

THE IMPACTS OF COST-REDUCING TECHNOLOGY IN THE GOLD AND OIL
INDUSTRIES

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ABSTRACT

This thesis explores the question of what drives the development of cost-reducing technology. It will also explore this question in the gold and oil industries. It will integrate Paul Romer's idea that investment in technology is an endogenous factor in the econometric testing. This matters because while a time lag may exist between investment in a commodity and one's return on such investment, the role of changes in price and elasticity aid in driving such investment.

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CHAPTER 1. INTRODUCTION

This paper proposes a microeconomic interpretation of Robert Solow and Paul Romer's analyses regarding technological innovation and applies that to various analyses regarding the gold and oil industries. The logic of the argument for this thesis is the following: the increase in demand or growing scarcity (fall in supply) of a good lead to a rise in prices. The rise in prices leads to increased revenues for the firm. Increased revenues imply relatively high returns for investment in technology. Investment in technology lowers the cost of supply, and thus leads to a fall in price. This could possibly have implications for the maximum extent of price increases owing to scarcity. For example, Moore's Law suggests that the number of transistors doubles every 18 to 24 months. With this seemingly exponential phenomena, computers and megabytes continue to get cheaper.

Evidence to support this argument can be achieved by looking at data pertaining to the real prices and quantity produced for oil and gold. This tends to moderate commodity prices in the long-run. For example, Moore's Law may suggest that the more of a technology produced for either oil or gold, the more likely that it will become cheaper. The author will attempt to show that when the increase in supply is substantial, then the quantity of a good will lead to a decrease in price. When the increase in demand is substantial, then an increase in price will lead to an increase in quantity. This increase in demand implies movement along the supply curve rather than a shift in the supply curve. This affects whether the increase in price encourages investment in new productive technologies.

Data from the Board of Governors of the Federal Reserve System, the Federal Reserve Bank of St. Louis, the U.S. Bureau of Economic Analysis, the United States Geological Survey (USGS), and other sources will be used to help support the argument. Data is taken from these

sources and imported into the Python programming language. Coding is used in Python to generate graphs and econometric output.

Many articles in scholarly journals have looked into the effects of technological innovation in the oil and gold industries. Examples include the use of fracking, cyanide, and amalgamation. However, few have seemed to carry a more microeconomic explanation of how technological change and innovation can affect the price and revenue of oil and gold. One example of someone giving a microeconomic take on technological change is Hugh Rockoff's (1984) paper on the real price of gold and its costs of production.

This thesis will explore the role of technological development that is the result of profit-seeking entrepreneurs. Therefore, the thesis question is, "Does entrepreneurship contribute to technological innovation and economic growth?" This body of work is primarily concerned with the issue of technology reducing costs and prices of production in the gold and oil industries. This lowering of costs and prices imply an increase in revenues and profits for an individual or firm that invests in such technologies. Over the last two centuries, multiple new technological advances, or methods, have been created to extract gold. Four examples of methods developed in the mid-to-late 19th century include quartz mining, hydraulic mining, drift mining, and free milling. New methods exist for the extraction of oil as well. One of the most recent examples is fracking, which has generated some controversy over environmental concerns. Another oil extraction method is that of steam injection, which is considered the main type of thermal stimulation in oil reservoirs. One interesting item that will be argued is that in the gold and oil markets, increases in the real price of an asset (e.g. gold, oil) have incentivized the development of technology that reduced production costs. This leads to an increase in the quantity demanded of a good each year.

The main hypothesis I will attempt to support is that as the demand for technology increases, the level of prices increase as a result of investment in technology. The level of profits also increases as a result. This would lead to increased returns in technology. This can be symbolized by the following expression:

$$\text{Demand}\uparrow \rightarrow P_i\uparrow \rightarrow \text{Expected Returns on Investment in Productive Technology}\uparrow \rightarrow \text{Investment in Technology.} \quad (1)$$

Given that π_i is the result from equation four, if the prices of goods and services are increasing, then total revenues should be increasing relative to total costs.

The objectives of this thesis are:

1. To present a microeconomic interpretation of Robert Solow and Paul Romer's analyses on technological innovation and its relationship to economic growth,
2. Explore the role of the profit-seeking entrepreneur in producing technological innovations, and
3. Attempt to support the hypothesis that as the demand for technology increases, the prices of technology also increase as a result of profit-seeking entrepreneurs investing in technological advances.

The rest of this thesis is organized as follows. The second chapter explores literature explaining technological advances in the extraction methods of gold and oil. Chapter three covers the supply-demand model and brings forth discussion on price elasticities. Following this is the econometric testing, where the augmented Dickey-Fuller (ADF) and Granger-Causality tests are used to support the objectives of this thesis. The final chapter is a summary of all of our findings.

CHAPTER 2. LITERATURE REVIEW

The analyses of Robert Solow and Paul Romer are known for being macroeconomic in nature. Thus, their studies into topics such as total factor productivity, gold, or technology are given on a grand scale rather than on an individual or firm level. In a paper foundational to growth theory, Robert Solow showed that technological improvements – called “total factor productivity” – is the key to economic growth in the long-run. Paul Romer developed Solow’s idea by endogenizing technology in a macroeconomic model. He claimed firms would invest in technology if they could capture some of the profits enabled by the technology.

Both Romer’s and fellow economist William Nordhaus’ analyses are variations of Solow’s model for economic growth. The Solow model helps to explain economic growth by the presence of technological change.

The Solow model implies that if there is an incentive to invest in technology, then entrepreneurs will invest in technology. However, a weakness in the Solow model is that technological change is an exogenous variable. This implies that technology is not a key variable in economic growth. Paul Romer’s endogenous growth model differs from the Solow model by emphasizing that technological change is an endogenous factor that results in long-run economic growth, rather than having long-run economic growth being a result of outside forces.

Paul Romer helped build upon the Solow Model by listing technological change as being an endogenous factor in economic growth. Romer believed that technological change was a key ingredient in the formula of economic growth and that profit-seeking entrepreneurs are incentivized to develop new technologies. His analysis of the production of technology relied on thinking behind the creation of knowledge at an abstract level.

Technological development is significant to this paper because it is a central component to economic growth. It is also significant because this thesis is an attempt to build on the work of Robert Solow and Paul Romer.

The Solow model shows how growth in the stock of capital, labor, and technology interact in an economy (Mankiw 2013). It also shows how they affect a nation's output of goods and services. Real income per capita is a function of "effective capital (i.e. capital per capita)," symbolized by:

$$y = f(k), \text{ where } k = K/L. \text{ Technology is exogenous such that} \quad (2)$$

$$y = A \cdot f(k). \quad (3)$$

Where y is the per capita output and k is the per capita capital stock. The Solow growth model can be expressed as $Y = Ak^\alpha$ (Solow 1956). The letter A symbolizes technology, whereas k^α symbolizes capital raised to some exponent. This means that if there is an increase in total factor productivity, then there is an increase in real income per capita. Solow's A is an exogenous factor in economic growth, meaning that the Solow model does not necessarily explain technological development.

A change in capital according to the Solow model can be expressed as $\Delta k_t = sy_t - \delta k_t$, where a change in capital (Δk) is dependent on the amount put into savings (sy_t) as well as the depreciation of capital (δk) over time. Also, capital in the current period is dependent on the amount of capital in the past as well as on economic growth. This can be represented on the equation $k_{t+1} = k_t + \Delta k_t$, where k_t is the level of capital stock in the current period and Δk_{t+1} is the change in the capital stock in the next period relative to the current period. Likewise, income in the next period is dependent upon this new level of capital, which can be symbolized by $y_{t+1} = f(k_{t+1})$, where y_{t+1} is the new level of income and k_{t+1} is the new level of capital.

The logic in the Solow model is that as capital grows, the value of depreciation, δk , increases. If depreciation is larger than savings, then the value of capital is shrinking. Conversely, if depreciation is smaller than savings, then the value of capital is growing.

When the amount of investment becomes equal with the amount of savings, the economy reaches what is called a *steady-state* (Mankiw 2012). In the long-run, a nation's economy converges toward this steady-state. If technology increases the efficiency of production, then a new equilibrium steady-state will emerge. For example, in the gold industry, when the value of the firm's equipment used for new productive technologies (i.e. cyanide process) is depreciating beyond the level of the firm's savings, then the firm brings less value. The same holds true with, for example, fracking technology in the oil industry.

Macroeconomist Paul Romer differs from Solow by implying a positive relationship between investment in technology with increase in profits. Technological progress is not explained by the Solow model. It is assumed as an exogenous factor. The Solow model shows that long-run economic growth depends on technological development.

Romer (1990) develops Solow's insight by positing three premises regarding technological change: 1) Technological change is central to economic growth, 2) Technological change arises from people's action as a result of market incentives, and 3) Working with raw materials carries rather different instructions than working with other economic goods. Romer pointed out that Solow's paper treated technology as an "exogenously provided public input," meaning that technology was non-rival and non-excludable. Furthermore, he pointed out that economist Karl Shell treated technological change as an input that the government provides. Romer concluded that Solow's and Shell's approaches, while consistent with Romer's first and

third premises, are inconsistent with his second premise—that profit-seeking entrepreneurs drive economic growth.

