Norwegian School of Economics
Bergen, Spring 2022

Innovation during Oil Price Booms

Modelling the effects of oil price changes on innovation in oil & gas abundant countries

Martin Schauer

Supervisor: Paul Pelzl

Master thesis, M.Sc Economics and Business Administration,
Major in Energy, Natural Resources and the Environment

NORWEGIAN SCHOOL OF ECONOMICS

Abstract

This paper investigates whether oil price booms have an effect on innovation in countries with abundant oil & gas reserves. To quantify innovation within all sectors of a country objectively, patent data is used. Using a linear regression, it is shown that patent applications decrease during times of increasing oil prices in comparison to countries without oil & gas reserves. Country and year fixed effects are included. The observed negative effect remains present after various robustness checks. The mechanisms leading to these results are expected to be crowding out effects at the individual, business and governmental level.

Keywords: natural resources, resource curse, innovation, patents, oil & gas, oil price

Contents

List of Figures / Equations / Tables

1. Introduction

Vast natural resources, in particular crude oil and natural gas, may bring a windfall to a country, yet usually do not lead to a sustainable development of the economy. Countless researchers (e.g. Sachs & Warner (1995), Gylfason et al. (1999), Auty (1998)) have been able to document this phenomenon (also referred to as the *resource curse*) that natural resource-abundant countries tend to have comparably low economic growth rates despite the immense earnings potential through the resources. However, not all resource-based countries have developed poorly. Some of the richest and fastest-growing countries have benefited substantially from their natural resources, such as Norway, Canada, Australia, the Netherlands, Sweden, Finland and New Zealand(Smith, 2007). Generally, explanations for the resource curse usually follow a crowding out logic; a high dependency on natural resources leads to reallocation of labour and capital into the resource sector and away from other growth-enhancing and knowledge-creating sectors (Peretto & Valente, 2011; Welsch, 2008).

The focus of this paper is set on innovation in natural-resource abundant countries. It has been observed that these countries are less likely to innovate (Kuznets, 1971; Maloney & Rodríguez-Clare, 2007; Omidi et al., 2019). Innovation is one of the key drivers of economic growth and as Andersen (2012) argues, insufficient learning and innovation systems are causing slow economic growth in natural-resource abundant countries.

To explore the effect of natural resources on innovation, this paper examines whether natural resource wealth influences the innovativeness of a country. While research around the topic of the resource curse has been conducted for decades, the connection between natural resources and innovation has been explored only to a limited extent. The results from this paper will give further input for the discussion and research on the effects of natural resource wealth, in particular considering the impact of the value of natural resources.

Natural resources are essential for our current societies and economies. They provide direct or indirect input to most production processes and supply us with energy across the world. The reserves are unevenly distributed leading to international trade and economic specialisations (Andersen et al., 2018). While various natural resources may have their effects on innovation, the focus of this paper is set entirely on crude oil and natural gas reserves[1]. Some oil & gas producing countries are highly dependent on exports of these commodities and consequently particularly exposed to the severe price fluctuations (visible in Figure 1).

Figure 1: Real Oil Price from 1980 until 2014[2]

Studies have shown the far-reaching and strong effects of oil price busts on these petrostates (Brown et al., 1999; Chang & Wong, 2003; Farzanegan & Markwardt, 2009; Herrera et al., 2019; Zhang, 2011). Oil & gas are resources that can particularly cause a resource curse (Gylfason, 2001). Moreover, petrostates are more likely to host a restrictive business environment, which besides the economic, social and political implications, is regarded to lead to a lower rate of innovation (Mazaheri, 2016). Summing up, oil & gas seem to be promising resources to focus this research on.

As innovativeness is hard to quantify, patent data is used as a proxy variable. Patents are closely linked to innovation and are commonly used to measure innovation in academic

[1] For simplicity, in this paper the word *oil* (also in combination with other words) always refers to crude oil, *gas* to natural gas and *oil & gas* to the two resources combined. The expression *petrostate* is used as a generic expression for any country with significant oil and/or gas reserves, regardless of their economic situation or the dependency on these resources. Countries without these reserves are defined as *non-petrostates*. An *oil price boom* is used to describe a period of particularly high (or increasing) oil prices, an *oil price bust* of particularly low (or decreasing) oil prices. *Oil & gas wealth* describes the momentary value of the oil & gas reserves of a country in a particular year (depending on the oil price and the reserves).

[2] WTI spot price inflation adjusted to the year 2014 with the U.S. consumer price index, as described in Section 3.2.

research. In addition, patents are linked to creating economic growth, especially in knowledge-based economies. They can enhance productivity and profitability; the availability of patents is crucial in R&D-intensive industries (Atun et al., 2007). The absence of patents can have disadvantageous effects on the whole economy of a country. The patent data used is panel data covering more than 18.8 million patent applications from 1980 until 2014 and inventors from 53 countries.

This paper hypothesizes that an oil price boom (and therefore an increase in oil & gas wealth) leads to fewer patent applications in petrostates. The key mechanisms are assumed to be crowding out effects on multiple levels. During an oil price boom, individuals are becoming less incentivised to innovate, oil & gas companies are attracting labour and resources away from other industries and governments are neglecting further growth-supporting policies (Ascher, 1999).

To empirically research this topic, a linear model is set up, containing patent data aggregated by country and by year, oil & gas reserves and yearly oil prices. Country and year fixed effects are considered. A regression is performed to compare the effects of oil price changes on innovation in petrostates with non-petrostates. To validate the results, various robustness checks are performed. While the paper analyses the effects on innovation caused by oil & gas wealth in petrostates, it is not within the scope to examine the reasons for these crowding-out effects nor is it the intention of this paper to find underlying causes for the resource curse. Instead, the goal of this paper is to explore innovation in the context of oil price booms (or busts) and to provide further input to the discussion and research of natural resources.

This paper is structured in the following way: In Section 2 the necessary background on innovation and natural resources is presented with a preliminary analysis, a literature review and an explanation of the hypothesis and the underlying mechanism. Section 3 depicts the data used in the analysis, while Section 4 explains the empirical strategy. The results of the regression and robustness checks are discussed in Section 5. The conclusion can be found in Section 6. The regression tables are presented in the Appendix.

2. Background

2.1 Preliminary Analysis

Firstly, a preliminary and simplified binary comparison between the patents per capita in petrostates and non-petrostates over time is conducted using the same data set (explained in detail in Section 3.1).

Countries are grouped according to their oil & gas rent in % of their GDP[3]. If the average oil & gas rent over the period 1980-2014 is higher than 4 % of the GDP, a country is considered a petrostate, all others are non-petrostates[4]. It has to be noted that the non-petrostate group is significantly larger than the petrostate group and the threshold is not based on any academic background. The following figures should thus only be seen as motivation and not as a sophisticated analysis.

The graphs in Figure 2 illustrate the average patents per capita in the two sample groups and include linear trend lines to display the general development over the period.

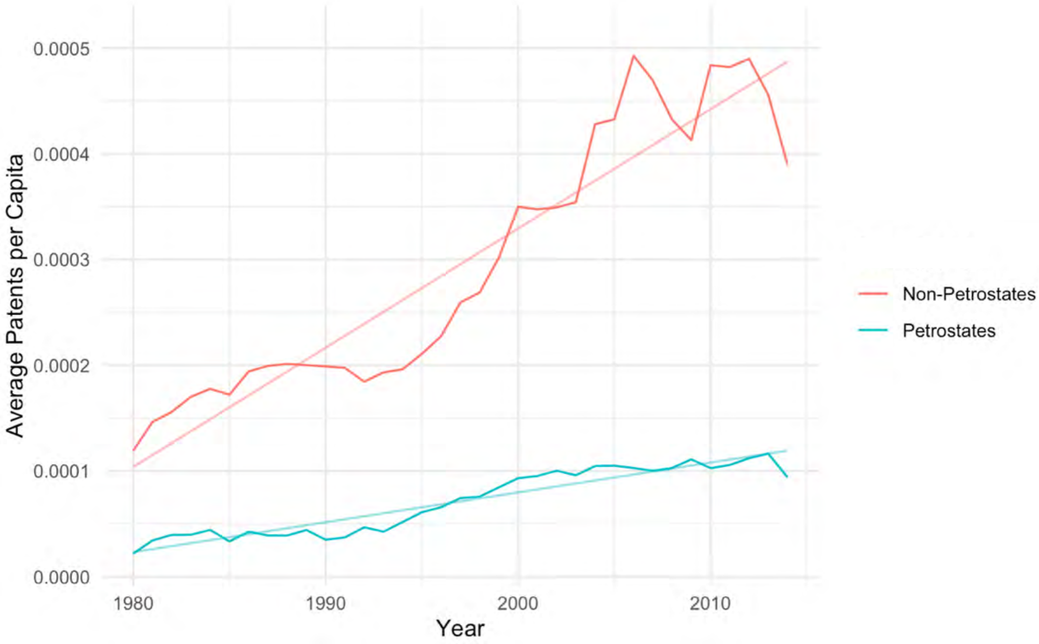

Figure 2: Comparison of Patent Applications per Capita

[3] Data Source: https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS & https://data.worldbank.org/indicator/NY.GDP.NGAS.

[4] The classification between petrostates and non-petrostates based on this metric is only valid for this section.

