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Natural Resource Exploration as Intangible Investment

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Natural Resource Exploration as Intangible Investment

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Abstract Natural resources are everywhere, and reported wellbeing is highly correlated with the quantity and quality of natural resource services like weather and biodiversity (Levinson 2012) (MacKerron and Mourato 2013) (Methorst et al. 2021). Yet, natural resources are currently classified as non-produced assets (U.N. Statistics Division sec. 10.14), and therefore natural resource services cannot be attributed to either labor inputs now or capital investment in the past. For those used to thinking about consumption growth as a consequence of labor growth or capital growth, this raises immediate concern that natural resource service growth is unmeasured within the standard gross domestic product (GDP) framework. Furthermore, this concern has evolved into arguments that GDP growth is a fundamentally flawed measure of wellbeing growth (Stiglitz et al. 2009).

This paper proposes a framework where natural resource service growth is attributed to an intangible asset: exploration. For example, a utility might start out with a non-produced watershed and then increase the watershed's value by searching for the aquifer with the cleanest water. The proposed framework is an adaptation of the framework currently used to track mineral exploration (U.N. Statistics Division sec. 10.106-108). The paper then applies that framework to the U.S. GDP statistics.

Tracking exploration raises measured investment in every year studied but does not change real GDP growth or real consumption growth noticeably. However, real asset growth increases by 0.05 percentage point per year between 1929 and 2019. Due to the faster growth of real assets used in production, for-profit business productivity growth falls by 0.01 percentage point per year between 1948 and 2019. Taken together, these empirical results suggest that broadening the scope of GDP to better track natural resource services does not fundamentally change growth.

Keywords Intangible, Natural Resource, Environment, Capital, Savings, Productivity

JEL codes E01, O17, and Q50

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Introduction

Historical property transactions provide clear evidence that exploration can increase market prices dramatically. Land in the explored Eastern United States sold for about $2 per acre (Blodget 1806), approximately five times the price of similar latitude land in the unexplored Louisiana Purchase (Lee 2017a and b) and approximately seven times the price of similar latitude land in the unexplored Gadsden Purchase (Schmidt 1962). Land in explored Lapland sold for about $0.20 per acre (Watson 1878), approximately 10 times the price of similar latitude land in unexplored Alaska (Golder 1920). New Zealand settlers also paid a premium for explored land (Banner 2000). Despite the much higher land values associated with exploration, the official guidelines for national accounting only track mineral exploration as a capital investment (U.N. Statistics Division 2008 sec. 10.106-108). As an alternative treatment, this paper recalculates the U. S. national income and product accounts (NIPAs) when all natural resource exploration is tracked as capital investment.

The paper does not change the treatment of non-produced natural resources. The official guidelines for national accounting are clear that land, water, radio spectrum, and similar natural resources are not produced capital and changes in their real value should be tracked as "other changes in the volume of assets" (U.N. Statistics Division 2008, sec. 12.17 to 12.30). Similarly, the official guidelines for environmental-economic accounting are clear that natural resources are not produced capital (U.N. Statistics Division 2012). However, both sources explicitly permit tracking land improvement and other investment that is complementary to natural resources as produced capital assets (U.N. Statistics Division 2008, sec. 10.80 and 10.159) (U.N. Statistics Division 2012, sec. 4.63 and 4.85). This paper values non-produced natural resources by starting with the market price for explored natural resources and then subtracting the value of exploration capital to get a residual value for unexplored natural resources. This residual value is then tracked using the recommended treatment of non-produced natural resources.

This paper collects empirical data on four categories of natural resource exploration: physical geography, chemical & microorganism, climate, and animals & plants. The paper then recalculates the NIPAs when those four exploration categories are tracked as investment. By construction, tracking exploration investment raises measured investment and measured gross domestic product (GDP) for every year studied. Between 1929 and 2019, the average ratio of nominal exploration investment to nominal GDP is 0.5 percentage point. The increase to measured GDP and measured consumption is similar in 1929 as it is in 2019 and therefore neither GDP growth nor consumption growth change noticeably. However, real asset growth increases by 0.05 percentage point per year when exploration is tracked as investment.

The paper is divided into four sections. Section 1 starts out by describing the four categories of natural resource exploration. Section 1 then describes the current and proposed treatment of those four exploration categories as well as the current and proposed treatment of non-produced natural resources. Section 2 estimates nominal investment for each category of natural resource investment and then splits that nominal investment between the government sector, the non-profit sector, and the for-profit business sector. Section 3 estimates depreciation rates for each category of natural resource exploration. Section 3 then uses those depreciation rates to calculate capital stock, net saving, GDP, productivity, and measures of consumption when natural resource exploration is capitalized. Finally, Appendix A lists the occupations associated with natural resource exploration.

1. Current and Proposed Treatment of Exploration

Exploration is defined as the collection of new information about a natural resource. Exploration does not include inspection costs paid by potential buyers to check land for known but undisclosed defects. Instead, those inspection costs are defined as a component of "ownership transfer costs" (U.N. Statistics Division 2008, sec. 10.51a and 10.81) and are already tracked by BEA as a component of brokers' commissions (NIPA Table 5.4.5, line 33 and 43).[1] To be clear, exploration need not collect completely original information. For example, an explorer might check previously collected information to make sure it is accurate. But exploration always adds information about a natural resource.

Exploration is generally done by the economic owner[2] of a natural resource because the owner benefits from the expected value increase associated with exploration. Of course, an individual natural resource may experience a value loss if exploration reveals previously unknown problems associated with that resource (Hadziomerspahic 2022). Nevertheless, exploration raises expected property values because accurate information can prevent future property damage and may even save lives (Shrader et al. 2022). A potential owner might also explore unclaimed natural resources to determine whether claiming ownership is feasible. In that case, the entire value of the newly claimed natural resource would be considered exploration capital.[3] A small portion of natural resources are permanently unowned because "it is not feasible to establish ownership over them" (U.N. Statistics

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1. Inspection costs for non-land natural resources, such as radio spectra, are small and not specifically tracked.

2. Economic ownership is not necessarily the same as legal ownership (U.N. Statistics Division 2008, sec. 3.21-9). For example, the U.S. Navy exercises substantial influence outside of the waters that are legally owned by the United States. Consistent with that economic ownership, the Navy has explored the global oceans.

3. In some cases, exploration may reveal that claiming ownership is not feasible. This unsuccessful exploration is capitalized just like dry oil wells and failed R&D projects (U.N. Statistics Division 2008, sec. 6.231 and 10.103).

Division 2008, sec. 10.167). The paper assumes that exploration of permanently unowned resources is very rare, and therefore all exploration investment measured in the empirical section involves owned natural resources.

Exploration is distinct from research and development (R&D). Exploration focuses on collecting information about specific natural resources, while R&D collects information on the broad natural world. For example, a forester might record the location and age of individual trees so that they can be harvested at maturity. In contrast, a biologist might record the general plant characteristics and model how each plant species has evolved in the past. In practice, the line between exploration and R&D is sometimes fuzzy. Exploration may also overlap with intangibles like computerized information or brand equity (Corrado, Hulten, and Sichel 2009). To avoid double-counting, this paper focuses on exploration subcategories that are not tracked in other categories of intangible capital.

Description of Natural Resource Exploration Categories Studied

Physical Geography exploration records the position of rocks, water, radio interference, and other stable natural resource attributes. For example, a ski resort may survey hills to determine which slopes are suitable for beginners and which slopes are suitable for experts. Or a sailor might map rivers to locate routes that are deep enough for large ships. To be clear, both skiable mountain slopes and deep river routes are non-produced natural resources and can't be changed through exploration. But property owners can use a natural resource better when they know its characteristics.

Chemical & Microorganism exploration records the composition of water and soil. For example, a water system plant operator might test local aquifers to determine the cleanest water source and the best treatments for the water source selected. Likewise, a soil consultant might test farmland to determine which fertilizer mix will enhance crop growth most.

Climate exploration records temperature, humidity, air quality, and other dynamic natural resource attributes. This category includes terrestrial disasters like earthquakes or avalanches. This category also includes atmospheric and extraterrestrial conditions that impact telecommunications (Luomala and Hakala 2015) without impacting people directly. In each location, property owners can use climate exploration to identify patterns and plan natural resource usage around those patterns.