After Paul Romer’s introduction of utilizing endogenous growth models, a trend followed where several other economists utilized endogenous growth models to explain economic growth. However, not all economists joined this bandwagon. For example, N. Gregory Mankiw, David Romer (no relation to Paul Romer), and David N. Weil (1992) report findings that they believe are at odds with this trend. While they did not agree that the Solow model is a complete theory to adequately explain economic growth, they did conclude that the evidence collected suggested that the Solow model is more consistent than the endogenous growth models. However, they also concluded that the endogenous growth models did provide the right explanation for technological change around the world. This is significant to the thesis because not every economist agrees on the role of endogenous growth models in explaining technological change. Further research and development can thus be useful in definitively resolving the nature of technological change.

Technological development can positively impact profit. Firms maximize profit, but this might mean raising costs if the resultant increases in revenue are greater than the increases in cost. The production function expressed by equation two is presumed to result in a profit in its output, resulting in the following equation:

$$\Pi = TR - TC \quad (4)$$

TR is equated to ‘total revenues’ while TC is equated to ‘total costs’. Taking the first derivative of equation four results in an equation predicated on additions of marginal units to the profit function:

$$\Pi^1 = MR - MC, \quad (5)$$

where Π^1 is the first derivative of the profit function, MR stands for ‘marginal revenues,’ and MC stands for ‘marginal costs.’

Equation four expresses the notion that the sale of one additional unit of a good brings a little bit more revenue to the firm. It also insinuates that there was a cost to producing that additional unit from the labor force with available capital. This initial private investment eventually makes the new technology available to firms that did not invest by introducing them to new methods and possibilities to explore for running their operations. The initial private investment by an individual or firm brings the new product to the market, upon which consumers can purchase. However, in some cases, other firms may build upon this new technology out of competition. For example, after a number of years after the advent of the smartphone, Apple released the iPhone which had twice the common resolution as well as other advantages relative to other smartphones upon its release.

Romer’s contribution shows that even if technological development leads to profits for the investing firm in the short run, adoption of new technological developments across the industry improves efficiency and productivity for those who did not incur the initial costs. This factors in to the thesis because firms will invest in technological developments if they believe that the new technological developments will be profitable. Firms that have not invested in the new technological developments may not be able to increase production at the same level as the firms that have.

But what exactly makes up the marginal cost of each additional unit and thus, ultimately the profit function? In regards to technology, the costs of producing or investing in technology is a major part of the cost function. This can be expressed in the following function:

$$MC (\text{Tech} (P)) = \alpha - \text{Tech} (P), \quad (6)$$

Where MC stands for ‘marginal costs,’ Tech stands for ‘technology,’ P stands for ‘Price,’ and α stands for ‘alpha,’ which is a constant value.

The supply curve assumes a given level of technology, among other factors. Equation five suggests that the prices of technology being produced or invested to make each unit by the firm makes up the marginal cost function. By extension, it also makes up part of the marginal profit function. The issue, however, is that the firm does not want to produce too many units of a particular good. This is because if it produces too many units, it would have excess inventory, and thus would not generate as much profit as a result.

Romer also explored the origins of this endogenous growth. Two alternatives to the origins of such endogenous growth are 1) the convergence controversy and 2) the struggle to construct an alternative to perfect competition at the aggregate level.

The convergence controversy is the result of the allegedly faulty interpretation made by economist William J. Baumol. Baumol believed to have found that poorer countries, such as Japan and Italy, had closed the per capita income gap with wealthier countries from the years 1870 until 1979.

Two objections were raised to Baumol’s findings by Paul Romer. One of Romer’s objections is that in the data set analyzed by Baumol, convergence had only taken place in the years after World War II. Romer’s other objection is that the data set only included economies that had successfully become industrialized by the end of the period. Romer believed that this implies a sample selection or confirmation bias that accounts for a lot of the evidence in favor of convergence.

The second version of the origins of endogenous growth starts from the observation that we had enough evidence to reject all of the available growth models throughout the 1950’s,

1960's, and 1970's. This is because aggregate-level models were lacking. With this being the case, this version of the origins of endogenous growth is concerned with the slow progress that was made in constructing formal economic models at the aggregate level. This implies that progress in the field of economics does not come solely from the application of hypothesis tests to data sets.

The evidence for economic growth that Romer had found posed a challenge for growth theorists that can be summarized by five basic facts: 1) There are many firms in a market economy, 2) Discoveries differ from other inputs in the sense that many people can use them at the same time, 3) It is possible to replicate physical activities, 4) Technological advances come from things that people do, and 5) Many individuals and firms have market power and earn monopoly rents on discoveries.

Paul Romer suggested five properties would be desirable of a model of long-run economic growth: 1) The accumulation of ideas is the source of long-run economic growth, 2) Ideas are non-rival, 3) A larger stock of ideas makes it easier to find new ideas, 4) Ideas are created in a costly but purposeful activity, and 5) Ideas can be owned and the owner can sell the rights to use the ideas at a market price. Romer placed special emphasis on the second and fifth properties. He did this by contending that one's ideas, while produced with capital and labor inputs, are different from ordinary goods and services. He discussed this along two dimensions. One is the extent to which one's ideas are rivalrous, meaning whether it can be used by more than one person at one time. The other dimension pertains to the excludability of one's ideas and the level of difficulty in preventing others from using their ideas.

2.1. Technology in the Gold Industry

2.1.1. Profit-Seeking Entrepreneurship

Nicolai Foss and Peter G. Klein sought to link the theory of entrepreneurship with the theory of the firm (Foss and Klein 2012). They did so because entrepreneurship is largely ignored in the study of economics, particularly in the modern theory of the firm. As a result, no credible theory of an entrepreneurial firm exists to guide decision-making that guides one through issues that involve entrepreneurship and organization.

Foss and Klein further note that economists have increasingly seen entrepreneurship as crucial to technological progress as well as to process of economic growth. They cited economist Joseph Schumpeter's explanation that entrepreneurship is necessary to explaining economic development. Frank Knight, according to Foss and Klein, saw entrepreneurship as necessary to the existence of profit as well as the firm itself. Foss and Klein note that in management research, the discovery of profit opportunities is the dominant approach to entrepreneurship. However, this approach pays less attention to how such opportunities are exploited. This implies that, for example, profit-seeking entrepreneurs in the gold and oil industries look for profit opportunities by investing in productive technologies, but not as much attention is placed on the process of how this is done.

2.1.2. Technology and Economic Growth

Macroeconomist Robert Solow (1956) suggested that technology is an exogenous force behind economic growth. Fellow macroeconomist Paul Romer (1990) notes that technological advances occur largely because of individuals responding to what he called "market incentives." Thus, profit seeking entrepreneurs attempt to use cost-minimizing means of production and will invest in technology if they believe it will increase profits by sufficiently lowering costs. What is

responsible for said profit is that the entrepreneur who interprets future prices of products better than others goes to buy some or all of the factors of production at prices that are too low, from the perspective of the future state of the market (Kirzner 1999). Thus, it would be good for the entrepreneur to purchase input factors at a price that is lower than the long-run equilibrium price. Entrepreneurs who overpay for factors, from this perspective, did a poorer job at interpreting future prices of products relative to others in the market.

2.1.3. Hydraulic Mining

Throughout history, firms have developed different mining strategies for extracting gold. A firm would choose one strategy over another based on the costs of production in extracting the gold. One gold extraction method is known as “hydraulic mining.” Hydraulic Mining (Lindgren 1896) consists of directing a stream of water under pressure against high gravel banks. Top gravel is usually poor, containing from 2-10 cents per cubic yard (or a range of \$0.28 to \$1.42 in real costs), while the lowest part on the bed rock may be very rich. In the late 19th century, the minimum cost was probably about 3 cents per cubic yard.

2.1.4. Drift Mining

Drift Mining consists of extracting the richest gravel on the bed rock of the old channels, opened up by the means of tunnels, inclines, or vertical shafts. The costs vary greatly depending on conditions. In the late 19th century, expenses could have been reduced to 90 cents per cubic yard (or \$12.75 per cubic yard in real costs) under the most favorable conditions. In mines worked by shafts or inclines, having to hoist the gravel or pump water, the expense increased to \$2-\$3 (or a range between \$28.32 to \$42.49 in real costs). Milling of gravel, when necessary, is usually considered to cost 33 cents per ton (or \$4.76 per ton in real costs). Lindgren (1896) did not provide a price level data set that transfers these nominal costs to real costs.

The key difference is that hydraulic mining takes place on the surface level, whereas Drift Mining takes place a layer deeper. Drift Mining is much more expensive, but it offers a greater return per cubic yard mined. These higher revenues improve the profitability of the process, enticing the entrepreneur to select the drift mining method. In contrast, lower costs of hydraulic mining make it profitable in spite of the relatively low yields it produces.

2.1.5. Quartz Mining

Quartz Mining is the most universally adopted method of exploiting quartz veins by incline shafts, following the dip of the deposits. Costs of mining vary considerably with the thickness of the vein, hardness of the country rock, and the depth and amount of water in the mine. The costs of this mining method have decreased considerably in the last 20 years. This is significant because a decrease in costs would lead to its appeal among firms for use in extracting gold as gold is now cheaper to produce. The reason for the decrease in costs for this gold extraction method is not known or given.

However, numerous writers have discussed quartz veins in detail. For example, Edward Sherwood Meade described a quartz vein as typically being associated with something called a placer (Meade 1897). However, placers are derived from quartz veins (Meade 1908). One feature that is notable of quartz veins are pockets of “rich ore full of native gold.” Quartz have to be discovered in order to be mined. Meade noted that new processes have to be developed over time in order to continue extracting quartz. Also, new machinery must also be developed to extract quartz.

