Oil Production in the Permian Basin

Causal Factors and Environmental Outcomes

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Business, Economics, and Society

Abstract

This paper seeks to examine the oil production industry in the Permian Basin region of West Texas and Southeastern New Mexico in more depth. As one of the most productive oil and gas fields in the world, the Permian Basin is a highly sensible location to investigate issues relevant to the industry. By conducting a preliminary investigation into potential causal factors of production levels as well as how these production levels correlate with environmental outcomes it is hoped that future studies can be more focused and intentional. It was found that total U.S. population is a significant predictor of Permian Basin oil production levels. Further, it was found that Permian Basin production levels are a significant predictor of the annual number of days in which ozone was the main air pollutant in the region as well as the annual number of days nitrogen dioxide was the main air pollutant in the region.

KEYWORDS: (Permian Basin, Oil Production, Air Quality)

JEL CODES: (Q47, Q53)

ON MY HONOR, I HAVE NEITHER GIVEN NOR RECEIVED UNAUTHORIZED AID ON THIS THESIS

Signature

Table of Contents

List of Tables

List of Figures

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Introduction

In 2022, President Biden claimed that Exxon, a prominent Texas oil company, “made more money than God” (Rapier, 2022). Several factors contributed to their economic success, including high oil prices and extraordinary levels of production in the Permian Basin (Rapier, 2022; Rapier, 2019). In the past 15 years, the Permian Basin region of Western Texas and Southeastern New Mexico has gone from being an irrelevant production center that nearly everyone considered to be in decline, to the most productive oilfield in the world in 2019 (Rapier, 2019).

While most of the success is due to improvements in technology such as the implementation of hydraulic fracturing, many other factors may play a role in the increased oil production in the Permian Basin (Federal Reserve Bank of Dallas; Popova and Long, 2022). This study will examine a multitude of these factors including the year, the total United States (U.S.) population, annual oil import totals from a variety of nations, the annual U.S. unemployment rate, and the annual U.S. Gross Domestic Product (GDP). Other governmental factors such as tariffs, price controls, or import quotas may also impact levels of domestic production; however, these factors were excluded from this study due to a lack of data within the timeframe. Discovering which factors may impact production levels will lead to greater understanding of the industry.

The Permian Basin region spans thousands of square miles in over 50 counties (see Appendix A for the full list of counties included) (Chevron n.d.; Shale Experts, n.d.). It has an arid or semi-arid climate and faces high water stress (ConocoPhillips n.d.; Nelson and Heo, 2020). As such, the environment is sensitive, and extensive oil production creates a risk of degradation or contamination. There have already been recorded levels of high emissions and increased solids in groundwater sources (Nelson and Heo, 2020; Hedden, 2020). These factors impact not only the environment, but public health as well, putting people at risk for a spectrum of diseases that range from asthma to cancer. While oil production has put the environment at risk, it is unknown how environmental measures correlate with the levels of production in the region. This study seeks to understand how various factors including population, year, GDP, unemployment rate, and import totals from several nations (see Appendix B for the full list of countries included) impact the levels of domestic production of crude oil and how these levels of production are related to local measures of air quality.

The null hypothesis of the study (H_0) is that the year, U.S. population, U.S. GDP, U.S. unemployment rate, and import levels from significant oil importers have no effect on the amount of oil produced in the Permian Basin, and altering the amount of oil produced in the Permian Basin has no effect on air quality. The alternative hypothesis of this study (H_a) is that the year, U.S. population, U.S. GDP, U.S. unemployment rate, and import levels from significant oil importers impacts the amount of oil produced in the Permian Basin. Furthermore, altering the amount of oil produced in the Permian Basin impacts air quality outcomes.

Data for this study was acquired through the Federal Reserve, the Bureau of Labor Statistics, the Energy Information Administration (EIA), the Environmental Protection Agency (EPA), the Texas Drilling website, and the Drilling Edge website.

This study used five separate regressions to find results. The regressions were run using R Studio. The first regression used data about the year, GDP, population, unemployment rate, import totals, and Permian Basin production levels to find results. For this regression, Permian Basin production levels were the dependent variable while the other factors served as independent or predictor variables. This way, it could be determined which factors, if any, correlated with production levels. The second regression used data about Permian Basin production levels and average annual days in which nitrogen dioxide was the main pollutant in the region to see whether altered levels of production impact a measure of air quality. The third regression used data about Permian Basin production levels and average annual days in which ground-level ozone was the main pollutant in the region to see if altered levels of production correlated with this measure of air quality. The fourth regression used production data and the average annual days in which particulate matter with a diameter of 2.5 micrometers or less was the main pollutant in the region to determine whether oil production correlates with levels of this air pollutant. Finally, the fifth regression used production data and the average median Air Quality Index of the region to determine whether altered levels of production lead to altered air quality.

Before running the regressions, it is expected that the results of the study will conform to the alternative hypothesis (H_a). That is, a correlation will be found between the year, population, GDP, unemployment rate, and import totals from significant oil producing nations and the amount of oil produced in the Permian Basin. Further, a correlation will be found between oil production levels in the Permian Basin and levels of air quality.

This paper is organized into first a literature review section which provides background information and context to the study, followed by a review of the theory and methodology of the study. Next, the results will be reviewed and analyzed. Finally, conclusions will be made and suggestions for further study will be recommended.

Literature Review

This literature review seeks to provide context and a frame of reference for this study. First, background information on the Permian Basin is provided. Then, presumed causal factors are discussed followed by a general summary of their implications. Next, governmental factors which may also impact domestic production levels are analyzed. The fourth section of this review discusses the relationship between the oil production process and environmental outcomes. Finally, the current environmental health of the Permian Basin is analyzed. Data for this literature review was found from a variety of sources including economics textbooks, government agencies, working papers, international trade organizations, scientific journals, finance journals, and legal decisions.

Production in the Permian Basin

The Permian Basin region, encompassing thousands of square miles in Western Texas and Southeastern New Mexico, is one of the oldest and most prolific oil and gas fields in the nation (Chevron, n.d.; Federal Reserve Bank of Dallas, n.d.). Originally discovered in the 1920's, the region enjoyed success for many years before beginning to decline in the 1970's (Federal Reserve Bank of Dallas, n.d.). The decline continued until around 2010 when technological innovations, namely horizontal drilling and hydraulic fracturing (fracking) allowed for an exponential rise in productivity as previously impenetrable reserves could now be reached (Federal Reserve Bank of Dallas, n.d.; Popova and Long, 2022). As of 2023, the Permian Basin is one of the world's most prolific oil and gas fields, producing an average of 5.7 million barrels of crude oil per day (Popova and Long, 2022; Cook and Ober, 2023).