Animal & Plant exploration records information about the wild plants and animals found in an area. This category includes not only endangered species that must be protected, but also common species that can be harvested for profit and even common pests that must be managed. For example, a forester may use animal & plant exploration to plan a logging project that minimizes disruption to endangered species while maximizing the yield of harvestable timber and minimizing workers' exposure to poison ivy. The category "animal & plant exploration" does not include information collected on food animals, horses, farm plants, or landscaping plants because those cultivated biological resources are tracked as elsewhere in the accounts (U.N. Statistics Division 2008, sec. 10.88-10.96) (Soloveichik 2021).

Current Treatment of Exploration Investment

The official guidelines for national accounting explicitly recommend tracking mineral exploration and implicitly recommend tracking construction-related exploration (U.N. Statistics Division 2008 sec. 10.106-108 and sec. 10.51). Consistent with those recommendations, BEA explicitly tracks mineral exploration as part of the structure type "mining exploration, shafts, and well" and implicitly tracks construction-related exploration in the construction cost component "architectural, engineering and miscellaneous costs". Because both mineral exploration and construction-related exploration are already included in the NIPAs, the paper does not study either of them. Instead, this paper studies physical geography, chemical & microorganism, climate, and animal & plant exploration.

For-profit business expenditures on those four exploration categories do not impact measured GDP. If those exploration services are produced for sale, then they are tracked as output of the producing company and intermediate input for the purchasing company. Those two impacts precisely cancel out so that the expenditures have no net impact on GDP. Own-account exploration by businesses is not tracked as either output or intermediate input, but exploration workers are tracked in the labor force statistics.

Government and non-profit expenditures on those four exploration categories do impact measured GDP. For those sectors, BEA measures output based on costs rather than market revenue. Expenditures on natural resource exploration are implicitly included in total costs and therefore implicitly included in measured output. In 2019, this paper later calculates that governments accounted for 43 percent of exploration, and non-profits accounted for another 1 percent of exploration.

Current Treatment of Exploration Capital Stock and Capital Services

The official guidelines for national accounting explicitly recommend tracking natural resources in a country's balance sheet (U.N. Statistics Division 2008 sec. 10.166-10.185). This recommendation is amplified in the official guidelines for environmental economic accounts (U.N. Statistics Division 2012). Neither of these guidelines distinguish between unexplored natural resources and explored natural resources. Hence, they both implicitly bundle produced exploration capital together with non-produced natural resources. Consistent with the official guidelines, BEA researchers who are studying land valuation also bundle these two assets in their empirical analysis (Wentland et al. 2020).

The joint production accounts published by BEA and the U.S. Bureau of Labor Statistics (BLS) track natural resource services to a limited degree. In particular, they track services that are used by the natural resource's owner or transferred by the owner to a third party. For example, marine ecosystem services are tracked if the owner fishes by himself, sells fishing licenses in an arm's-length transaction, or gives fishing licenses to his friends as a favor. However, externalities are not recorded as transactions (U.N. Statistics Division 2008 sec. 3.92-3.95), and therefore environmental services that cannot be captured by the owner of a natural resource are not tracked in the joint production accounts (U.N. Statistics Division 2012 sec. 5.38-5.40). For example, marine ecosystem services like carbon sequestration are not tracked. When calculating natural resource services, the services associated with exploration capital are bundled together with the services associated with non-produced natural resources.

Proposed Treatment of Exploration Investment, Capital Stock, and Services

This paper tracks both purchased exploration and own-account exploration as intangible capital investment. In the for-profit business sector, measured value added increases by the same amount as the newly tracked investment. Owner-occupied housing is treated as production in the NIPAs, and therefore homeowner exploration increases to measured real estate sector value added (U.N. Statistics Division 2008, sec. 6.37). In the non-profit and government sector, measured value added increases by the same amount as the newly tracked consumption of fixed capital (CFC).

The value of a specific exploration project is calculated by starting with its initial value and then subtracting past CFC. In turn, the total exploration stock is then calculated by summing the depreciated value of all previous exploration projects. This method is known as the perpetual inventory method and is a standard NIPA technique. The value of completely unexplored natural resources is difficult to observe because unexplored natural resources are rarely sold nowadays. This paper calculates the value of unexplored natural resources using a residual methodology. First, the value of explored natural resources is estimated from market transactions and expert judgment. Second, the value of produced exploration capital is subtracted. Following the official guidelines, this residual value is tracked as a non-produced natural resource (U.N. Statistics Division 2008 and 2012).

In theory, natural resource services should not be impacted by changes in the framework used to track natural resources. After all, neither market rents nor environmental services are impacted by the precise national accounting treatment for that asset. In practice, natural resource services are generally imputed using standard formulas rather than observed directly. As a result, imputed services in the paper's productivity calculations change slightly when exploration capital is tracked separately.

Table 1. GDP Impact of Exploration Investment by For-Profit Businesses and Owner-Occupied Homes

Current treatment in GDP	Adjusted GDP	Change to GDP
1. Purchased exploration services are tracked as intermediate inputs. 2. Own-account exploration is not tracked.	1. Purchases of exploration are tracked as purchased investment. 2. Own-account exploration is tracked as own-account investment.	Increases by newly tracked value of exploration investment.

Table 2. GDP Impact of Exploration Investment by Governments and Non-Profits

Current treatment in GDP	Adjusted GDP	Change to GDP
Purchased and own-account exploration add to current consumption.	1. Purchased and own-account exploration are both tracked as investment. 2. CFC on the stock of exploration capital is tracked in current consumption.	Increases by newly tracked CFC on exploration capital.

Table 3. Balance Sheet Impact of Exploration Capital

Current treatment	Adjusted treatment	Change to assets
The market value of a natural resource is tracked as a non-produced asset.	1. Exploration capital is tracked as a produced intangible asset. 2. The residual value of natural resources (market value less produced exploration capital) is tracked as a non-produced asset.	1. and 2. precisely cancel so that there is no change to total assets.

Table 4. Natural Resource Service Impact of Tracking Exploration

Current treatment	Adjusted treatment	Change to capital services
1. Natural resource services are assumed to equal their market value times their rental rate. 2. Environmental services that cannot be captured by the owner are not tracked.	1a. Natural resource services increase by the newly recognized services from produced exploration capital. 1b. Natural resource services decrease because a portion of the rent for natural resources is attributed to exploration. 2. Environmental services that cannot be captured by the owner are not tracked.	In theory, 1a. and 1b. precisely cancel so that there is no change to total natural resource services.

2. Nominal Investment and Prices for Natural Resource Exploration

Worker Time Devoted to Exploration

Civilian exploration time between 1998 and 2019 is mostly estimated using a three-step approach. First, the paper uses detailed annual data from the Occupational Employment and Wage Statistics (OEWS) to count the number of employees in each occupation. Second, the paper uses occupation task descriptions collected by BLS and expert judgment to estimate the share of each occupation's time potentially devoted to exploration.[4] Appendix A gives a list of the occupations studied and an example of the exploration tasks performed by each occupation. Finally, the paper uses data from the American Community Survey (ACS) to estimate self-employment rates and average work hours for each occupation tracked. These components are multiplied to get potential exploration time.

Potential exploration time may not match actual exploration time. On the one hand, exploration projects are sometimes done by workers whose BLS tasks do not include any exploration. For example, a particle physicist might explore how cosmic rays impact climate (Svensmark et al. 2017). On the other hand, exploration workers sometimes broaden their focus sufficiently that their work is considered R&D rather than exploration. For example, Charles Darwin started out by cataloging the finches in the Galapagos and then used that catalogue to develop a general theory of evolution (1859). For simplicity, this paper assumes that exploration time by non-exploration workers offsets non-exploration time by exploration workers so that aggregate potential exploration time equals aggregate actual exploration time.

