DRILLING FOR INNOVATION: APPLYING INDUCED INNOVATION THEORY TO THE OIL AND GAS INDUSTRY

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Economics

Abstract

In this study I apply the theory that changing energy prices induce innovation to producers of energy, specifically the oil and gas industry. Using pricing, production and patent data from 1980 – 2011, I model the share of total patents that are applicable to oil and gas as a function of expected future commodity prices, production of each commodity and previous stock of knowledge. In the building of the model, I develop knowledge stock variables and expected future prices specific to the industry. I find a significant, positive and highly elastic correlation between expected commodity prices and innovation, that is in line with previous work and the induced innovation theory.

KEYWORDS: (Energy, Oil, gas, Innovation, Induced Innovation, Patent)

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CHAPTER I

INTRODUCTION

Oil and gas account for about 27% of total power generation in the United States, 34% in the European Union and 65% in Asia and Africa (EIA). In the US the commodities have traded at a fairly constant relative price, an mcf (thousand cubic feet) of natural gas about one sixth of a barrel of oil, for most of the previous decades. In 2007 the price relationship broke down. Natural gas began trading lower relative to oil, today at a price about one twenty fifth of oil. Historically, global energy demand is the largest variable in market oil and gas prices. Demand is heavily linked to the world economy. Innovation in this industry is essential to maintaining the availability and affordability of one of the world's most important resources; this paper attempts to analyze and quantify the factors affecting and driving innovation in oil and gas.

Supply and demand fundamentals are at their strongest in the oil and gas industry. Oil prices and production have congruently risen to record highs over the last decade (EIA). The only logical explanation for this, that demand has been rising at equally high rates, is true. China, India, much of the Middle East and North Africa have led the way in rapid consumption growth (EIA). China alone has nearly doubled its energy consumption per capita in the last decade. No such similar phenomena exist in the market for natural gas. In 2006-2007, US gas production began a sharp rise as firms perfected more cost-effective methods to exploit gas resources, especially from previously uneconomical shale formations. As the industry caught up to firms like Encana (ECA) and Chesapeake Energy (CHK), who led the charge toward shale gas operations, production climbed toward all-time highs. Demand for natural gas was and is sluggish to meet the incredible supply; power plants and other consumer applications of natural gas have improved only marginally. Demand for natural gas did not shift to match the supply movement, as happened in the market for oil, and natural gas prices decreased with every additional unit of output (EIA).

Today the industry is left with two distinctly different models. Natural gas operations are faced with record low prices and are forced to compete on cost control and operating efficiency. Oil operations see record high prices, record regulation and record competition. Startup costs of exploration and acquisition are higher than in the past, operational costs are marginally higher and the payoff is more than ever. In the United States, movements towards cleaner energy and a growing negative perception of the oil and gas industry, spurred by industry gaffes like the 2009 deep-water horizon spill in the Gulf of Mexico, have grown at rates that alarm industry players. This speaks to a growing uncertainty about the future that has driven the industry to look for new ways to ensure their future profits.

There are two scenarios in which a firm would be inclined to innovate, both in the hopes of increasing profits. Much innovation has already happened in oil and gas, with much the same motivations. Shale gas, sometimes called a revolution for the industry, is the product of perfecting the art of hydraulic fracturing, and an equally revolutionary business model. Instead of going after high investment, high return oil reserves, as had been the strategy for the life of the industry, gas operators attempted a highly efficient, cost controlled, assembly – line model that would make Henry Ford smile. Innovation in oil operations is different; operators seem to be informally competing to see who can launch the biggest platform in the Gulf of Mexico. Currently, BP (BP) holds that honor with their Atlantis Deepwater Platform, which successfully processes oil and gas in over 7,000 feet of water (Offshore Technology). Atlantis Deepwater hub is mentioned in 15 patents, while 2,766 patents mention hydraulic fracturing in the abstract (USPTO); these innovations were spurred by many factors, presumably all in the hopes of increasing profits.

In this study, I attempt to answer several key questions about the nature of innovation in oil and gas. Is the industry more innovative in high or low price environments? Which commodity price has the most effect on innovation?

