UNITIZATION OF OIL RESERVES IN ALASKA AND THE SUPPLY ELASTICITY OF A COMMON POOL RESOURCE

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ABSTRACT

Unitization, a common but not omnipresent policy that is lauded in both the economics and environmental worlds for its efficiency, attempts to solve the "tragedy of the commons" common pool failure of oil production by creating a system in which all those with interests in one reserve produce jointly and split profits accordingly. This paper empirically demonstrates what other researchers have hypothesized – that unitization reduces the elasticity of supply with respect to price. It then extrapolates to potential impacts this policy could have on the environment at large by forecasting a future production path based on the model from the previous section. Finally, it demonstrates how unitization could slow the accumulation of greenhouse gases in the atmosphere.

JEL Classification: Q38, Q48, Q54

Keywords: Oil, Oil Reserves, Oil Production, Unitization, Climate Change, Alaska

I. Introduction

Oil extraction is a process that imposes both environmental externalities on society and production externalities on other firms using a common pool. As a consequence, production is often inefficient from the perspectives of both society at large and other firms in the industry. By addressing the common pool problem, unitization, a well-recognized policy solution that consolidates participating interests and selects a single firm to develop the reserve with net returns shared by all parties, can largely contribute to solving both of these problems.

Unitization does not always take place, however, often because of imperfect information and timing concerns in drawing up the contract. This means that firms continue to extract as individual competing entities, leaving efficiency gains unrealized and the environment under pressure. In quantifying the effect unitization has on oil production, I hope to provide further impetus for implementing this policy. I also demonstrate the impacts of this policy for the accumulation of greenhouse gases, highlighting its role in climate change policy.

In this paper, I first give a brief background of the Alaskan oil industry, highlighting what makes it unique from oil production in other parts of the world. Next, in Section III, I review the relevant literature, discussing policies that have been used over time in an attempt to make oil production more economically efficient and less harmful to the environment, finally focusing on unitization. I also introduce the general theory behind unitization in this section. In Section IV, I introduce the data I use, and in Section V I detail the economic methods I use to recover the industry supply curve. I demonstrate how producers' daily decisions about extraction activity are affected by price and I show how unitization affects the elasticity of supply. In Section VI, I analyze my results, quantifying the effect unitization has on the supply of oil. I conclude in Section VII with a discussion of the impacts on both the oil industry itself and on the energy industry at large, extrapolating the implications of these conclusions to global climate change and making recommendations for future research.

II. Background and Thesis

Because climate change is driven substantially by the addition of carbon dioxide to our atmosphere, delaying the addition of carbon to the atmosphere will slow down the rate of climate change. Petroleum combustion is responsible for a significant percent of this CO2 (Hansen et. al, 2005). Therefore, reducing the amount of oil supplied and thus burned up into the air is key. I hypothesize that unitization contributes positively to this campaign against global climate change, at its simplest by lowering producers' desire to supply as much oil as quickly and lowering consumer demand through driving up price.

Production of oil and gas is different from production in many other industries. The process begins when an individual or firm purchases a tract of land or leases mineral rights from a landowner. At this point, the American "rule of capture" policy makes it such that mineral rights owners have a right to exploit the property to their own economic benefit on all physical levels, i.e. both above and below ground (Cooper, 1973).

In the state of Alaska, all land was initially owned by the state, which was leased in exploratory licenses to those seeking oil, and then to production licenses to those who discovered it – or at least believed they had. Wildcatting – the exploration and initial attempts at drilling for new productive oil reserves – began there in the 1800s, but major finds did not come until the middle of the next century (Cicchetti, 1972). These successes brought people, infrastructure, money, environmental degradation, and eventually the trans-Alaska overland pipeline, which served to further incentivize producers. Though Alaska made up over 10% of US oil production as of 2011 (EIA), second only to Texas, this means it is only about 1% of world production – and it comes with a heavy price tag – both economic and environmental.

The production of crude oil brings with it several problems when considering its extraction and sale. Because oil is found in large, pressurized underground pools, the classic "tragedy of the commons" arises, complicating relations between firms in the industry. First, the common access nature of these pools allows whatever number of individuals or firms who possess mineral rights to the aboveground tracts of land. Though the mineral rights to a certain tract of land are leased to certain individuals and firms, the resources are not considered property of the firm until they are extracted – commonly referred to as the "rule of capture". This implies that if a mineral rights lessee knows that his land shares a reservoir with another nearby landholder, he will attempt to extract as much of the resource as possible before his neighbor can – engaging in a "race to extract" the resources. His sensitivity to price is thus very high, allowing his production path little flexibility. A second obstacle that firms encounter is that when secondary extraction techniques such as the injection of water and gas are employed, the complicated geology of gas and oil fields can result in pockets of oil becoming trapped. Were additional wells not drilled, these pockets of nonrenewable resources would otherwise have been extractable. These are the two major ways that competition in this industry results in wasted resources.

Over the years, many different policies have been employed in an attempt to mitigate these issues. One of the first was direct government regulation in the form of production caps and controls. This proved to be inefficient, however, as in addition to spurring animosity between government and firms, it also failed to adequately take into account the heterogeneous nature of individual firms (Adelman, 1964; Weaver, 1986). In the Texas and Oklahoma region, the most important United States production region before Alaska, prorationing – or capping the number of wells allowed and then allocating rents on the basis of proportional land ownership – was the most common solution chosen by competing firms. However, this type of contract does not improve production efficiency to nearly the degree desired because it does not leave adequate decision-making power in the hands of the producers (Khoury, 1969; Cooper, 1983; Libecap & Wiggins, 1984). A third option considered in production is that one firm could buy out all of the producing area, but this is improbable due to the massive expense that would be involved in doing so (Lueck & Schenewerk, 1996).

One policy method that economists over the years have lauded as highly effective in easing the issues that result from the common pool nature of oil and gas resources is unitization (Bain, 1947; Libecap & Wiggins, 1984; Asmus & Weaver, 2005; Goorha & Mohan, 2008). Unitization is defined as

> "[a] combination of most, if not all, of the separate tracts in the field into one tract so that the reservoir or field can be developed as a single entity, without regard to surface boundary lines" (Meyers & Williams, 1995).

Unitizing oil reserves can be an effective policy because it forces firms to work in agreement so that they reach their goals as one (McDonald 1971; Libecap & Wiggins 1985b; Libecap & Smith 2001).