2.1.6. Free Milling

Free Milling is another method of gold mining. It entails that gold ores contain native gold that easily *amalgamates* with quicksilver. It also contains a certain percentage of gold

chemically combined or very intimately mixed with the metallic sulphurates which make up a small fraction of the ore. Average costs of milling in 1868 was generally over \$2 (or just over \$28.32 in real costs). Mines with their own chlorination report the cost to be \$8 or \$9 per ton (\$113.41-\$127.48 in real costs). The cost of milling has been greatly reduced in the last 20 years (prior to publication in 1896). Costs of milling in general may be said to vary.

Meade gave an example of free milling being used in a particular mill known as the Empire mill in 1853. It began with ore being roasted in heaps before being crushed in a 16-stamp mill. Lindgren gives the following description for the rest of the free-milling process:

The pulp passes over blankets, where much gold and pyrites is caught; these blankets are wrung out in water at intervals, and the mixture of gold and pyrites is subjected to amalgamation in pans. From the blankets the pulp passes through a revolving cylinder holding mercury, where a part of the fine gold is amalgamated; finally the pulp is subjected to an amalgamation in a Blaisdell pan holding mercury and iron balls; three-fourths of the gold is caught on the blankets (Lindgren 1896).

Based on this description, it does not appear that free-milling is used in quartz mining. By extension, this should mean that this extraction process can be used on all gold that is mined.

2.1.7. Gold Extraction Process

The oldest technique for recovering gold is the method of *amalgamation* (Craig and Rimstidt 1998). Amalgamation is a process of extracting gold in which a combination of gold and mercury is mixed together to form an amalgam. Geologists James R. Craig and J. Donald Rimstidt found that the process of amalgamation dates back hundreds of years. Before the advent of the cyanide process, amalgamation was the primary method for extracting gold.

Another method for gold extraction referenced by Craig and Rinstidt is that of the use of chlorine gas. In the 1850's, soluble gold salts were found to be produced by chlorine gas. This process was initially used at the Deetken Mine in California in 1858. This process was unsuccessful, as this process did not produce high recovery rates of gold.

Hugh Rockoff (1984) described the development of the cyanide process for extracting gold from the mines. Rockoff described the essence of the cyanide process as “the use of dilute solutions of potassium cyanide to dissolve gold mixed with certain impurities and the use of fine zinc shavings to precipitate the gold.” He described this process as an innovation that appeared to have sudden macroeconomic disturbance, as it revolutionized gold's metallurgy. This process is part of the reason for the increase in world gold production from 1890 to 1905. Regions that integrated to the cyanide process during this time period—Australia, Mexico, and Canada—found it to be rather profitable. The cyanide process is an example of technological progress in gold production that can increase supply, or shift the supply curve to the right. This would lower the costs of gold in the long-run, raising the price level by implication.

The cyanide process is an innovation of gold extraction that is believed to have been a sudden appearance, and therefore a “potentially serious macroeconomic disturbance (Rockoff 1984).” The process' initial breakthrough came in 1886 and was perfected by the end of the decade. Rockoff's paper from 1984 does not appear to allege that the cyanide process is used in quartz mining, and thus is an extraction process that can be used on all gold mined.

Rockoff suggests that hydraulic mining and the cyanide process extract gold from ore. This means that the gold extracted using these innovations is not “pure” gold. The major effect of using the hydraulic mining method was to partially offset the richest placer deposits that were exhausted. This hints at a decrease in supply. However, it is not clear from the literature whether

drift mining collects gold ore as well, but one would presume in the affirmative as drift mining, in the discussion earlier, moves a layer deeper towards the bed rock than the hydraulic mining method.

From 1911 through 1993, the amalgamation method and the cyanide process were both used for gold recovery rates, and appeared to be competing methods of extracting gold over the span of several decades. The cyanide process had a slight lead in gold recovery from 1911 to 1918. Amalgamation had the lead from 1919 to 1938. The cyanide process was in the lead again from 1939 until 1942 before the amalgamation process dominated from 1946 until 1967. Craig and Rimstidt (1998) note that at this time, health concerns were raised regarding the use of mercury in the amalgamation process. As a result, the total amount of gold recovery via the amalgamation process dropped by over 99 percent in 1970.

In 1971, the price of gold skyrocketed. This is presumably due to President Nixon disbanding the link between the U.S. dollar and gold. This affected firms in the gold industry by investing in technological development using other methods such as the cyanide process. In the 1980's, the gold industry began using the cyanide process for recovering gold. The cyanide process is likely to remain as the primary method of extracting gold, unless an alternative method for extraction is discovered to be a major breakthrough. This is likely due to the health concerns from using the amalgamation process, and because the cyanide process has proven to be a more efficient method of recovering gold relative to the methods preceding it.

Figures 2.1 and 2.2 show us the rates of change between non-monetary and total stocks of gold versus the inflation-adjusted price of gold from the years 1870-1914. Graph 2.3 displays the rates of change between the revenues from the industrial production of gold against the

previously mentioned inflation-adjusted price of gold from 1870-1914. These graphs are generated from a data set from the U.S. Gold Commission.

The dotted line in figure 2.1 signals the rough estimate of when the cyanide process was invented. After this time, the production of gold began increasing. Roughly 10 years later, the real price of gold begins decreasing while the production of gold is still increasing. In this case, with the Cyanide Process being invented in the late 1880's, prices started to fall a little over 10 years later in response to increased production.

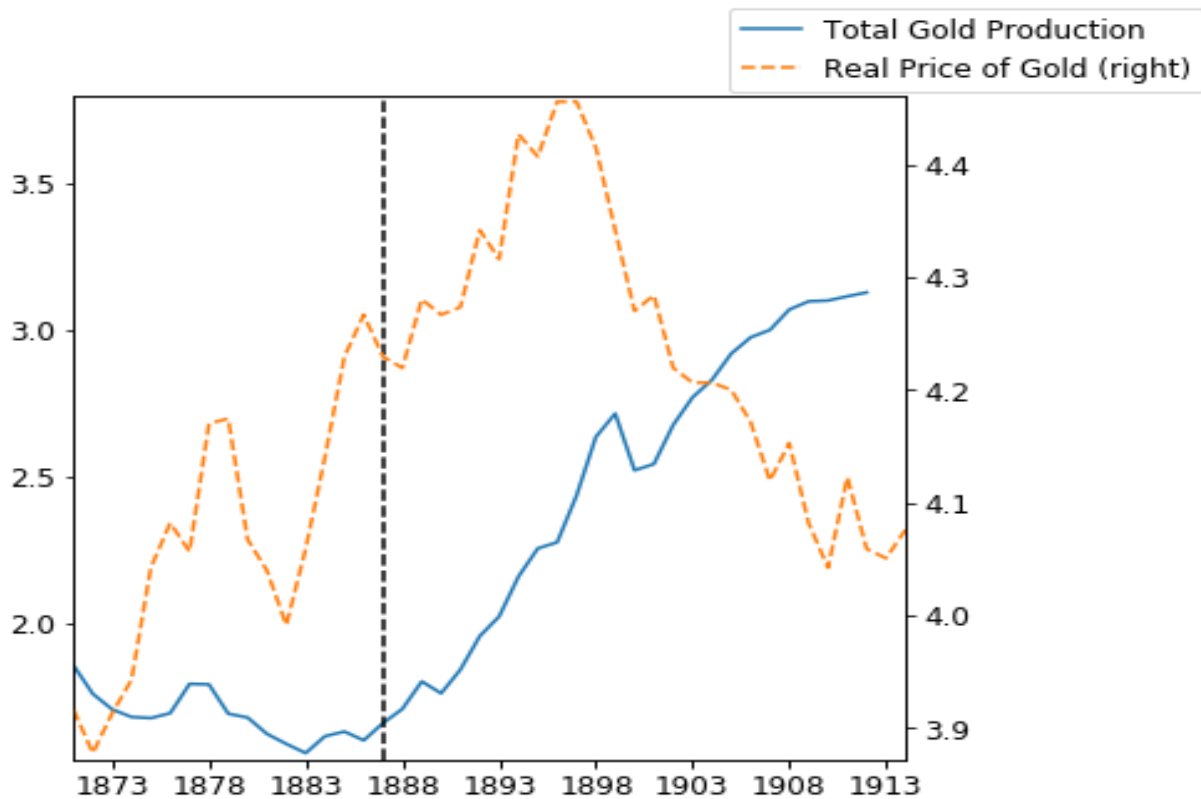


Figure 2.1. Total Gold Production

Figure 2.2 shows more volatility regarding gold production for monetary and non-monetary uses. Non-monetary gold production appears to decrease after the invention of the cyanide process. This suggests there may be a possible relationship between gold production and the United States' monetary policy in operation at the time, the classical gold standard.