In the next section, we review the previous literature that has made this study possible; specifically work relating to patenting and innovation in industry. We build a theory to explain the dilemmas of innovation faced by oil and gas firms, and delve into the data relevant to this hypothesis. Finally, I explain the method of analysis, present conclusions, identify further research or alternative hypotheses and discuss applications to relevant policy and world circumstances.

CHAPTER II

PREVIOUS LITERATURE

An analysis of innovation in the oil and gas industry hinges on a number of themes that I will soon address. First, the relationship between market forces and innovation has been extensively studied across numerous industries. Next, the effects of energy prices on innovation paint a clear picture of innovation outside the industry. Finally, some analysis of innovation in the industry sheds light on the spillover and knowledge transfer of oil and gas patents.

We begin with a look at how energy prices affect innovation. Crabb and Johnson, in their 2010 article on the effects of oil prices and CAFE standards on energy-efficient automotive technology, question whether technological innovation is sparked by regulation or energy prices. The authors use induced innovation theory to model innovation as an effect of gasoline prices, assuming that innovation in car fuel economy will be dependent on expected future prices as opposed to simply current prices. Modeling energy-efficiency patents as a function of demand (expected energy prices, unemployment rate), supply (knowledge stock in energy-efficient patents) and fuel-efficient standards, the authors find that regulation has little impact. Importantly, they find that expected energy prices are the most significant influence on innovation.

Preceding Crabb and Johnson's study, Popp reaches similar conclusions in his 2002 article on induced innovation and energy prices; that there is a strong correlation between energy prices and innovation across multiple fields. Popp uses a model similar to Crabb and Johnson, one that takes expected future energy prices as the important variable. Popp's construction of knowledge stock could be more applicable to this study than Crabb and Johnson; Popp modeled decay and diffusion for a group of industrial patents, while Crabb and Johnson used energy efficient patents. The specifics of Popp and Crabb will become integral to our analysis when constructing our model.

Important takeaways from these induced innovation articles are the impact of future prices rather than spot prices and the strong positive correlation between rising energy prices and related innovation. Rising energy prices to the rest of industry are a bad thing, increasing the cost associated with an unavoidable and supremely important factor of production. In the oil and gas industry, rising prices are a huge positive that increases profits. So, if we re–phrase rising energy prices as non-favorable changes in energy prices, a drop in energy prices may induce innovation for the oil and gas industry.

On the issue of future energy prices, a unique question emerges when translating this theory to energy producers. If we believe that energy producers are induced into innovation in the same way that energy consumers are, future prices will ultimately be the demand-side determinant for them as well. A supply-side case can also be made for the past energy prices inducing innovation for the producers. If the price of oil in the preceding period is higher than expectations, firms will look for a place to use the extra cash and will be more likely to fund R&D and ultimately patenting. There is literature to address this, none as definitive as Popp, who concludes that future prices are the most effective. This question will again be addressed when developing our model.

Further justifying the decision to use expected future prices, Kortum and Lerner (1998) address the problem of time lag in patenting in their article on the surge in patenting that occurred in the late 1990s. If patents are induced by future prices, as asserted in Crabb and Popp's findings, yet aren't granted until the following period, then the current price in the period that the patent is granted may be most closely related to the induction of that patent. This is even truer as oil and gas companies are producers, rather than consumers of energy and oil and gas firms participate in hedging activities that secure some level of profits. Kortum and Lerner's finding that patents are generally granted multiple periods after the application is filed further supports this notion.

Managi et. al.'s 2006 article on technology indices in offshore oil and gas find findings similar to those mentioned above. The finding most relevant to this study is the method they used to assign some level of importance to the patents granted. The number of citations a patent receives is used to rate its importance amongst other patents. This method can be useful in assigning importance to patents in our study. Though importance is not the main focus of this study, it could be important in further studies.