Both oil and gas reserves can be unitized, but while gas and oil are both very important resources and are both abundant in Alaskan reservoirs, I have decided to focus on oil production rather than on natural gas for several reasons. First, demand for, potential profit from, and the environmental impact of combustion of oil resources are all greater than for natural gas, meaning that focusing on oil will both yield more interesting results and be more relevant to the entire world. Second, there are more options for transporting oil than for transporting gas, and Alaska is a location that sports such geographic and climactic characteristics that creating infrastructure and thus transporting either of these resources is incredibly costly and difficult. At first both oil and gas were primarily stored and used locally, making profit margins for producers incredibly low, and even as tankers came into prominent use they were often impractical due to the freezing of the Arctic waters (Adelman, Bradley & Normal, 1971). The 1977 completion of the Trans Alaska Pipeline gave far greater access to the oil industry, however, lowering both transportation and storage costs substantially and giving oil producers far greater access to the market at large. Finally, oil extraction techniques exhibit a great deal more variety than gas extraction techniques, including common "secondary" techniques that involve the re-injection of siphoned-off natural gas into a nearby well with the purpose of speeding oil extraction by increasing pressure within the system, showing just how little value natural gas has in comparison to black gold.

Thirty-three states have passed statutes that have some way to mandate unitization, but none of these states mandate it in every instance (32 Energy & Min. L. Inst. 13, 2011), and the remaining states do not mandate it at all. Still, these numbers demonstrate a steady increase over the last century, for unitization in the early 1900s was known but virtually unseen, and even by the latter half of the century unitized wells were still in the minority (Bain, 1947; Libecap & Wiggins, 1985a). Alaska is one of the states, however, that has enacted a unitization mandate. Since 1978 there has existed the option to petition for a unit, where a certain percentage of operators on a proposed unit must be in favor of the unit's creation (Alaska Oil and Gas Conservation Act, 1978). In this case, some operators are voluntarily opting to unitize, but others are forced to cooperate by a state ruling. The relevant theory behind unitization policy is discussed in the following section.

III. Literature Review

The seminal paper on property rights, "The Nature of the Firm" (Coase, 1937), analyzes how through bargaining, the inefficiency from creation of externalities can be eliminated, regardless of the initial allocation of property rights (as long as property rights are assigned to someone). In the case of oil extraction, the externalities in question are those that result from the "tragedy of the commons". More recently, the focus of this field has been called the "tragedy of the anticommons", concern for the inefficiency of uncontracted lands with overlapping interests. Buchanan and Yoon (2000) develop an early econometric model to analyze the problem of resource underutilization in the context of both the tragedies of the commons and the anticommons, ultimately discerning that the problems are not so very different. Underutilization and overutilization of resources both result in significant losses to efficiency. Schulz, Parisi, and Depoorter (2002) build on this, finding that this pattern results because individuals' private incentives fail to capture the external effects of exclusion. In practice, however, bargaining is limited by transactions costs. In the oil industry, transactions costs come in the form of giving up the law of capture, decreasing profit margins due to ignored heterogeneity, and opportunity costs incurred during the process of drawing up individual contracts. Together, this research highlights a need for some sort of joint contract in order to maximize gains to production.

In creating a joint operating contract, as Coase (1937) pointed out early on, the cost per transaction on a one-to-one basis would be prohibitively high; a far better option that oil producers have is trading all rights to a single operator through a unitization contract. Kim and Mahoney (2002) further the theories from work by Schulz, Parisi, and Depoorter by synthesizing the possibilities of underutilization and overutilization of a resource into one problem. They analyze past case studies comparing unitized and non-unitized oil fields, citing those operating under unitization contracts as more successful because of their ability to internalize the problems associated with joint property rights.

Economically, unitization minimizes rent dissipation for this non-renewable resource because it allows firms to invest a significant amount less in capital and other production expenses, as each individual firm does not need to drill and operate their own well (or wells), manage their own labor forces, or develop their own infrastructure (McDonald, 1971; Weaver, 1986; Lueck & Schenewerk, 1996). It also increases the likelihood that firms will correct intertemporal inefficiency, namely in that it halts the "race to extract" because competition is no longer a factor (Goorha & Mohan, 2008). Decreasing this competition allows firms to leave the oil in the ground for the most efficient amount of time, which is important because it prevents firms from over-supplying and thus losing an opportunity to react properly to price, and at the same time allows maximization of the volume of resources extracted, so that no potential profit is lost due to inability to extract and sell remaining pockets of oil.

The environmental implications of this type of policy are also critical. Unitization contracts can minimize environmental damage primarily by combatting the "tragedy of the commons". Because each firm is not constructing its own infrastructure, drilling its own wells, or operating its own processing plants, the land is subjected to far less degradation. Increased intertemporal efficiency is important for the environment, as well, as it minimizes the dangerous practice of storing excess oil that does not get supplied immediately to the market aboveground (Alaska Land Act of 1976, 1976; Weaver, 1986; Asmus & Weaver, 2005; Mikkelsen & Langhelle, 2008).

These two sets of implications form the crux of the motivations behind the creation of unitization policy overall, and they are relevant to extraction sites all over the world. Despite the high degree of variation between geographic, political, and macroeconomic conditions that influence a firm's decisions on drilling and operating a well, these are outcomes that are expected to fairly consistently hold true across time and space. I further hypothesize, however, that the implications of this policy go far beyond this, in that the effect it has on oil supply then in turn affects emissions levels from fossil fuels and thus global climate change.

There are still some barriers to unitization, however, among which are many of the same concerns as for any Coasian bargaining scenario. Asymmetrical information is one key deterrent to successful unitization (Libecap & Wiggins, 1985a). Many parameters must be considered in drawing up a unitization contract in order to determine agreeable lease values and unit shares, including the current level of oil and gas production, cumulative levels of oil and gas production, number of wells, surface acreage, bottom hole pressure, gross acre feet of pay (volume of the producing formation), net acre feet of pay (nonporous and non-oil-bearing rock is subtracted from the gross measure), and remaining reserves (original oil-in-place less cumulative production) being among the most prominent. Some of these parameters are objective, while employees of involved firms (e.g. geologists, economists) determine others, making determining the final conditions of the contract a long and arduous process.

Differences in interests among the owners frequently result in contractual failure, as well (Libecap & Smith, 2001). One key difference that occurs is when reserves contain more than one resource – i.e. both oil and natural gas – and this heterogeneity is ignored. Such situations can lead to some firms producing with lower profit margins as members of a unit than they did on their own (Libecap & Wiggins, 1985a; Goorha & Mohan, 2008).