Farms, nonfarm gardens, and fisheries are not tracked in the OEWS, so exploration in those sectors cannot be measured with the approach described earlier. Farm exploration time from 1929 to 2019 is estimated using a two-step approach. First, the paper uses a one-time OEWS report on the agricultural workforce to estimate the share of time in that industry devoted to exploration. The paper then multiplies that exploration share with an estimate of farm and nonfarm garden[5] time that is derived from BEA's data on the farm workforce and survey data on gardening time. Finally, the paper estimates fishing exploration time using expert judgment and BLS data on the fishing workforce.

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4. Mining workers are excluded because their exploration is tracked in "mining exploration, shafts, and wells." The paper also excludes construction-related occupations whose exploration is likely tracked in structures.

5. Both home-produced food and do-it-yourself landscaping are in scope for GDP (U.N. Statistics Division 2008, sec. 6.32 and 6.37). But neither activity is currently included in the measured agricultural sector.

Historical civilian exploration time is calculated from the occupations self-reported by civilians in the decennial population Census. The Census occupation codes are first matched with the OEWS codes and then adjusted for coding changes over time. Between Census years, BEA's estimate of the civilian workforce is used as an interpolator. Because the Census data is only available once a decade, it is not possible to measure short-term changes in exploration time reliably. However, long-term trends in exploration time can be measured for the period in which Census microdata is available. Hence, the paper's discussion focuses on the long-term impact of exploration investment on the NIPAs.

Military exploration is difficult to observe directly because the military is not included in the annual OEWS and no major wars overlapped with the decennial Census. The paper uses broad occupation classifications for each branch in 2018 to estimate their propensity to explore **relative** to the civilian nonfarm workforce. The paper then extrapolates military exploration historically based on the number of people in each branch and the civilian propensity to explore in each year. By construction, military exploration is volatile and peaks during major wars.

Nominal Exploration Investment

One might think that nominal investment can be calculated simply by multiplying the time estimates calculated earlier with exploration worker wages. In fact, hourly exploration costs are higher than just exploration worker wages. To start out, exploration workers generally receive noncash benefits like health insurance. In addition, exploration workers typically require support from generalist workers like managers, janitors, and other overhead. Some exploration also requires expensive materials or machinery. For example, a military mapper might use aircraft to collect terrain data and computers to process the collected data. This paper estimates the total hourly exploration costs without attempting to split those costs between exploration worker wages, exploration worker noncash benefits, support worker costs, and non-labor costs.

Data tracking hourly exploration costs could not be located, so the paper uses hourly costs for similar activities as proxies. Architectural and engineering services are a proxy for physical geography exploration. These two activities both carefully survey natural resources and analyze the measurements to plan natural resource usage. Chemical & biological R&D is a proxy for chemical & microorganism exploration. These two activities both select and analyze samples in a laboratory or in the field. The National Oceanic and Atmospheric Administration's (NOAA's) budget per exploration hour is a proxy for climate exploration.[6] Finally, landscaping output is a proxy for animal & plant exploration. These two

6. Budget data for NOAA were not located before 2001. Before then, physical R&D costs are an extrapolator.

activities both deal with biological resources regularly. For each of these four categories, the paper calculates hourly costs by comparing similar output statistics to similar worker time.

Figure 1. Exploration Investment as a Share of Nominal GDP

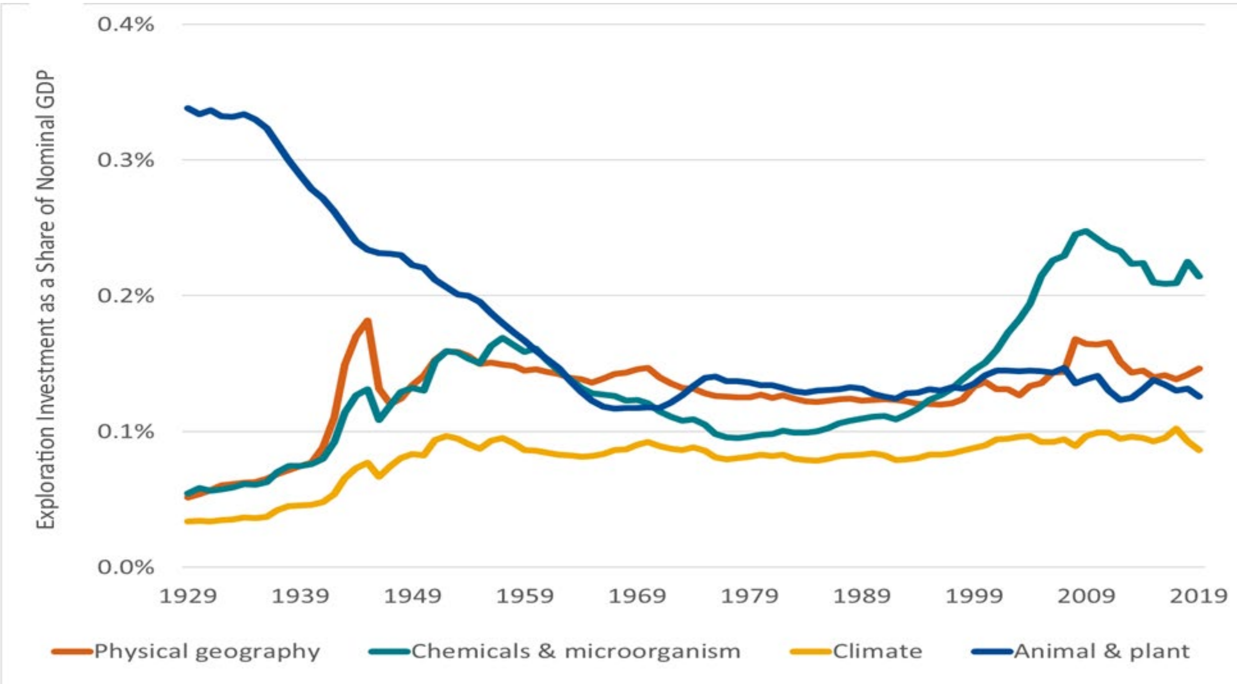

Figure 1 shows that natural resource exploration is a large investment category. Between 1929 and 2019, total exploration investment averaged 0.5 percent of nominal GDP. This ratio is smaller than the 4 percent of revenue that oil and gas companies spend on mineral exploration (Johnson 2010) and the 3 percent of revenue that construction companies spend on inspections and architecture (Ford 2020). But total GDP is much larger than just revenue for those two sectors, and so the four categories of natural resource exploration shown in figure 1 account for much more total investment than just mineral exploration and construction-related exploration.

The low GDP share for climate exploration might seem surprising. However, the results in figure 1 are not a data error. In fact, the Government Accountability Office has already written a report documenting low federal spending on climate science (2018). One might argue that climate exploration “should” be a large investment category because climate change is a major topic of concern and some experts believe that climate change will cause trillions in damages (IPCC 1996). However, it is common for spending on prevention before a crisis to be much lower than the potential loss from a crisis. For example, federal spending on pandemic prevention was very low during the 2010s (Greenberg 2020). This paper does not study the reasons behind a particular investment level. Instead, it simply documents how the NIPAs change when exploration is tracked as an intangible capital investment.

The stable GDP share for animal & plant exploration after 1960 may also seem surprising. It is true that the farm sector has grown much slower than the overall economy and now accounts for only a small share of total GDP. But suburban landscaping has grown much faster than the overall economy and now accounts for a noticeable share of total GDP. In other words, even Americans who buy all of their food at the grocery store may still be bothered by weeds and insects.

Investment by Sector: Data Sources and Estimates

The paper starts out by assuming that all military exploration belongs to the government. Next, the paper assumes that the smoothed share of civilian government workers in the ACS and the decennial Census proxies for the civilian government share of investment. Finally, the paper assumes that the smoothed share of non-profit workers in the private civilian workforce proxies for the non-profit share of private civilian investment. Readers should note that self-reported class of worker in the ACS and the decennial Census may not match national accounting rules (BEA 2019).