Hall and Ziedonis' 2001 paper on determinants of patents in the semiconductor industry makes important distinctions for this study. The authors address the problem by compiling data and analyzing them through a patent production function; this relates the patents successfully granted to the history of R&D spending. They break the analysis into production/efficiency style patents and design style patents, an important distinction when observing whether something has induced a certain type of innovation. This could be applied to our analysis in gas patents vs. oil patents or onshore vs. offshore. Though their model is used for semiconductor firms, the method is similar enough to be tailored to oil and gas. Some factor of previous term change in relative commodity price could be substituted for previous term R&D. The model would have to include capital expenditures and gas vs. oil production split. Hall and Ham find that semiconductor firms have a propensity to accumulate vast arrays of patents, some irrelevant, merely as bargaining chips in a highly competitive industry. There is no literature to support such a claim in the oil and gas industry, but it is possible.

The prior work, described above, paints a picture of energy price dependent innovation and patents lagging between application and grant. Together this leaves some interesting questions about innovation in the energy production sector, which we model in the following section.

CHAPTER III

THEORY

This paper has two central ideas formed out of the findings of the literature presented above. First is an understanding of microeconomic principles, cost of production and profitability. Second is the well-publicized theory of induced innovation. The model presented in Popp's 2002 paper that codifies the induced innovation principles as they relate to this subject is a base on which we build our theory. While much of the literature has used energy prices as a cost of production, this paper uses oil and gas, the commodities that produce energy, as the product and stand in for revenue, but keeps the changing prices of energy as an independent variable.

Theory around firm profitability hinges on 3 major factors; fixed cost, marginal cost and revenue (price received). This analysis mainly focuses on revenue and marginal cost. Revenue is relatively intuitive as it is the market price for oil or gas. Firms do engage in hedging practices but rarely are they substantially different from the market price, so as a baseline the market price equals revenue. Marginal cost is the cost of operation, in this case the cost of continuing to drill, explore and exploit oil and gas resources. Fixed cost is the cost of business that exists whether operating or not.

Induced innovation theory keeps this model of cost and profitability at its core. Most of the previous literature, like Popp's 2002 article and Crabb and Johnson's 2010 work, assume that energy prices are an increase in cost, mostly affecting marginal cost, but also affecting fixed cost through electricity and other utilities. Assuming revenue is relatively constant, as is the case in many consumer applications, increasing marginal cost narrows the gap between cost and revenue that represents profit. Central to much of economics is the thought that actors in the economy, firms and individual people, are profit maximizing. The pursuit of profit maximization is the driving factor behind induced innovation theory.

Assuming that oil and gas firms are profit maximizing, as all firms are, we can assume that changes in their profits will affect innovation in the same way that previous literature has explained. The difference between oil and gas firms and previous literature is the ever-changing revenue curve that is substantially out of the firm's control. Innovations should then be focused on efficiency and cost reduction rather than differentiation or other strategies to increase revenue. Innovations could be focused on a number of things to reduce cost, most obviously on drilling and completion cost as well as increased efficiency in gathering and transportation of the resource.

To assess these hypotheses, I construct a model similar to Crabb and Johnson's, tuned specifically to the oil and gas industry. I model that oil and gas patents as a share of total patents are a function of the expected future prices of oil and natural gas, the production of oil and natural gas and the existing knowledge about the technology. Thus, to keep with previous literature I construct a model such that

$$Log(\frac{OGPat}{TotPat})_t = \beta_O(1-\lambda_O)P^*_{Ot} + \beta_{NG}(1-\lambda_{NG})P^*_{NGt} + B_{WO}W_{Ot} + \beta_{WNG}W_{NGt} + \beta_K K_t + e_t \quad (3.1)$$

where

OGPat = number of oil and gas patents with applications dating from month

t

TotPat = total number of patents with applications dating from month t

P^{*}_{Ot} = expected price of domestic oil in month t

P^{*}_{NGt} = expected price of domestic natural gas in month t

W_{Ot} = production of oil in month t

W_{NGt} = production of natural gas in month t

K_t = knowledge stock in oil and gas technology in month t

e_t = error term in month t, due to linearization, measurement error or factors not considered in this model

For the sake of simplicity and to keep with previous literature I utilize a log – linear model, allowing errors in linearization to accumulate in the error term. Keeping with Crabb and Johnson's theory, I include no constant term in the model because of the stability of variables like knowledge stock and the risk of collinearity if a constant were included.