Another consideration is that because of the highly competitive nature of the oil industry, temporal considerations are often an issue. While unitizing lowers transactions costs by assigning all rights to a single producer, firms still do not wish to incur opportunity costs from spending time and money negotiating rather than racing their competitors to extract the oil to which they already have access.

A fourth theory, given by Libecap & Smith (2001), is that firms may have difficulty giving up the law of capture. By signing a unitization contract, a firm loses the sole right to mineral extraction. However, firms often want to retain even the rights to those land holdings that have not yet yielded very high levels of production as a hedge against nearby discoveries or changes in other competitive conditions (Rogers, 1970). Oil does have a very high potential resource value, so it is understandable that firms would be hesitant to give up these rights in favor of a policy that will instead implement shared profits.

Despite its shortcomings, unitization is still widely seen as a good solution, as I describe above. To test this theory, Goorha and Mohan (2008) compare unitized and non-unitized reservoirs. Their use of econometric models is limited, however, as they focus primarily on legal influence, and their conclusion suggests that unitization is not always the best option, due to many of the same considerations discussed above. A second influential and relevant comparison of unitized and non-unitized oil reservoirs, however, written by Lueck and Schenewerk (1996), relies on dynamic economic models based in optimal control theory to prove the effectiveness of the policy. This approach yields several major conclusions that I then use to guide my own expectations. Key among these are (a) that unitization yields to a lower rate of production, (b) a unitized well will have a longer life, and (c) total ultimate extraction will be greater for a unitized well. Taken together, these conclusions imply a greater concern for the future and greatly inform my analysis.

Literature dealing directly with unitization policy is not the only relevant background information for my research. Notably, in the dominant portion of literature on petroleum resources as a whole, several key trends in modeling production present themselves as particularly well accepted and relied upon. From an engineering standpoint, considerations of initial reservoir allocation, cumulative predicted production capacity, and interactions with other wells appear consistently as crucial physical characteristics to take into account (Muskat, 1981; Lake, 2007; Aleksandrov & Espinoza, 2010; Cologni, & Manera, 2011). These all serve as important controls for pressure, which is key because pressure decreases as a well empties and so acts less to aid in extraction. Economic considerations focus on price as a primary determinant (Gately, 1984; Ghalayini, 2011; Cologni & Manera, 2011), an intuitive input due to the simple assumed relationship of price to supply. Dees et al. (2007) refer to this as the "economic input" to a successful model – the other components being geological, as I discuss above, and institutional, to which I attribute the consideration of unitization in my own model. In this literature, there is also a great deal of discussion of dominant versus non-dominant producers within the industry, sometimes referred to as "swing producers" (Gately, 1984; Griffin, 1985; Morecroft & van der Heijden, 1992). According to this literature, OPEC has a great deal of control over world oil price and thus, to a certain degree, supply. It is also important to note, however, that the United States is still considered a large oil producer – though Alaska's role in the context of the world is definitely small. Trends over time are a final fundamental component to these studies. Gately (1984) and Griffin (1985) give detailed overviews of key events in the world oil market throughout the world oil crisis that show how political events throughout those years affected the supply and demand of world oil, and Ramcharran (2002) comes to the same conclusions through a discussion of more recent events. This conclusion is understandable, given the long-standing history of this industry: it has seen many changes throughout the years.

Dées, Karadeloglou, Kaufmann, & Sánchez (2007) incorporate all of these considerations into their model, describing them as "geology, economics, and institutional factors". In their econometric methodology, they use a general regression where:

$$Prod = \alpha + \beta_1 \Delta Q_t + \beta_2 ROIL + \beta_3 Local + \beta_4 Asym + \mu$$

Specifically, the determinants of oil production that they choose are the slope of production at the given point in time (ΔQ_t), the real price of oil (ROIL), consideration of any local events or trends (Local), and the product of ΔQ_t and a dummy for whether or not the producer has passed the peak on their production curve (Asym). My regression is modeled strongly on this methodology, with modifications made to better fit my question and the specific per-well nature of my data. It is important to note that the authors successfully used this model to "backcast" prices and quantities; I assume that my closely related model will have the same capability.

Solving the property rights dilemma in the field of oil production has many potential impacts. First and foremost, as previously discusses, it is meant to increase economic efficiency and minimize local environmental impact. However, contrary to the recommendation from Harold Hotelling (1937) – that the socially optimal price of an exhaustible resource increase at the rate of interest – oil prices have experienced shock after shock in the past several decades, putting this sector of the economy in a precarious position. The presence of a "backstop technology" for this essential resource is hypothesized to shorten suppliers' planning horizon, but if unitization does indeed slow production, it is possible that enacting this policy will then allow us to reach the backstop technology before exhausting our petroleum resources. This outcome would have even further implications for global climate change, as well, as I discuss in Section VII.

I contribute to this literature by analyzing the effects of unitization on oil production over time, comparing total extraction and producer behavior with respect to price for unitized and non-unitized wells. After calculating the price elasticity of production of these wells, I quantify the expected benefits of unitization based on my results and extrapolate this knowledge into the future. Using these modeled results, I am able to forecast a change in the amount of resulting carbon emissions. Carbon dioxide is the leading carbon forcing gas (Hansen, et. al, 2005), so carbon levels have a significant impact on climate change, thus this forecast will allow me to infer how this policy could potentially impact global climate change.

IV. Data

The data for my analysis comes from three sources: The Alaskan Department of Natural Resources (DNR), the Alaskan Oil and Gas Conservation Commission (AOGCC), and the Energy Information Association (EIA). The data I have obtained from the Alaskan DNR gives information on the leasing and unitization status of individual wells. The AOGCC collects information regarding the physical characteristics and production of wells within the state of Alaska, recorded on a month-to-month basis. Though the dataset spans 1919 to 2010, most of the information is concentrated from 1962 onward, since that's when the first major productive oil discovery in Alaska was made (Cooper, 1973). The data from these two sources are connectable using the unique identifying API Number for each well. Finally, the EIA provides the price data that I will be using. Data on futures prices and spot prices are not available at all after 1983, but first purchase price, which is, according to the EIA, a "transaction involving…the physical removal of the crude oil from a property (lease) for the first time," is available back to 1859. I will be using the national average prices, for which monthly values begin in 1974, likely because of oil's new importance due to the 1973 world oil crisis. Only annual data is available for years prior, but since the volatility of oil price was so low up until the oil crisis, I will simply apply the annual average to each month within that year. All prices have been adjusted for inflation to 1983 dollar values using the US Bureau of Labor's Producer Price Index (PPI) specific to oil production.

