)	(-2.089)**	(-1.57)
Δ Consumption Oil	0.877	1.391	1.577	-1.494	-3.063	-0.044
	(1.38)	(0.85)	(1.48)	(-0.80)	(-2.33)**	(-0.03)
Δ Consumption NG	-0.193	0.929	-1.532	0.089	1.469	1.219
	(-0.27)	(0.50)	(-1.28)	(0.042)	(0.99)	(0.77)
Δ Consumption Hydro	NA	NA	NA	NA	NA	NA
Δ Consumption Nuc	0.062	0.111	-0.031	0.434	0.053	0.170
	(0.30)	(0.21)	(-0.09)	(0.73)	(0.12)	(0.38)
Observations	30	30	30	30	33	33
R-Squared	0.221514	0.227706	0.245652	0.255853	0.548331	0.591833
Adjusted R-Squared	-0.026186	-0.018024	0.005633	0.019079	0.421863	0.477546
Durbin-Watson stat	2.407275	1.973131	2.689545	1.859746	1.310358	2.349609

Significance Level: * 10%, **5%, ***1%

<Table 12>

Regression Results	Country: United States of America					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.212 (2.33)**	0.259 (0.99)	0.334 (2.57)**	0.142 (0.54)	0.723 (1.68)*	NA
Δ Oil Price(t-1)	0.184 (2.45)**	0.495 (2.29)**	0.118 (1.11)	0.451 (2.07)**	0.016 (0.04)	NA
Δ GDP Per Capita	1.094 (1.01)	4.376 (1.40)	0.901 (0.58)	1.660 (0.53)	-4.07 (-0.80)	NA
Δ Consumption Coal	-1.809 (-1.68)*	-3.58 (-1.16)	-2.49 (-1.63)	-0.249 (-0.08)	-1.35 (-0.26)	NA
Δ Consumption Oil	1.863 (2.60)***	2.240 (1.08)	0.829 (0.81)	2.742 (1.32)	6.95 (2.06)**	NA
Δ Consumption NG	0.220 (0.34)	2.233 (1.21)	-0.629 (-0.69)	1.040 (0.56)	-3.046 (-1.01)	NA
Δ Consumption Hydro	-0.181 (-1.03)	-0.367 (-0.72)	-0.154 (-0.61)	-0.205 (-0.40)	1.017 (1.23)	NA
Δ Consumption Nuc	0.500 (1.79)*	1.704 (2.124)**	0.450 (1.13)	1.122 (1.38)	3.268 (2.49)*	NA
Observations	33	33	33	33	33	NA
R-Squared	0.582093	0.532394	0.405205	0.385399	0.412580	NA
Adjusted R-Squared	0.442790	0.376525	0.206940	0.180532	0.216773	NA
Durbin-Watson stat	1.948014	1.584310	2.453107	2.002138	2.321074	NA

Significance Level: * 10%, **5%, ***1%

<Table 13>

Regression Results	Country: Canada					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.062	0.521	0.099	-0.050	-0.525	0.246
	(0.53)	(1.53)	(0.49)	(-0.261)	(-1.31)	(0.95)
Δ Oil Price(t-1)	0.057	0.712	0.125	-0.033	0.463	0.084
	(0.69)	(2.92)***	(0.86)	(-0.240)	(1.41)	(0.36)
Δ GDP Per Capita	0.198	-0.602	0.350	0.328	1.753	-0.672
	(0.41)	(-0.42)	(0.42)	(0.411)	(1.05)	(-0.60)
Δ Consumption Coal	0.073	-0.096	-0.134	0.481	-1.333	-0.284
	(0.28)	(-0.12)	(-0.29)	(1.115)	(-1.20)	(-0.46)
Δ Consumption Oil	-0.557	-2.762	-0.262	-0.613	0.793	-2.601
	(-0.66)	(-1.12)	(-0.18)	(-0.442)	(0.27)	(-1.28)
Δ Consumption NG	-0.224	3.029	-0.362	-0.535	0.893	0.179
	(-0.35)	(1.63)	(-0.32)	(-0.510)	(0.42)	(0.12)
Δ Consumption Hydro	0.115	-2.102	2.161	0.502	1.037	-0.509
	(0.60)	(-1.06)	(1.83)*	(0.44)	(0.39)	(-0.32)
Δ Consumption Nuc	0.547	0.665	0.098	0.572	-0.074	-0.083
	(0.80)	(1.19)	(0.29)	(1.81)*	(-0.07)	(-0.19)
Observations	33	33	33	33	29	31
R-Squared	0.154171	0.380313	0.216452	0.282736	0.204619	0.112893
Adjusted R-Squared	-0.127771	0.173750	-0.044731	0.043647	-0.113533	-0.209692
Durbin-Watson stat	2.185889	1.692029	1.793565	2.077040	1.868946	1.960317