Figure 1: Historical Oil and Gas Production in the Permian Basin

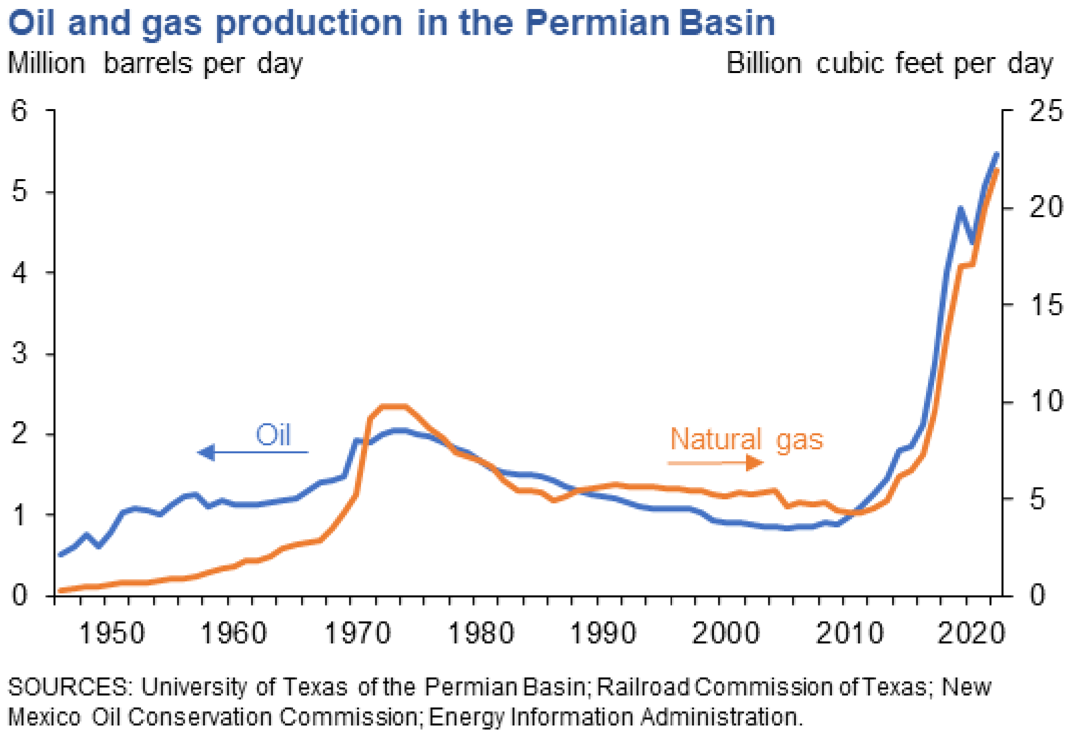
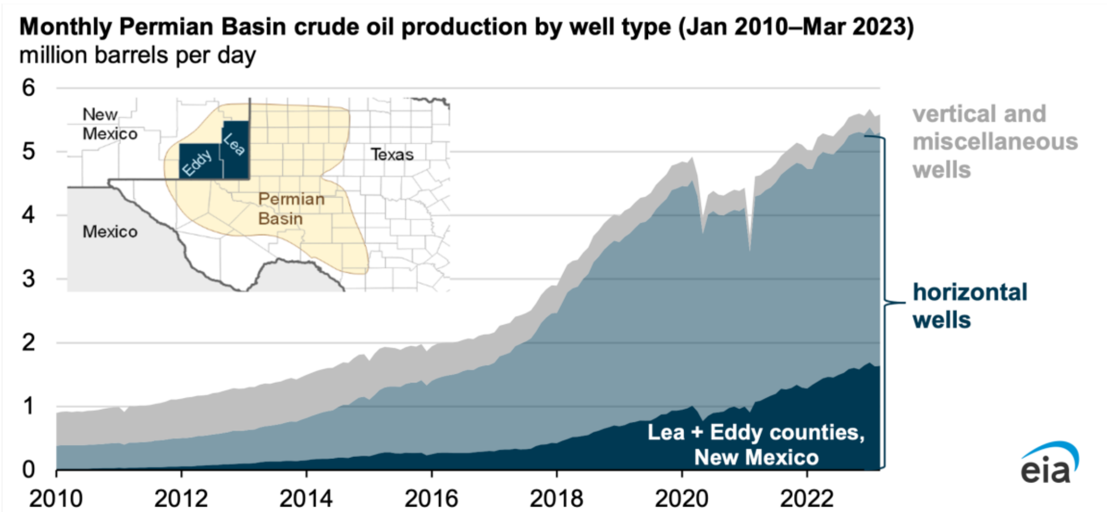


Figure 2: Historical Crude Oil Production in 2 NM Counties



Source: Energy Information Administration, 2023

Causal Factors

Several factors have been included in this study as potentially having a causal relationship with oil production levels. The factors selected include the total amount of oil imported from multiple nations, the year, the U.S. GDP, the total U.S. population size, and the U.S. unemployment rate. These factors are not intended to provide an exhaustive list of all factors that may impact oil production levels, rather this study seeks to sample a few variables that may be relevant.

The year may be related to production totals in the Permian Basin region for several reasons. First, demand for oil tends to increase over time (Meredith, 2023). OPEC producers predict that demand for oil will also continue to increase in the future (Meredith, 2023). Greater demand for oil necessitates greater levels of production, so as time passes, more oil will need to be produced. The year is also related to population. Population's relation to oil production will be explained in the following paragraph, but it should be noted that population size and year are related. Population tends to increase each year even though the rate of growth may be small (Mather, 2023). Furthermore, having a variable for time may serve as a proxy for technological development. There have been many advances in oil extraction technology over the past several decades including horizontal drilling and hydraulic fracturing (fracking) which have made producing oil more efficient and accessible, especially in the Permian Basin region (Federal Reserve Bank of Dallas, n.d.; Popova and Long, 2022). Due to the year's relation to demand, population size, and technological advances, it seems reasonable to assume that the year may correlate with levels of oil production in the Permian Basin.

The U.S. population increased by nearly 50 million from 2000 to 2020 (Federal Reserve, n.d.). This means that the population requiring fuel and energy greatly increased.