OGPat, the dependent variable, is presented as a fraction of successful applications to control for the changing role of patents through time (Crabb and Johnson 2010). This method also controls somewhat for the effects of changing energy prices as addressed in Popp; isolating the OGPats that are induced from the overall innovations induced by changing energy prices.

Keeping with previous literature, I model innovation as a function of the expected future prices, rather than a reaction to current events. I model expectations of price exactly as Crabb and Johnson before me; using an adaptive expectation model with a twenty- four month memory, so that

$$P^*_{Ot} = P_{Ot} + \lambda_{PO} P_{Ot-1} + \lambda^2_{PO} P_{Ot-2} + \ldots \lambda^{24}_{PO} P_{Ot-24} \tag{3.2}$$

$$P^*_{NGt} = P_{NGt} + \lambda_{PNG} P_{NGt-1} + \lambda^2_{PNG} P_{NGt-2} + \ldots \lambda^{24}_{PNG} P_{NGt-24} \tag{3.3}$$

where

P^*_{NGt} = expected price of domestic oil in month t

P^*_{NGt} = expected price of domestic natural gas in month t

This models an expected price that is formulated on previous prices of the given commodity; each commodity follows different expected paths as their adjustment coefficients, λ, differ. Innovations may be more reactive to short run changes in prices, or long run natural gas expectations; all of these scenarios are included with this generation of P^* and inclusion of the adaptive expectation parameter λ.

I keep with Crabb and Johnson's justification of the semi log form of equation 1; frequent negative changes in the explanatory variables make use of a log-log form unrealistic. If there is concern around this form consider that oil and gas patents could be a function of past prices and current values of production, regardless of expectations about the future, since R&D spending is dependent on the past cash flow from past prices.

The remaining independent variable, K, represents the stock of knowledge accrued from past innovations in the sector. Innovations may be spurred by a previous innovation, or slowed by a locking of a sub-area through previous patent protection.

Knowledge stock is found through a process developed by extensive previous literature (Caballero and Jaffe 1993, Popp 2002, Crabb and Johnson 2010).

Though there are limitations in using patent counts as a proxy for innovation, like the argument that not all innovations are patented and the most important innovations may not be patented in hopes of maintaining secrecy, no better measure exists outside of a report directly from oil and gas firms, which is impractical in this sense. As previously mentioned, the literature has acknowledged the differences in importance between patents; a problem solved in the generation of rates of decay and diffusion of knowledge. These papers model the share of all potential citations between patents as a function of decay and diffusion. Based on the estimation of decay and diffusion, β_1 and β_2 respectively, knowledge stocks are constructed as

$$\mathrm{K}_t = \sum_{s=1}^{t} OGpat(\exp(-\mathrm{B}_1(t-s)))(1-\exp(-\mathrm{B}_2(t-s))) \tag{2.4}$$

For the sake of comparison with literature, I have calibrated values of β_1 and β_2 from previous literature. To ensure accuracy, I have limited the values used to studies similar in methodology and data to this, and have run the model using each alternative level of K.

What I have constructed above is a model that has microeconomic and business principles at its core while keeping with previous literature in the development of a realistic model that accounts for changes in importance and citation of patents. This model and the theory behind it are extensively supported by previous literature (Hall and Grilliches, Caballero and Jaffe 1993) and similarly utilized by papers like Popp 2002 along with Crabb and Johnson 2010. Coupled with the right data, this models an accurate simulation of innovation reality.

CHAPTER IIII

DATA

Data for this study are primarily patents and commodity prices, both of which are readily available. In keeping with previous literature, I use only granted U.S. patents. Oil and gas is a global business; seemingly the technology is global as well. Though this statement is true, there is previous literature stating that the U.S. is the largest market for patent protection, because of its position at the top of the economic food chain and its litany of patent protection (Caballero and Jaffe 1993). It is possible that patents relating to oil and gas are not included in our dataset because the applicant chose not to protect in the U.S., future work could attempt to solve this issue. Our dataset includes all patents in the U.S. without regard for the origin of the applicant, which should help to solve some of the problems relating to the use of only U.S. patents.