Figure 2. Government and Non-Profit Share of Exploration Investment by Category

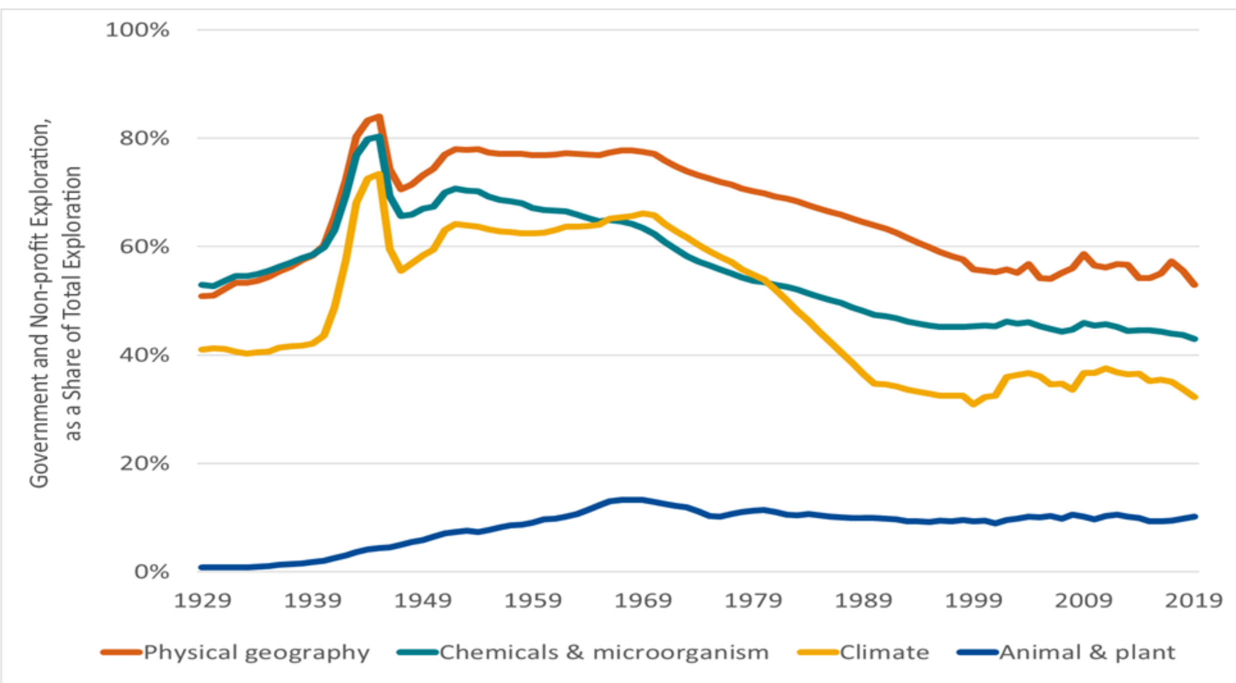

Figure 2 shows that the government and non-profit sectors account for a large share of every exploration category except animals & plants. Interestingly, the average government and non-profit share of exploration investment is quite close to the average share for other investment reported in BEA's currently published statistics. As a result, including exploration in measured investment does not change the average government and non-profit share of investment much.

The paper then allocates private investment across industries. Exploration by agricultural workers and pioneers is allocated to the farm sector, exploration by water and waste-water treatment plant operators is allocated to the utility sector, exploration by sailors is allocated to the water transportation sector, exploration by nonfarm gardeners is allocated to the real estate sector, exploration by insurance underwriters is allocated to the insurance industry, and exploration by foresters and fishermen is allocated to the forestry, hunting, and fishing sector. All remaining private exploration is then allocated across industries in proportion to BEA's existing estimates of nominal investment for each industry.

3. Depreciation, Capital Stock, GDP, Productivity, and Consumption

Natural resource exploration is a long-lived capital asset. To start out, exploration capital is an intangible asset and therefore does not suffer from physical wear. Furthermore, the market competition that creates depreciation for R&D assets (Li and Hall 2018) is not relevant to natural resource exploration because the owner of a particular natural resource has a secure monopoly on usage of that particular natural resource. Finally, the changing consumer tastes that reduce the value of old software and entertainment originals are rarely relevant because very little natural resource exploration is focused on fashion items. The combination of all of these factors means that natural resource exploration can last for decades if not centuries.

One might think that exploration depreciates as a natural resource is depleted. It is true that previous researchers viewed mineral depletion as depreciation of mineral exploration (Ryan et al. 2001). However, many of the natural resources studied in this paper are not impacted by usage at all. For example, past usage of radio spectrum does not change current spectrum properties at all. Furthermore, even natural resources that are impacted by usage are rarely completely depleted. For example, a forest owner might harvest a few deer and leave the rest to reproduce. In that example, exploration enables a dynamic usage strategy that maximizes output and minimizes costs. Because depletion of non-mineral natural resources is so rare, it does not contribute to depreciation.

Obsolescence due to changing market conditions has only a small and inconsistent effect on natural resource exploration. It is true that proven petroleum reserves, which are created by mineral exploration, were revised downwards by 20 percent in 2020 due to lower oil prices (Energy Information Administration 2022). But the average revision for proven petroleum reserves between 1977 and 2020 was 2.5 percent upwards (Energy Information Administration 2022). In other words, measured depreciation could be negative if historical revisions are used as a proxy for obsolescence. In order to avoid the problem of negative depreciation rates, this paper does not consider obsolescence associated with changing market prices. Instead, the paper focuses on obsolescence associated with usage changes. Voluntary sellers of a natural resource typically transfer exploration together with the non-produced natural resources. For example, farm sales typically include information on crop history, water quality, etc. (Bocci et al. 2019). Therefore, property sales alone do not create exploration. However, previous exploration may become obsolete when natural resources are transferred from the farm sector to the non-farm sector. Between 1982 and 2017, the National Resource Inventory (USDA 2020) reports that approximately 0.5 percent of acreage changed its broad sector each year. Assuming that exploration is sector-specific, the paper calculates an obsolescence rate on natural resource exploration of 0.5 percent per year.[7]

Depreciation Rates by Category

Physical geography exploration has a very long lifespan. Natural disasters large enough to suddenly change a landscape are very rare. And geological processes like continental drift or erosion generally take millions of years to change landscapes. Hence, the paper fixes depreciation for physical geography exploration at the minimum rate of 0.5 percent per year from obsolescence.

Chemical & microorganism exploration also has a long lifespan. Since the 1980s, the Environmental Protection Agency has maintained a list of contaminated sites that are a high priority for cleanup. Only 438 sites out of the 1,759 sites tracked have been declared clean, for an annual cleanup rate of approximately 1 percent per year. The paper then adds the 0.5 percent depreciation rate associated with obsolescence. In total, the paper fixes depreciation for chemical & microorganism exploration at 1.5 percent per year.

Climate exploration has an uncertain lifespan. Many climate scientists believe that weather patterns were very stable before human activity raised atmospheric carbon dioxide (Brooke, Bevis, and Rissing 2019). If that situation had continued, then climate exploration might have had the same 0.5 percent annual depreciation rate as physical geography exploration. Instead, the paper calculates its

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7. This minimum rate may overestimate depreciation if exploration retains its value after a sector change. It may underestimate depreciation if exploration is sometimes lost due to poor record-keeping by property owners.

depreciation rate by comparing variation in local climates with historical climate change. Across weather stations at similar latitudes, there is a 2º C standard deviation of normal temperatures (Prism Climate Center 2021). For example, New England is colder than London despite being further south (Mann 2005). Over the past century, average global temperatures have risen at approximately 0.01º C per year (A.1.2 of Intergovernmental Panel on Climate Change 2021). Therefore, the paper calculates that one year of global warming is equivalent to 0.5 percent (0.01/2) of normal climate variation.[8] The paper then adds the 0.5 percent depreciation rate associated with obsolescence. In total, the paper fixes depreciation for climate exploration at 1 percent per year.

Animal & plant exploration has the shortest lifespan. Trees are typically harvested for timber between age 25 and age 40 (Spicer 2014), and therefore their annual probability of harvest is around 3 percent. Fisheries can collapse if an area is overfished or damaged by climate change. One study estimated that 58 percent of the marine species tracked collapsed over the past few decades (Hutchings and Reynolds 2004),[9] which corresponds to an annual collapse probability of about 3 percent. Data on the lifespan for farm and garden exploration is assumed to match the lifespan for timber and fishing exploration. The paper then adds the 0.5 percent depreciation associated with obsolescence. In total, the paper fixes depreciation for animal & plant exploration at 3.5 percent per year.