While the trend line in non-petrostates is considerably steeper and therefore suggests that the average patent applications per capita have been increasing at a faster rate than in petrostates, a log-transformation of the patents per capita (Figure 3) reveals that patents in both groups grew at a similar rate.

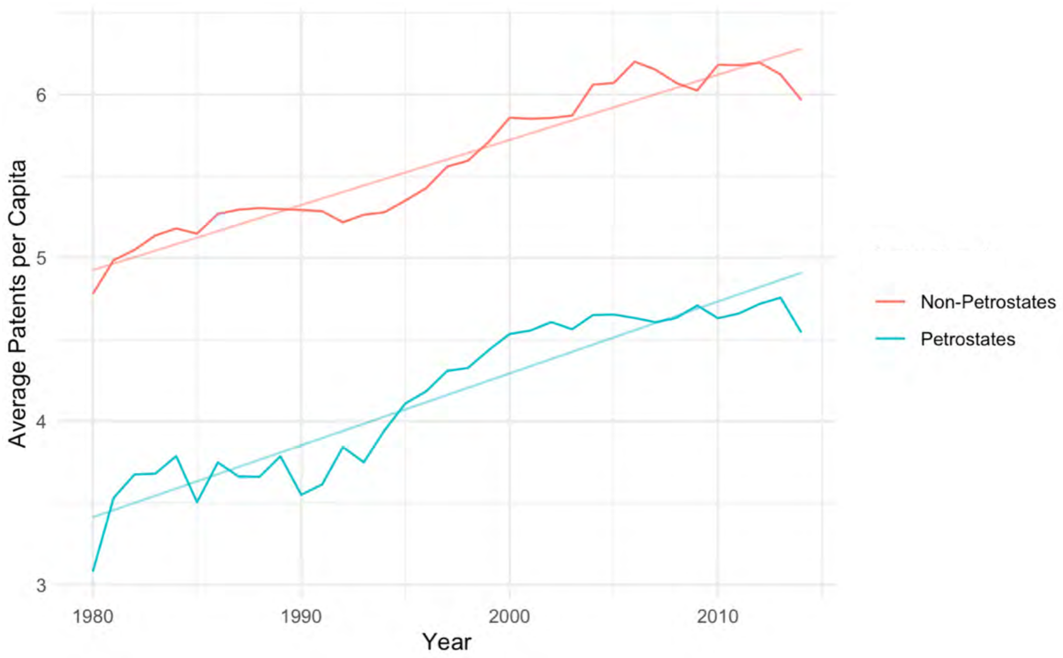

Figure 3: Comparison of Patent Applications per Capita (log-transformed)

Furthermore, Figure 4 shows the difference in patents per capita between petrostates and non-petrostates (red line) in the context of the real oil price (black line, inflation-adjusted as described in Section 3.2).

As the patent data is aggregated on a yearly level, the oil price is displayed as the yearly average (because of that the graph is smoother than in Figure 1). The higher the red line, the bigger the lead of non-petrostates over petrostates. To display the two graphs combined in one figure, the oil price is given in USD and the difference in patent applications in patents per 250.000 capita. While this is an uncommon unit it enables the values to be plotted in similar magnitude.

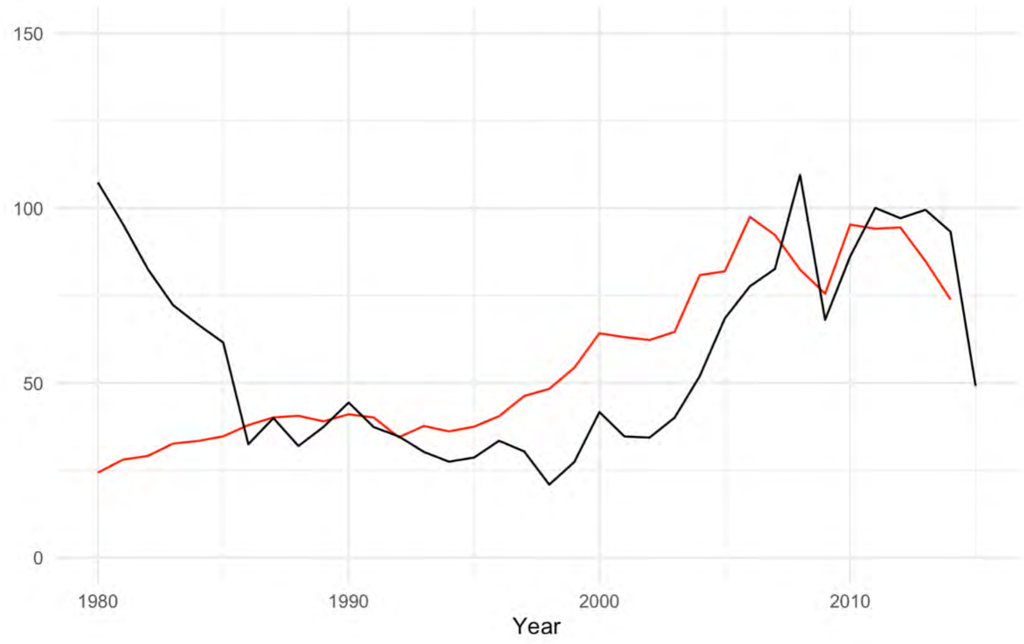

Figure 4: Differences in Patent Applications per Capita in Context of the Oil Price

As visible in Figure 4, it seems that from 1990 onwards similar trends are noticeable. During the oil price boom from 1997 until 2008, the gap in patents per capita between the two groups expanded further but decreased during the oil price bust in 2008. Nevertheless, the figure is not a detailed analysis but shows that a more sophisticated approach is worth exploring.

Besides, the fluctuations in the oil price over the period are visible in Figure 4. As with most other commodities, fundamentally the oil price is based on demand and supply. Due to increasing demand to fuel global economic developments and the low price elasticity of demand (Hamilton, 2009) continuously surging prices (such as from 2000 until the peak in 2008) are possible. In addition, from 1980 to 2014, there have been several instances where the oil price rapidly surged or crashed. These have often been caused or influenced by geopolitical and economic events such as wars in oil-producing countries (Iran-Iraq War, invasion of Kuwait), financial crises (1998 and 2008) but also due to production cuts by OPEC in 1999 and 2008 (U.S. Energy Information Administration (EIA), 2022). Hence, this period should provide a good opportunity for the analysis of whether the oil price influences innovation in petrostates.

2.2 Literature Review

Most of the existing papers exploring the effects of an increase in the oil price on innovation focus on innovations in one specific industry, researching the hypothesis of induced innovation. It describes that "a change in the relative prices of the factors of production is itself a spur to invention" (Hicks, 1932). Several studies have been conducted on the effects of high oil prices on innovation in renewable energy (Gasimzade, 2015), biofuels (Guillouzouic-Le Corff, 2018), energy-efficient technologies (Crabb & Johnson, 2007) and electric vehicles (He et al., 2021). As these technologies are substitutes for oil or gas, in times of high oil prices there is a particular incentive and benefit for the innovators to find alternatives and become independent from the expensive input factor. All aforementioned papers have been able to record a positive effect on innovation in the substitute industries due to high oil prices.

As this paper distinguishes innovation based on countries and not on specific industries, it is not capable but also not intended to research towards induced innovation. Instead, the overall impact on a country's innovativeness caused by changes in the natural resource wealth is analysed. Only few academic papers were found covering this aspect.

One example is Mazaheri (2016), which shows that oil wealth is negatively associated with entrepreneurship and innovation. Similar to the approach of this paper, patent data is used to capture innovation. Countries are categorised binary whether they are a *long-term oil producer* or a *nonproducer*. The suggested explanation is that petrostates are more likely to host restrictive business environments - regardless of the economic development or the political stability of the country. This overregulation affects entrepreneurship and innovation as it is harder to establish a business, acquire permits, pay taxes or resolve contracts (Mazaheri, 2016).

A study by Maloney & Rodríguez-Clare (2007) focused on innovation in Latin America, where some countries possess vast mineral resources, has found a negative relationship between innovation and natural resource abundance.

Omidi et al. (2019) used the Global Innovation Index and the total natural resource rent from 2011 to 2016 to investigate the resource curse and the effect of institutional quality. The result of their study concludes a negative effect of natural resource rent on innovation. On top of that, the importance of institutional quality on the effect of natural resource rent on innovation in resource-abundant countries is emphasized.

Continuing with institutional quality, Majbouri (2016) has examined the aspect of corrupt environments in petrostates. It states that a negative impact of oil & gas rents on entrepreneurship (often linked to innovation) is to be expected if corruption is present. However, in resource-abundant countries with no or low levels of corruption (e.g. Norway, Canada, United Kingdom) the oil & gas rents have a positive or no effect.

Papyrakis & Gerlagh (2004) identified reasons why natural resources reduce the incentives for innovation. Firstly, for individuals, there is less of a need to support consumption through additional labour income. Secondly, in their simplified model where entrepreneurial activities can either be allocated to innovation or to manufacturing, resource wealth leads to a crowding out away from innovation.

Research and Development (R&D) expenditures can be considered as the necessary financial input factor for innovation. (Pakes & Griliches, 1984). Welsch (2008) documents a negative relationship between resource abundance and R&D expenditures.