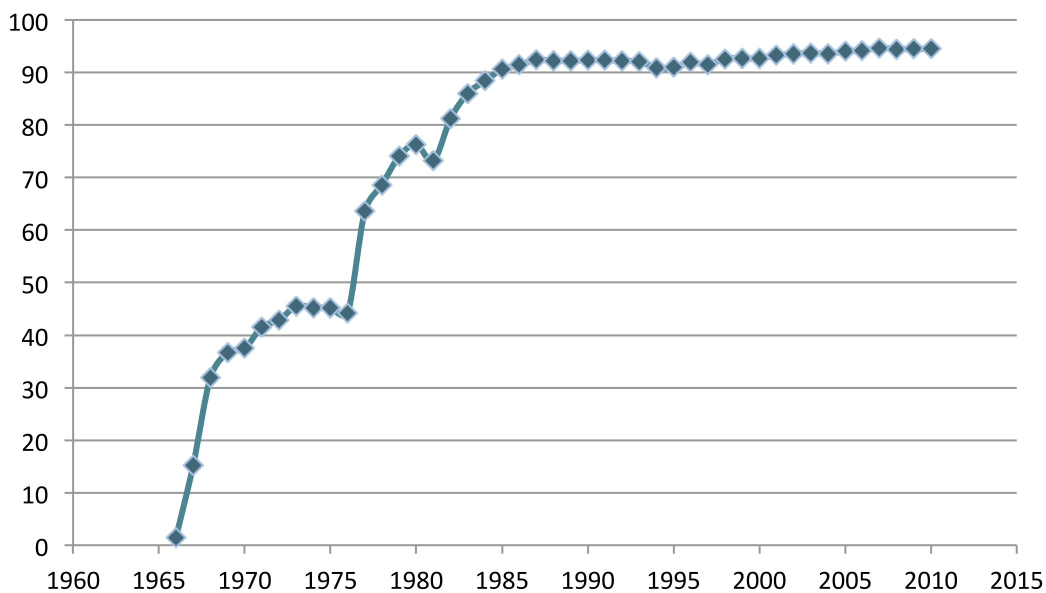
DNR Variables

API_WELLNO: Unique identifying number for each well.

UNITIZED_DATE: Date on which the well became a part of a unit. If an API number was listed as being unitized on two different dates, only one of these dates was used for the well in question. In almost all cases, the nearest date to the first production date that preceded it is the one that remains in the dataset. The one exception to this is if all unitization dates came later than the first production date: in this case the nearest date to the first production date is simply used.

FIRST_REPORT_DATE: Earliest date on which actual production began.

Fig. 1 Percent of Wells Unitized



Note 1965: 1.45%, 2009: 94.50%

AOGCC Variables

REPORTDATE: Date of production report, always the first of the month (so there is only one per month).

FIRST_REPORT_DATE: Date of first production report.

PRODOIL: amount of oil, in barrels (bbls), produced from that well in that month.

PRODDAYS: Number of days of production during that month.

DTD: Drillers' total depth, or the maximum depth of the well bore, measured in feet. Higher values indicate greater difficulty of extraction.

TVD: Total vertical depth, or the maximum depth of the well vertically from bottom to surf, measured in feet. Higher values indicate greater difficulty of extraction.

WH_ONOFFSHORE: Dummy variable for whether a well was drilled on- or offshore, where 0= onshore and -1= offshore.

ELEV_GR: Distance in feet from Ground to Mean Sea Level.

WTRDEPTH: Depth of water in feet for offshore surface location.

WELLTYPE: Well Type, made into a dummy variable where 1= oil production, 2= gas production, 4= injection (enhanced recovery), 5= disposal project.

METHODOPER: Method of operation, made into a dummy variable where 1= flowing, 2= gas lift, 3= rod pump, 4= hydraulic pump, 5= submersible, 6= water injection, 7= gas injection, 0= miscible injection (water-alternating-gas). Initially observations were included that exhibited the values 8 and 9, representing "shut-in" and "plant products", respectively, but every well of these types produced no oil, and so these observations were dropped.

Table 1 Summary Statistics for AOGCC Data 1958-2010

Variable	Mean	Std. Dev.	Min.	Max.
Proddays (days/mo)	27.11	7.14	0	32
DTD (ft)	10,620.94	2,214.65	0	26,090
TVD (ft)	8,371.33	1,868.71	0	20,211
Elev_GR (ft)	47.88	67.05	0	3,324
Wtr_Depth (ft)	89.53	28.24	18	863
Prodoil (bbls/mo)	30,116.56	47,770.91	0	699,367

EIA

PRICE: The average price of oil, in dollars per barrel, for the given month, adjusted to 1983 dollars using PPI (1958-2010).

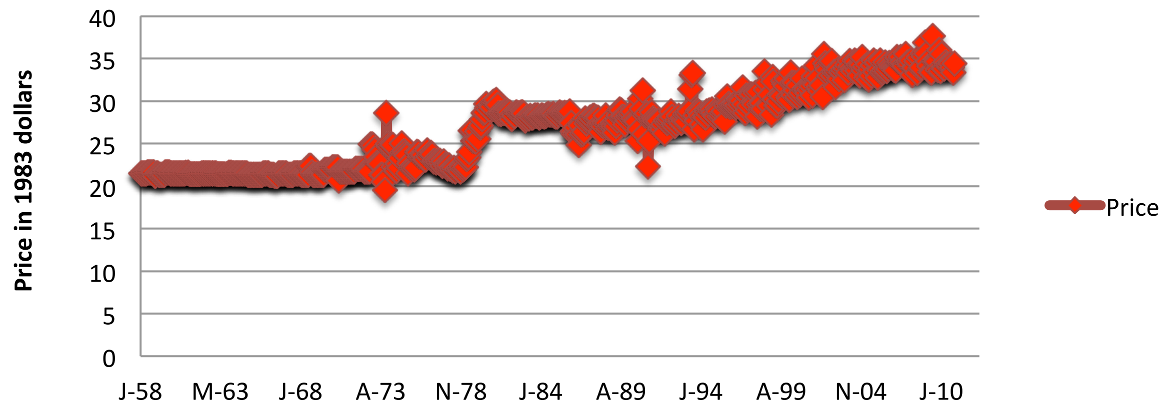
F_PRICE_REF: Prices forecast for the "reference case" by EIA out to 2025, adjusted to 1983 dollars using PPI (2010-2025).