I consider patents granted, rather than R&D or some other factor, as the measure of innovation, other measures are near impossible to obtain and are notoriously tainted by accounting liberties. By utilizing patents granted, I can identify clearly and effectively the innovations relating to oil and gas; R&D spending may include research into employee training or something unrelated to the focus of this study. This notion is in line with much of the previous literature eg. Crabb and Johnson 2010.

An attentive reader will have noticed that this model uses the application date of granted patents as the measure of innovation; this is to avoid inconsistencies in the data.

Crabb and Johnson make the point that R&D is a good measure of innovative effort, but is not an indicator of the result. They also make the point that applications were not publicly available until 2001; successful applications are the only measure that will yield any substantial time series. Popp discusses at length the time lag between price changes and the instance of innovation; his conclusion is that there is a substantial time lag, which is sufficiently accounted for via expected price values. His conclusion sheds light on the reason for using the date of application for successful patents. Most patents take 12-16 months to work through the bureaucracy of the patent and trademark office; this means the date the patent is granted is an inaccurate representation of when the innovation actually occurred. Though the date of application is not wholly accurate, it is perhaps more precise than any other measure.

Critical to this study is the definition of oil and gas patents (OGpat). I have identified the patent classifications most applicable to oil and gas through a random sample of patents held by oil and gas firms. Of the 100 patents examined, 63 were in one of the following classes, the remaining were an amalgamation of patents not clearly relating to the production of the given commodity. For this paper the OGpats are defined as falling into any of these patent classes:

507 – Earth Boring, Well treating, Oil Field Chemistry

055 – Gas Separation

096 – Gas Separation Apparatus

166 – Wells

175 – Boring or Penetrating Earth

In the period 1975 – 2011 there were 37,426 patents granted in such categories making up .81% of total granted patents in the period. It is worth noting that 15 of the examined patents were classified under class **702** and **703,** which relate to data process, measuring, calibrating and testing. These patents were granted at a rate 4 times higher then the rest of the classes, which leads an astute mind to think that they encompass innovations other than those relating to oil and gas. For this reason those classifications were not included in the measure of OGpat.

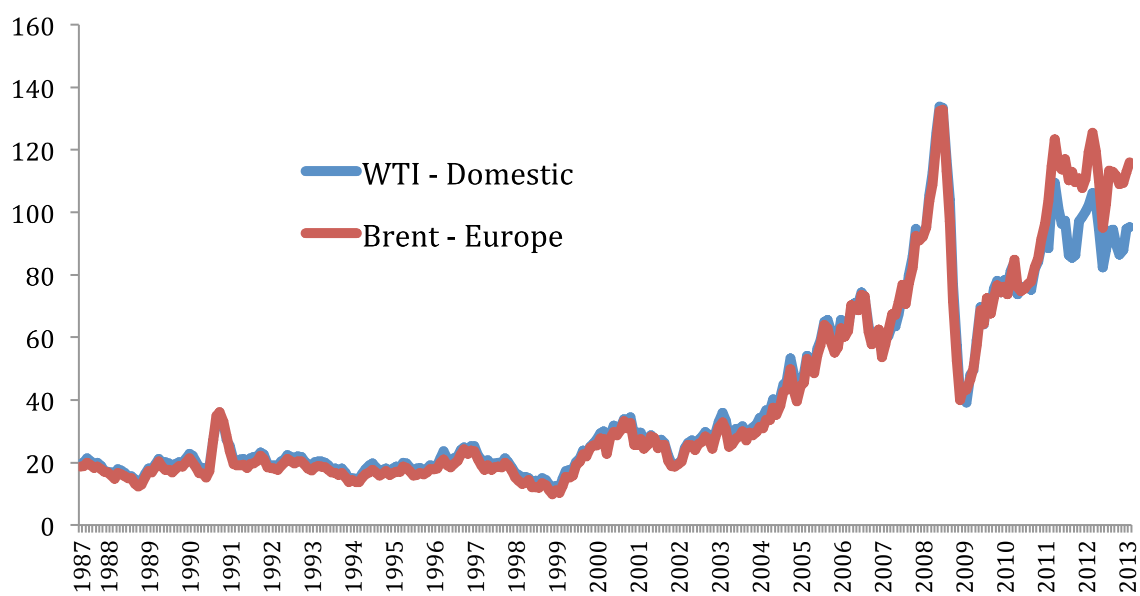
In contrast to much of the previous literature, which largely uses annual data, this paper uses quarterly measurements from 1986 – 2011. It is my hope that quarterly data will give added clarity to the relationship between prices and technology without clouding the relationship through over observation. To make the variables work in quarterly terms, I use a sum of the successful patent applications in the given quarter, and the average of the given commodity price. Knowledge stocks that were discussed above have been generated quarterly with the same approach to the data. This model, like Crabb and Johnson's, allows quarterly variations to act with a lag, so that alternative time periods are a subset of the quarterly data.