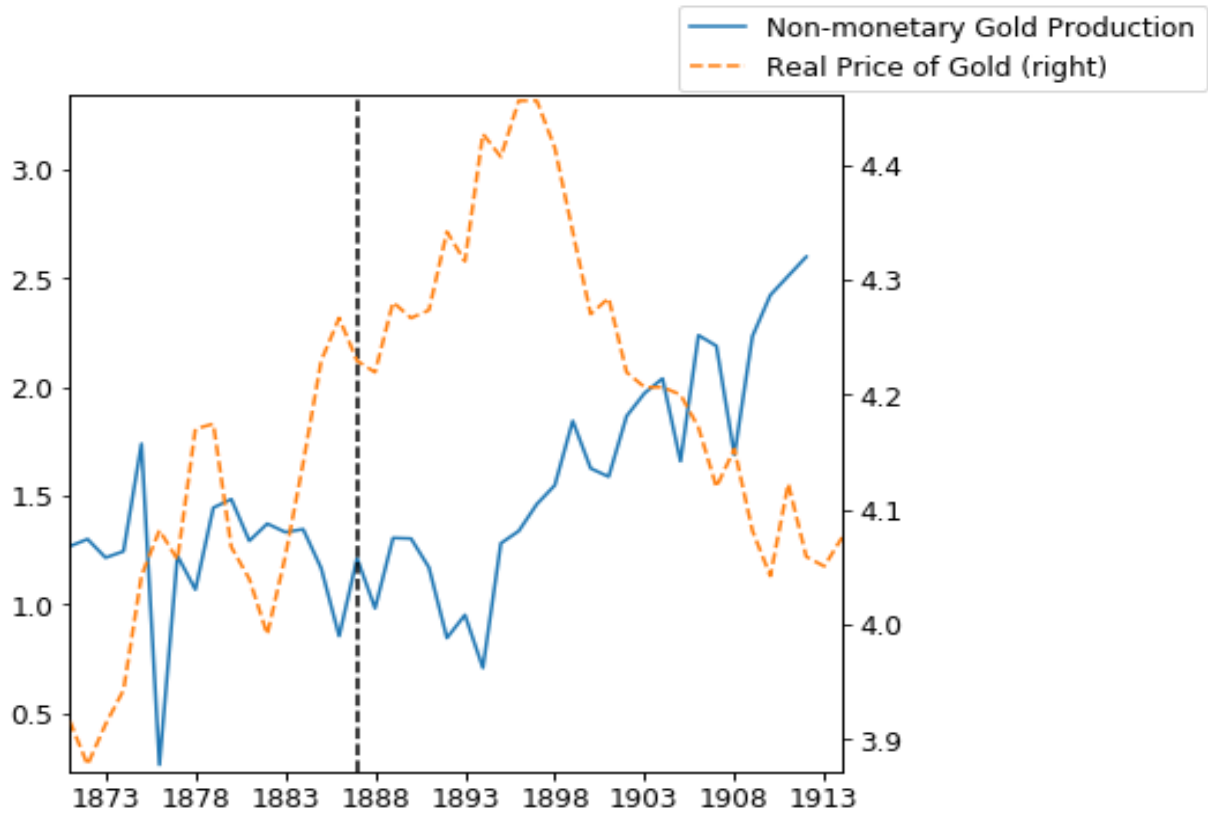


Figure 2.2. Non-monetary Gold Production

Figure 2.3 shows that the revenues for firms in the gold industry are increasing after the invention of the cyanide process. This suggests that the cyanide process was indeed profitable for profit-seeking entrepreneurs who extracted gold using the cyanide process.

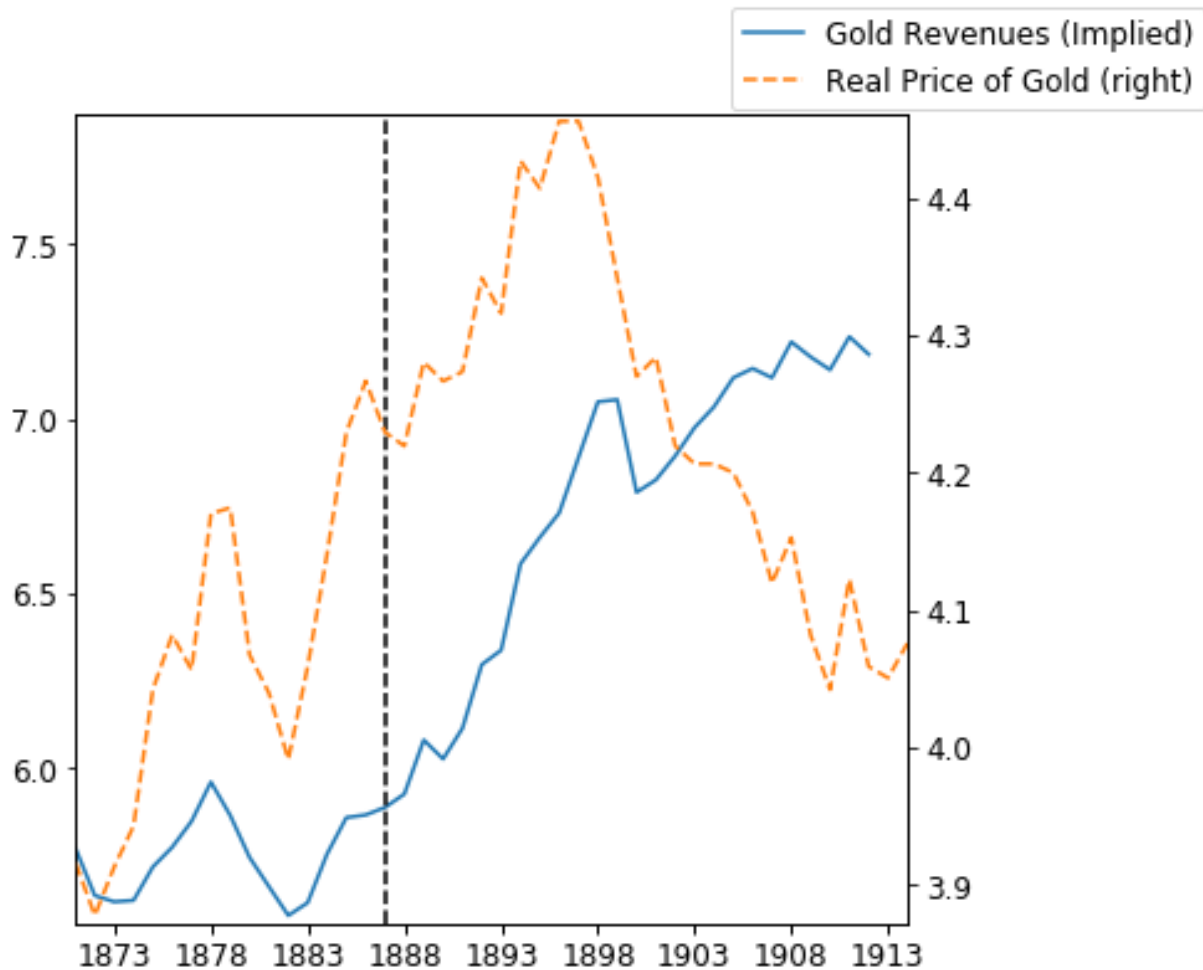


Figure 2.3. Gold Revenues (Implied)

2.2. Technology in the Oil Industry

A sub-thesis to this paper is that the oil industry is an example of profit-seeking entrepreneurs seeking to develop new technologies to reduce costs. Oil is considered to be a *consumption asset* (Hull 2014). As a consumption asset, oil usually provides no income to the investor, and can also be subject to significant storage costs. This means that oil is an asset held primarily for consumption purposes rather than for investment purposes. In contrast, an *investment asset* is an asset held for investment reasons by many investors.

Oil, and gold, is also seen as a non-renewable resource. Spencer Dale, former Chief Economist of the Monetary Policy Committee at the Bank of England and current Chief

Economist at BP, notes that 1) oil is an exhaustible resource and 2) the supply and demand curves for oil are relatively inelastic (Dale 2015). Dale mentioned regarding oil's exhaustibility that while estimates of recoverable oil resources are frequently increasing, it is unlikely that the world's oil reserves will ever be completely exhausted. More discoveries are being made and technology is improving at a faster rate, according to Dale, than the existing oil reserves are being consumed. This is significant to the thesis because discoveries being made and technology moving at faster rate means that profit-seeking entrepreneurs should get more profits.

Recently, fracking technology has revolutionized oil production. The term 'fracking' is synonymous with the term 'hydraulic fracturing'. Fracking is the process in which rock is drilled with a high-pressure liquid in order to release gases inside the rock. Fracking techniques have resulted in increased production of gas and oil in the United States. Fracking is the method by which shale oil is produced (U.S. Department of Energy). Shale oil is produced in only four countries—the United States, Canada, China, and Argentina (EIA.gov). While fracking was initially discovered in the Civil War era, fracking innovations did not seriously occur until the 1930's. Drillers at this time had used acid rather than nitroglycerine while drilling. This increased their productivity.

In the 1990's, George P. Mitchell seemed to have discovered a second key technology for the oil industry—horizontal drilling. He combined this technique with that of fracking. The combination between fracking and horizontal drilling had enabled greater access to oil and natural gas (EPA.gov 2018). The demand for energy is a key reason why fracking has been successful for a number of companies, and continues to be implemented to this day (Emspak 2018).

However, some issues and concerns have been raised in regards to fracking. One key issue is that of unclear possibilities of profitability (Sovacool 2014). With ongoing investment in the production of shale oil, not everyone who engages in fracking see a profit.

It has been argued that the decline in oil prices have been one of the causes in many of the recessions in the United States (Luskin 2016). The recent drop in oil prices have come as a result of what has been termed “supply-side technology.” This term refers to the technological breakthroughs of fracking and horizontal drilling.