The contribution of this paper to the literature is threefold. Firstly, innovation data is analysed in the context of the oil price, to show whether changes in a country's oil wealth caused by a price boom/bust have an effect on innovation in petrostates in comparison to non-petrostates. Secondly, previous literature usually grouped countries binary either as petrostates or as non-petrostates, instead this paper scales the oil & gas reserves continuously. It is hypothesised that the larger the oil & gas reserves of a petrostate are, the greater the effect will be. Thirdly, a recent data set with novel geospatial information (de Rassenfosse et al., 2019) is used to allocate patents more accurately to the countries of the innovators that has not been explored for this type of research.

2.3 Hypothesis and Mechanism

While the preliminary research did not lead to clear results, the literature suggests that the expected result is to find a negative effect on innovation in petrostates in times of increasing oil prices. As a result, the hypothesis is created, that an oil price boom (and thus a general increase in a petrostate's oil & gas wealth) leads to a negative effect on innovation in comparison to non-petrostates.

The key mechanisms explaining this hypothesis are crowding out effects. While these are typically used to describe the effects for businesses, comparable effects following this logic are identified. Still, the opposite effects of petrostates becoming more innovative during times of an oil price boom seem plausible as well. In total, three levels are considered.

Firstly – on the individual level – an oil & gas boom is expected to have negative effects. Persons may become less innovative as the oil price boom leads to a generally higher income and a larger welfare state may reduce an individual's need to innovate. Papyrakis & Gerlagh (2004) have shown that resource rents allow individuals to reduce their work effort leading to ultimately a lower total economic output. Furthermore, resource abundance encourages potential entrepreneurs to seek income rather through natural resources than through innovation (Sachs & Warner, 2001). During an oil price bust, the government and the population face lower incomes. To compensate for potential cuts in governmental support and fewer jobs in oil & gas related industries, the population is required to create new income sources and become more innovative.
On the other hand, a large welfare state financed by the oil income and wealth accumulated through higher income might allow individuals to pursue their ideas and focus on innovating.

Secondly, companies within the oil industry are expected to have the traditional crowding-out effects on companies outside of their industry. Due to the price boom, oil & gas companies attract the necessary input factors (labour but also capital) away from other companies, who then struggle to conduct business and innovation activities (Gylfason & Zoega, 2006; Papyrakis & Gerlagh, 2004). This is crucial as insufficient investments in human capital and scientific infrastructure impairs innovation efforts, but also the ability to use and benefit from new technologies (Maloney, 2002).
Still, the emergence or proliferation of an industry offers innovation potential. However, in the oil & gas industry complex technologies are needed to extract and process the oil. For

example, off-shore drilling requires special technologies and know-how that often can only be provided by specialised foreign companies, thus leaving limited room for local companies to benefit (The Economist, 2022).

Thirdly, for governments, an oil & gas boom may reduce the perceived need for policies to support non-oil industries, long-term planning and sustainable management of the resources (Ascher, 1999; Auty, 1998; Gylfason, 2001). During an oil price boom, a petrostate might focus its entire financial and human resources on the currently highly profitable oil & gas sector. The government is satisfied with the increasing oil & gas income and sees no need to invest funds into alternative (and potentially less profitable) industries. While this maximises the oil revenues in the short-term, the lack of innovation may hinder economic diversification and long-term development. An example of this can be found in the low R&D expenditures in natural resource-abundant countries (Welsch, 2008).

Meanwhile, positive effects of oil & gas booms on innovation seem plausible as well. The additional income during an oil price boom allows more R&D funding and can be used to support initially-less profitable and risky innovation processes, as failure will have less severe consequences. In case of an oil price bust, a petrostate's government has to keep the economy and welfare state running, even though significantly less income from the crucial oil industry is available. This means that "more expandable" expenses like R&D are to be cut – leading to fewer innovations – to avoid affecting the welfare state – which could result in civil unrest.

In contrast, the economy of non-petrostates is assumed to be unaffected by changes in the oil price. While weak spillover effects might occur, innovation should continue as normal regardless of an oil price boom or bust.

It has to be noted that it is not the intention of this research to assess the magnitude or relevance of each of the mechanisms explained above.

3. Data

3.1 Patent Data

Measuring innovation is a challenging task due to a variety of input factors and activities. To quantify the innovativeness of a country objectively, the output factor *invention patent*s have been chosen as a proxy variable.

Firstly, these terms need to be described and connected. An invention can be regarded as a new idea, offering creative new insight and opportunities or the detection of unsatisfied market needs (Seeni & Brown, 2015), while innovation describes the "successful exploitation of new ideas" (Bessant, 2003). Hence, an invention is necessary to start the innovation process, which describes all aspects necessary to make an invention a commercial reality. For this paper, these terms are assumed to be similar. Patents can be seen as the final output of innovation (Seeni & Brown, 2015) and are historically linked to innovation (Tidd & Bessant, 2021). As a patent ensures an inventor the legal right to exclusive usage of the invention, it encourages innovation (Hall, 2007).

One weakness of using patent applications as a proxy is that not all inventions are applied for a patent. Fontana et al. (2013) suggest that only a low number of innovations are patented and that the inventor's propensity to file for a patent varies across industries and organisation types. For example, for pharmaceutical or chemical products it might be more beneficial to not apply for a patent, as in order to be patented the formula needs to be published. By not applying for a patent, the invention can stay secret and competitors are prevented from reverse-engineering (Moser, 2007). Other reasons for not patenting an invention are high application costs, the need for the invention to be commercially viable or the difficulty to detect and enforce patent infringements (Athreye et al., 2018).

Despite this consideration of not being able to reflect the entire number of inventions, patent data is seen as a reliable indicator for innovation in academic research. As long as the rate of inventions filed for patent is similar within the sample group, there should be no bias.

The patent data used in this research is provided by de Rassenfosse et al. (2019) as part of the publication "Geocoding of worldwide patent data". The data set provides accurate geospatial information on the inventors and the applicants of 18.8 million unique patent applications over the period from 1980 until 2014. Only invention patents are tracked, other filings such as plant patents or designs are not included (de Rassenfosse et al., 2019). This is desirable, as inventions are assumed to better represent the innovativeness of a country than new designs.

The strength of this data set over data directly from national patent offices is, that it allows the accurate identification of all inventions from a country regardless of where the application has been filed, as some patents might be filed in patent offices in other countries or in supranational offices such as the European Patent Office.

The patenting process after an application can take several years until the decision of whether a patent is granted (EPO, n.d.). To avoid a bias from these time-consuming processes, the year of the patent application and not the year when a patent is granted is considered, as it is closer to the time of the invention and avoids a bias from efficiency differences of patent offices.

Data sets locating both the patent inventor and the patent applicant are available. The inventor is one or more individual persons, who conducted the necessary R&D for the invention. In cases where the patent applicant diverges from the inventor, the applicant is expected to be the organisation where the inventor is employed, which thus owns the right to the invention and files the patent. The inventor data was used, as it locates the country of the inventor and avoids a bias in case the patent for the invention is filed by an applicant in another country (i.e. international companies or research collaborations).

The data set GEOC_INV_PERSON.TXT[5] was used, which provides the geographic coordinates of the location of the inventors and has 30,601,669 rows. The number of inventors is higher than the number of patent applications (18,822,350) as in many cases more than one person has been registered as inventors. In the case of multiple inventors associated with a patent application, the patent is counted once for each inventor. It is also possible that one person has filed multiple patents within one year, in this case, each patent is counted separately (de Rassenfosse et al., 2019).

The basic data has been gathered by de Rassenfosse et al. from the following sources:

- PATSTAT (European Patent Office)
- OECD REGPAT

[5] Data Source: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/OTTBDX

- World Intellectual Property Organization
- German patent and trademark office
- French national industrial property institute
- United Kingdom intellectual property office
- Korean intellectual property office
- Japanese patent office
- China national intellectual property administration

These nine sources offer a high coverage of all patents filed in the observed period. 81 % of all *first filing* applications worldwide are included in the data set. Only patents filed for worldwide protection were considered. Particularly good coverage was reported for countries where the national patent office is included, while it is “less satisfactory, but still acceptable” for Canada and Southern Europe. The data is less qualitative for countries that are less integrated with the international patent system. However, these only account for a small share of the total patents (de Rassenfosse et al., 2019).

The total number of patents is aggregated by country and by year. For 3,705 patent applications (less than 0.012 % of the total data set) no data on the address and the country was available, even though having the longitudinal and latitudinal values. It seems as if the automatic identification was not possible, if the position is not on a country’s mainland or when a clear distinction of the address was impossible. While de Rassenfosse et al. (2019) emphasized highly detailed geospatial data on the location of the inventor, for this analysis the country level is sufficient. Two measures have been undertaken to add the required country information for these 3,705 data rows. Firstly, using the R package *map.where*, the country information for 1,466 patent applications has been added. Afterwards, for further 2,146 patent applications, where this automated identification was unsuccessful, the country data was added using the coordinates in Google Maps (if a clear identification of the country was possible). In the end, only 93 patent applications (out of the total 30,601,669) are without country information and are consequently unsuitable for this research.