This relationship may not necessarily be causal (Chefurka, 2013). As the population grows, it needs more energy and may increasingly search for oil reserves; however, it may also be that the population is able to expand due to more oil becoming available (Chefurka, 2013). In either case it is clear that population size is linked with fuel access, so it seems reasonable that there would be a link between population size and oil production totals in the Permian Basin.

U.S. GDP was also selected as a factor due to oil's importance to the economy. Similarly to population size, GDP may not be a cause of altered levels of oil production. In fact, the opposite may be true. The U.S. oil and natural gas industry provides for around 8% of the nation's total GDP (American Petroleum Institute, n.d.). One plausible explanation may be that as more oil is produced domestically more profit is made, thus increasing the U.S. GDP. The U.S. shale boom, or the rapid increase in oil production due to technological advancements after 2010 added around 1% to the U.S. economy and accounted for around 10% of total economic growth during this post-2010 time period (Yücel & Plante, n.d.). Regardless of whether these variables have a causal relationship, they are closely linked, and it may be that economic success is an effective predictor of oil production levels.

The U.S. unemployment rate was selected as a factor due to the oil industry's size. Oil is an important commodity and accounts for many jobs. Several hundred thousand people are employed in oil and natural gas extraction in the U.S. and this number tends to fluctuate annually (EIA, 2016). There is also an established link between oil price level and volatility and the unemployment rate (Chan & Dong, 2022). When oil prices fluctuate in response to shocks or increase rapidly, unemployment rates tend to increase regardless of location (Chan & Dong, 2022). Oil price often faces volatility due to supply shocks which refers to production levels (Chan & Dong, 2022). Unemployment levels may be an indicator of the health of the oil and gas industry, and thus levels of production.

The U.S. continuously produced more than enough oil to meet the nation's fuel needs, yet it still imports a large amount of crude oil (Tillier, 2022). At first glance this may seem nonsensical. However, U.S. producers tend to extract a different type of oil than other nations (Tillier, 2022). While the U.S. tends to produce light, sweet crude oil, main foreign importers tend to producer heavier and less sweet crude oil (Tillier, 2022). The weight (heavy/light) refers to how easy the oil is to refine, and the sweetness refers to the sulfur content (sweeter = less sulfur) (Tillier, 2022). U.S. refiners are generally only capable of refining the heavier crude oil rather than the lighter oil extracted domestically (Tillier, 2022). As such, the U.S tends to be quite dependent on imported sources of oil. While levels of imported oil may not have a causal relationship with domestic levels of production, the two are likely linked. When oil prices are ideal or demand is high, the U.S. may both import higher levels of oil and produce higher levels of oil. All these factors were selected as they seem to have a relationship with oil production levels even though the relationship may not be causal.

Governmental Factors

There may be several other factors linked to levels of oil production including a variety of governmental actions. Interventions such as tariffs and quotas may impact the domestic oil industry but were excluded from this study due to a lack of data.

Tariffs were first placed on imported crude oil in 1975 (Horsnell, n.d.). Since then, the subject has been the topic of much debate. Oil, unlike many other goods, is intrinsically linked to politics. As such a critical energy source, it has been used as a means of political or economic control. U.S. tariffs on imported crude oil are often passed as a means of protectionism in order to protect the domestic industry and promote energy independence (Horsnell, n.d.).

It is unclear whether tariffs lead to a decrease in foreign oil imported. It may be that tariffs have no effect on the amount of oil imported as the demand for oil tends to be inelastic (EIA, 2023). Furthermore, domestically produced crude oil does not satisfy all the demands of refiners, as crude oil is not a homogeneous product and refiners may need crude oil of a different quality or quantity than is produced domestically (Foreman, 2018). Although tariffs are often passed with the intention of bolstering domestic producers and reaffirming national energy security, tariffs may end up harming domestic consumers by increasing the costs they must pay (Kupfer, 2020; Collier and Venables, 2009; Scheppach, 1980). Although some of the burden of tariffs may be passed onto consumers, tariffs can be beneficial to domestic producers (Kupfer, 2020; Scheppach, 1980). Imposing tariffs on importing oil may lead to higher oil prices which increases the revenue made by domestic producers (Fitzgerald, 2021). However, high oil prices may not necessarily influence domestic producers to increase drilling (Ivanova, 2022).

Other actions including quotas may have an impact on domestic production levels. Quotas, or a limit on the amount of crude oil that could be imported, were first implemented in the 1930’s (Cicchetti & Gillen, 1973). These quotas were intended to increase national security by diminishing dependence on foreign sources of oil (Cicchetti & Gillen, 1973). In the latter half of the 20th century, quotas were often viewed as an alternative to tariffs (Willett, 1975). However, quotas came with many costs. Imposing quotas could strengthen foreign oil cartels, such as OPEC as well as leading to increased price fluctuations (Willett, 1975). Quotas often mean prioritizing national security (referring to energy independence) over the domestic economy (Willett, 1975). Due to their many shortcomings, quotas have not been implemented within the timeframe of this study and therefore have no impact on production levels within the period (U.S. Customs and Border Control, 2023). Due to the lack of data and clarity regarding the actual relationship between governmental actions and domestic production levels, these factors were excluded from this study, but may be of interest to future researchers.

The Relation Between Oil Production and Environmental Outcomes

One of the largest concerns surrounding oil production is its potential for environmental degradation. Although the large-scale environmental impact of oilfields is generally small when compared with other activities such as the use of motorized vehicles, oil production can still have a strong impact on the local environment (Allison and Mandler, 2018). There are five significant pollutants associated with oil production including: methane, a potent greenhouse gas; volatile organic compounds (VOCs); ground-level ozone (smog); nitrogen dioxide; and particulate matter with a diameter of 2.5 micrometers or less (EPA, n.d.; Mckoy, 2023). These pollutants impact both the environment and public health, leading to a myriad of diseases (Mckoy, 2023).

Oil production, especially fracking, which is common in the Permian Basin, can also impact local water quality (Federal Reserve Bank of Dallas, n.d.; EIA, 2021). Although water quality was unable to be included in this study due to a lack of data, it is highly relevant to the climate and health of residents in the region. The significant water usage involved in the production process can limit water availability, a concern in the arid Permian Basin (EIA, 2021; ConocoPhillips, n.d.). Furthermore, the process of fracking creates a risk of toxic waste fluids contaminating local water sources (EIA, n.d.). Given the potential for air and water pollution created from oil production, it is important to understand how degradation can be measured and understood.