F_PRICE_HIGH: Prices forecast for the "high price case" by EIA out to 2025, adjusted to 1983 dollars using PPI (2010-2025).

Table 2 Summary Statistics for EIA Data

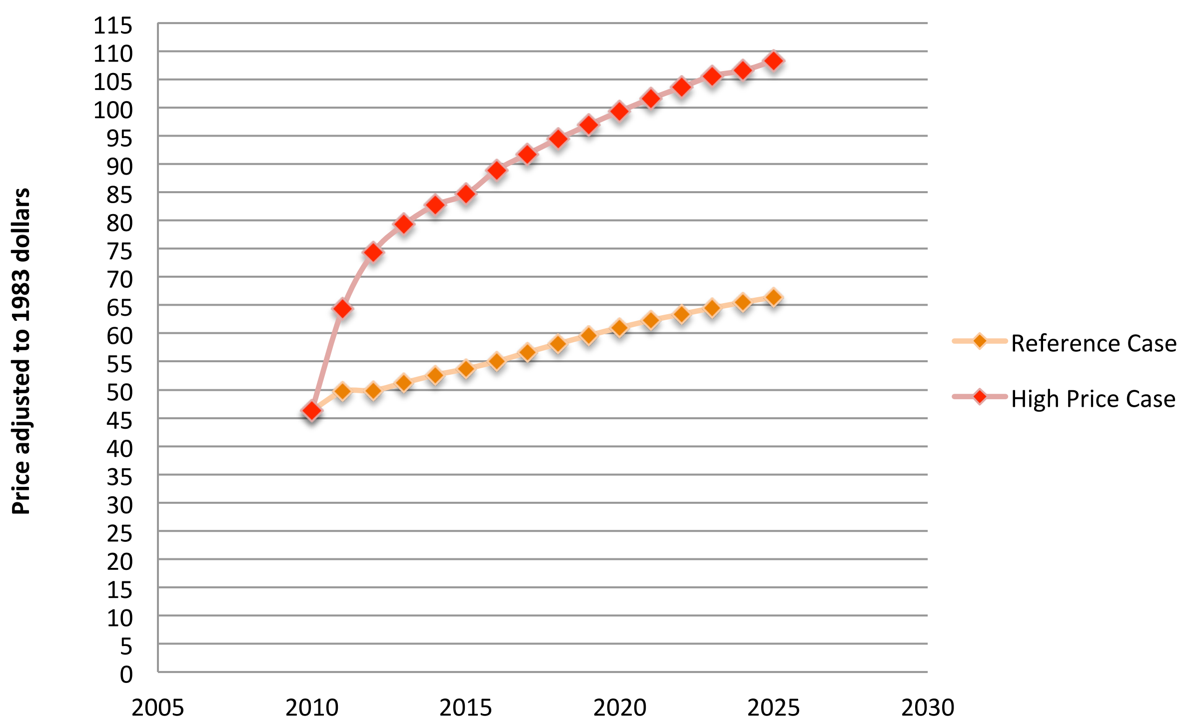
Variable	Mean	Std. Dev.	Min.	Max.
Price ($/bbl)	26.87	4.63	19.54	37.63
FPriceRef ($/bbl)	57.24	6.10	46.30	66.42
FPriceHigh ($/bbl)	89.28	16.45	46.30	108.28

Fig. 2 Monthly Average Price of Crude Oil in 1983 Dollars (Jan. 1958 – Dec. 2010)



Note The maximum price of $37.63/bbl occurred in Jul. 2009; the minimum price of $19.54/bbl occurred in Dec. 1973.

Fig. 3 EIA Forecast of Average Annual Crude Price in 1983 Dollars (2010 – 2025)



V. Theoretical Framework and Empirical Specification

In order fully answer my question I proceed in three steps. First, I extract an industry supply curve by regressing monthly quantity from each well on a number of key variables taken from the literature, most notably price. I run two versions of this regression, one including unitization and one without that consideration, and compare these in order to confirm that the policy truly does have an impact. More importantly, I am able to use the regression that includes unitization to isolate the effect of unitizing a well on its production levels and on how those levels vary with price. One established method of isolating a causal relationship is by using a differences-in-differences strategy, which allows the elimination of the effects of trends that prevail across the groups in question (Angrist and Pischke, 2009), but an ideal differences-in-differences approach to answer my question would require an exogenous mandate to unitization as the treatment. Because individual wells all changed their unitization statuses on different dates, however, this data does not lend itself to division into two discrete sets. Therefore, rather than using a direct differences in differences method, I will instead be differencing across many times by employing fixed-effects regressions and comparing the results. Fixed effects regressions control for between-well differences by generating dummy variables for each of the 7,939 wells, allowing me to "circumvent" issues that may result from any unobserved differences (Arezki and Brückner, 2011).

Second, I use the exact same setup to regress the number of days of production on the same variables as above. There are two key components to total production: reservoir characteristics and firm behavior. Reservoir characteristics are a factor in that key attributes such as the initial amount of oil, the pressure, and total depth directly influence how quickly oil will come out of the ground on its own. The more interesting component of production, however, is firm behavior because it is more likely, for obvious reasons, to change as price and other factors change. In regressing the number of days of production per month on the same two sets of independent variables, both those excluding and that including unitization, I can determine how producer's decisions are actually affected by the policy.

Finally, I use estimators from a regression from part A and apply them to the future prices projected by the EIA for both the reference and the high-price case. By doing this, I am able to forecast levels of oil production in Alaska. This also allows me the ability to begin determining how implementing a unitization policy could affect global climate change.