The full data set contains information about patent filings from inventors from 54 different countries and territories. It provides distinct information about territories and islands. The data from the autonomous region Åland Islands was combined with the data of mainland Finland, as it is a legal part of Finland (UM, n.d.). In contrast, British Oversea Territories (Gibraltar) and Crown dependencies (Guernsey, Jersey or Isle of Man) are treated separately from the

United Kingdom, as they are distinct legal entities with their own laws and regulations (Ministry of Justice, 2010). Oversea territories located far away from the mainland (e.g. La Reunion of France) were not considered in the original data set by de Rassenfosse et al. (2019).

A population requirement is introduced to prevent a bias due to an over-representation of micronations, who usually have a large population in a small area, unique characteristics and non-representative economies tailored to very specific industries (e.g. financial services or tourism). Only countries with a total population[6] of more than 200,000 inhabitants have been considered; thus excluding Andorra, Gibraltar, Guernsey, Jersey, Isle of Man, Liechtenstein, Monaco and San Marino. The exclusion of these countries is expected to have no significant effects as the remaining 45 countries are responsible for more than 99.991 % of the total inventions. Table 4 in the Appendix lists the sample group.

While membership in these organisations was not a criterion to be in the sample group, it is worth mentioning that the sample group covers all member states of the OECD (as of 2014), all emerging economies associated with BRICS and all members states of the European Union and the European Economic Area (except Liechtenstein).

Generally, the patent data is used starting from the first available year (in most cases 1980). Still, some historical considerations had to be made, as several countries changed significantly during the observed period, for example by having been part of the former USSR, Yugoslavia or Czechoslovakia. Moreover, a quick check of the data from these countries made it obvious that the data from the years before the independence is irregular and most likely incomplete. Thus it is deemed unsuitable for further analysis and data is only considered starting from the first full year of independence of these formerly unified countries. The German patent data is available already starting from 1980 (before the reunification of the Federal Republic Germany and the German Democratic Republic). As the reunification led to no other changes of the borders and both the patent as well as the natural resource data is only available for the two countries combined, Germany is treated as one single entity for the whole period. Table 5 in the Appendix lists the countries with diverging starting years.

[6] Data Source: https://data.worldbank.org/indicator/SP.POP.TOTL
This data set from the World Bank is used as a supplementary source for the patent data and later for the oil & gas reserves to put them into context of the population size. For both cases the values from the year 1980 are used as the decisive number.

A weakness of this patent data set is the limited number of countries included. Most of the countries have rather developed and diversified economies and are located in Europe, North America or Asia. There is little data available from countries in Latin America, Africa or the Middle East. As of this, only few countries are included where the production and export of oil & gas play a major role in the economy. No information is available on countries with the largest oil reserves and where the oil rents are a dominant part of the economy, such as Venezuela, Saudi-Arabia, Iran, Iraq, Kuwait, UAE, and Oman (Blazevic et al., 2021). In these countries, the effect of changes in the oil price on innovation would have been particularly insightful. Further, it is unfortunate that the patent data is only available until 2014, as there was a severe oil price bust in 2014 and the price continued at a low level for the following years. This could have brought further valuable insights.

As the patent data set consists of sources from several patent offices over a period of 35 years, several assumptions have to be made for further analysis:

- All inventions filed for a patent are of the same quality and required similar input; This means that comparable amounts of time, funds and knowledge had to be allocated.
- In case two or more inventors are registered as inventors, the invention has required two (or more) times the effort of an invention that has only one registered inventor.
- As previously outlined, not every invention is filed for patent due to various reasons. A constant[7] rate of patent applications is assumed for all countries.
- The quality of the data reported from the various patent offices is constant.
- Patent applications are filed immediately after invention.

[7] Constant meaning a constant relationship (i.e., staying at the same level, but also following the same trends similarly)

3.2 Oil & Gas Wealth Data

In order to estimate the oil & gas wealth of the countries in the sample group in different years, two aspects are considered, their oil & gas reserves and the yearly oil price.

Data on the oil & gas reserves is sourced from BP's Statistical Review of World Energy[8]. It provides information about the oil reserves from 13 countries and the gas reserves from 17 countries. For all other countries in the sample, no information about their oil & gas reserves is available. This can be interpreted, that they have no or negligible reserves. To analyse both the oil and the gas reserves in one value combined, the gas reserves are converted into *Barrel of Oil Equivalents* (BOE). The conversion rate used is 6,000 cubic feet of gas (≈ 170 cubic meters) equalling 1 BOE (USGS, 2000). Table 6 in the Appendix lists the oil & gas reserves per country.

As the petrostates in the sample vary greatly in size and population, the oil & gas reserves need to be made comparable. Therefore the oil & gas reserves are considered per capita, as it is expected that the effect of oil & gas wealth (welfare state, creation of new jobs, …) may be more diluted in a large population than in a small population.

To examine each year's number of patents filed in the context of the prevailing oil price, the oil benchmark West Texas Intermediate (WTI) is used. The data is provided by the Federal Reserve Bank of St. Louis[9]. Other crude oil benchmarks (e.g. Brent Blend, Dubai Crude) could have been used as well, as they usually behave very similarly, albeit on slightly different levels (Owyang, 2020; U.S. Energy Information Administration (EIA), 2022). These differences in the price levels are not an issue, as the relevant part of the model are the price changes and the general movements of the oil price over time and not the absolute numbers.

The oil price is used for both oil and gas reserves, as in general a positive correlation between the two prices is visible (U.S. Energy Information Administration (EIA), 2022). While the oil price is not a perfect substitute for the gas price due to e.g. short-term effects, local effects or supply busts, long term and globally the oil price can be considered a reliable indicator.

[8] Data Source:
https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html
[9] Data Source: https://fred.stlouisfed.org/series/WTISPLC

As the patent filings are aggregated on a yearly basis, only one value of the oil price is needed per year. For this, the average annual spot price is used. This leads to a stable price that should represent the price level of the year and smooths out fluctuations within a year. While using a monthly oil price average would represent the price fluctuations better, monthly patent data is not considered useful as innovation processes take a long time from the first ideas until the patent application and are not flexible enough to react to intramonthly changes in the oil price.

To account for the inflation during the observed 35 years, data on the Consumer Price Index (CPI) is included. As the WTI is linked to the USA and oil & gas is typically traded in USD in the world markets, the CPI data used is based on the U.S. city average[10]. This inclusion of inflation makes it possible to view the oil price in the context of the price level of 2014. As 1 USD has less purchasing power in 2014 than in 1980, even if the nominal price stayed the same, a barrel of oil was effectively more expensive at the beginning of the period. This index-adjusted oil price can be regarded as the real oil price. Table 7 in the Appendix lists the average oil & gas prices with and without inflation adjustments.

To use the oil & gas data and the oil price data in the analysis the following assumptions have to be made:

- The oil & gas reserves are similar in exploitability as well as in product quality.
- If no data on the oil & gas reserves is available, the reserves are assumed to be zero.
- Changes in the price of the WTI are a perfect proxy for changes in other oil indices.
- Oil & gas are considered as equivalent products that follow similar trends.
- The oil price is applicable for the gas reserves as well.

[10] Data Source: https://fred.stlouisfed.org/series/CPIAUCSL

4. Empirical Strategy

As the hypothesis is that patent applications in petrostates are decreasing during an increasing oil price compared to non-petrostates, this means that in times of an oil price boom, petrostates are becoming less innovative. To test this hypothesis a linear model specification is set up:

$$\ln(patents_{it}) = \beta \times OilGasReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 1: Baseline Linear Model – Main Hypothesis

The dependent variable $patents_{it}$ is the total number of all invention patent applications registered by residents of country i in year t. As in the study by Mazaheri (2016), the patent data is transformed with a natural log (ln). This is a very common way for regression models in case there is a non-linear relationship between the dependent and the independent variable to keep the model linear. Additionally, highly skewed data is approximately distributed normally (Benoit, 2011) and the results can be easily interpreted as the change in per cent.

The independent variable $OilGasReserves_i$ represents the level of oil & gas reserves per capita country i possesses. Instead of using the yearly reported reserves, the reserves are kept at the level of 1980 (or the first following year available and per the availability of the patent data). While the author understands that new explorations have been undertaken and the worldwide proven oil & gas reserves have almost tripled since the year 1980 (BP, 2021), this approach removes the possibility of changes due to endogenous effects (i.e. increased or decreased search for oil fields depending on the political environment) (Brooks & Kurtz, 2016). To avoid any changes in the independent variable, the population data is fixed as well to the value of 1980 for the per-capita calculation. Therefore the variable $OilGasReserves_i$ is time-independent and constant over the whole period. Other academic research papers have been using this approach of estimating a country's resource wealth by multiplying initial reserves with current prices as well (Allcott & Keniston, 2018; Pelzl & Poelhekke, 2021).

Furthermore, $OilGasReserves_i$ is scaled by the average across the petrostates, easing the interpretation of the results. As the calculated coefficient of the model is based on a country with a reserve level of 1, the estimator can be interpreted as the effect of an oil price increase on patent applications for a petrostate with average oil & gas reserves. Consequently, $OilGasReserves_i$ is a continuous variable starting at 0 (in case a country has no reserves) without an upper limit. This approach considers the vastly differing magnitudes of the oil &

gas reserves in the sample. Using a traditional binary variable to indicate whether a country has reserves or not would have been too simplified and could have led to an unclear result.