Environmental Outcomes in the Permian Basin

The Permian Basin region in Texas and New Mexico has an arid or semi-arid climate and experiences high water stress (ConocoPhillips, n.d.; Nelson and Heo, 2020). This means the climate is already sensitive and has scarce natural resources. Groundwater is an important water source in the region (Nelson and Heo, 2020). While depleting groundwater is a concern, contaminating the remaining sources is also a possibility due to increased oil production activities (Nelson and Heo, 2020). Researchers have found that certain areas of the Permian Basin have already experienced an increase in total dissolved solids (TDS) levels in groundwater, a measurement which may indicate that dangerous levels of ions such as arsenic or lead could be present which may present health risks to anyone exposed (Nelson and Heo, 2020). Groundwater was also found to be at risk from oilfield brine or fluid contamination which could result in increased levels of heavy metals (Nelson and Heo, 2020). Furthermore, many oil wells in the region are considered shallow, which poses a greater risk to groundwater sources than deeper wells (Vaidyanathan, 2016). Other researchers have indicated that examining the extent to which oil production damages groundwater is difficult as many compounds or chemicals used in the production process are not commonly tested for in labs (Vaidyanathan, 2016).

The groundwater of the region is not the only part of the environment impacted by oil production. The air has also already faced pollution from the production process. Some of the biggest concerns regarding oil production and air quality are the potential for increased methane and volatile organic compounds (VOCs) to be released. In 2020, the Permian Basin region was found to have the highest methane levels ever recorded at a U.S. oil and gas basin (Hedden, 2020). Recently, a large producer in the region was forced to settle with the EPA for violating the Clean Air Act (EPA, 2023). The producer emitted too many VOCs and too much methane and has been forced to pay a fine and reduce their emissions (EPA, 2023).

These emissions not only negatively impact the environment, but public health as well (EPA, 2023. They, as well as other pollutants such as nitrogen dioxide, ground level ozone, and particulate matter can lead to asthma, bronchitis, and cancer (EPA, 2023; Mckoy, 2023). As air and water quality in the region may be compromised or at risk, it is important to measure the extent to which they have been impacted, not only to protect the environment, but the health of the local population. So, understanding factors which may alter production levels and how these production levels impact the environment is critical.

Theory and Methodology

Data Selection

To better understand factors which impact domestic production levels and how these levels correlate with various local environmental outcomes, several regressions were performed. Data for these regressions was collected from a variety of sources. It was necessary to acquire data regarding annual levels of oil imports, oil production levels in the Permian Basin, U.S. population size, U.S. unemployment rate, U.S. GDP, and air quality measures in the Permian Basin region. Due to the limitations of data availability, the time period of this study was 2000 to 2020.

Import data was collected from the Energy Information Administration (EIA) which provided separate data sets for each country of interest (see Appendix B for the full list). This source provided data for the total annual amount of oil imported in thousands of barrels; however, it did not differentiate between crude and other types of oil. Each amount was then written into an Excel spreadsheet.

Data for Permian Basin production levels had to be pieced together from several sources. Data was provided for oil production between 2007 and 2020 by the EIA annual drilling report. This source provided the average daily production level (in barrels) by month for the period of 2007 to 2020. Each average was placed into Excel then multiplied by the total number of days in the month to create a monthly average production. Each monthly average in a year was then added to create an annual production figure. Data from 2000 to 2006 had to be pieced together from county level data. The Texas Drilling website, which acquires its data from the Texas Railroad Commission (Texas Drilling, n.d.) provided an annual production figure of total barrels for each Texas county in the Permian Basin. Annual county level data for New Mexico was provided by the Drilling Edge website, a site aimed at condensing information provided by state and local governments regarding oil and gas production for practitioners in the industry. Data for each county was then aggregated by year to provide an annual production level for the years from 2000 to 2006. After calculating an annual production figure, these numbers were exported to the same Excel spreadsheet as the import data.

Data regarding the annual U.S. population and GDP were acquired from the Federal Reserve. Population was counted in total persons and was not seasonally adjusted. GDP was calculated in billions of dollars and was not seasonally adjusted. Each annual figure was exported into the Excel spreadsheet. The unemployment rate was found through the Bureau of Labor Statistics which provided the percentage of the labor force (civilian noninstitutional population 16 years and over) which was unemployed. This figure was entered as a percent rather than a decimal (i.e., 4 rather than 0.04). Each annual rate was then exported into the Excel spreadsheet.

Finally, environmental data was acquired from the Environmental Protection Agency (EPA). The agency produces an annual report on various air quality measures by county across the U.S. The measures selected for this study were total days where nitrogen oxide was the largest pollutant, total days where ozone was the largest pollutant, total days where particulate matter with a diameter of 2.5 micrometers or smaller was the largest pollutant, and the median air quality index (AQI). Nitrogen oxide, ozone, and particulate matter are pollutants associated with the oil production process (Mckoy, 2023). All three pollutants have known health risks and have been shown to contribute to a spectrum of problems from asthma to death (Mckoy, 2023). The AQI is a government measure intended to communicate the level of air pollution in an area and the risk it poses to public health (National Weather Service, n.d.). It measures the five pollutants required to be monitored by the Clean Air Act: ground-level ozone, particle pollution/particulate matter, nitrogen dioxide, sulfur dioxide, and carbon monoxide (National Weather Service, n.d.). AQI is measured on a scale from zero to five hundred (Air Now, n.d.) The lower the AQI, the better the air quality is with any number below fifty being considered good (Air Now, n.d.). Not every county in the region was present on these reports, so the counties that were available were compiled in Excel before being averaged to find an annual region-wide average for each of the four values in question. A description of each variable is presented in the table below.