All data for the generation of this model is collected from readily available government sources. Pricing from the Energy Information Administration (EIA) and Patent data from the U.S. Patent and Trademark Office. The relevant timeframe of 1986 – 2011 is a product of the availability of pricing data from the EIA; further work could attempt to expand the observed time period. All monetary values are adjusted to 2011 dollars.

Commodity prices are marked at many different points along the proverbial and literal pipeline. To accurately model firm level revenues, one would have to look at the cash flow statement or production tables in each firm's annual filings. Because this is impractical for the entire industry and this analysis seeks to model the general price environment for the industry, domestic prices of relevant commodities are used, West Texas Intermediate (WTI) oil and domestic wellhead natural gas prices. Naturally, there are many other pricing points around the world that report prices different than the ones mentioned above. This paper seeks only to model price environments, the general environment that the industry is receiving. In reality any of the reported prices could have been used as they are highly correlated. Figure 4.1 demonstrates the correlation between domestic and foreign prices.

FIGURE 4.1

DOMESTIC VS. FOREIGN PRICE OF OIL 1987 – 2013 (US$/BARREL)



Source: EIA January 2013

Values for decay and diffusion of knowledge have been calibrated from previous literature; Popp's 2002 estimations of decay and diffusion represent those of the energy – related industrial sector, while Crabb and Johnson's 2010 values represent the energy efficient automotive sector. It appears that knowledge decays more quickly in the automotive sector than energy related industrials, while diffusion appears much slower in automotives. I have generated quarterly knowledge stocks for each decay and diffusion and will include each in the model.

CHAPTER V

RESULTS

It appears that knowledge decays more quickly in Crabb and Johnson's automotive data than in Popp's sample of energy-related industrials; diffusion of knowledge is much slower in automotives. Calibrated ancillary parameters are presented below.

FIGURE 5.1

Estimated Ancillary Parameters

	Crabb and Johnson Automotive Data	**Popp Energy Related Industrials**
$\boldsymbol{\beta_1}$ **decay of knowledge**	.259***	.353***
$\boldsymbol{\beta_2}$ **diffusion of knowledge**	$8.54x10^{-6}$***	.00199***

*** Indicates significance at the one percent level

This leads to an obvious conclusion that knowledge stocks will be helped by dissemination of new technology and stimulation of R&D. The effects of further stimulation of innovation could prove beneficial to society as demand for energy continues to increase and prices continue to rise. Further innovations could help in increasing supply, efficiency and ultimately reducing cost of energy.

Figure four below shows results for primary regression, with robustness tests. Column one shows results using Crabb and Johnson's values from energy efficient automotives, while column two show the results when Popp's decay and diffusion values for energy related industrials Crabb and Johnson's values from energy efficient automotives are used in generation of K. As the results show, the results are largely the same regardless of which values are used in the generation of knowledge stocks.

Figure 5.2

Estimated Primary Parameters Directly Relating to Impact on Innovation (β)

	Crabb and Johnson K	**Popp K**
Observations	96	96
R-Squared	.4974	.4501
F	14.97***	14.73***
Expected Price of Natural Gas	.0106	.0096
Expected Price of Oil	.0016**	.0017**
Quarterly Production of Natural Gas	$-8.1\ x\ 10^{-8}$**	$-7.89\ x\ 10^{-8}$**
Quarterly Production of Oil	$9.44\ x\ 10^{-7}$***	$8.94\ x\ 10^{-7}$***
Stock of Previous Knowledge	4.4834***	.0347***
Constant	-2.964***	-2.941***

Significance is indicated as *** for the one percent level, ** for the five percent level and * for the ten percent level.