$OilPrice_t$ is the average spot price for one barrel of oil in year t. To account for the inflation and to make the oil prices comparable, the price is inflation-adjusted to the year 2014. Analogous to the patent data, the oil price data is transformed with a natural log (ln).

γ_i are country fixed effects that control for the unobserved and time-invariant factors that influence the innovation activities in a country such as economic, technological, educational, financial or social situations. As patent applications may differ substantially from year to year, δ_t are year fixed effects and control for the various events (e.g. economic crises) which influence patent applications worldwide in a particular year. The residual divergence from the model for each country i in year t is captured in the error term ϵ_{it}.

The most important part of the model is the term β – the weighted average of all underlying treatment parameters. It reflects the magnitude of the effect of the independent term (the oil & gas reserves multiplied by the oil price) on the dependent term (the total patent applications of a country in a year). As $OilGasReserves_i$ is continuous, the more reserves a country possesses, the stronger is the influence on the outcome for a given β.

The following assumptions of the model must be fulfilled for β to be an unbiased estimator:

- In the absence of an oil price change, there is a similar development in patent applications across petrostates and non-petrostates.
- The oil & gas reserves stay in a constant proportion. While petrostates explore new reserves and exploit the existing reserves, it is assumed that this happens to a similar extent and that the initial proportion of reserves between the petrostates is preserved.
- Innovation processes in non-petrostates are fully independent of the oil price.
- A change in the oil price affects inventions immediately in the same year.

5. Results

5.1 Main Hypothesis

Based on the data and the model outlined in the previous sections, the effect of changes in oil & gas wealth on patent applications is estimated in a regression framework. As visible in Column 1 of Table 1 in the Appendix, the estimate on β equals a value of -0.115. The result is statistically significant at the 1 % level (p = 0.002).

As the coefficient is negative, this means that consistent with the literature and parts of the preliminary analysis, a negative effect on innovation can be detected in petrostates during increasing oil prices. Considering the log-transformation in the model, a 1 % increase in a petrostates oil & gas wealth, leads to 0.12 % fewer patent applications in a country with average reserves in comparison to non-petrostates.

Still, this does not automatically mean that during an oil boom in absolute numbers fewer patents were applied for in a petrostate than in the previous year, as it could also mean that the growth in patents is slower than in non-petrostates. [11]

5.2 Robustness Checks

To check the validity of this result, a variety of robustness checks have been conducted. These feature different dependent variables, independent variables or different data sets. If possible, finding from the literature review were incorporated and assumptions were checked.

While several aspects have been considered, the existence of another underlying factor that correlates with the oil price and is influencing innovation, cannot be fully excluded. The tables with the results are in the Appendix.

[11] For simplicity, only the implications of an increasing oil price are discussed, still the opposite effect of more patent application during decreasing oil prices is valid.

5.2.1 Population Size

Firstly, to check that mere population changes (under otherwise constant innovation activities per capita) are not the driving force, the model is adapted to patents per capita (similar to the approach by Mazaheri (2016)).

Populational data from the World Bank[12] containing information for all countries from the sample group for every year is used. A focus has been set on the population of the working age (15 to 64 year), as the vast majority of patents is expected to be filed by inventors within this age group (Kaltenberg et al., 2021). This age restriction also prevents an influence by e.g. a surge in births or high child mortality.

$$\ln(patents\_per\_capita_{it}) = \beta \times OilGasReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 2: Model for the Robustness Check – Patents Per Capita

The consideration of patent applications per capita confirms the hypothesis. The result (Table 1, Column 2) is very similar to the result of the main hypothesis. Furthermore, no significant changes in the total population size due to the oil price were found (Table 1, Column 3).

5.2.2 Global Innovation Index

The Global Innovation Index[13] has been used as a proxy for a country's innovativeness in the research by Omidi et al (2019). The index is published by the World Intellectual Property Organisation evaluating the innovation landscape around the world and ranking 130 countries (WIPO, 2021). It has not been considered the main data set for innovation, as the data is only available since 2011. Despite this smaller sample size, the data set was used to check whether this index suggests a similar negative effect on innovation in petrostates during an oil boom.

$$\ln(GII_{it}) = \beta \times OilGasReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 3: Model for the Robustness Check – Global Innovation Index

[12] Data Source: https://data.worldbank.org/indicator/SP.POP.1564.TO
[13] Data Source: https://www.globalinnovationindex.org/analysis-indicator

The result (Table 1, Column 4) documents a lower innovation score for petrostates during times of high oil prices. However, the result is statistically not significant, which is not that surprising considering the short sample period.

5.2.3 R&D expenditures

Another approach to check the robustness of the main result is by using a proxy that captures an input factor for innovation instead of an output factor. Hence, the financial input in form of the total R&D expenditures[14] is considered instead of patent applications.

$$\ln(R\&D_{it}) = \beta \times OilGasReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 4: Model for the Robustness Check – R&D Expenditures

The result (Table 1, Column 5) displays a negative and statistically significant effect of an oil & gas wealth increase on the R&D expenditures in petrostates – albeit weaker in magnitude. This indicates that comparatively fewer funds are allocated for R&D during an oil boom, but also an increase in R&D expenses in non-petrostates to compensate is plausible. Assuming a correlation between R&D expenses as financial input for innovation and patent applications as the output, this could even be seen as a cause for the decrease in patent applications.

5.2.4 Institutional Quality

The papers from Omidi et al. (2019) and Majbouri (2016) highlighted the necessity of institutional quality for a country to benefit from an oil boom. Thus it is checked for potential heterogeneous effects on innovation during an oil price boom due to the institutional quality. This could mean that countries with low institutional quality experience decreasing innovation during oil booms, while countries with high institutional quality are less affected or might even benefit from an oil boom.

The additional data chosen is sources from the *Institutional quality dataset*[15] by Kunčič (2014). Based on 30 different indicators, covering legal, political and economic institutions, 190

[14] Data Source: https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm
[15] Data Source: https://www.cambridge.org/core/journals/journal-of-institutional-economics/article/institutional-quality-dataset/3510AFB01B41639E003885D381E77AF3

countries were evaluated and scored from 5 (= highest institutional quality) to 1 (= lowest institutional quality) (Kunčič, 2014).

An interaction term for the institutional quality score is added to the baseline model:

$$\ln(patents_{it}) = \beta_1 \times OilGasReserves_i \times \ln(OilPrice_t) + \beta_2 \times OilGasReserves_i \times \ln(OilPrice_t) \times InstitutionalQuality_i + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 5: Model for the Robustness Check – Institution Quality

One issue with this additional interaction term is that it could lead to less clear and less significant results. This is the case, as neither of the coefficients (Table 2, Column 1) are statistically significant. Consequently, the effects of institutional quality on innovation during an oil price boom in petrostates can neither be confirmed nor denied.

5.2.5 Oil & Gas Data Set

To check whether the results may be driven by the choice of the oil & gas reserve data set, another data set published by OPEC [16] was used. It provides oil reserves for 12 countries of the sample group and gas reserves for 20 countries. The fact that this data set does not provide information for all 45 countries is not a major issue, as it can again be explained by many countries in the sample having no or insignificant reserves.

The result (Table 2, Column 2) from the baseline model with the OPEC data confirms the main hypothesis. The estimated coefficient is negative and statistically significant – albeit of lower magnitude than with the data from BP.

In another robustness check, *oil & gas production data*[17] is used. This could be of relevance if a country with vast reserves is only producing low levels of oil & gas as the economy is focused on other industries. Analogous to both reserves data sets, the value from 1980 (or the earliest available) is fixed for the whole period and is multiplied by the time-varying oil price.

$$\ln(patents_{it}) = \beta \times OilProduction_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 6: Model for the Robustness Check – Production Volume

[16] Data Source: https://asb.opec.org/data/ASB_Data.php,
Table 3.1 World proven crude oil reserves by country and Table 9.1: World proven natural gas reserves by country

[17] Data Source: BP Statistical Review of World Energy 2021

The regression with production data confirms the main hypothesis. The result (Table 2, Column 3) is a statistically significant negative coefficient of even higher magnitude.

5.2.6 Oil & Gas Individually

So far, all regressions have considered the oil & gas reserves of a country combined. To check the assumption, that the two resources are comparable and that both have a significant effect on their own, individual regressions for oil and for gas reserves are conducted.

$$\ln(patents_{it}) = \beta \times OilReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 7: Model for the Robustness Check – Oil Reserves

$$\ln(patents_{it}) = \beta \times GasReserves_i \times \ln(OilPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 8: Model for the Robustness Check – Gas Reserves

Both results (Table 2, columns 4 and 5) show a negative and statistically significant effect of an oil price change on patent applications in petrostates. This means that both oil and gas have an effect individually. The magnitude of the coefficient of either regression is of similar magnitude to the baseline model.

Further, to prove the assumption that the oil price can be used as a substitute for the gas price, a regression with only the gas reserves using the *Average German Import price* of gas[18] has been conducted. As with the oil price, it is assumed that this gas price is a perfect proxy for the gas price in all countries.

$$\ln(patents_{it}) = \beta \times GasReserves_i \times \ln(GasPrice_t) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 9: Model for the Robustness Check – Gas Price

Both approaches to calculating the gas wealth – using the oil price and the gas price (Table 2, columns 5 and 6) – lead to comparable, statistically significant and negative results.