Table 1: Variables used in the model

Variable Name	**Description**
year	The year from which the data came, from 2000 to 2020
alg_import	The total amount of oil imported from Algeria annually in thousands of barrels
ang_import	The total amount of oil imported from Angola annually in thousands of barrels
can_import	The total amount of oil imported from Canada annually in thousands of barrels

con_import	The total amount of oil imported from the Republic of Congo annually in thousands of barrels
equ_import	The total amount of oil imported from Equatorial Guinea annually in thousands of barrels
irq_import	The total amount of oil imported from Iraq annually in thousands of barrels
kuw_import	The total amount of oil imported from Kuwait annually in thousands of barrels
lib_import	The total amount of oil imported from Libya annually in thousands of barrels
nig_import	The total amount of oil imported from Nigeria annually in thousands of barrels
qat_import	The total amount of oil imported from Qatar annually in thousands of barrels
sau_import	The total amount of oil imported from Saudi Arabia annually in thousands of barrels
uae_import	The total amount of oil imported from the United Arab Emirates annually in thousands of barrels
ven_import	The total amount of oil imported from Venezuela annually in thousands of barrels
per_produce	The total amount of oil produced annually in the Permian Basin in barrels

us_pop	The total annual U.S. population in persons
gdp	The annual U.S. GDP in billions of dollars, not seasonally adjusted
unemp_rate	The annual percent of the labor force which is unemployed
no_days	The average total number of days annually in which nitrogen dioxide was the largest source of air pollution in the Permian Basin region
ozone_days	The average total number of days annually in which ground level ozone was the largest source of air pollution in the Permian Basin region
pm_days	The average total number of days annually in which particulate matter with a diameter of 2.5 micrometers or less was the largest source of air pollution in the Permian Basin region
med_aqi	The average annual median air quality index measured from 0 to 500 in the Permian Basin region

Equations

The five regression equations are described below.

Regression 1

$$Per\_produce = b0 + b1(alg\_import) + b2(ang\_import) + b3(can\_import) + b4(con\_import) + b5(equ\_import) + b6(irq\_import) + b7(kuw\_import) + b8(lib\_import) + b9(nig\_import) + b10(qat\_import) + b11(sau\_import) + b12(uae\_import) + b13(ven\_import) + b14(us\_pop) + b15(gdp) + b16(year) + b17(unemp\_rate)$$

Regression 2

$$no\_days = b0 + b1(per\_produce)$$

Regression 3

$$ozone\_days = b0 + b1(per\_produce)$$

Regression 4

$$pm\_days = b0 + b1(per\_produce)$$

Regression 5

$$\mathrm{med\_aqi} = b0 + b1(per\_produce)$$

Modeling

After all the data was collected and organized into an Excel spreadsheet, it was then imported into R Studio. A total of five regressions were run using R Studio. The first regression included eighteen variables: import totals from Angola, Algeria, Canada, Republic of Congo, Equatorial Guinea, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela; the year; the population; the GDP; the unemployment rate; and production totals from the Permian Basin. In this regression, the import totals, year, population, GDP, and unemployment rate were the predictor variables while the domestic production level was the response variable.

The second regression used two variables: domestic production levels and annual days where nitrogen dioxide was the main air pollutant in the Permian Basin region. This regression utilized production levels as the predictor variable and days where nitrogen dioxide was the main pollutant in the region as the response variable. The third regression similarly used production levels as the predictor variable but has days where ground level ozone was the main pollutant in the Permian Basin region as the response variable. The fourth regression utilized production levels as the predictor variable while days where particulate matter with a diameter of 2.5 micrometers or less was the main pollutant in the Permian Basin region served as the response variable. Finally, the fifth regression used production levels as the predictor variable and the annual average of median AQI measurements taken from the Permian Basin region as the response variable. These regressions sought to test the hypotheses of the study.

Hypotheses

The null hypothesis of the study (H_0) is that the year, U.S. population, U.S. GDP, U.S. unemployment rate, and import levels from significant oil importers have no effect on the amount of oil produced in the Permian Basin, and altering the amount of oil produced in the Permian Basin has no effect on air quality. The alternative hypothesis of this study (H_a) is that the year, U.S. population, U.S. GDP, U.S. unemployment rate, and import levels from significant oil importers impacts the amount of oil produced in the Permian Basin. Furthermore, altering the amount of oil produced in the Permian Basin leads to impacted air quality outcomes.

Limitations

This study was not without limitations. Both the data and the model possess several shortcomings which may impact validity. The data provided for the totals of oil importation from a few countries of interest had several years where the data was unavailable or suppressed. These years were entered as zero in the data table; however, this may not be accurate. Zero likely does not represent the actual levels of importation and due to the unavailability of data, the model may be skewed or inaccurate during these years. Furthermore, data on levels of production in the Permian Basin may be inaccurate. From 2000 to 2006 data was collected by county from subscription-based sites aimed towards practitioners in the oil and gas industry. While the sources of their data are reliable, there may be bias present in how the information was presented. Furthermore, the data from 2007 to 2020 was calculated based on average production levels, so the figures within this period are likely different than the actual total levels of production. This dataset also did not list which counties were included, so it may be that counties present in the first period were excluded in the second or vice versa. Further, there may be multiple factors which impact domestic production levels which were excluded. Data regarding air quality may also not be representative of reality. Only five to six of the well over fifty counties in the region had data available. While the quality measures are relatively localized and having several monitoring stations throughout likely provides a good overview of the region, it may still paint inaccurate trends or miss trends that do exist. Data regarding the most important pollutants associated with oil production: methane and VOCs, was unavailable. Furthermore, the data found does not represent actual levels of pollutants, rather it represents days where the pollutants in question were the main sources of air pollution. As such this study cannot provide an accurate overview of air quality in the region. Finally, an important outcome associated with oil production is water quality which was excluded due to a lack of data. So, this study cannot make any conclusions with certainty. Rather, it is hoped that this study may uncover initial trends which merit more extensive research.

Results and Analysis

Regression Results

The following tables show the results of each regression.

Regression 1 (Response variable = per_produce)

Table 2: Part 1 of the first regression's results

Variable	Coefficient	P-value
alg_import	-1.07e2	0.8943
ang_import	-7.02e2	0.5569
can_import	-1.49e3	0.2161
con_import	5.52e3	0.2472
equ_import	2.89e3	0.2452
irq_import	6.42e2	0.2032
kuw_import	-2.97e3	0.1144
lib_import	-8.74e2	0.5982
nig_import	-1.12e3	0.0878
qat_import	-1.07e4	0.4168
sau_import	-2.91e2	0.3108
uae_import	-2.68e3	0.4938
ven_import	7.92e2	0.2810
year	7.93e8	0.0625
us_pop	-2.94e2	0.0397
gdp	2.21e5	0.0933
unemp_rate	2.74e7	0.5780

Table 3: Part 2 of the first regression's results

Intercept	Adjusted r-squared
-1.35e12	0.9956

Regression 2 (Response variable = no_days)