Capital Stock and Net Saving

Because natural resource exploration is such a long-lived category, measured capital stock depends on investment during the 1800s and even earlier. The paper uses occupation data from Census to estimate on-the-job natural resource exploration for the 1850 to 1928 time period. Before 1850, historical estimates of the U.S. economy (Lebergott 1966) are used to extrapolate on-the-job natural resource exploration before 1850. The paper also estimates off-the-job exploration time by pioneers before 1900. Those pioneer exploration numbers are calibrated to the 1803 Louisiana Purchase price (Lee 2017a and b) and research showing that the frontier closed around 1890 (Turner 1893). Finally, the paper assumes that large tracts of territory acquired by the United States from Indian tribes, Mexico, Russia, or other countries came without much exploration capital.

Total current-cost exploration stock is calculated by summing the depreciated real value of all previous exploration projects and then multiplying that value by the exploration price index. Specific data

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8. If climate changes suddenly, the reduction in the value of climate exploration could be tracked with other natural disaster losses in “other changes in the volume of assets” (U.N. Statistics Division 2008, sec. 1.69).

9. A few species later recovered, but their new habitat and new fishing regulations may be sufficiently different that historical exploration capital is not useful to fishermen anymore.

tracking either physical geography exploration costs, chemical & microorganism exploration costs, climate exploration costs, or animal & plant exploration costs was not located. Instead, the paper uses BEA's pre-existing price index for mining exploration (NIPA Table 5.4.4, line 22) as a deflator.[10] This price index has grown consistently over time. As a result, current-cost capital stock measures are always higher than historical-cost capital stock measures. Current-cost CFC is calculated by multiplying current-cost exploration stock by the depreciation rates estimated earlier. Finally, net savings is calculated as the difference between the investment shown in figure 1 and current-cost CFC.

Figure 3. Exploration Capital Relative to Natural Resource Value

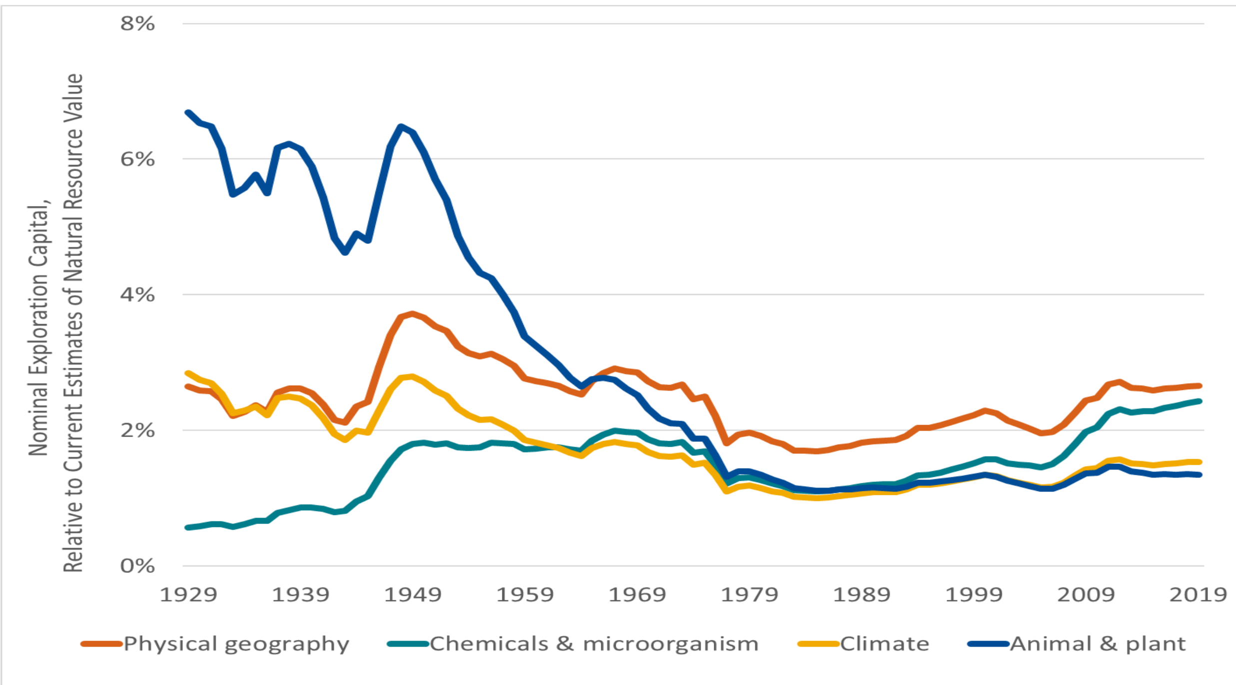

Figure 3 shows that exploration capital accounts for a large share of natural resource value. To remind readers, the market value for natural resources covers both non-produced natural resources and produced exploration capital. Explicitly tracking the exploration capital shown above does not change measured nominal wealth, but rather reframes a portion of the market value as due to produced exploration capital rather than due to non-produced natural resources.

10. That table only reports mining exploration prices back to 1946, but prices back to 1901 can be calculated from BEA's fixed asset tables for NAICS 2120. Before 1901, labor costs are used as an extrapolator.

Figure 4. Revision to Measured Saving Relative to Natural Resource Value

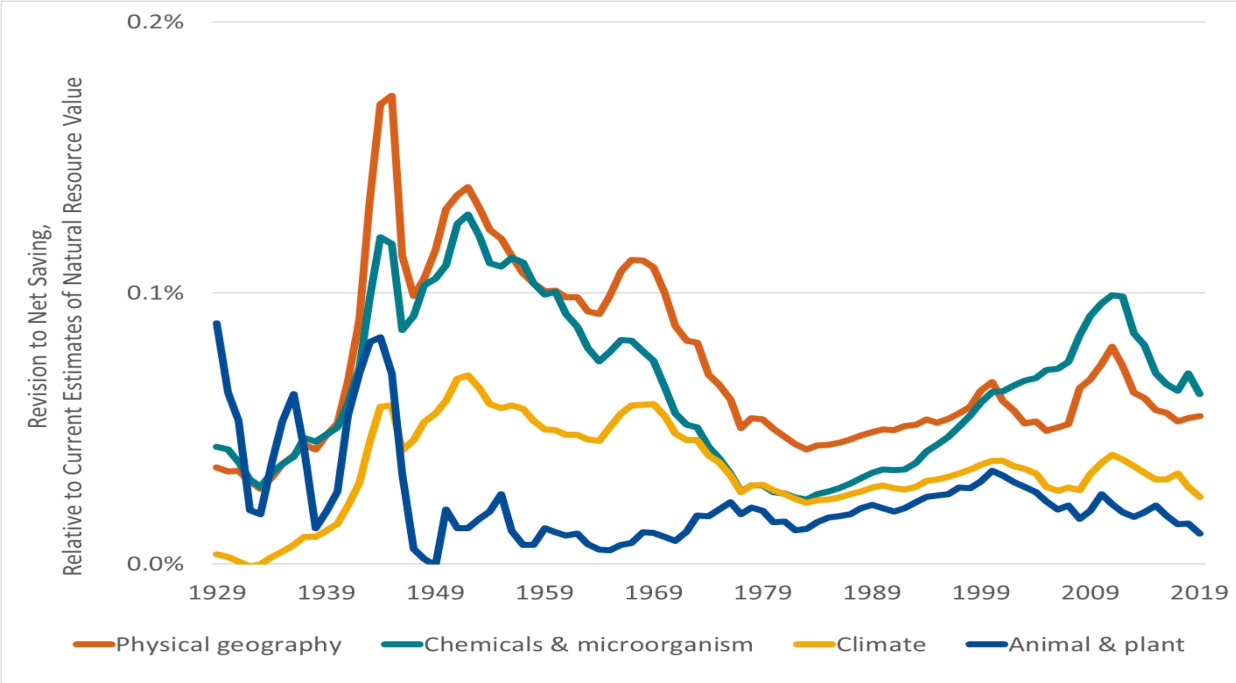

Figure 4 shows that net savings unambiguously increase when natural resource exploration is tracked. This upward revision to measured savings has important implications for measured natural resource prices. The joint BEA-BLS production accounts currently assume that land, air, water, radio spectra, and other natural resources are non-produced assets (U.N. Statistics Division 2008, sec. 10.166–10.185, 10.184, and 10.185). As a result, increases to their nominal value are entirely attributed to price growth. Figure 4 shows that a small share of the nominal value increase should be instead attributed to real growth of exploration capital. Between 1929 and 2019, the paper calculates that non-produced natural resource price growth overestimated by 0.2 percentage point per year and real growth is under-estimated by 0.2 percentage point per year. As a result, overall asset growth is underestimated by 0.05 percentage point per year." and real asset growth is underestimated by 0.05 percentage point per year.