[18] Data Source: BP Statistical Review of World Energy 2021

5.2.7 Size-Adjustments

As outlined in Section 3, to make the oil & gas reserves of the petrostates more comparable, they are adjusted on a per capita basis. Another approach for this size adjustment would be to use the surface area of a country[19].

The coefficient when using the oil & gas reserves per km^2 (Table 2, Column 7) is negative - albeit not statistically significant. When inspecting the data, it is visible that the consideration of the surface area has led to drastic changes in the oil & gas reserves. For example, due to its enormous size the gas reserves per km^2 of Russia – the largest gas producer in the data set – are diminished and account for only a tenth of the gas reserves of the Netherlands. Furthermore, oil & gas reserves are often found offshore. These areas were not included in the surface area data set.

In addition, a robustness check without either adjustment (population or surface areas) has been conducted using the oil & gas reserves in absolute terms.

The result (Table 2, Column 8) estimates again a statistically significant negative coefficient – yet of lower magnitude.

5.2.8 Inflation

In the baseline model, the oil price is adjusted to the consumer price index to account for inflation throughout the sample period. To ensure that the adjustment using the U.S. CPI is not the crucial factor driving results, a robustness check was conducted using the non-adjusted yearly average oil price.

The result (Table 2, Column 9) is again a negative and statistically significant coefficient of similar magnitude.

[19] Data Source: https://data.worldbank.org/indicator/AG.SRF.TOTL.K2

5.2.9 Only Petrostates

As outlined previously, some countries in the sample group appear to possess no oil & gas reserves. While these are defined as non-petrostates and included to diversify the sample, a robustness check is conducted with the baseline model and only petrostates in the sample.

The result (Table 3, Column 1) estimates again a negative coefficient of similar magnitude and is statistically significant.

5.2.10 Different Periods

As a total period of 35 years is considered, it could be that the effect is only impactful during a certain period (i.e. in the beginning or at the end of the observed period). Hence, the baseline model was regressed with two samples period limited to distinct decades.

During the period 1980 - 1999, no statistically significant result (Table 3, Column 2) was found. This is not too surprising, as the patent data for every country of the sample only becomes available by the year 1995. The period 2000 – 2014 has led to similar results (Table 3, Column 3) as the baseline model. It thus cannot be confirmed whether the effect was present over the whole period or is just a more recent development.

5.2.11 Time Lag

One assumption of the baseline model is that an oil price change affects innovation already in the same year. As invention processes often take longer, a model with a time lag has been created, where the effect of the oil price in the previous year on patent applications is estimated. This can be interpreted that an invention process was started under the conditions of the previous year's oil price, but due to a lengthy invention process, the patent is applied for (and therefore registered in the data set) in the following year.

$$\ln(patents_{it}) = \beta \times OilReserves_i \times \ln(OilPrice_{t-1}) + \gamma_i + \delta_t + \epsilon_{it}$$

Equation 10: Model for the Robustness Check – Lag I

The result (Table 3, Column 4) displays again a similar coefficient – negative, statistically significant and of similar magnitude.

While this specification of the model is a simple way to include a time lag, it assumes that all inventions filed in a year have been started in the previous year and are only affected by the previous year's oil price. As a result, another more elaborated approach was undertaken considering effects of the oil price in the year of the filing and the year prior.

$$\begin{aligned} \ln(patents_{it}) = {} & \beta_1 \times OilReserves_i \times \ln(OilPrice_t) \\ & + \beta_2 \times OilReserves_i \times \ln(OilPrice_{t-1}) + \gamma_i + \delta_t + \epsilon_{it} \end{aligned}$$

Equation 11: Model for the Robustness Check – Lag II

From a conceptual standpoint, this seems more plausible, as it offers innovations to be more time flexible and considers the oil price of both years. One issue of this approach is that the introduction of an additional variable might lead to less significant and less meaningful results.

This is the case – the results (Table 3, Column 5) are statistically not significant. Thus it stays unclear which year's oil price is decisive.

6. Conclusion

Summing up, the regressions of the model have shown that innovation in petrostates decreases during an oil price boom in comparison to non-petrostates. This effect remains valid after controlling for country and year fixed effects and after a variety of robustness check.

Consequently, this paper highlights a novel aspect of the resource curse. Previous literature focused either on a specific industry or the reserves in general. In contrast, this research has focused on all innovations within a country and includes not just the reserves, but also the changing value of the reserves.

While the coefficient of -0.115 may suggest that the effect on patent applications is marginal, it has to be considered that the oil price has been varying substantially during the observed period. In the case of the almost 300 % price increase from 2001 until 2008, the estimate indicates a decrease in patent applications in a petrostate by approximately 34.5 % compared to non-petrostates.

As the effect on innovation was detected both for oil and for gas individually, it could be applicable for other natural resources (e.g. minerals) as well, but also any other commodity that can lead to economic dependencies and has a varying value. Nevertheless, as oil and gas are rather similar products, a generalisation of the effects of resource wealth on innovation in resource-abundant countries based on the study alone is not recommendable. Further research is necessary to cover other resources and extend these findings. In addition, research focusing on the different technology classes or industries affected could be very insightful. Furthermore, the level of geographical detail of the data from de Rassenfosse et al. (2019) offers potential, e.g. to analyse possible differences within a country.

References

Allcott, H., & Keniston, D. (2018). Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America. *Review of Economic Studies*, *85*(2), 695–731. https://doi.org/10.1093/restud/rdx042

Andersen, A. D. (2012). Towards a new approach to natural resources and development: The role of learning, innovation and linkage dynamics. *International Journal of Technological Learning, Innovation and Development*, *5*(3), 291–324. https://doi.org/10.1504/IJTLID.2012.047681

Andersen, A. D., Marìn, A., & Simensen, E. O. (2018). Innovation in natural resource-based industries: A pathway to development? Introduction to special issue. *Innovation and Development*, *8*(1), 1–27. https://doi.org/10.1080/2157930X.2018.1439293

Ascher, W. (1999). *Why Governments Waste Natural Resources: Policy Failures in Developing Countries*. Johns Hopkins University Press. https://books.google.co.uk/books?id=BNN6-zkm5M8C

Athreye, S., Fassio, C., & UK Intellectual Property Office. (2018). *When do firms not use patents and trademarks to protect valuable innovations? : evidence from the SIPU 2015 survey* (Issue September).

Atun, R. A., Harvey, I., & Wild, J. (2007). Innovation, Patents and Economic Growth. *International Journal of Innovation Management*, *11*(02), 279–297. https://doi.org/10.1142/s1363919607001758

Auty, R. M. (1998). Resource Abundance and Economic Development. *Resource Abundance and Economic Development*, 1–340. https://doi.org/10.1093/0199275785.001.0001

Benoit, K. (2011). Linear Regression Models with Logarithmic Transformations. *London School of Economics*, 1–8. http://www.kenbenoit.net/courses/ME104/logmodels2.pdf

Bessant, J. (2003). *Challenges in Innovation Management*. https://doi.org/10.1016/B978-008044198-6/50052-8

Blazevic, V., Eichner, H., Kammerer, R., Hrgovcic, V., Arifin, Z., Meyer, E., & Sanusi Barkindo, M. (2021). *OPEC Annual Statistical Bulletin*. www.opec.org

BP. (2021). Statistical Review of World Energy globally consistent data on world energy markets . and authoritative publications in the field of energy. *BP Energy Outlook 2021*, *70*, 8–20.

Brooks, S. M., & Kurtz, M. J. (2016). Oil and Democracy: Endogenous Natural Resources and the Political Resource Curse. *International Organization*, *70*(2), 279–311. https://doi.org/10.1017/S0020818316000072

Brown, S. P. A., Balke, N. S., Yücel, M. K., Yucel, M. K., & Yiicel, M. K. (1999). Oil price shocks and the U.S. economy: Where does the asymmetry originate? *Federal Reserve Bank of Dallas, Working Papers*, *23*.

Chang, Y., & Wong, J. F. (2003). Oil price fluctuations and Singapore economy. *Energy Policy*, *31*(11), 1151–1165. https://doi.org/10.1016/S0301-4215(02)00212-4

Crabb, J. M., & Johnson, D. K. N. (2007). Fueling the Innovative Process : Oil Prices and Induced Innovation By Fueling the Innovative Process : Oil Prices and Induced Innovation in Automotive Energy-Efficient Technology. *Development*, *September*.

de Rassenfosse, G., Kozak, J., & Seliger, F. (2019). Geocoding of worldwide patent data. *Scientific Data*, *6*(1), 1–15. https://doi.org/10.1038/s41597-019-0264-6

Farzanegan, M. R., & Markwardt, G. (2009). The effects of oil price shocks on the Iranian economy. *Energy Economics*, *31*(1), 134–151. https://doi.org/10.1016/j.eneco.2008.09.003

Fontana, R., Nuvolari, A., Shimizu, H., & Vezzulli, A. (2013). Reassessing patent propensity: Evidence from a dataset of R&D awards, 1977-2004. *Research Policy*, *42*(10), 1780–1792. https://doi.org/10.1016/j.respol.2012.05.014

Gasimzade, E. E. (2015). Influence of Oil Prices on Innovation in Renewable Energy Sector. *The Journal of Economic Sciences: Theory and Practice*, *72*(2), 73–86.