The Environmental Information Administration found a variety of factors that drive the price of oil. These factors are: 1) supply of oil among Non-OPEC countries, 2) supply of oil among OPEC countries, 3) Oil inventories, 4) Spot Prices, 5) Financial Markets, 6) Demand for oil among Non-OPEC countries, and 7) Demand for oil among OPEC countries.

Fracking technologies used to extract oil imply the existence of the costs of production. Firms will invest in these fracking technologies if they expect to receive revenues that outweigh these costs, but as Sovacool (2014) mentioned, this does not always happen.

2.3. Moore’s Law, Use, and Measurement of Technology

An engineer, entrepreneur, and businessman by the name of Gordon Moore observed that the number of transistors that can be placed within a unit of space doubles every 18 to 24 months. This has come to be known as *Moore’s Law*. Thus, Moore’s Law seems to suggest an exponential growth in the world of technology. One possible extension of Moore’s Law is that as these transistors become more efficient, computers and other machines will become smaller and faster over time. The faster electrical signals are processed by microchips, the more efficient computers become.

Data has shown that the price of one megabyte has decreased dramatically over the span of the last 6-7 decades that computing technology has been in existence. One megabyte in 1957 was worth over \$400,000,000 in 1957. As of 2016, one megabyte had dropped to the price of \$0.0035, less than even one penny. This means that, in relation to Moore's Law, as computers and other machines become more efficient and the number of transistors continue to grow, the prices of megabytes and arguably other computing technologies continue to decrease. This conclusion makes investing in computing technologies attractive as investors would like to purchase or invest when prices are low. As prices of megabytes have been currently dropping exponentially for decades, firms are willing to buy more of them per the law of supply-and-demand. Firms thus may be more willing to invest in computer technologies, such as software, hardware, etc. Also, if firms determine that such investment in computer technology will likely be profitable, then they are more willing to invest in computer technologies.

It has been argued that what Gordon Moore observed was a case of exponential growth with two as the exponent (Richards 2018). Dr. Jay W. Richards, Research Assistant Professor for the Busch School of Business and Economics at the Catholic University of America, noted how the economic effects resulting from the exponential growth pertaining to Moore's Law is staggering. Richards suggested that many technologies start out as a rare piece, with only a select few people making use of them. Then over time, these technologies become mass produced, and thus become arguably cheaper and improved. These technologies, perhaps at some point, may become used at a universal level.

A corollary of Moore's Law is known as Bell's Law, named after electrical engineer Gordon Bell (Gilder 2018). Bell's Law describes how after every decade, prices drop at a hundredfold rate for processing power. This leads to the creation of a new computer architecture.

George Gilder, technological guru and co-founder of the Discovery Institute, noted that Moore's Law is partly responsible for the computer speed that helps make advances in artificial intelligence and improvements in the use of computer algorithms.

As mentioned, economic growth is ultimately dependent on technology. There are three main measures of technology: 1) Physical Technology, 2) Human Capital, and 3) Institutional and Social Capital. Examples of physical technology include the Industrial Revolution, the invention of the car or microchip, etc. This particular measurement of technology is what initially comes to mind for many people upon thinking about technology, as it entails a tangible sense of technological innovation at work.

The second method of measuring technology previously mentioned is that of "human capital." Human capital is the quantifying of one's skill-set. Things that make up this skill-set in individuals include, but are not limited to, items such as work or internship experience, computer skills, professional licenses, aptitude, etc. This human capital aids productivity and creates value for the firm. Earning a degree implies that one is investing in their own human capital. Many join a particular organization to further develop their human capital.

Every technology that takes advantage of human labor requires individuals to develop human capital. Without the development of human capital, individuals will have immense difficulty creating new inventions and innovations. New technology is embedded in capital, as increased revenues are shared through increased wage of skilled labor and increased rent of capital. Lower input costs also allow for greater productivity and employment in related sectors.

The final measurement of technological innovation is that of social capital. Technical innovation requires that markets be robust in order to generate the revenue required to justify their payoff. Free markets across a large scale are rather difficult to develop for a variety of

reasons. First, conflicts may emerge between legal jurisdictions. Second, for a lot of human history, travel may have been dangerous. Third, aristocratic values tended to demean commerce.

An economy of exchange requires individuals to put their trust in strangers. This trust is not possible without institutions that promote trust. Also, a rule of law comes into play to aid in establishing trust. This can be found in the societal norms such as property rights, individual autonomy, and mutual respect between individuals. These norms are necessary for the sustainability of economic development.

Different firms follow different strategies when electing to invest in a particular technological innovation (Grenadier and Weiss 1995). Some may adopt new technologies when they first become available, while others may wait for some time before electing to do so. Firms may adopt every technological innovation as it becomes open for use, while others may bypass many technological innovations altogether. Grenadier and Weiss (1995) primarily discuss four investment strategies, that of a (1) *compulsive* strategy of investing in all technological developments, (2) a *leapfrog* strategy of not investing in a new technology but waiting for the next generation of developments, (3) a *buy-and-hold* strategy of only purchasing early technological developments, and (4) a *laggard* strategy of waiting for the next generation of technological innovations before investing in the previous generation's developments. They briefly discuss a fifth strategy of a *bystander* that neglects to invest in any technological development, but had omitted such strategy in their presentations.

Three areas of concern that Grenadier and Weiss bring to the table are (1) the speed of arrival of new innovations in a given industry, (2) the level of significance of each innovation to the firm or industry, and (3) the uncertainty surrounding the future of technological innovations.

These areas of concern may determine the type of strategy firms elect to take when investing in technological innovations in the gold and oil industries as well as other industries.

CHAPTER 3. METHODOLOGY

In the data chapter, price elasticity graphs will be presented. The price elasticity formula, as presented by Pyndick and Rubinfeld (2013) can be presented as changes in quantities of a good relative to changes in price. Price elasticities of demand usually result in a negative value, as prices of goods and the demand for such goods usually have an inverse relationship. For example, when there is a price increase, the quantity demanded of a good fall. Likewise, when the price of a good decreases, the quantity demanded rises. When the price elasticity's absolute value is greater than 1, demand for a good is deemed to be *price elastic*. This is because the percentage decline is decreasing faster than the percentage increase in price of the good. If the price elasticity's absolute value is less than 1, then the demand for a good is deemed to be *price inelastic*. Pyndick and Rubinfeld argue that when there are no close substitutes, demand will tend to be price inelastic. When there are close substitutes, increases in price will influence consumers to buy less of one good and more of the good substituting it.

On the supply side, price elasticities refer to changes in the quantity supplied that result from increases in price. Elasticity of supply is positive. If the supply curve shifts, we observe a movement along the demand curve and therefore should see negative elasticities implied by observations when the efficiency of supply factors are increased substantially. Thus, from a supply perspective, there is a positive relationship between price and production of goods for the supplier. However, the elasticity of supply relative to, for example, most manufactured goods are negative. Therefore, increases in prices for the input of raw materials implies that the supplier faces higher costs. This means that the quantity supplied will fall.

The traditional production function frames the quantity of a good produced by firm as a function of the firm's capital, labor, and technical efficiency. The quantity produced of a particular good is a function of technology, labor, and capital used to produce the good.

Technical efficiency, A , refers to the cost of producing a unit. As technical efficiency falls, the number of units that a firm can produce profitably increase, and, therefore, the firm's profits also increase. This fall in cost, then, represents a rightward (downward) shift in the firm's marginal cost curve. In essence, this results in a rightward shift in the supply curve.

In aggregate, the overall technical efficiency of capital, A , is comprised of the technical efficiency of production processes across the economy. While total factor productivity represents the efficiency of productivity technology and organization across the economy, each good can be viewed along the same lines. The level of production of a particular good is dependent upon efficiency increases procured by technology, a_i , used to produce the good.

An increase in a_i yields a decrease in marginal costs, thus shifting the firm's supply curve to the right. It is useful to treat the value of a_i , and as a result, of A as being endogenous. The appropriate level of technology in the market place is a function of profit expected from an improvement in the efficiency of affected productive capital. Improvements in technology tend to reduce the marginal cost associated with production of the good. Thus, as productive technology improve efficiency, the supply curve shifts to the right.

Firms will only invest in a technology if revenues expected from use of a technology are expected to exceed the costs incurred in development of that technology. That is, the firm's supply curve can only shift to the right if the firm in question incurs the fixed cost of investment or the cost of acquiring technology already developed. Since profits are a function of revenues and costs, and revenues are simply defined as the product of price and the quantity of the good

produced, we expect that when total revenues are relatively high, in particular due to a high price of the good produced, the probability of development of cost reducing technology increases.

In the case that a firm is not operating in a perfectly competitive market, the sustainability of a high price is especially significant to investment. Thus, a relatively high price that exists alongside a relatively large absolute value of elasticity of demand encourage a greater level of investment than a high price that is observed alongside a relatively small and negative elasticity. Expressed another way, relatively high past prices will exert greater positive effect on the quantity produced if the demand curve is relatively elastic.

What exactly makes up the marginal cost of each additional unit and thus, ultimately the profit function? In regards to technology, the costs of producing or investing in technology is a major part of the cost function. The value of factor productivity for production of a particular good, i , is dependent upon expectations of profits associated with a marginal increase in a_i . If producers think that the cost of a marginal increase in factor productivity, da_i , will more than compensate by an increase in revenues that results from the new technology, then they will invest in technology that lowers the marginal cost of production for a given quantity.