Significance Level: * 10%, **5%, ***1%

<Table 14>

Regression Results	Country: Germany					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.153	0.46	0.184	0.539	-0.084	0.673
	(1.01)	(1.68)*	(1.01)	(1.24)	(-0.12)	(1.03)
Δ Oil Price(t-1)	0.305	0.480	0.338	-0.100	0.563	0.782
	(2.68)***	(2.34)**	(2.47)**	(-0.30)	(1.13)	(1.24)
Δ GDP Per Capita	-0.085	0.810	-0.321	0.732	-0.219	1.176
	(-0.25)	(1.31)	(-0.79)	(0.76)	(-0.14)	(0.79)
Δ Consumption Coal	1.415	-1.88	1.657	1.042	-1.295	-1.110
	(1.62)	(-1.18)	(1.58)	(0.41)	(-0.34)	(-0.26)
Δ Consumption Oil	0.416	-1.06	0.976	0.743	-0.941	0.109
	(0.41)	(-0.58)	(0.81)	(0.25)	(-0.21)	(0.022)
Δ Consumption NG	-0.350	0.980	-1.154	-3.403	0.712	-1.500
	(-0.36)	(0.55)	(-0.99)	(-1.23)	(0.16)	(-0.35)
Δ Consumption Hydro	-0.092	-0.78	-0.033	2.489	-3.087	-0.693
	(-0.21)	(-0.98)	(-0.06)	(1.99)**	(-1.62)	(-0.34)
Δ Consumption Nuc	0.097	2.052	0.124	0.543	-0.268	1.128
	(0.35)	(4.07)***	(0.37)	(0.68)	(-0.22)	(0.73)
Observations	33	33	33	33	33	30
R-Squared	0.363757	0.626408	0.371277	0.269395	0.175808	0.137804
Adjusted R-Squared	0.151676	0.501877	0.161702	0.025860	-0.098922	-0.190651
Durbin-Watson stat	2.885748	2.512647	3.042909	2.052328	2.333122	2.119002

Significance Level: * 10%, **5%, ***1%

<Table 15>

Regression Results	Country: Japan					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.057	0.179	0.106	0.315	NA	-0.206
	(0.67)	(1.15)	(0.91)	(0.78)		(-0.44)
Δ Oil Price(t-1)	0.033	0.308	-0.013	-0.172	NA	0.459
	(0.48)	(2.38)**	(-0.14)	(-0.51)		(0.98)
Δ GDP Per Capita	-0.046	0.531	0.000	0.535	NA	-0.112
	(-0.23)	(1.48)	(0.00)	(0.58)		(-0.10)
Δ Consumption Coal	-0.136	1.186	-0.808	2.621	NA	-3.923
	(-0.33)	(1.57)	(-1.44)	(1.35)		(-1.59)
Δ Consumption Oil	-0.848	-1.418	-0.993	-3.611	NA	-1.983
	(-1.42)	(-1.29)	(-1.22)	(-1.28)		(-0.55)
Δ Consumption NG	0.384	-0.290	0.910	1.274	NA	3.300
	(1.34)	(-0.55)	(2.33)**	(0.94)		(2.22)**
Δ Consumption Hydro	0.005	0.029	0.050	0.237	NA	0.881
	(0.02)	(0.09)	(0.21)	(0.29)		(0.96)
Δ Consumption Nuc	0.072	0.677	-0.276	-0.421	NA	-1.251
	(0.52)	(2.68)***	(-1.47)	(-0.64)		(-1.76)*
Observations	33	33	33	33	NA	30
R-Squared	0.277960	0.542499	0.278976	0.201514	NA	0.333159
Adjusted R-Squared	0.037280	0.389999	0.038634	-0.064648	NA	0.079124
Durbin-Watson stat	2.191745	2.396891	2.235320	2.047196	NA	3.123269