V. A. Supply Curves

The first set of regressions I run is set up to provide estimates of how key factors marginally influence oil production. My model closely follows the literature I discussed in Section III, and is most similar to that used by Dees et al. in modeling the world oil market (Dees et al, 2007). The dependent variable, therefore, is PRODOIL, and the primary regressor in my model is a measure of price. In addition, these values are the same for every well for each given date, so directly controlling for price allows me to determine its effect on the wells as a group, rather than individual effects entering the model separately via the fixed effects found using well dummies. I have decided to use a measure of the simple moving average price, calculated as:

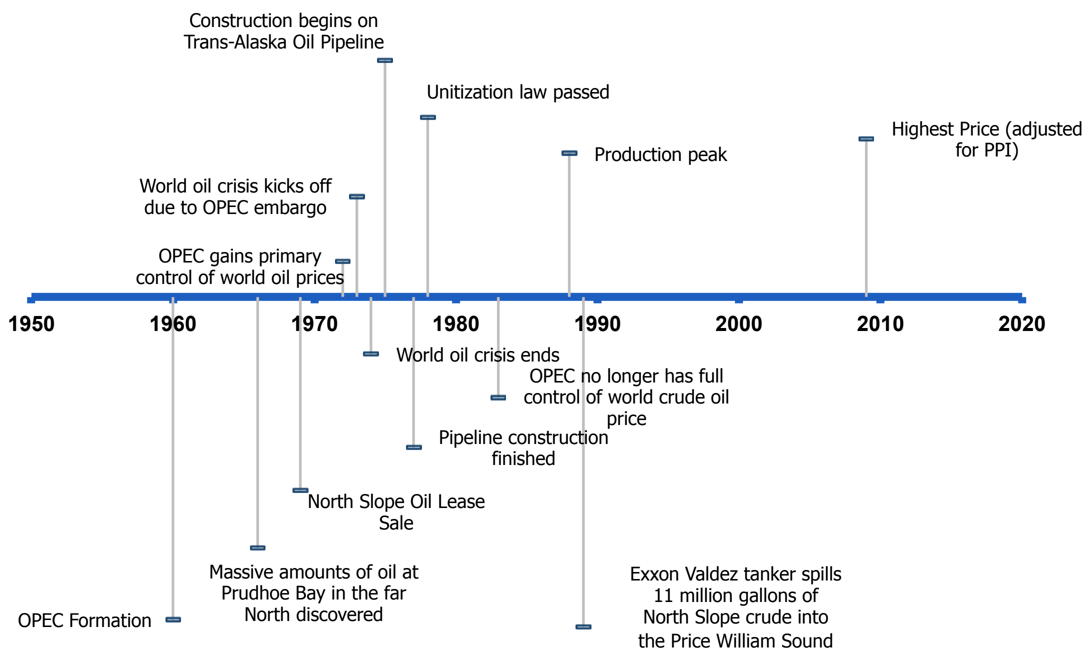
$$MOVINGAVG\_PRICE_t = \frac{(\mathrm{PRICE}_t + \mathrm{PRICE}_{t-1})}{2}$$

where *t* is time in months. This measure accounts for the fact that there may be some lag in how prices affect production decisions and is able to smooth irregularities seen in the data. Results do not change substantially, as demonstrated in the appendix, when I use instead PRICE and LAG1_PRICE ($PRICE_{t-1}$) in specifications (i) through (iv), in turn.

Next I include well fixed-effects that control for geologic, economic, and institutional factors (Dées et al., 2007). The fixed effects approach I take controls for all geological factors that are constant over time for each well, many of which I see in my data, but the key geological factor is the time-varying amount of oil already extracted from each well. Due to the nature of oil reserves, as oil is extracted, pressure decreases, and thus the natural factors influencing the rate production lessen. Because these wells are losing oil over time, I control for the size of the remaining stock of oil in order to control for this constant pressure decrease the wells experience as they produce. A separate AOGCC dataset contains all injection data for Alaskan oil and gas production, and by either using GIS methods to map out all of these wells or researching producer-specific behavior it would be possible to determine which injection wells impacted producing wells and in what ways. This would be very useful information because it would allow us to factor in more exact knowledge regarding the pressure of the wells into the production regressions. I use a proxy for this value, however, due to the difficulty I would encounter in determining exact values. The proxy I use is MONTHS_OPER_PROD: the number of months the well has been in operation, i.e. the difference between REPORT_DATE and FIRST_REPORT_DATE. This is actually an inverse proxy for the amount of oil already removed from the well because after production begins, it continues until the well is closed, so the value of MONTHS_OPER_PROD will be greater for each month that the well is in production. In combination with a well fixed-effect, which controls for the initial stock of oil, these variables measure the remaining stock at any point in time.

YEAR and YEARSQ are variables included in order to control for time series effects. Figure 4, below, shows a timeline of important events that likely impacted the Alaskan oil industry by shocking demand or supply due to changes in price, policy, and technology.

Fig. 4 Timeline of Events related to Alaskan Oil Production

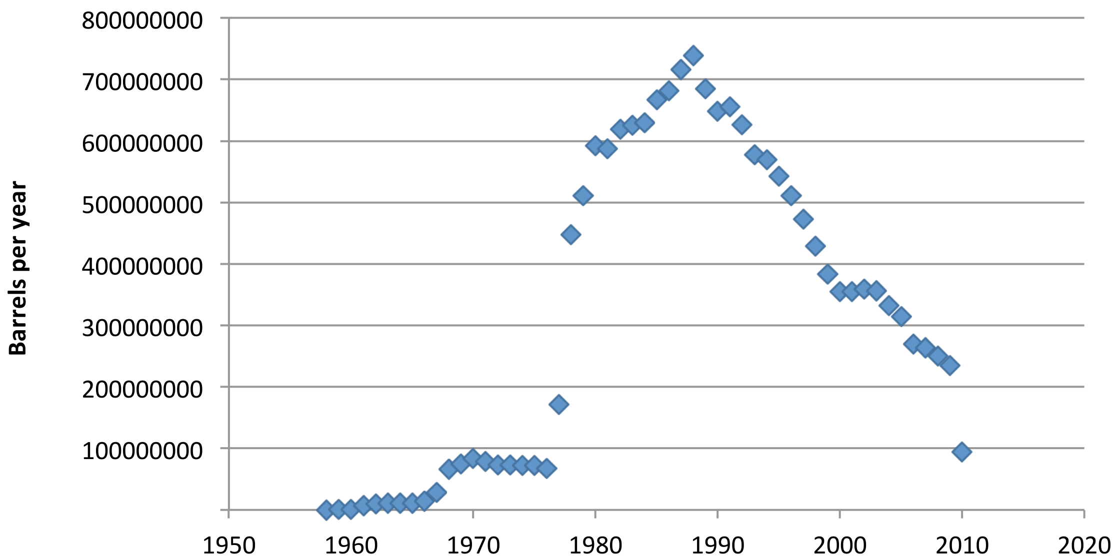


Sources: AHS, 2012;OPEC, 2012; PBS, 2006

The actions of OPEC in 1973, for example, "effectively cartelized the world oil market, exploiting its power to raise prices above competitive levels by restricting production" (Gately, 1984; Pindyck, 1978). My model assumes that a rise in price is expected to increase production; with the spike due to OPEC, however, subsequent production behavior would likely not follow this model, and thus the model should not be estimated in the same manner as if the spike arose endogenously in the world oil market

Both YEAR and YEARSQ are scaled so that Year = 1 for the first year or production, 1958, and increases by 1 for each year after. Directly inputting the year is an intuitive component, as time changes exactly in this manner, but incorporating YEARSQ (which is equal to the squared value of the year) is useful as well due to the quadratic shape of the path of oil supply in Alaska. Summing up production across all wells and all months to get the cumulative production for each year, the time path of production, shown in Figure 5, below, exhibits a quadratic shape, which the squared variable better estimates.