The supply curve assumes a given level of technology, among other factors. Equation five suggests that the prices of technology being produced or invested to make each unit being by the firm makes up the marginal cost function. By extension, it also makes up part of the marginal profit function. The issue, however, is that the firm does not want to produce too many units of a particular good. This is because if it produces too many units, it would have excess inventory, and thus would not generate as much profit as a result. It will only produce more units if the cost of production falls or the revenues earned from sale of a unit increase.

The paper argues that investment in technology can be described as 1) a function of the real price of the good produced and 2) as a function of elasticity. As elasticity increases (e.g. due to demand factors), producers of a commodity have significant incentive to invest in new means of producing the good demanded. The result of implementation of new, cost-reducing technology is to lower prices as the result of greater quantities being produced at a given price. The supply curve shifts right due to an improvement in technology. Since the result is a movement along the supply curve (driven by improvement in the efficiency of productive technology), changes in observed elasticity should be less positive, if not negative.

The hypotheses of this this based on the model presented are the following:

- (H1) Price increases lead to further investment in technological advances.
- (H2) Increase in price elasticity does not lead to further investment in technological advances.
- (H3) Increases in investment in technological advances do not influence price.
- (H4) Increases in investment in technological advances influence price elasticity.

3.1. Oil Data Collection

In the oil market, when there is an increase in a fall in the supply of oil, the price of oil tends to increase. Oil producers invest in technological advances in order to reduce costs of production. Increases in the demand for oil helps bring prices back to its original point, but this time a higher quantity of oil is sold. This helps generate more profits for the oil producer as a result.

3.2. Gold Data Collection

Data given for production of gold came from the U.S. Geological Survey, or USGS for short. Data from the USGS keeps track of include the quantity of gold produced throughout the

world, imports and exports of gold, etc. The CPI term was gathered from the St. Louis Federal Reserve. The Real Price of Gold was determined in the Python language by dividing the nominal Price of Gold by the CPI factor. Data gathered from the USGS data-set for use on Python span over a century.

3.3. Usage of Software

Much of the statistical analysis will be done using the Python software, a general-purpose programming language that generates output from the series of code. The Python software is a useful programming language because, like statistical software such as STATA and SAS, one can also conduct statistical and data analysis with Python. However, it is also a more versatile programming language, where you can use code to generate graphs, conduct mathematical analyses, among other things.

CHAPTER 4. DATA

The author will be using econometric testing and figures to support the thesis. Data used for the econometric testing come from multiple sources. First, the data for oil production used for figure 4.2 was taken from the Board of Governors of the Federal Reserve System. Second, nominal price data was collected from the Federal Reserve Bank of St. Louis. Finally, data for both the GDP Deflator, otherwise known as the price level, as well as oil investment data were provided by the U.S. Bureau of Economic Analysis.

The first econometric testing being used will be the Augmented Dickey-Fuller (ADF) test. This test tests for a unit root while also allowing for serial correlation in the error term (Pyndick and Rubinfeld 1998). The null hypothesis in the ADF test is that a unit root exists in time series data. The alternative hypothesis is that the variable being test is stationary, meaning that the probability distribution does not change over time. If the alternative hypothesis is true and stationarity exists as a result of the ADF test, then one can represent the model via an equation with fixed coefficients that are estimated from the given data. The ADF test is displayed by Pyndick and Rubinfeld in the following equation:

$$Y_t = \alpha + \beta t + \rho Y_{t-1} + \varepsilon_t. \quad (7)$$

Y_t is the variable output, α is the constant value, β is the coefficient of a given variable, ρ is the value corresponding to the number of lags being utilized in the ADF test, and ε_t is the error term. In our first ADF test, our null hypothesis (H_0) is that that the Real Price of Oil contains a unit root. The alternative hypothesis (H_A) is that the Real Price of Oil follows a stationary process.

In the second ADF test, the null hypothesis (H_0) is that the Real Oil Investment variable contains a unit root. The alternative hypothesis (H_A) follows a stationary process.

For the final ADF test, the null hypothesis (H_0) is that the Real Price Elasticity of Oil variable contains a unit root. The alternative hypothesis (H_A) follows a stationary process.

If none of the above null hypotheses are able to be rejected, then logged versions of the aforementioned variables will be tested. However, if none of these logged variables pass the ADF test, then logged-differenced values will be tested. The exception to this will be for the Real Price Elasticity of Oil. The reason for this is that one cannot log negative values, of which the data for this variable contain several.

After completing the Augmented Dickey-Fuller test, we then test to see whether changes in one variable are causing changes in another. This can be accomplished by using the Granger-Causality test. The idea behind the Granger Causality test is that if one variable granger-causes another, then changes in one variable should precede changes in another variable. To state that one variable cause another should preclude that two conditions have been met. The first condition is that one variable should help to predict another. The second condition is that the other variable should *not* help to predict the first. Thus, the null hypothesis (H_0) for the Granger Causality test is that “X does not cause Y.” The alternative hypothesis is that “X does cause Y.” The second time the Granger Causality test is run, the null hypothesis (H_0) is that “Y does not cause X.” The alternative hypothesis (H_A) is that “Y does cause X.”

The Granger-Causality test identifies the persistence of causation of time (i.e., if 1 lag is optimal, then effects are transmitted quite quickly). It does this by using an information criterion such as the Aikaike Information Criterion (AIC). If too many lags are used, then there is the potential for false results (i.e. rejection of the null hypothesis when it really should not be rejected). If too few lags are used, then one runs the risk of biased results due to residual autocorrelation. Autocorrelation helps determine how much correlation exists between data

points in a time series. It occurs when a regression's error term is correlated. If the error term appears to follow a pattern, this can be seen as evidence of autocorrelation. Using differenced or log-differenced data helps to limit the growth of the variance associated with autocorrelation in the data. Determining the optimal lag structure via the Granger-Causality test is important because adding more lags than necessary can lower the degrees of freedom, thus hindering one's interpretation of the results. A lot of the data I have collected for the econometric testing of oil come from the Federal Reserve Bank of St. Louis and the U.S. Bureau of Economic Analysis. Oil production data was taken from the Board of Governors of the Federal Reserve System.

Summary statistics for the real price of oil, real oil investment, and real price elasticity of oil can be found on Table 4.1.

Table 4.1 contains the summary statistics for the real price of oil, real oil investment, and the real price elasticity of oil.

Table 4.1. Oil Descriptive Statistics

	count	mean	std	min	25%	50%	75%	max
Real Price of Oil	47	49.38	24.41	14.99	31.23	40.78	64.77	105.60
Real Oil Investment	47	0.11	0.09	0.02	0.04	0.07	0.17	0.37
Real Price Elasticity of Oil	46	-0.01	1.31	-4.20	-0.21	-0.05	0.05	5.94

The average real price of oil per unit is over \$49. Its standard deviation value suggests that the real price of oil can be volatile. The maximum value for real oil investment is 2%, while the maximum score is 37%, meaning that investment in oil is fairly low. Investment in oil also shows a wide disparity between the maximum and minimum values, which implies that investment is more likely to take place under certain conditions.

When there is an increase in demand, the real price is rising as it shows movement along the supply curve. Likewise, an increase in supply implies a decrease in the real price. However, both appear to show that the quantity being produced is increasing. A rightward shift in the

supply curve implies that prices become cheaper for consumers to purchase, therefore more is demanded. In retrospect, a rightward shift in the demand curve implies higher revenues for the supplier assuming that demand is held constant.

Figure 4.1 shows that much of the relationship between the real price of gold and quantity produced is primarily supply-driven. The x-axis is the percent-changes in the moving average of gold production. The y-axis is the percent-changes in the moving average of gold price. The figure displays a two-year moving average. A two-year moving average shows how much more profound supply-driven changes have in this relationship. Supply-driven changes are indicated by falling prices of gold coupled with increasing supplies. This occurs in the bottom right quadrant of figure 4.1. This supports the thesis in that investment in technological help bring about supply-driven changes.

Figure 4.2 describes this relationship in a line graph, showing how supply-driven changes occurred mostly throughout the 1980's and into the early years of the 1990's.

Figures 4.3-4.4 displays the relationship between the real price and quantity produced for the oil industry. The x-axis in figure 4.3 is the percent-changes in the moving average of oil production. The y-axis in figure 4.3 is the percent-changes in the moving average of oil prices. The two-year moving average, as displayed in figure 4.3 shows that the real price elasticity of oil is becoming less positive and more negative in recent years as a result of fracking technology as depicted in the two right quadrants. Figure 4.4 depicts the same result in the form of a line graph. The red lines show that changes in the real price elasticity of oil are primarily supply-driven, similarly depicted in the gold industry. Supply-driven changes in oil are indicated by falling prices of oil coupled with an increasing supply of oil. This can be seen in the bottom right quadrant of figure 4.3.