Significance Level: * 10%, **5%, ***1%

<Table 16>

Regression Results	Country: Spain					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.082 (0.29)	0.035 (0.13)	0.313 (1.28)	0.673 (1.28)	-0.191 (-1.00)	0.119 (0.342)
Δ Oil Price(t-1)	0.169 (0.85)	0.645 (3.41)***	0.063 (0.36)	-0.156 (0.36)	0.253 (1.87)*	0.396 (1.59)
Δ GDP Per Capita	-0.337 (-0.61)	0.452 (0.86)	-0.301 (-0.62)	-0.542 (-0.62)	0.902 (2.41)**	0.585 (0.85)
Δ Consumption Coal	0.603 (0.67)	2.182 (2.56)**	-0.159 (-0.20)	-0.156 (-0.20)	0.479 (0.78)	1.611 (1.43)
Δ Consumption Oil	2.644 (1.37)	5.76 (3.15)***	2.72 (1.62)	6.353 (1.62)	-1.426 (-1.08)	-0.492 (-0.20)
Δ Consumption NG	-0.187 (-0.22)	-1.96 (-2.47)**	0.274 (0.37)	-1.166 (0.37)	-0.272 (-0.47)	0.058 (0.05)
Δ Consumption Hydro	0.343 (1.00)	0.465 (1.42)	0.173 (0.57)	0.075 (0.57)	0.127 (0.54)	0.342 (0.79)
Δ Consumption Nuc	0.317 (0.78)	0.098 (0.25)	0.646 (1.82)	-0.091 (1.82)	0.205 (0.74)	-0.035 (-0.07)
Observations	33	33	33	33	33	33
R-Squared	0.123738	0.560056	0.208940	0.212059	0.365639	0.193305
Adjusted R-Squared	-0.168349	0.413408	-0.054746	-0.050589	0.154185	-0.075593
Durbin-Watson stat	2.108674	2.438068	1.903481	2.168292	2.562874	1.557177

Significance Level: * 10%, **5%, ***1%

<Table 17>

Regression Results	Country: New Zealand					
Method: Least Squares	Observation Years: 1975 - 2007					
Dependent Variables	Δ Total Energy R&D	Δ Renewable Energy R&D	Δ Total Nuc. Energy R&D	Δ Fossil Fuel R&D	Δ Power & Stor. Tech. R&D	Δ Energy Eff. R&D
Independent Variables	Reg 1.	Reg. 2	Reg. 3	Reg 4.	Reg 5.	Reg 6.
Δ Oil Price	0.062 (0.31)	-0.115 (-0.42)	NA	0.078 (0.26)	-0.637 (-1.22)	0.165 (0.24)
Δ Oil Price(t-1)	0.546 (2.80)***	0.639 (2.42)**	NA	0.492 (1.72)*	0.025 (0.06)	0.963 (1.41)
Δ GDP Per Capita	-0.243 (-0.53)	0.0732 (0.118)	NA	-0.372 (-0.55)	-0.019 (-0.01)	-1.313 (-0.95)
Δ Consumption Coal	-0.193 (-0.54)	0.096 (0.199)	NA	-0.535 (-1.02)	-0.708 (-0.70)	-1.900 (-1.23)
Δ Consumption Oil	-2.69 (-1.70)*	-3.288 (-1.52)	NA	-4.136 (-1.77)*	3.562 (1.17)	11.849 (1.78)*
Δ Consumption NG	-0.348 (-1.40)	-0.416 (-1.23)	NA	-0.546 (-1.50)	0.196 (0.32)	-0.050 (-0.03)
Δ Consumption Hydro	0.050 (0.07)	-0.446 (-0.47)	NA	-0.581 (-0.57)	-1.651 (-0.90)	-1.693 (-0.71)
Δ Consumption Nuc	NA	NA	NA	NA	NA	NA
Observations	27	27	NA	27	33	28
R-Squared	0.582010	0.465720	NA	0.507183	0.164620	0.209909
Adjusted R-Squared	0.428014	0.268880	NA	0.325618	-0.069287	-0.066622
Durbin-Watson stat	1.425182	1.075034	NA	2.210199	2.835272	1.829772