Nominal GDP

To review national accounting rules, the GDP impact of exploration depends on the sector. Measured output in the for-profit business sector increases by the newly tracked investment and measured output for the government and non-profit sectors increases by the newly tracked CFC. Most animal & plant exploration is done by for-profit businesses, so the revision to GDP from animal & plant exploration closely tracks the revision to measured investment shown in figure 1. In contrast, governments and non-profits account for a large share of investment in the other three categories, so the revision to GDP from those exploration categories is moderately smaller than the revision to investment shown in figure 1. Nevertheless, the revision to GDP closely follows the general revision to investment shown in figure 1.

Figure 5. Revision to Nominal GDP as a Share of Nominal GDP

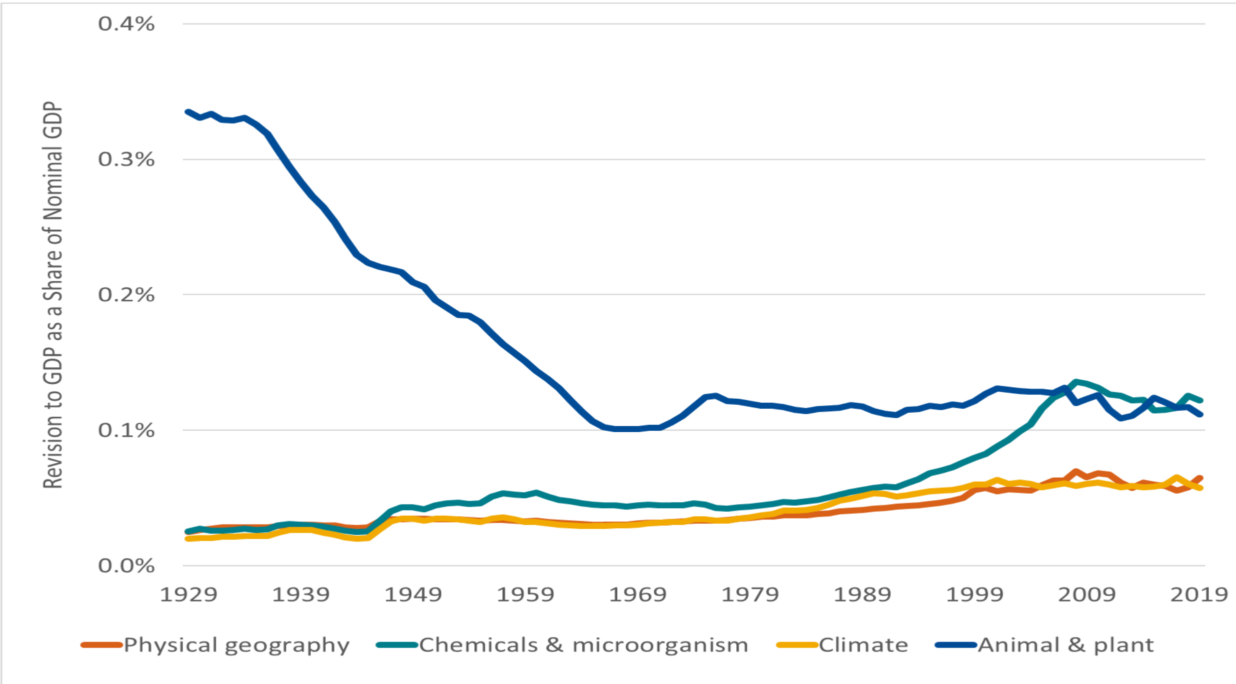

Figure 5 shows that nominal GDP growth falls only slightly when exploration investment is capitalized. This slight growth decrease is due to the declining nominal GDP share for animal & plant investment. The other three exploration categories have grown slightly faster than the overall economy. Combining all four exploration categories, nominal growth falls by 0.001 percentage point per year between 1929 and 2019. Over the same time period, exploration prices have grown 1.1 percentage point per year faster than overall GDP prices. Combining all four exploration categories, real growth between 1929 and 2019 falls by 0.004 percentage point per year. Neither the nominal growth decrease nor the real growth decrease are enough to change economic history noticeably.

Total Factor Productivity (TFP)

The productivity calculations in this paper are based on existing industry-level production accounts that track labor, capital services, and intermediate inputs by industry (Garner et al. 2020). However, the paper uses a simplified methodology to calculate TFP that studies only three direct changes associated with tracking exploration capital. First, capitalizing exploration increases measured output by the newly tracked exploration investment. Second, capitalizing exploration assets increases measured input by the newly tracked capital services associated with exploration. Third, the measured capital services associated with non-produced natural resources are revised due to changes in the nominal value and price series for those assets. The paper uses the nominal investment numbers shown in figure 1, the government investment shares shown in figure 2, the price index for exploration, the capital stock numbers shown in figure 4, and expert judgment to calculate revised measures of output and input for 57 mostly for-profit business industries in the joint BEA-BLS production accounts.[11]

Figure 6. Relative Revision to For-Profit TFP Index from Tracking Exploration

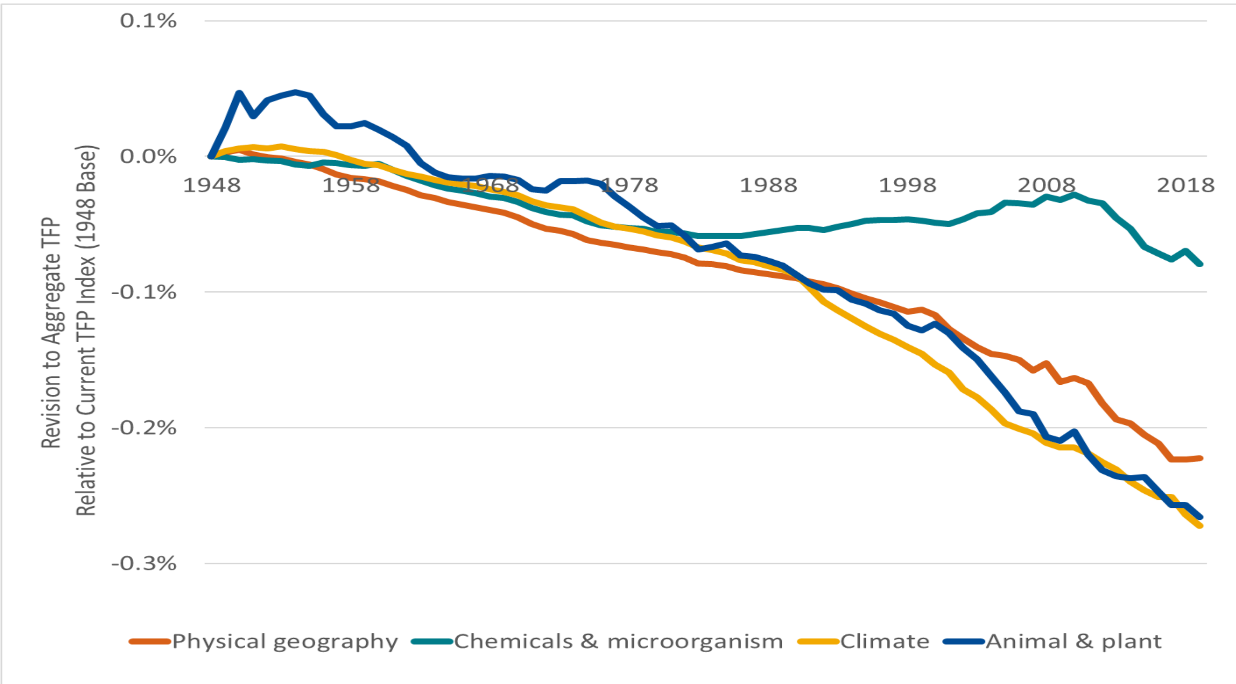

Figure 6 shows that measured TFP growth falls by 0.01 percentage point per year when exploration capital is tracked. This growth decrease can be decomposed into the difference between real output growth and real input growth. On the one hand, figure 5 showed that output growth is almost unchanged when exploration investment is tracked. On the other hand, figure 4 showed that net savings in exploration capital are always positive and therefore real assets grow noticeably faster when exploration capital is tracked. The combined effect of both of these revisions is a noticeable drop in productivity growth.