These data explain between 41 and 45 percent of the variation in quarterly innovative activity. Results from previous literature are slightly lower, though largely similar. Crabb and Johnson note that attempting to explain an inherently creative process with a mathematical model has innate difficulties. Though the F-statistics for my regressions are not as strong as those of previous work, it does indicate explanatory power, which supports the theory of induced innovation in the oil and gas industry.

Obvious results from figure three are that stock of previous knowledge (K) and the constant term that captures all other forces not observed, are the most affective in inducing innovation. This finding is predictable and in line with the findings of previous literature; no model can attempt to capture every indicative force and innovation intuitively builds on prior work (Popp 2002).

When attention is directed at the expected future prices of gas and oil, results show a strong, positive and statistically significant association with OGpats. This effect is more conclusive when related to the price of oil than gas. Oil has a smaller coefficient, meaning the change in innovation from a unit increase in oil prices is about .001 additional innovations, at a 95% confidence interval, the results are conclusively positive. Natural gas shows a positive correlation that appears more significant than oil, though the confidence interval includes zero, which means expected future price of natural gas could have no effect on innovation. This is true through 80% confidence. These findings are again in line with previous work; both Popp and Johnson find a similar strong and positive correlation between oil prices and innovation.

Findings like these may lead a reader to believe that oil is the only affective commodity at changing patterns of innovation, a notion that is far from the truth. Factually, the effect of oil on innovation is slow and positive, while gas shows a strong effect that is more volatile. This could be attributed to changing patterns of production; while oil production has been fairly consistent in the period examined, natural gas production has been much more volatile, spiking at the beginning of the new millennium (EIA). Prices followed the volatility of natural gas production, which may have led the model to see possible a scenario where natural gas prices have no effect on innovation.

Quarterly production data of natural gas and oil were also examined. The effects of each were miniscule. Oil production carried a primary coefficient of $9.44 \, x \, 10^{-7}$; even at the 1% significance level, this is too small to truly have an effect on innovation. Natural gas production primary coefficient, $-8.1 \, x \, 10^{-8}$, was more signicant than natural gas prices, yet still too small to have a meaningful effect on innovation. Previous work did not include measures of production, including variables for macro economic strength instead. Production data serves to demonstrate some measure of the activity and health of the industry, just as macro data shows the health of the economy.

To demonstrate the sensitivity of OGpats in relation to changing commodity prices, figure 5 presents the change in innovation activity from a sustained ten percent rise in the price of oil and natural gas. I chose to use the primary parameters (**β**) of expected prices from the simulation using Popp's knowledge stock; the values are so similar, within .0001, that this simulation will be largely unaffected by use of other K stock.

FIGURE 5.3

Implied Effects of Changes in Average Commodity Price

Hypothetical sustained change in average variable values	**% Change in OGpats/Totpats**	**Change in number of OGpats**	**Implied elasticity of innovation response**
10% increase in price of oil	33.15%	84 more per quarter	+3
10% increase in price of natural gas	33.38%	84 more per quarter	+3

A sustained ten percent increase in the price of natural gas, with a primary coefficient of .0106, will lead to 84.4 more patents quarterly. In some cases this may be true, though I just made the case for oil being more affective of innovation. Because of the low confidence of this coefficient, and the fact that the interval contains zero all the way to the seventy percent interval, this finding cannot be thought of as wholly true.