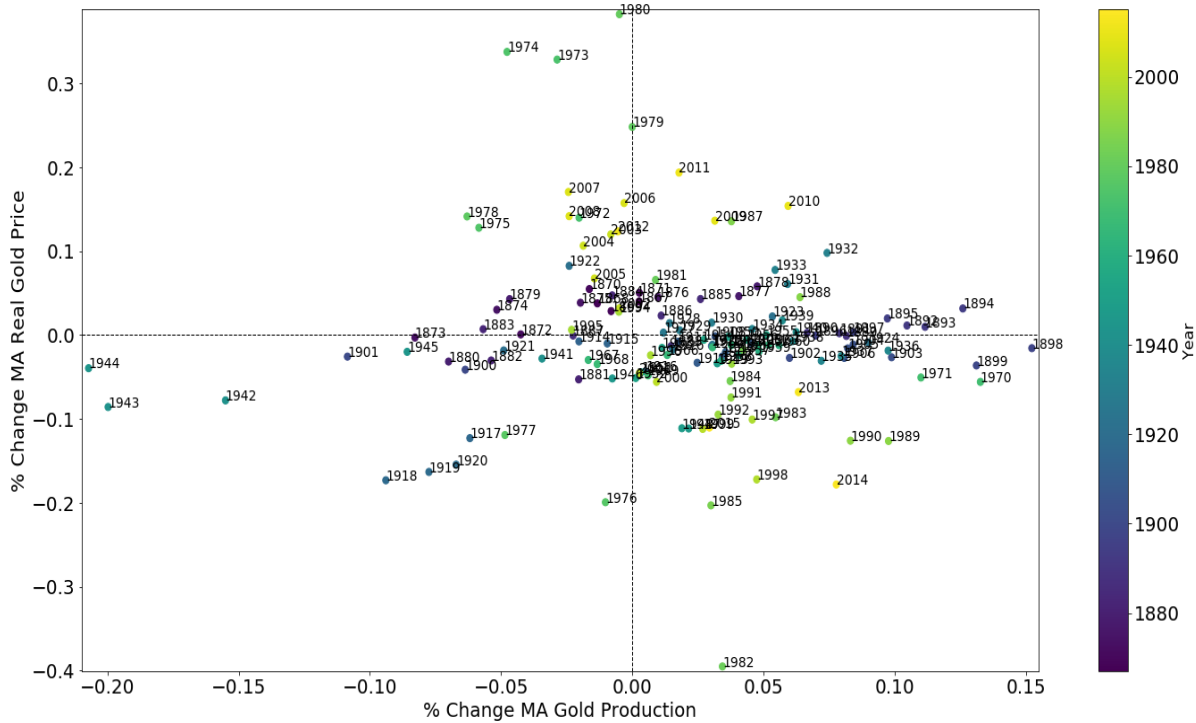


Figure 4.1. Percent Change MA Gold Production

The red-shaded areas indicate supply-driven changes in price, as shown in the line graph representation found in figure 4.2. The red-shaded areas from the late 1890's to the early 1900's is believed to be a result of the development of the cyanide process of gold extraction. This development of rising production and falling prices came to an end in the mid-1910's, presumably due to the first world war of 1914-1918. The development once again broke down when President Richard Nixon effectively terminated gold's convertibility with the U.S. dollar in 1971. A new development for gold extraction known as heap leaching began in the 1960's in Nevada and some other states, which may have helped re-start this development in rising production and falling price.

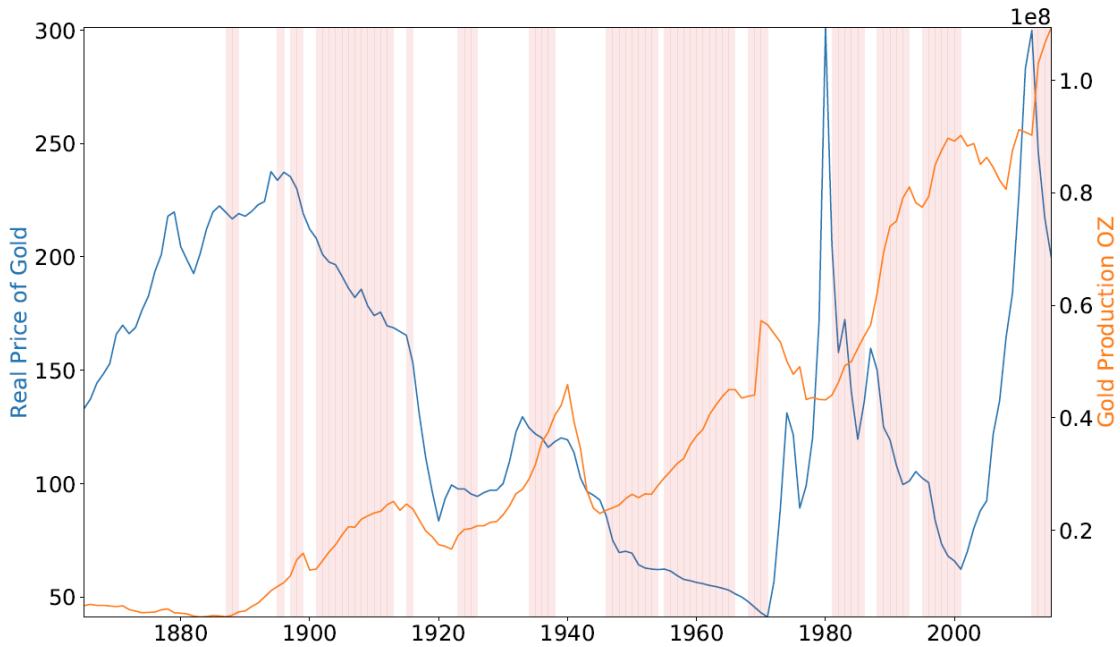


Figure 4.2. Real Price of Gold. Red areas indicate years where the 2-year moving average of prices were decreasing and the 2-year average moving prices were increasing. Elasticity values suggest that these price changes were motivated a falling cost of supply.

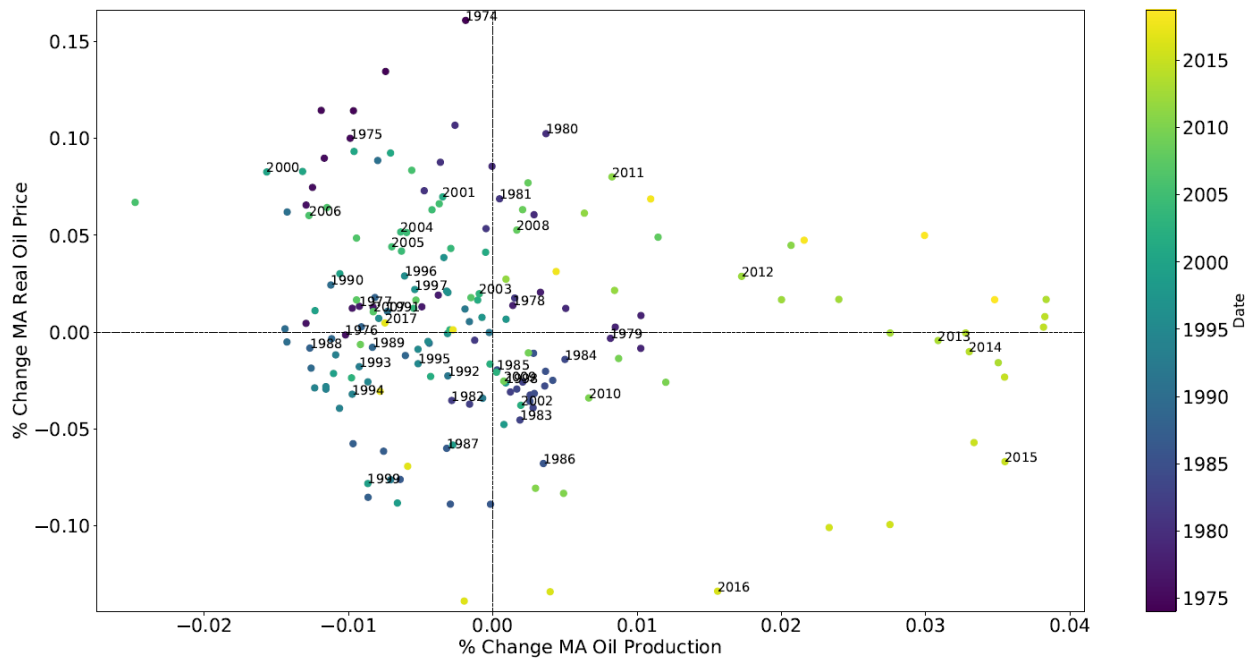


Figure 4.3. Percent Change MA Oil Production

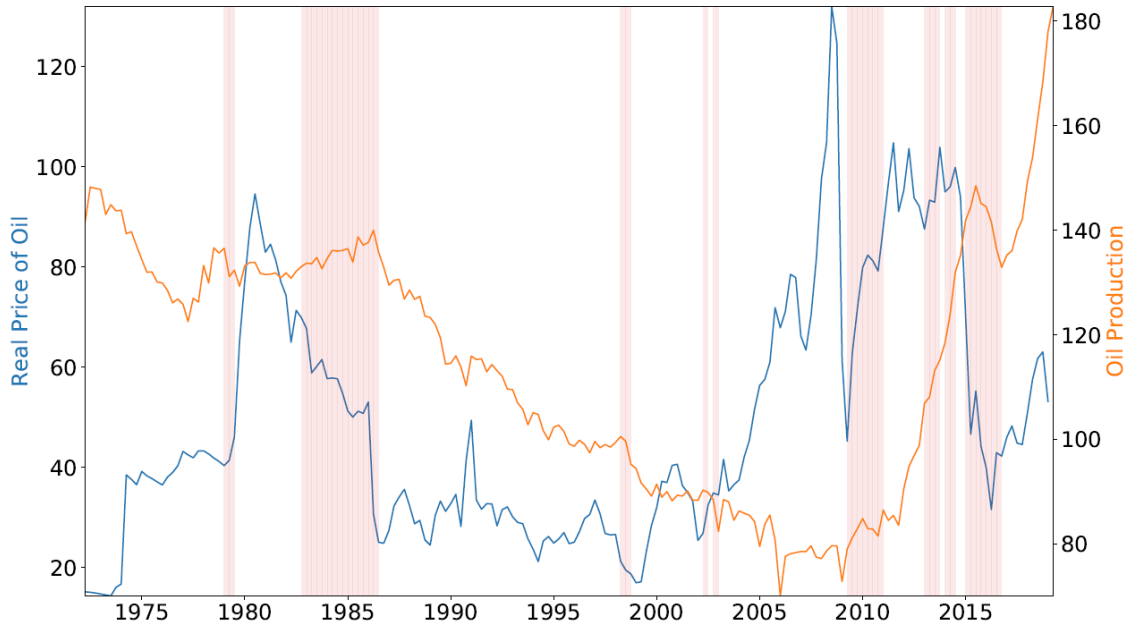


Figure 4.4. Real Price of Oil

CHAPTER 5. RESULTS

In order to conduct a Granger-Causality test, one must first conduct an Augmented Dickey-Fuller (ADF) test and then determine the Granger-Causality among all variables. Being unable to find any gold investment data, these econometric tests were only done on the oil investment data imported from the Federal Reserve Bank of St. Louis and the U.S. Bureau of Economic Analysis.