Fig. 5 Total Annual Oil Production in bbls/year (1958 – 2010)



Note Peak oil production in 1988: 739000000 bbls/year

Incorporating time series variables also serves to control for the fact that the production path cannot have been expected to remain fixed in place over the span of 52 years that this data covers. Many factors over the period of time that certainly influence production have continuously changed, prominent among them technology and demand shocks.

The full regression, therefore, appears as follows:

$$PRODOIL = \beta_0 + \beta_1 MOVINGAVG\_PRICE + \beta_2 MONTHS\_OPER\_PROD + \beta_3 YEAR + \beta_4 YEARSQ + \varepsilon \tag{1}$$

The parameter estimate β_1 therefore reflects the full marginal effect that the moving average of a 1-month lagged price and the current price has on production for each well. The remaining coefficients represent the marginal effect of well-specific characteristics on production. The effect of price on production in this regression is important because it tells us how that relationship is viewed when unitization is not considered as a factor. The second regression in my set, however, does consider unitization, and it is this that answers the key question of this paper.

Unitization status is the institutional factor in which I am interested, and I examine the effect it has on production by adding two variables: UNITIZED and UN_MOVINGAVG_INT. UNITIZED, a dummy variable for whether or not the well was unitized at the time of extraction, is determined using UNITIZED_DATE and REPORTDATE; 1 = unitized, 0 = not unitized. UN_MOVINGAVG_INT is a variable that interacts economics and institution, equaling UNITIZED ∗ MOVINGAVG_PRICE for each well at a given production date. Specification (2) then appears as follows:

$$PRODOIL = \beta_0 + \beta_1 MOVINGAVG\_PRICE + \beta_2 MONTHS\_OPER\_PROD + \beta_3 YEAR + \beta_4 YEARSQ + \beta_5 UNITIZED + \beta_6 UN\_MOVINGAVG\_INT + \varepsilon \tag{2}$$

The total effect of MOVINGAVG_PRICE on PRODOIL is now dependent on both β_1 and β_6, so their sum will produce this estimate. By including this interaction variable, I can back out the effects of price on unitized wells compared to their non-unitized counterparts.

Because several papers within the literature use logged measures of price and production in their modeling (Cologni & Manera, 2011; Aleksadrov & Espinoza, 2010) I also include results from models with logged values of production (LN_PRODOIL) and price (LN_MOVINGAVG_PRICE) in order to check the robustness of my estimates, both with and without including the impact of unitization. The results of these regressions, numbered (v) through (x), are included directly in Section VI for comparison with my key regressions.

Additionally, while the number of days per month the wells produces (PRODDAYS) is intuitively another factor in the amount of oil a well produces in a given month, because I later compare the effects of unitization on producer behavior by using PRODDAYS as the regressor on the same independent variables, I omit this variable from my primary regression. By instead using reduced forms, I avoid problems with endogeneity when comparing the two questions. I do, however, run variants of the regression that show how PRODDAYS would have played a role in predicting PRODOIL. The empirical specification and results for these regressions, numbered (xi) and (xii), are given in the appendix.

Finally, I ran two versions of a non-fixed-effects OLS specification. First I ran two regressions – specifications (xiii) and (xiv) – which, aside from all of the independent variables present in the fixed effects regressions in my model, contained only the variables describing key geophysical characteristics of individual wells. The next two OLS regressions I ran, specifications (xv) and (xvi), contained as many independent variables as I could incorporate without encountering the issue of multicollinearity. Specifications (xiv) and (xvi) incorporate UNITIZED and UN_MOVINGAVG_INT, but include the same other variables, respectively. Though the results of these regressions displayed some variation in the magnitudes of the coefficients that are included in both sets of regressions, the sign on each remains the same for all of the regressions. For full empirical specification and results, see the appendix.

V. B. Firm Behavior: Production Days

In deciding how many days per month to produce (PRODDAYS), firms directly influence how much oil they extract. The important question here is: do firms respond to changes in price by changing the amount of effort they put in to production? In other words, is there a margin on which firms can respond to prices in order to alter output?

In order to establish an answer to this question, I employ another set of fixed effects regressions in order to control for the geophysical well characteristics that stay constant over time. Equations (3) and (4), below, specify how I will determine this relationship.

$$PRODDAYS = \beta_0 + \beta_1 MOVINGAVG\_PRICE + \beta_2 MONTHS\_OPER\_PROD + \beta_3 YEAR + \beta_4 YEARSQ + \varepsilon \quad (3)$$

$$PRODDAYS = \beta_0 + \beta_1 MOVINGAVG\_PRICE + \beta_2 MONTHS\_OPER\_PROD + \beta_3 YEAR + \beta_4 YEARSQ + \beta_5 UNITIZED + \beta_6 UN\_MOVINGAVG\_INT + \varepsilon \quad (4)$$

In this case it is again β_1 in the first equation and a combination of β_1 and β_6. In the second that give the effect of price on PRODDAYS, this time indicating how the firm's decision making changes.

I do not specify any log versions of these regressions, because with such a small range, it is clear that PRODDAYS will not have any significant outliers. Also, having established the validity of the fixed effects method in part A, I do not repeat the attempt to duplicate these results using standard OLS regressions as I did above.