Significance Level: * 10%, **5%, ***1%

<Table 18>

IV: Oil Price (t-1)	Oil Cross-Price Elasticity of Energy Demand by Country					
DV: Energy R&D Type	Total Energy R&D	Renewable Energy R&D	Nuclear Energy R&D.	Fossil Fuel R&D	Power & Energy Stor. Tech. R&D	Efficiency R&D
Norway	-	-	-	-	-	-
Netherlands	-	0.53	-	0.563	0.801	1.107
U.S.	0.184	0.459	-	0.451	-	-
Canada	-	0.712	-	-	-	-
Germany	0.305	0.48	0.338	-	-	-
Japan	-	0.308	-	-	-	-
Spain	-	0.645	-	-	.253*	-
New Zealand	0.546	0.639	-	.492*	-	-

Korean Abstract (국문초록)

에너지 R&D 수요에 대한 석유가격의 교차 탄력성: 12 개국에 대한 패널분석을 중심으로

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본 연구는 에너지 R&D 수요에 대한 석유 가격의 변동 추이가 에너지 안보에 미치는 영향을 분석하고 있다. 2008 년 7 월 인플레이션에 따른 실제 유가가 배럴당 120 달러로 인상 되었을 때, 에너지 안보 확보 방안에 대한 논란이 전문가와 국제 지도자들 사이에 야기된 바 있다. 이러한 에너지 안보의 효율적인 확보를 위해서는 에너지 R&D 투자 부문에 대한 석유가격 변동의 영향을 줄이는 것은 물론 에너지 안보에 대한 담론을 국가적 차원에서 국제적인 차원으로 재조정 할 필요가 있다.

글로벌 경제 팽창이 에너지 수요를 확대 시킴에 따라, 2030 년 경에는 이산화탄소 배출량이 약 60% 정도가 증가할 것으로 예측되고 있다. 따라서, 에너지 공급의 증가와 투입요소의 다각화는 물론 환경의 질을 개선시키기 위한 기술의 진보가 시급해졌다. 그러나 석탄, 천연가스, 석유 가격에 비해 가격 경쟁력을 가질 수 있는 에너지 기술의 개발은 좀 더 일관적이며 계획된 각국 정부의 R&D 전략에 달려있다는 것이 본 논문의 주장이다.

기존 연구 고찰 및 분석에 따라, 본 연구는 다음과 같은 점을 제시하였다. 첫째, 본 연구는 석유 공급과 수요의 최근 변동 동향을 파악하여 석유 대체 자원의