Guillouzouic-Le Corff, A. (2018). Did oil prices trigger an innovation burst in biofuels? *Energy Economics*, *75*, 547–559. https://doi.org/10.1016/j.eneco.2018.08.031

Gylfason, T. (2001). Nature, Power and Growth. *Scottish Journal of Political Economy*, *48*, 558–588. https://doi.org/10.1111/1467-9485.00215

Gylfason, T., Herbertsson, T. T., & Zoega, G. (1999). A mixed blessing: Natural resources and economic growth. *Macroeconomic Dynamics*, *3*(2), 204–225. https://doi.org/10.1017/s1365100599011049

Gylfason, T., & Zoega, G. (2006). Natural resources and economic growth: The role of investment. *World Economy*, *29*(8), 1091–1115. https://doi.org/10.1111/j.1467-9701.2006.00807.x

Hall, B. H. (2007). Patents and patent policy. *Oxford Review of Economic Policy*, *23*(4), 568–587. https://doi.org/10.1093/oxrep/grm037

Hamilton, J. D. (2009). Understanding crude oil prices. *Energy Journal*, *30*(2), 179–206. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol30-No2-9

He, J., Li, J., Zhao, D., & Chen, X. (2021). Does oil price affect corporate innovation? Evidence from new energy vehicle enterprises in China. *Renewable and Sustainable Energy Reviews*, *156*(November 2021), 111964. https://doi.org/10.1016/j.rser.2021.111964

Herrera, A. M., Karaki, M. B., & Rangaraju, S. K. (2019). Oil price shocks and U.S. economic activity. *Energy Policy*, *129*(August 2018), 89–99. https://doi.org/10.1016/j.enpol.2019.02.011

Hicks, J. R. (1932). *The theory of wages*. Macmillan.

Kaltenberg, M., Jaffe, A. B., & Lachman, M. (2021). The Age of Invention: Matching Inventor Ages to Patents Based on Web-Scraped Sources. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3842743

Kunčič, A. (2014). Institutional quality dataset. *Journal of Institutional Economics*, *10*(1), 135–161. https://doi.org/10.1017/S1744137413000192

Kuznets, S. (1971). *Economic growth of nations : total output and production structure*. Belknap Press of Harvard University Press ; Distributed by Oxford University Press.

Majbouri, M. (2016). Oil and entrepreneurship. *Energy Policy*, *94*, 10–15. https://doi.org/10.1016/j.enpol.2016.03.027

Maloney, W. (2002). Innovation and Growth in Resource Rich Countries. *Central Bank of Chile, Working Papers Central Bank of Chile*.

Maloney, W., & Rodríguez-Clare, A. (2007). Innovation shortfalls. *Review of Development Economics*, *11*(4), 665–684. https://doi.org/10.1111/j.1467-9361.2007.00422.x

Mazaheri, N. (2016). *Oil Booms and Business Busts: Why Resource Wealth Hurts Entrepreneurs in the Developing World*. https://doi.org/10.1093/acprof

Ministry of Justice. (2010). *Background briefing on the Crown Dependencies: Jersey, Guernsey and the Isle of Man*. https://web.archive.org/web/20191102104306/http://www.justice.gov.uk/downloads/about/moj/our-responsibilities/Background_Briefing_on_the_Crown_Dependencies2.pdf

Moser, P. (2007). Why Don't Inventors Patent? *National Bureau of Economic Research, Inc, NBER Working Papers*.

Omidi, V., Shahabadi, A., & Mehregan, N. (2019). The impact of natural resources on innovation. *Iranian Economic Review*, *23*(3), 675–691. https://doi.org/10.22059/ier.2019.71793

Owyang, M. (2020). *WTI vs. Brent oil prices: When and why do they diverge?* https://fredblog.stlouisfed.org/2020/05/wti-vs-brent-oil-prices-when-and-why-do-they-diverge/

Pakes, A., & Griliches, Z. (1984). Patents and R&D at the firm level: A first report. *University of Chicago Press*, 55–72. https://doi.org/10.1016/0165-1765(80)90136-6

Papyrakis, E., & Gerlagh, R. (2004). Natural Resources, Innovation, and Growth. *SSRN Electronic Journal*, *October*. https://doi.org/10.2139/ssrn.609764

Pelzl, P., & Poelhekke, S. (2018). Good Mine, Bad Mine: Natural Resource Heterogeneity and Dutch Disease in Indonesia. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3256382

Pelzl, P., & Poelhekke, S. (2021). Good mine, bad mine: Natural resource heterogeneity and Dutch disease in Indonesia. *Journal of International Economics*, *131*, 103457. https://doi.org/https://doi.org/10.1016/j.jinteco.2021.103457

Peretto, P. F., & Valente, S. (2011). Resources, innovation and growth in the global economy. *Journal of Monetary Economics*, *58*(4), 387–399. https://doi.org/10.1016/j.jmoneco.2011.07.001

Sachs, J., & Warner, A. (1995). Natural Resource Abundance and Economic Growth. *National Bureau of Economic Research*, *3*. https://doi.org/10.3386/w5398

Sachs, J., & Warner, A. (2001). The Curse of Natural Resources. *European Economic Review*, *45*, 827–838. https://doi.org/10.1016/S0014-2921(01)00125-8

Seeni, A., & Brown, T. (2015). *Measuring Innovation Performance of Countries using Patents as Innovation Indicators*. *May 2021*.

Smith, K. (2007). Innovation and Growth in Resource-based Economies. *CEDA Growth*, *58*.

The Economist. (2022). *Guyana's tiny population braces for a gusher of petrodollars*. https://www.economist.com/the-americas/2022/03/26/guyanas-tiny-population-braces-for-a-gusher-of-petrodollars

Tidd, J., & Bessant, J. (2021). *Managing Innovation Integrating Technological, Market and Organizational Change*.

U.S. Energy Information Administration (EIA). (2022). *What drives crude oil prices? An analysis of 7 factors that influence oil markets, with chart data updated monthly and quarterly.* http://www.eia.gov/finance/markets/reports_presentations/eia_what_drives_crude_oil_prices.pdf

UM, (Finnish Ministry for Foreign Affaires). (n.d.). *The special status of the Åland Islands*. https://um.fi/the-special-status-of-the-aland-islands

USGS. (2000). *World Petroleum Assesement*. *1996*, 4. http://energy.cr.usgs.gov/WEcont/world/woutsum.pdf

Welsch, H. (2008). Resource Dependence, Knowledge Creation, And Growth : Revisiting The Natural Resource Curse. *Journal of Economic Development*, *33*(1), 45–70. https://doi.org/10.35866/caujed.2008.33.1.003

WIPO. (2021). Global Innovation Index 2021. In *Malaysian Science and Technology Information Centre (MASTIC)* (Issue June).

Zhang, Q. (2011). The impact of international oil price fluctuation on China's economy. *Energy Procedia*, *5*, 1360–1364. https://doi.org/10.1016/j.egypro.2011.03.235

7. Appendix

Regression Tables

Table 1: Results with varying Dependent Variables

Dependent Variable →	ln (Total Patent Applications)	ln (Patents Per Capita)	ln (Population)	ln (Global Innovation Index)	ln (R&D Expenditures)
Sample →	1466 observations, 45 countries, 35 years			180 obs. 45 countries 4 years	1241 obs. 41 countries 35 years
	(1)	(2)	(3)	(4)	(5)
Oil & Gas Reserves × ln (Oil Price)	-0.115** (0.037)	-0.116** (0.036)	0.001 (0.004)	-0.021 (0.033)	-0.040** (0.0135)

Table 1 shows the effect of resource wealth on the total patent applications with different dependent variables. The underlying patent and oil & gas data are described in Section 3. Further data input is described as part of the robustness check in Section 5.2 The data is clustered on a year-level and country-level basis. The regressions control for country fixed effects and year fixed effects. The number of observations is lower than the product of countries and years, due to partly incomplete data. Standard errors are given in the parentheses below.

***Significant at 0.1% level **Significant at 1% level; *Significant at 5% level

Table 2: Results with varying Independent Variables

Dependent Variable →	ln (Total Patent Applications)								
Sample →	1466 observations, 45 countries, 35 years					1321 obs. 45 countries 31 years	1466 observations, 45 countries, 35 years		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Oil & Gas Reserves × ln (Oil Price) +	-0.040 (0.081)								
Oil & Gas Reserves × ln (Oil Price) × Institutional Quality	-0.025 (0.024)								
OPEC Reserves × ln (Oil Price)		-0.089** (0.034)							
Oil Production × ln (Oil Price)			-0.150** (0.053)						
Oil Reserves × ln (Oil Price)				0.128*** (0.048)					
Gas Reserves × ln (Oil Price)					-0.100*** (0.033)				
Gas Reserves × ln (Gas Price)						0.119*** (0.033)			
Oil & Gas Reserves *(adjusted for surface area)* × ln (Oil Price)							-0.044 (0.027)		
Oil & Gas Reserves *(absolute)* × ln (Oil Price)								-0.023* (0.010)	
Oil & Gas Reserves × ln (Oil Price) *(non-inflation-adjusted)*									-0.108*** (0.029)

Table 2 shows the effect of resource wealth on the total patent applications with different independent variables. The underlying patent and oil & gas data are described in Section 3. Further data input is described as part of the robustness check in Section 5.2. The data is clustered on a year-level and country-level basis. The regressions control for country fixed effects and year fixed effects. The number of observations might be lower than the product of countries and years, due to partly incomplete data. Fewer observations for the gas price are possible, as the gas price used is only available since 1984. Standard errors are given in the parentheses below.