An Augmented Dickey-Fuller test was conducted on the real price of oil, real oil investment, and the real price elasticity of oil (see Tables 5.1-5.3). Based on the values from the ADF Statistics, p-values, and Critical Values, the only variables that pass the test are the log-difference of the real price of oil, the log-difference of the real oil values, and the real price elasticity of oil as well as its difference values. The real price elasticity of oil could not be logged as doing so gave some negative values.

In Tables 5.1 and 5.2, the p-value for both the logged and non-logged versions of the Real Price of Oil and the Real Oil Investment were greater than 0.05. Thus, while the ADF statistic would otherwise be statistically significant, the p-value prevents that from being the case. However, the log-difference for both pass the ADF test.

Table 5.1. Real Price of Oil

ADF Statistic	-2.2324	ADF Statistic Log	-2.5596	ADF Statistic Log Diff	-6.4644
p-value	0.194706	p-value Log	0.101638	p-value Diff	0.00000
Critical Values:					
1%	-3.581	Log 1%	-3.581	Log-Diff 1%	-3.585
5%	-2.927	Log 5%	-2.927	Log-Diff 5%	-2.928
10%	-2.602	Log 10%	-2.602	Log-Diff 10%	-2.602

Table 5.2. Real Oil Investment

ADF Statistic	-1.35039	ADF Statistic Log	1.161275	ADF Statistic Log Diff	-5.24686
p-value	0.605816	p-value Log	0.690028	p-value Diff	0.000007
Critical Values:					
1%	-3.585	Log 1%	-3.585	Log-Diff 1%	-3.585
5%	-2.928	Log 5%	-2.928	Log-Diff 5%	-2.928
10%	-2.602	Log 10%	-2.602	Log-Diff 10%	-2.602

Table 5.3. Real Price Elasticity of Oil

ADF Statistic	-6.75792	ADF Statistic Log	6.382573
p-value	0.00	p-value Diff	0.00
Critical Values:		Critical Values:	
1%	-3.589	Diff 1%	-3.606
5%	-2.93	Diff 5%	-2.937
10%	-2.603	Diff 10%	-2.607

In our Granger Causality test, we tested between the variables that had passed the Augmented Dickey-Fuller test, the log-difference real price of oil, the log-difference real oil investment, and the differenced real price elasticity of oil.

In our Granger Causality test, we test if variable Y is caused by variable X.

$$Y_t = \sum_{i=1}^m \alpha_i Y_{t-i} + \beta_i X_{t-i} \quad (8)$$

The explanatory power of the above equation is compared to the explanatory power of the restricted equation:

$$Y_t = \sum_{i=1}^m \alpha_i Y_{t-i} \quad (9)$$

We check for granger causality according to the following hypotheses in regard to the market for oil:

(H1) Price increases do not lead to further investment in technological advances.

P-value > .05

Result: Accept null hypothesis that price changes do not influence investment in technology. This does not, however, mean that changes in price have zero influence on investment in technological advances. It does suggest the data does not provide statistically significant support for this hypothesis. We would expect to see some economic significance behind price increases having an affect on investment on some level. However, the F-statistic is less than 1.96 and the p-value is much greater than the 0.05 threshold, so it

(H2) Increase in price elasticity does not lead to further investment in technological advances.

P-value > .05

Result: Accept null hypothesis that price changes do not influence investment in technological advances.

As Table 5.4 shows that this result occurs after 3 lags, it is possible that there can be some statistical significance to this result using additional lags. Again, while we expect there to be some relationship between these two variables, the data does not support a statistically significant relationship.

(H3) Increases in investment in technological advances do not influence price.

P-value < .05

Result: Reject null hypothesis that increases in investment influence price.

This result, coupled with the results of the first hypothesis, suggest that price changes and changes in investment appear to have a weak relationship. However, given that this result allows the null hypothesis to be rejected, we would expect that price changes have some influence on changes in investment.

(H4) Increases in investment in technological advances influence price elasticity.

P-value < .05

Result: Reject null hypothesis that increases in investment do not influence price elasticity. Similar to the result and discussion of hypothesis 3, the results of the second and fourth hypotheses appear to suggest a weak relationship between changes in investment and changes in price elasticity. Likewise, as the null hypothesis can be rejected in this case, we can expect that changes in the price elasticity may have some influence upon changes in investment in technological advances.

Table 5.4. Granger Causality

Null Hypothesis	Lags	F-stat	p-value	Significance
Differenced Real Price Elasticity of Oil -/> Log-Difference Real Oil Investment	5	1.072861	0.3957155	
Differenced Real Price Elasticity of Oil -/> Log-Difference Real Price of Oil	4	8.345235	9.94E-05	*
Log-Difference Real Oil Investment -/> Differenced Real Price Elasticity of Oil	1	6.485067	0.0147298	*
Log-Difference Real Oil Investment -/> Log-Difference Real Price of Oil	1	7.019678	0.0113136	*
Log-Difference Real Price of Oil -/> Differenced Real Price Elasticity of Oil	4	4.417198	0.0058966	*
Log-Difference Real Price of Oil -/> Log-Difference Real Oil Investment	3	1.264493	0.301119	

By running a Granger-Causality test, we find that the real price elasticity of oil does not have a significant influence on real oil investment, but the converse may be true. Also, the real price of oil does not appear to influence the real investment in oil extraction technologies, but the converse may be true. Thus, two of the four hypotheses presented in the methodology section appear to be either incorrect or inconclusive.

CHAPTER 6. CONCLUSION

Using data from the Board of Governors of the Federal Reserve System, the Federal Reserve Bank of St. Louis, the U.S. Bureau of Economic Analysis, the United States Geological Survey, and other sources, this study tested the relationship between technological innovation and economic growth.

As this research is conducted on oil and gold, this thesis will primarily be of interest to an audience of natural resource economists as they study items such as fracking and gold extraction methods. They be interested in this thesis as it deals with investing in the earth's natural resources. It may also serve the interest of entrepreneurs who are interested in investing in new, developing technologies. This is because the results show that increases in price will help drive investment in technological advances.

The purpose of this research was to generate a microeconomic interpretation of macroeconomic studies conducted by economists Robert Solow and Paul Romer. Robert Solow found that technology, or total factor productivity, was a key factor in long-run economic growth. Paul Romer went a step further in finding that firms would invest in technology if they had reasonable belief that profits would result from it.

Several gold extraction methods were presented through the use of description and the costs of mining. Eventually, many of these methods of gold extraction were replaced by new methods. A lot of these methods did not appear to substantially impact gold production and prices in the mid-19th century, as prices were increasing and production appeared to be either stagnant or decreasing. While the cyanide process is suggested to be the dominant method, alternative methods do exist, such as the heap leaching method. This alternative method of gold extraction may have aided in increasing production and falling prices depicted in figure 4.2.

The data and the graphs show that technological change and innovation has an effect on the growth of the oil and gold industries. Growth is traditionally measured by increases in revenues and profits. However, this thesis shows that increases in the investment in technology also plays a hand in growth at the microeconomic level, not just at the macroeconomic scale as presented by Robert Solow and Paul Romer.

While not every firm is likely to see an immediate profit, this study finds support that increase in price as well as increases in elasticity help drive investment in technological innovation. This may help firms determine their investment strategy with oil technologies such as fracking, as Grenadier and Weiss (1995) gave a broader overview of firm investment strategies in any industry towards technological advances.

This research is limited partially because it only looks at the oil and gold industries. Therefore, one suggestion for further research would be to consider the role of technological innovations in other industries. For example, economist Tyler Cowen recently noted the agricultural industry for increasingly utilizing new technologies (Cowen 2019).

This research is also limited due to the data collected for oil spanning the past 43-45 years. A larger data-set may help to determine more precise measurements as well as provide further, more conclusive evidence of this thesis. Furthermore, further econometric testing could be used to determine the precise relationship between investment in oil extraction technologies, the real price of oil, and the price elasticity of oil.

Overall, the results of the oil data should be similar to the gold industry. Increases in the real price of gold as well as increases in the rate of elasticity should help drive investment in technologies in the gold industry, similar to the gold industry. However, results may potentially vary significantly given that the gold data contains more data points relative to oil.

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