11. Four industries with a significant non-profit presence (education, social assistance, performing arts, and other services) are excluded because their output is difficult to measure directly.

Real Government and Non-Profit Consumption

BEA's standard formula for calculating consumption assumes that current consumption is equal to government and non-profit spending minus investment plus CFC. Exploration investment has consistently exceeded exploration CFC, so tracking exploration decreases the nominal level of government and non-profit consumption for every year studied. But the impact on consumption quantity indexes is theoretically ambiguous and depends on the precise levels of investment and capital in each year. In order to match the TFP graph shown earlier, this paper calculates a consumption quantity index with a base year of 1948.

Figure 7. Relative Revision to Consumption Quantities from Government and Non-Profit Exploration

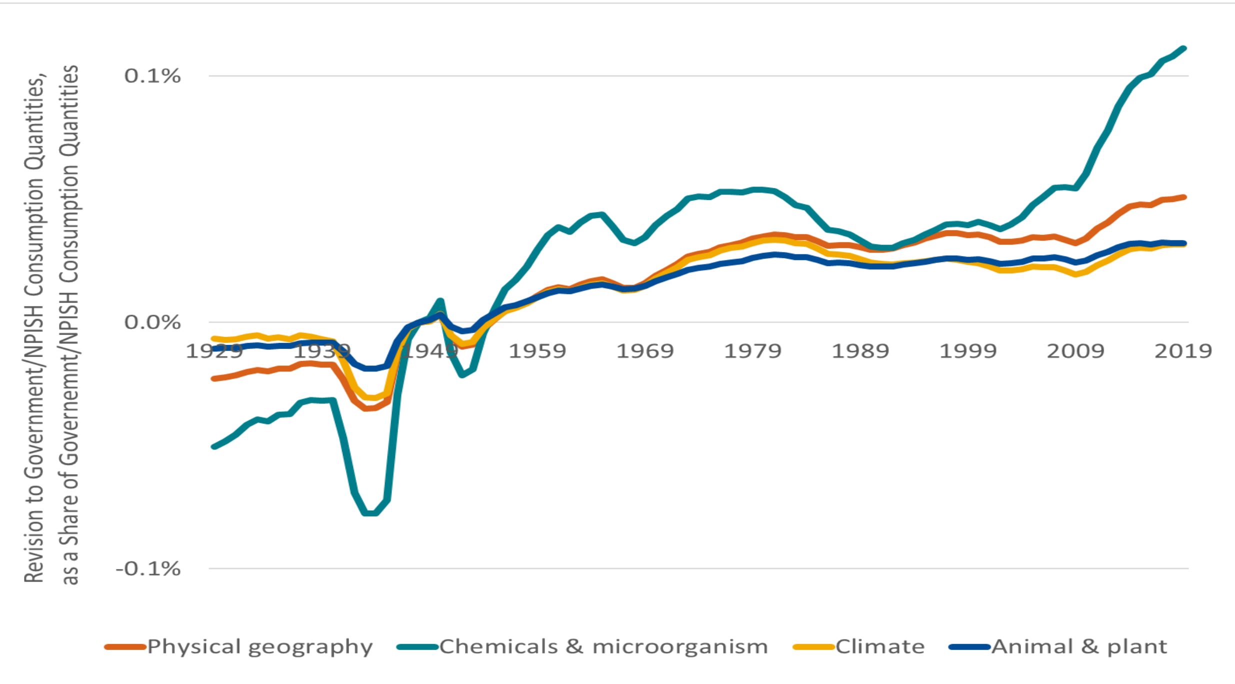

Figure 7 shows that tracking government and non-profit exploration investment has only a small impact on measured consumption growth. This null result suggests that broadening the scope of GDP to better track natural resource services is unlikely to fundamentally change measured growth.

Real Individual Consumption

BEA's standard formula for calculating individual consumption is not directly impacted by exploration capital owned by for-profit businesses. As a result, simply tracking natural resource exploration will not necessarily change measured individual consumption. However, BEA's standard formula for calculating individual consumption might not apply if natural resource exploration is associated with unmeasured quality change. As an experiment, the paper calculates a possible measure of quality-adjusted consumption associated with natural resource exploration. In order to produce an experimental measure, the paper makes the following assumptions about unmeasured quality change: (a) each industry has a production process where a $1 increase in exploration capital services per unit of output increases quality by $1 per unit of output; (b) current output prices do not track any of the quality improvement associated with exploration; and (c) industry output quality is not impacted by indirect factors.

Figure 8. Relative Experimental Revision to Quality-Adjusted Individual Consumption

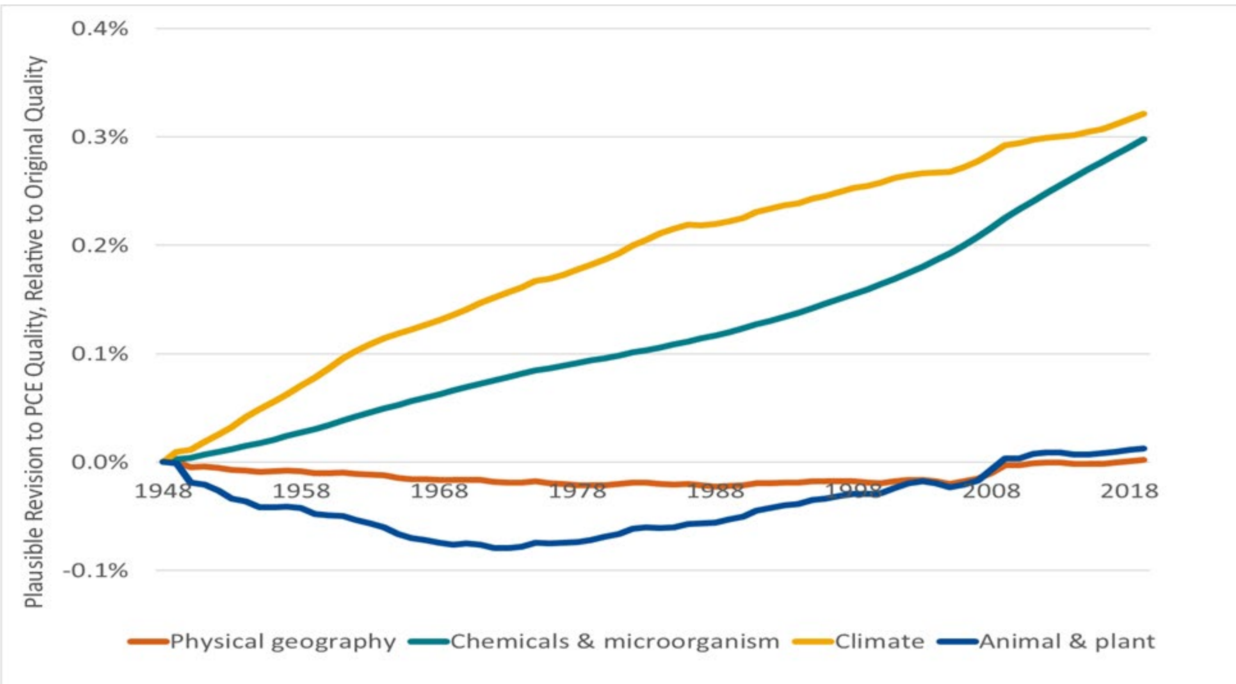

Figure 8 shows that the unmeasured quality growth potentially associated with natural resource exploration is likely small. Intuitively, natural resource exploration services have grown at approximately the same rate as overall consumption. This null result is somewhat sensitive to the exact assumptions made—but does not change dramatically for reasonable tweaks to the formula.