***Significant at 0.1% level **Significant at 1% level; *Significant at 5% level

Table 3: Results with varying Samples

Dependent Variable →	Ln (Total Patent Applications)				
	Petrostates	1980-1999	2000-2014	Lag I	Lag II
Sample →	538 obs. 17 countries 35 years	791 obs. 45 countries 20 years	675 obs. 45 countries 15 years	1430 observations, 45 countries, 34 years	
	(1)	(2)	(3)	(4)	(5)
Oil & Gas Reserves × ln (Oil Price)	-0.134*** (0.009)	0.026 (0.074)	-0.118*** (0.030)	-0.124*** (0.037)	-0.123 (0.087) -0.001 (0.088)

Table 3 shows the effect of resource wealth on the total patent applications with different sample variations. The underlying patent and oil & gas data are described in Section 3. The sample variations are described as part of the robustness check in Section 5.2 The data is clustered on a year-level and country-level basis. Unless specified, the regressions are based on equation 1 and control for country fixed effects and year fixed effects. A country is included in "Petrostates" if at least either the oil or the gas reserves are greater than 0 (Table 7). Lag I means that the patent data is regressed with the oil price of a previous year, Lag II with the oil price of the previous and the same year. The number of observations might be lower in some cases, due to a focus on a specific period and unavailability of data. Standard errors are given in the parentheses below.

***Significant at 0.1% level **Significant at 1% level; *Significant at 5% level

Data

The main data used in the regression described in Section 3 is shown in the following. The additional data for the robustness checks is only used for one regression and not included here. (The sources for these data sets are included in their respective section and the same preparations and calculations have been undertaken e.g. BOE and resource level).

Table 4: Countries in the Sample

Australia	Austria	Belgium	Brazil	Bulgaria
Canada	Chile	China	Croatia	Czech Republic
Denmark	Estonia	Finland	France	Germany
Greece	Hungary	Iceland	India	Ireland
Israel	Italy	Japan	Latvia	Lithuania
Luxembourg	Malta	Mexico	Netherlands	New Zealand
Norway	Poland	Portugal	Romania	Russian Federation
Slovak Republic	Slovenia	South Africa	South Korea	Spain
Sweden	Switzerland	Turkey	United Kingdom	United States

Table 5: Historical Considerations

Country	Starting Year
Croatia	1992
Czech Republic	1992
Estonia	1992
Latvia	1992
Lithuania	1993
Russian Federation	1992
Slovak Republic	1993
Slovenia	1992

These considerations are only for newly formed countries within the sample period. The data for all other countries starts in 1980 (Malta in 1982 due to data unavailability)

Table 6: Oil and Gas Resources by Country

Country	Oil Reserves (in billion barrels)[20]	Gas Reserves (in trillion m^3)[20]	Gas Reserves (in billion BOE[21])	Combined Reserves (in billion barrels)	Oil & Gas Reserve Level[22]	Oil Reserve Level[22]	Gas Reserve Level[22]
Australia	2.122811	0.1413360	0.83138824	2.95419936	0.181512660	0.318797337	0.346393210
Austria	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Belgium	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Brazil	1.317967	0.0516750	0.30397059	1.62193753	0.008078483	0.021306112	0.026179282
Bulgaria	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Canada	39.527523	2.4297000	14.29235294	53.81987604	1.870.010.241	3.480.605.362	3.865.403.387
Chile	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
China	13.352621	0.7083284	4.16663775	17.51925895	0.013620614	0.028307304	0.032623641
Croatia	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Czech Republic	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Denmark	0.450000	0.0854850	0.50285294	0.95285294	0.314846099	0.294886601	0.210583725
Estonia	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Finland	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
France	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Germany	0.000000	0.2583750	1.51985294	1.51985294	0.062271187	0.030779317	0.000000000
Greece	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Hungary	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Iceland	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
India	2.756959	0.3344250	1.96720588	4.72416478	0.009027883	0.010716007	0.009456302
Ireland	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Israel	0.000000	0.0029250	0.01720588	0.01720588	0.014231580	0.007034366	0.000000000
Italy	0.378450	0.1535160	0.90303529	1.28148529	0.051327340	0.036002238	0.016077093
Japan	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Latvia	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Lithuania	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Luxembourg	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Malta	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Mexico	47.224000	1.7813250	10.47838235	57.70238235	0.496016415	1.350.104.519	1.670.781.073
Netherlands	0.000000	1.9896139	11.70361106	11.70361106	2.653.099.547	1.311.370.424	0.000000000
New Zealand	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Norway	3.952062	0.3850900	2.26523529	6.21729685	1.778.440.398	2.412.678.412	2.319.020.912
Poland	0.000000	0.0767000	0.45117647	0.45117647	0.040681399	0.020107946	0.000000000

Country	Oil Reserves (in billion barrels)	Gas Reserves (in trillion m^3)	Gas Reserves (in billion BOE)	Combined Reserves (in billion barrels)	Oil & Gas Reserve Level	Oil Reserve Level	Gas Reserve Level
Portugal	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Romania	1.090193	0.2925000	1.72058824	2.81078124	0.248522382	0.200672307	0.117691993
Russian Federation	211.127382	63.1293898	371.34935188	582.47673410	8.568.811.579	6.643.368.533	3.641.140.648
Slovak Republic	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Slovenia	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
South Africa	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
South Korea	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Spain	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Sweden	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Switzerland	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
Turkey	0.000000	0.0000000	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000
United Kingdom	8.437500	0.7205250	4.23838235	12.67588235	0.241416004	0.356874866	0.359198636
United States	36.533000	5.3961328	31.74195748	68.27495748	0.448086191	0.476388349	0.385450098

[20] Source: BP Statistical Review of World Energy 2021
[21] Conversion rate: 6,000 cubic feet of gas (170 cubic meters) equals one barrel of oil
[22] Oil Reserve Level = $\frac{Oil\ \&\ Gas\ Reserves}{Average\ Oil\ Reserve}$

Table 7: Oil and Gas Prices

Year	Consumer Price Index (USA)	Oil Price USD/bbl	Oil Price adjusted[23] USD/bbl	Gas Price USD/MMBtu	Gas Price adjusted[23] USD/MMBtu
1980	0.8238333	37.37500	107.39093	n/a	n/a
1981	0.9093333	36.66667	95.4496	n/a	n/a
1982	0.9653333	33.63583	82.48038	n/a	n/a
1983	0.9958333	30.39500	72.25057	n/a	n/a
1984	1.0393333	29.27550	66.67688	4.00	9.110263
1985	1.0760000	27.97275	61.53875	4.25	9.349803
1986	1.0969167	15.04000	32.45637	3.93	8.480954
1987	1.1361667	19.16192	39.92296	2.55	5.312805
1988	1.1827500	15.95958	31.94143	2.22	4.443097
1989	1.2394167	19.59083	37.41634	2.00	3.819781
1990	1.3065833	24.49292	44.37406	2.78	5.036554
1991	1.3616667	21.48125	37.34346	3.23	5.6151
1992	1.4030833	20.56142	34.68928	2.70	4.555186
1993	1.4447500	18.45817	30.24278	2.51	4.112508
1994	1.4822500	17.18583	27.44574	2.35	3.752945
1995	1.5238333	18.42750	28.62561	2.43	3.774806
1996	1.5685833	22.15417	33.43287	2.50	3.772751
1997	1.6052500	20.59917	30.37615	2.66	3.922516
1998	1.6300833	14.38833	20.89423	2.33	3.383545
1999	1.6658333	19.25167	27.35663	1.86	2.643061
2000	1.7219167	30.29833	41.65167	2.91	4.00043
2001	1.7704167	25.92417	34.66212	3.67	4.907003
2002	1.7986667	26.09750	34.34583	3.21	4.224547
2003	1.8400000	31.14000	40.06144	4.06	5.223168
2004	1.8890833	41.43833	51.92505	4.30	5.388193
2005	1.9526667	56.46583	68.45157	5.83	7.067507
2006	2.0155833	66.10333	77.63336	7.87	9.242719
2007	2.0734417	72.36250	82.61283	7.99	9.121804
2008	2.1525425	99.56750	109.49433	11.60	12.756515
2009	2.1456467	61.69333	68.06217	8.53	9.410585
2010	2.1807617	79.42750	86.21612	8.03	8.716319
2011	2.2492300	95.07667	100.06123	10.49	11.039957
2012	2.2958608	94.20083	97.12588	10.93	11.269389
2013	2.3295175	97.93583	99.51795	10.73	10.903339
2014	2.3671500	93.25833	93.25833	9.11	9.11

[23] Adjustment: Price * CPI (2014) / CPI (year)