Table 4: Part 1 of the second regression's results

Variable	Coefficient	P-value
per_produce	-3.65e-9	0.040057

Table 5: Part 2 of the second regression's results

Intercept	Adjusted r-squared
5.69	0.1617

Regression 3 (Response variable = ozone_days)

Table 6: Part 1 of the third regression's results

Variable	Coefficient	P-value
per_produce	6.23e-8	0.000081

Table 7: Part 2 of the third regression's results

Intercept	Adjusted r-squared
107	0.5446

Regression 4 (Response variable = pm_days)

Table 8: Part 1 of the fourth regression's results

Variable	Coefficient	P-value
per_produce	-1.82e-8	0.183

Table 9: Part 2 of the fourth regression's results

Intercept	Adjusted r-squared
118	0.04333

Regression 5 (Response variable = med_aqi)

Table 10: Part 1 of the fifth regression's results

Variable	Coefficient	P-value
per_produce	3.39e-9	0.0116

Table 11: Part 2 of the fifth regression's results

Intercept	Adjusted r-squared
29.69	0.254

Please see Appendix C for graphs of the results.

Findings

These regressions provided numerous interesting results. The intercept of the first regression is uninterpretable, as it is impossible for all the dependent variables to be zero. However, the coefficients can be interpreted, and many are surprising. It seems reasonable for the coefficients to be negative; it seems predictable that as the amount of foreign oil imported increases, the amount of oil produced in the Permian Basin decreases. As such, it is unsurprising that Algeria, Angola, Canada, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, and the United Arab Emirates all have negative coefficients. It was unexpected; however, for Congo, Equatorial Guinea, and Iraq to have positive coefficients. It may be that these countries primarily import a different type of oil than is produced in the Permian Basin region so as demand for oil increases, the amount that must be produced domestically as well as imported increases.

It was expected that many of the other variables (year, population, GDP) would also have positive correlations. Year and GDP did have positive correlations; however, population had a negative correlation. It may be that demand for oil is not a static amount per person and rather that as the population increases the allocation of oil becomes more efficient which necessitates less oil to be produced. Finally, it was expected that the coefficient for unemployment rate would be negative, or in other words, that as unemployment decreased the amount of oil produced would increase. However, it had a positive coefficient meaning that as unemployment increases, so does the amount of oil produced. It may be that these two variables are related to a third variable such as prices. While higher prices may present an unfavorable job market, they may encourage the oil industry to produce more as it will be more profitable. These coefficients paint an interesting image of which factors impact oil production and how.

There are several other figures of interest in this first regression including p-values and the r-squared value. Only one variable was significant at the 0.05 level in this model: U.S. population. U.S. population had a p-value of 0.0397 meaning that the null hypothesis (that U.S. population does not impact oil production levels in the Permian Basin) can be rejected and the alternative hypothesis (that U.S. population does impact oil production levels in the Permian Basin) can be accepted. This p-value means that if the null hypothesis were true, there would be a 3.97% chance of seeing results at least this extreme. As such, it is reasonable to reject the null hypothesis for this variable. For the sake of this study, U.S. population is considered the only statistically significant variable in the model. There were, however, several other variables that were significant at the 0.01 level including import totals from Nigeria, year, and U.S. GDP. These variables had p-values above 0.05 but below 0.1. The r-squared value of this regression was particularly interesting. The adjusted r-squared value was calculated to be 0.9956 meaning 99.56% of the variation in Permian Basin oil production levels is explained by the independent variables.

The next four models also provided interesting results. The second regression surprisingly had a negative coefficient meaning that as oil production in the Permian Basin increases, the annual number of days where nitrogen dioxide is the main air pollutant decreases, albeit by a miniscule amount. This does not mean that the levels of nitrogen dioxide decrease as production increases, they may remain the same or even increase; however, it decreases as the main source of air pollution. It may be that nitrogen dioxide levels increase along with oil production, but oil production causes a much more significant increase in another pollutant which increasingly serves as the main air pollutant. This model was found to be statistically significant at the 0.05 level; Permian Basin production levels had a p-value of 0.04, meaning that the null hypothesis (that oil production levels do not relate to number of days where nitrogen dioxide is the main air pollutant) can be rejected. However, this model had a low adjusted r-squared value of 0.1617, meaning only 16.17% of the variation in days where nitrogen dioxide is the main pollutant can be explained by oil production levels in the Permian Basin.

The third model possessed a positive coefficient, meaning that as oil production levels in the Permian Basin increase, the annual number of days where ground level ozone is the main air pollutant increase as well. This relationship was also statistically significant at the 0.05 level with a p-value of 0.000081, meaning the null hypothesis (that oil production levels in the Permian Basin have no effect on the number of days where ground level ozone is the main pollutant) can be rejected. This p-value is noticeably low; if the null hypothesis was true, results at least this extreme would only occur 0.0081% of the time. The adjusted r-squared value was higher than that of the previous model but is not especially high. With an adjusted r-squared value of 0.5446, it is known that 54.46% of variation in the annual number of days where ground level ozone is the main air pollutant is explained by oil production levels in the Permian Basin.

The fourth model, similarly to the second, had a negative coefficient. This means that as oil production in the Permian Basin increases, the annual number of days where particulate matter with a diameter of 2.5 micrometers or less is the main pollutant decreases. This does not mean that levels of pollution from particulate matter decrease as production increases. Levels of the pollutant may remain constant or even increase. However, the amount of time it serves as the main air pollutant decreases. Similarly to the second model, it may be that increased oil production increases another pollutant more significantly than it does particulate matter meaning that even if oil production increases levels of particulate matter, the other pollutant will increasingly become the main pollutant. This model was not significant with a p-value of 0.183, meaning the null hypothesis (that altering oil production levels has no impact on annual days where particulate matter with a diameter of 2.5 micrometers or less is the main pollutant) is accepted. The adjusted r-squared of the model was low at 0.04333, meaning oil production levels in the Permian Basin region explain 4.333% of variation in the number of days where particulate matter with a diameter of 2.5 micrometers or less is the region's main air pollutant.

Finally, the fifth model had a positive coefficient. So, as oil production levels in the region increase, so too does the annual average of the region's median AQIs. This model was statistically significant at the 0.05 level with a p-value of 0.0116. This means that the null hypothesis (that altering levels of oil production has no effect on the average of the median AQIs) can be rejected and the alternative hypothesis (that altering levels of oil production impacts the average of the median AQIs). If the null hypothesis was true, there would be a 1.16% chance of seeing results at least this extreme. This model had a relatively low adjusted r-squared value of 0.254, meaning Permian Basin oil production levels explain 25.4% of the variation in the annual average of the median AQIs.