Conclusion

Natural resources are everywhere, and reported wellbeing is highly correlated with the quantity and quality of natural resource services like weather and biodiversity (Levinson 2012) (MacKerron and Mourato 2013) (Methorst et al. 2021). Yet, natural resources are currently classified as non-produced assets (U.N. Statistics Division sec. 10.14) and therefore natural resource services cannot be attributed to either labor inputs now or capital investment in the past. For those used to thinking about consumption growth as a consequence of labor growth or capital input growth, this raises immediate concern that natural resource service growth is unmeasured within the standard gross domestic product (GDP) framework. Furthermore, this concern has evolved into arguments that GDP growth is a fundamentally flawed measure of wellbeing growth (Stiglitz et al. 2009).

This paper shows that natural resource service growth can be explained by new exploration investment and therefore can be measured within the standard GDP framework. For example, a utility might start out with a non-produced watershed and then increase the watershed's value by searching for an aquifer with the cleanest water. Tracking exploration raises measured investment in every year studied and raises real asset growth by 0.05 percentage point per year between 1929 and 2019. However, the increase to measured investment is similar in 1929 as it is in 2019, and so the revisions to real GDP growth and real consumption growth are very small. These empirical results suggest that broadening the scope of GDP to track natural resource exploration and natural resource services does not fundamentally change growth.

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Appendix A: Share of Time Spent on Exploration for Selected Occupations

O*Net Code	Occupation Title	Sample Exploration Task	Physical geography	Chemical & microorganism	Climate	Animal & plant
19-4012	Agricultural Technicians	Record environmental data from field samples of soil, air, water, or pests to monitor the effectiveness of integrated pest management (IPM) practices.	5%	15%	0%	15%
19-3091	Anthropologists and Archeologists	Record the exact locations and conditions of artifacts uncovered in diggings or surveys, using drawings and photographs as necessary.	42%	0%	0%	0%
19-2011	Astronomers	Calculate orbits and determine sizes, shapes, brightness, and motions of different celestial bodies.	27%	0%	0%	0%
19-2021	Atmospheric and Space Scientists	Gather data from sources such as surface or upper air stations, satellites, weather bureaus, or radar for use in meteorological reports or forecasts.	0%	9%	53%	0%
53-6011	Bridge and Lock Tenders	Log data, such as water levels and weather conditions.	0%	0%	5%	0%
27-4012	Broadcast Technicians	Monitor strength, clarity, and reliability of incoming and outgoing signals, and adjust equipment as necessary to maintain quality broadcasts.	19%	0%	3%	0%
53-5021	Captains, Mates, and Pilots of Water Vessels	Measure depths of water, using depth-measuring equipment.	1%	3%	2%	0%
17-1021	Cartographers and Photogrammetrists	Compile data required for map preparation, including aerial photographs, survey notes, records, reports, and original maps.	100%	0%	0%	0%

O*Net Code	Occupation Title	Sample Exploration Task	Physical geography	Chemical & microorganism	Climate	Animal & plant
49-9092.00	Commercial Divers	Operate underwater video, sonar, recording, or related equipment to investigate underwater structures or marine life.	6%	0%	3%	3%
19-1031	Conservation Scientists	Compile or interpret biodata to determine extent or type of wetlands or to aid in program formulation.	33%	42%	8%	17%
17-3025	Environmental Engineering Technologists and Technicians	Collect and analyze pollution samples, such as air or ground water.	0%	67%	0%	0%
19-4042	Environmental Science and Protection Technicians, Including Health	Collect samples of gases, soils, water, industrial wastewater, or asbestos products to conduct tests on pollutant levels or identify sources of pollution.	0%	56%	0%	0%
19-2041	Environmental Scientists and Specialists, Including Health	Collect, synthesize, analyze, manage, and report environmental data, such as pollution emission measurements, atmospheric monitoring measurements, meteorological or mineralogical information, or soil or water samples.	12%	67%	0%	21%
45-2092	Farmworkers and Laborers, Crop, Nursery, and Greenhouse	Identify plants, pests, and weeds to determine the selection and application of pesticides and fertilizers.	0%	0%	0%	4%

O*Net Code	Occupation Title	Sample Exploration Task	Physical geography	Chemical & microorganism	Climate	Animal & plant
33-3031	Fish and Game Wardens	Collect and report information on populations or conditions of fish and wildlife in their habitats, availability of game food or cover, or suspected pollution.	0%	2%	0%	17%
19-4071	Forest and Conservation Technicians	Inspect trees and collect samples of plants, seeds, foliage, bark, and roots to locate insect and disease damage.	6%	2%	4%	24%
45-4011	Forest and Conservation Workers	Examine and grade trees according to standard charts and staple color-coded grade tags to limbs.	0%	0%	0%	15%
33-2022	Forest Fire Inspectors and Prevention Specialists	Compile and report meteorological data, such as temperature, relative humidity, wind direction and velocity, and types of cloud formations.	5%	0%	9%	3%
19-1032	Foresters	Map forest area soils and vegetation to estimate the amount of standing timber and future value and growth.	4%	5%	0%	59%
19-3092	Geographers	Create and modify maps, graphs, or diagrams, using geographical information software and related equipment, and principles of cartography, such as coordinate systems, longitude, latitude, elevation, topography, and map scales.	84%	0%	0%	0%
19-4043	Geological Technicians, Except Hydrologic Technicians	Collect or prepare solid or fluid samples for analysis.	17%	16%	6%	0%

O*Net Code	Occupation Title	Sample Exploration Task	Physical geography	Chemical & microorganism	Climate	Animal & plant
19-2042	Geoscientists, Except Hydrologists and Geographers	Identify risks for natural disasters, such as mudslides, earthquakes, or volcanic eruptions.	37%	9%	11%	1%
19-2043	Hydrologists	Measure and graph phenomena such as lake levels, stream flows, and changes in water volumes.	31%	11%	39%	0%
13-2053	Insurance Underwriters	Evaluate possibility of losses due to catastrophe or excessive insurance.	0%	0%	10%	0%
19-1022	Microbiologists	Monitor and perform tests on water, food, and the environment to detect harmful microorganisms or to obtain information about sources of pollution, contamination, or infection.	0%	14%	0%	0%
19-5011	Occupational Health and Safety Specialists	Collect samples of dust, gases, vapors, or other potentially toxic materials for analysis.	0%	15%	0%	0%
19-5012	Occupational Health and Safety Technicians	Collect data related to ecological or human health risks at brownfield sites.	0%	13%	0%	0%
37-3012	Pesticide Handlers, Sprayers, and Applicators, Vegetation	Identify lawn or plant diseases to determine the appropriate course of treatment.	0%	0%	0%	11%
53-5011	Sailors and Marine Oilers	Measure depth of water in shallow or unfamiliar waters, using leadlines, and telephone or shout depth information to vessel bridges.	1%	0%	2%	0%

O*Net Code	Occupation Title	Sample Exploration Task	Physical geography	Chemical & microorganism	Climate	Animal & plant
19-1013	Soil and Plant Scientists	Study soil characteristics to classify soils on the basis of factors such as geographic location, landscape position, or soil properties.	0%	38%	0%	7%
37-3013	Tree Trimmers and Pruners	Inspect trees to determine if they have diseases or pest problems.	0%	0%	0%	5%
19-3051	Urban and Regional Planners	Create, prepare, or requisition graphic or narrative reports on land use data, including land area maps overlaid with geographic variables, such as population density.	53%	4%	0%	0%
51-8031	Water and Wastewater Treatment Plant and System Operators	Collect and test water and sewage samples, using test equipment and color analysis standards.	0%	15%	0%	0%
19-1023	Zoologists and Wildlife Biologists	Study animals in their natural habitats, assessing effects of environment and industry on animals, interpreting findings and recommending alternative operating conditions for industry.	0%	0%	0%	74%