Our primary result, a coefficient of .0017 for the impact of expected oil prices on OGpats, shows that a perpetual ten percent rise in the price of oil, ceteris paribus, will yield an additional 83.8 OGpats a quarter. This data is significant to the five percent level, meaning the effect will be positive in nearly every case. An attentive reader may question the validity of such findings, as it is about a 33% increase in the average quarterly rate of oil and gas patenting. When it is applied to the real world, this finding holds water. Oil and gas firms perceiving a ten percent rise in cash flows see the potential of new fields and exploration projects that were previously uneconomical. Many such fields were unattainable because of lacking technology, thus firms innovate the technology in hopes of reaping the benefits that come with increased prices. This phenomenon has been observed in natural gas production. Firms realized that domestic natural gas operations were marginally more beneficial than domestic oil at the turn of the millennium, they innovated and perfected technology like hydraulic fracturing and horizontal drilling and production has nearly doubled (EIA).

My findings of a very elastic, +3, response to changes in commodity price is somewhat different than those of previous work. Popp and Crabb both find that innovation is inelastically sensitive to fuel prices. This may be attributable to differences in the reaction of consumers and producers of energy to changing prices. Further work will be needed to clarify the reason for this difference.

CHAPTER VI

CONCLUSION

This paper has flipped the theory of induced innovation developed by Popp, Crabb and Johnson from the consumers of energy to the producers. Previous work shows a strong correlation between rising price of oil and gas and innovation. Those theories are built on the assumption that energy is a cost affecting profitability at some level. This paper is the first to treat the rising cost of energy as a revenue side effect on business, cash flows and profitability change with the price of energy.

Overall, findings support the theory of induced innovation in the oil and gas sector. By using a dynamic model of innovation in the industry, I have shown a strong, positive correlation between oil prices and innovation, and a weak though still positive relationship involving natural gas and patenting. I have further proven the theory developed in literature that stocks of previous knowledge are incredibly affective of innovation, and supported the notion of using expected prices rather than spot prices.

Though fantastic, this paper does not cover every aspect of innovation in the oil and gas industry. As with every question, the answer lies in more data. Because of availability issues, I began my observation in 1980; future work could extend this period. Further focus could give more clarity around specific effects. Perhaps examining a period of abnormal price movement could reveal interesting data around individual commodity effects.

Because of data availability constraints, I have relied heavily on previous work to generate the knowledge stock variable. I took advantage of readily available rates of knowledge decay and diffusion that were not specific to oil and gas. Though they were close, Popp's energy related industrials; ultimate accuracy cannot be achieved until this data has been specifically developed. Given that prior knowledge is such an important factor in innovation, developing industry specific data is high on the list of possible refinements.

Further calibration of the model can be done to reduce the risk of correlation between production, pricing, and the commodities examined. Our findings were within the grey area of the Durbin Watson test that signals no need for immediate fixing but can be improved. Clarifying and identifying possible instances of autocorrelation could be difficult due to the historical linkage of commodity pricing, yet is worth some effort in the future.

On a theoretical basis, this paper shows a possible alternative side to induced innovation theory. As previously addressed, induced innovation generally means innovation is caused by the rising cost of production that is energy prices. My analysis has treated energy prices as a proxy for future cash flows, a theory that could be applied to nearly any industry. Industries reliant on fairly universal commodity pricing like agriculture, mining or commercial fishing are obvious possible extensions. This paper attempted to identify the effects of specific commodities, thus acting as an intermediary step in a study of innovation related to cash flows.

Because oil and gas are so important to national security and wellbeing in the generation of power, an analysis such as this would not be complete without making a policy recommendation. It is intuitive to think that oil and gas innovations would largely be directed at reducing cost, or reaching previously unreachable resources. Any innovation then, is good for energy security, as it ultimately feeds an increase in supply and thus is in the best interest of the country. Obvious ways to boost innovation are similar to those in any industry; reduce taxes with direct incentives toward R&D spending. More specific to this sector, policymakers could add an incentive to buy domestically produced oil and gas that would increase demand, yielding an increase in price, which I have proven to be effective in sparking perpetual innovation.

This paper began by posing the question of whether energy producers are more inclined to innovate when prices are high or low. By building on previous literature and moving toward a potential new chapter in the book of induced innovation, I have shown with confidence that firms are more inclined to innovate when they envision prices in the future to be favorable to their balance sheet. This work could be extended in multiple ways and across multiple industries to further support this finding and aid in the worldwide innovation.

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