These models found a variety of interesting results. Several variables were found to be significant causal factors and environmental outcomes associated with oil production in the Permian Basin including total U.S. population, total days where nitrogen dioxide is the region's main pollutant, total days where ground level ozone is the region's main pollutant, and the average of the region's median AQIs. These factors are all worthy of further investigation.

Conclusion

Aims and Findings

This study hoped to provide an initial broad investigation into several factors that may influence levels of oil production in the Permian Basin as well as how these levels impact a variety of local environmental outcomes. It was found that one of the seventeen predictor variables used to determine causes of altered oil production was significant: U.S. population size. While there may very well be other factors which have a causal relationship with oil production levels, population size was the only significant variable found in this study.

Likewise, several environmental variables were found to have a significant relationship with oil production levels including total days where nitrogen dioxide is the region's main pollutant, total days where ground level ozone is the region's main pollutant, and the average AQI. These demonstrate that the amount of oil produced has a significant relationship with different environmental outcomes. As such, more research is merited into the variety of outcomes associated with levels of oil production as well as the extent to which these outcomes vary with production levels. This study has provided a limited insight into some of these factors, summarized a variety of relevant findings from scientific literature, and noticed areas worthy of future research.

Practical Implications

This study has indicated that oil production levels may not always be an arbitrary number and may be impacted by outside factors such as the population size. If producers and governments are aware of which factors impact production levels and to what extent, they can be better prepared to respond to changes and negate instability. Furthermore, if producers and the government are aware of which pollutants are impacted by the production process and to what extent, they will be able to do more to protect the environment and maximize efficiency by choosing to produce at levels which minimize risk of environmental degradation while maximizing profit.

Additional Considerations

This study was not intended to be an exhaustive investigation of causal factors and environmental outcomes associated with oil production levels. There are many other factors that may be significant. While the relationship between population size and oil production levels merits further research, so do many other factors such as government interventions, other population variables, and oil imports from nations not included in this study. There are many environmental outcomes deserving of further study, including actual levels of the pollutants used in this study and other air pollutants such as methane. Finally, other environmental measures such as water quality and soil quality should be studied.

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Appendix A: This Appendix provides a list of counties included in the Permian Basin region.

Figure 3: Map of the region

Source: Natural Gas Intelligence (2022)

Figure 4: Location of the region

Source: The Energy Consulting Group

List of Counties:

Andrews County, TX

Bailey County, TX

Borden County, TX

Brewster County, TX

Chaves County, NM

Cochran County, TX

Coke County, TX

Concho County, TX

Cottle County, TX

Crane County, TX

Crockett County, TX

Crosby County, TX

Culberson County, TX

Dawson County, TX

Dickens County, TX

Ector County, TX

Eddy County, NM

Edwards County, TX

Fisher County, TX

Floyd County, TX

Gaines County, TX

Garza County, TX

Glasscock County, TX

Hale County, TX

Hockley County, TX

Howard County, TX

Hudspeth County, TX

Irion County, TX

Jeff Davis County, TX

Kent County, TX

Kimble County, TX

King County, TX

Knox County, TX

Lamb County, TX

Lea County, NM

Loving County, TX

Lubbock County, TX

Lynn County, TX

Martin County, TX

McCulloch County, TX

Menard County, TX

Midland County, TX

Mitchell County, TX

Motley County, TX

Nolan County, TX

Pecos County, TX

Presidio County, TX

Reagan County, TX

Real County, TX

Reeves County, TX

Runnels County, TX

Schleicher County, TX

Scurry County, TX

Sterling County, TX

Stonewall County, TX

Sutton County, TX

Terrell County, TX

Terry County, TX

Tom Green County, TX

Upton County, TX

Val Verde County, TX

Ward County, TX

Winkler County, TX

Yoakum County, TX

Appendix B: This appendix provides a list of countries included in the study for import data.

Algeria

Angola *

Congo *

Canada

Equatorial Guinea *

Iraq

Kuwait

Libya

Nigeria

Qatar *

Saudi Arabia

United Arab Emirates

Venezuela

* These countries OPEC status changed (member/non-member) within the study timeframe but are still included

Appendix C: This appendix provides graphs of the regression results.

Figure 5: Added variable plots of the first regression (how each predictor variable impacts production levels when all other variables are held constant)