중요성을 역설하는 데 중점을 두었다. 둘째, 본 연구는 국제 에너지 소비 패턴과 에너지 공급 다각화 비율을 분석하였다. 셋째, 1975 년에서 2007 사이의 33 년 간 12 개 IEA 회원국의 자료를 바탕으로 하여, 석유 가격의 변동과 정부의 에너지 연구 개발(R&D)부문 사이의 회귀 분석을 진행하였다. 소비 패턴과 석유 가격을 독립 변수로 지정하여, 6 가지 종속 변수를 산출하는 방식으로 연구를 진행하였다. 6 가지 종속 변수는 전체 에너지 연구 개발, 핵원자력 에너지 연구 개발, 대체 에너지 연구 개발, 화석 연료 에너지 연구 개발, 에너지 효율 연구 개발, 전력과 에너지 저장 기술 연구 개발(power and energy storage technology R&D)을 포함하였다. 네번째 본 연구는 12 개 IEA 회원국중 8 개국에서 관찰된 결과를 바탕으로 시간회귀 분석(time series regression)을 진행하였다.

다섯 째, 본 연구의 회귀 분석에 따르면 각국 정부의 R&D 변화와 석유 가격 탄력성 사이의 관계는 유의미성을 보였다. 여섯째, 본 연구는 일관성 있는 에너지 R&D 투자에 대한 필요성을 반영하는 국제 에너지 안보 전략은 물론, 상승하는 국제 경제에서의 상호 의존성과의 연관성을 강조하며 결론을 맺는다. 연구 결과, 본 연구는 오일 가격과 에너지 R&D 투자량 사이에 양의 상관 관계가 존재함을 관찰하였다. 또한 에너지 R&D 수요와 가격 탄성사이의 관계는 6 개 종속 변수 중 3 가지 변수에서는 양의 상관 관계를 발견할 수 있었다. 시간 회귀 분석(Time-series regression over time) 결과, 12 개국 중 7 개 국가는 오일 가격이 국가 내 서로 다른 에너지 R&D 부문 선택에 영향을 줄 수 있음을 보여주었다. 그러나 그 상관성의 정도는 국가마다 차이를 보였다.

각국 정부는 에너지 R&D 투자 부문에 대한 수요가 석유가격 변동 추이를 반영함에 따라 단기적으로는 합리적으로 반응한 것으로 보인다. 그러나 장기적으로는 에너지 안보 전략에 손실을 야기할 수 있는 에너지 R&D 부문에서의 비일관적인

투자변화는 비합리적으로 보인다. 다수의 정부가 이산화탄소 배출량의 감소와 에너지 투입요소의 다각화를 통한 에너지 안보 확보의 중요성을 인식하고 있음에도 불구하고, 제대로 조정이 되지 않고 비일관적이며 잘못된 방식으로 기획된 R&D 투자는 이러한 목표를 달성함에 있어서 장애를 야기하고 있다.

정부는 단기적으로는 에너지 수요를 대체하기 위한 투자를 변화시키면서 합리적으로 대응하였다. 그러나 다른 한편으로는, 각국 정부가 화석 연료를 대체하기 위한 기술을 확보하기 위해 노력하더라도, 정부의 시장 변화에 대한 반응은 연구 개발이 증가 혹은 감소하는 결과를 야기하였다. 이러한 행위는 에너지 연구 개발이 화석 연료를 대체하지 못하더라도, 석유 가격의 변동으로 인한 투자량의 변화가 연구 개발 부문 자체를 곧 대체 가능성으로 인식하였다는 것을 의미할 수 있다. 석유 가격 변동에 따른 연구 개발 부문 투자의 변화는 장기적인 측면에서의 에너지 공급 및 다각화 대신 단기적인 수요 대체를 기반으로 한 비생산적인 에너지 정책을 야기했던 것으로 볼 수 있는 것이다.

키워드: 에너지 연구개발 수요에 대한 유가 변동 추이, 유가, 천연 가스, 대체 에너지, 에너지 연구 개발, 화석 연료, 재생 가능한 에너지, 핵 원자력 에너지, 전력과 에너지 저장 기술, 에너지 효율성, 에너지 다양성, 에너지 안보, 국제 에너지 기구(IEA), 경제 협력 개발 기구(OECD), 석유 수출국 기구(OPEC)

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