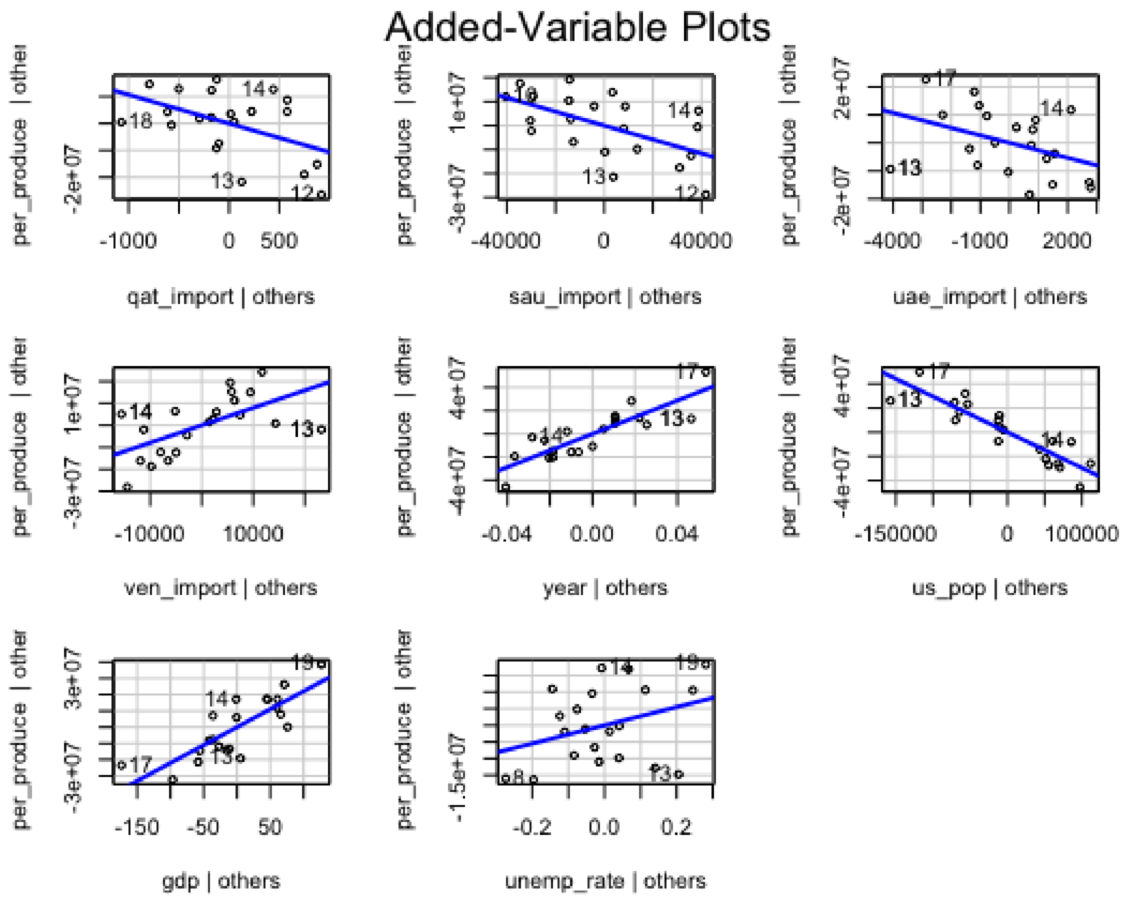


Figure 6: Scatterplot with a regression line of the second regression

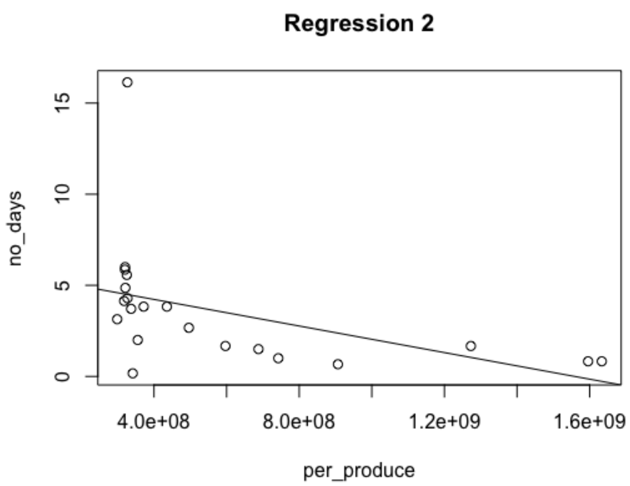


Figure 7: Scatterplot with a regression line of the third regression

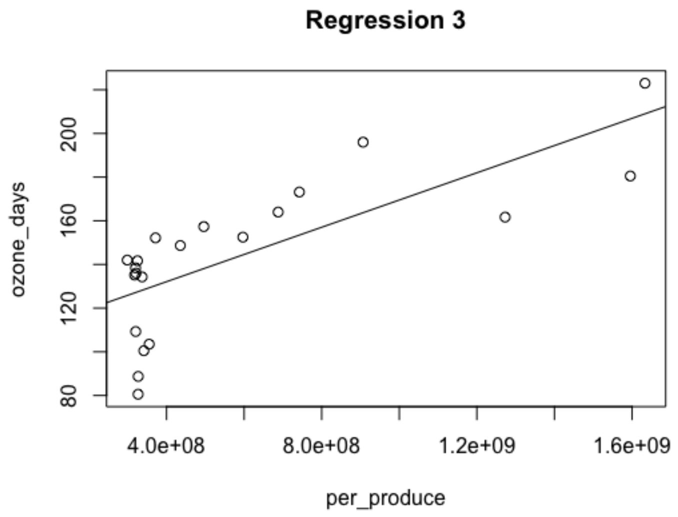


Figure 8: Scatterplot with a regression line of the fourth regression

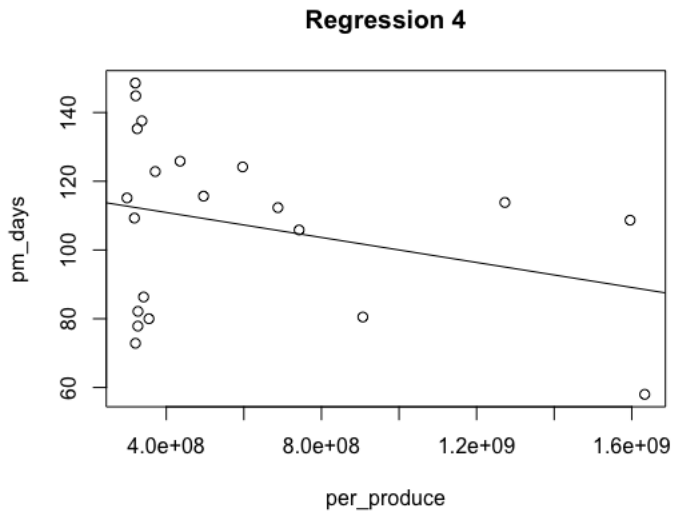
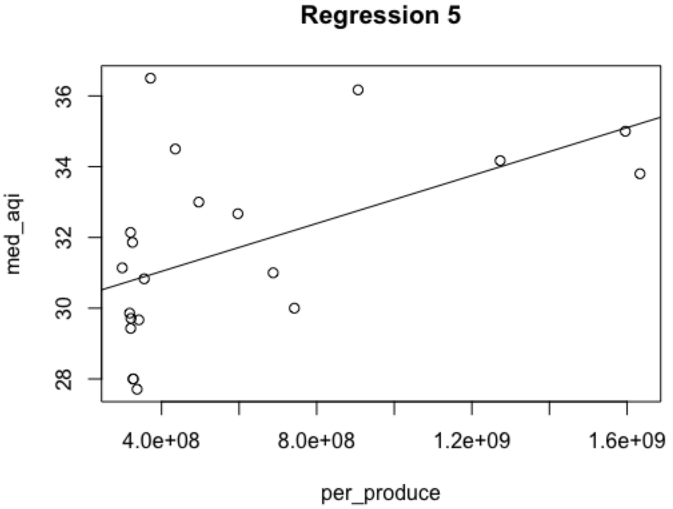


Figure 9: Scatterplot with a regression line of the fifth regression



Source: All figures in this appendix were imported from R Studio