V. C. Projection Model

Using the estimators for the effect of oil price from specification (2) (the coefficients on both MOVINGAVG_PRICE and UN_MOVING_INT and the future prices projected by the EIA), I am able to forecast oil production for over a decade. The high price scenario is likely far more applicable to this model, so I use that as well as the reference case. The expectation is that if unitized wells are less elastic, then the low supply will continue to drive prices up, leading to a scenario that yields values more like these. Forecasting the average annual supply per well of Alaskan oil is therefore done using the following equations, one for each measure of price:

$$Q_t = Q_0 + (\beta_1 + \beta_6) * (FPriceRef_t - FPriceRef_0) + \beta_2(12t) + \beta_3(t) + \beta_4(YEARSQ_t - YEARSQ_0) \quad (5)$$

$$Q_t = Q_0 + (\beta_1 + \beta_6) * (FPriceHigh_t - FPriceHigh_0) + \beta_2(12t) + \beta_3(t) + \beta_4(YEARSQ_t - YEARSQ_0) \quad (6)$$

Q_t is the quantity produced in any year we are interested in forecasting, where *t* is the year. For Q_0, the quantity produced in the base year, instead of using a number from my sample, I use the total amount of oil produced in Alaska in 2010 so that I am able to compare to the EIA projections of total Alaskan oil supply. Also, since the EIA only forecasts prices annually, my quantity variable is measured in average barrels per year. In each of these equations, I will input both 0 and 1 for UNITIZED in order to obtain separate values that allow me to compare future production based on unitization status. I then project these values to 2025 and compare them not only to each other, but also to the projections that the EIA put out for future Alaskan supply.

I also calculate that each barrel of crude oil is, once burned up through human use, responsible for 0.43 metric tons of CO_2 emissions (derived from US EPA, 2007). Using this number, I can show the change in carbon emissions resulting from the change in oil produced as a result of unitizing oil reserves using the following equation:

$$\frac{0.43\ metric\ tons\ CO_2}{1\ barrel\ crude\ oil} * (Q'_{non-unitized} - Q'_{unitized}) = \frac{metric\ tons\ CO_2/well}{year} \tag{7}$$

VI. Results

In this section I present estimates of how each independent variable marginally impacts the total amount of oil the average well produced each month. First I analyze the results of the fixed effects regressions on total production, given in Table 3 and Table 4, below.

Table 3 Comparison of Fixed Effects Regression Results for Oil Production

	(1) FE using PRODOIL	(2) FE using PRODOIL	(v) FE using PRODOIL	(vi) FE using PRODOIL
MovingAvg_Price	2,754.52***	12,040.72***		
	(39.48)	(134.56)		
LN_MovingAvg_ Price			78,247.39***	297,516.8***
			(1,119.31)	(3,528.5)
Months_Oper_Prod	343.64***	320.17***	332.44***	277.75***
	(13.51)	(13.41)	(13.48)	(13.43)
YearSimple	-13,574.14***	-14,637.43***	-13,812.32***	-15,369.89***
	(168.44)	(167.68)	(168.96)	(169.13)
YearSimpleSq	72.93***	91.38***	78.46***	110.22***
	(0.6461)	(0.6796)	(0.6298)	(0.7686)
Unitized		297,972***		255,581.3***
		(3,740.15)		(3,471.84)
Un_MovingAvg_Int		-9,797.05***		-8,229.38***
		(135.24)		(125.08)
Constant	321,050.5***	-54,103.28***	139,809.1***	-595,961.5***
	(4,752.92)	(5,813.41)	(5,505.14)	(12,165.2)
Observations	511,540	511,403	511,540	511,403
R-squared	0.2537	0.2646	0.2537	0.2633
F-Statistic for Reg.	43,099.09***	30,402.10***	43,105.41***	30,201.88***

Note: *** p<0.01, ** p<0.05, * p<0.1; standard errors in parentheses

Table 4 Continued Comparison of Fixed Effects Regression Results for Oil Production

	(vii) FE using LN_PRODOIL	(viii) FE using LN_PRODOIL	(ix) FE using LN_PRODOIL	(x) FE using LN_PRODOIL
MovingAvg_Price	-0.00569***	0.05617***		
	(0.00116)	(0.00397)		
LN_MovingAvg_			-0.17648***	1.185***
Price			(0.03275)	(0.10395)
Months_Oper_Prod	0.00942***	0.00925***	0.00941***	0.00907***
	(0.00040)	(0.00040)	(0.00039)	(0.00040)
YearSimple	-0.22236***	-0.22852***	-0.22149***	-0.23036***
	(0.00439)	(0.00494)	(0.00495)	(0.00498)
YearSimpleSq	0.00015***	0.00026***	0.00014***	0.00033***
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Unitized		1.864***		1.480***
		(0.11035)		(0.10233)
Un_MovingAvg_Int		-0.06510***		-0.05094***
		(0.00399)		(0.00369)
Constant	17.064***	15.380***	17.476***	12.991***
	(0.13906)	(0.17136)	(0.16109)	(0.35840)
Observations	508,378	508,245	508,378	508,245
R-squared	0.2714	0.2718	0.2714	0.2717
F-Statistic for Reg.	46,937.78***	31,357.59***	46,939.42***	31,341.44***

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$; standard errors in parentheses

By using a fixed-effects regression, I have controlled for the average differences across wells due to any observable or unobservable factors, primarily the geophysical characteristics that describe these wells. The fixed coefficients on these dummies then accumulate the "across-group action" (Dranove, 2009), leaving only the within-group effects – or the changes each well experiences on its own – visible in the coefficients.

It is important to note that for every version of the regression run with the variables UNITIZED and UN_MOVINGAVG_INT, the coefficient on MOVINGAVG_PRICE ($\hat{\beta}_1$) is positive and the coefficient on UN_MOVINGAVG_INT ($\hat{\beta}_6$) is negative, immediately telling us that there is consistent agreement in how unitizing a well changes its production behavior. Specification (6), however, is unique in that the magnitude of $\hat{\beta}_6$ actually exceeds that of $\hat{\beta}_1$, indicating the possibility of a downward sloping supply curve, which would imply that the firm is producing less and less as price increased. Given our priors, the effect of unitization is overestimated in this regression, despite the significance of the results.

The positive coefficient on "MOVINGAVG_PRICE", represented in the regression by β_1, is consistent with a supply curve interpretation, and it is significant with a p-value of 0.000 in each specification of this regression. This value represents the full effect of price on production in those regressions that don't include any variables related to unitization (specification (1) but not specification (2), and their respective derivate specifications). Those that incorporate the effects of unitization include the interaction term UN_MOVINGAVG_INT. The total effect of price on a unitized well's production is therefore equal to $\hat{\beta}_1 + \hat{\beta}_6$ (Braumoeller, 2004). The key result of this regression, therefore, is that the total effect of price on a unitized well is actually far less than on that of a non-unitized well. To demonstrate this, the elasticity of supply from regression (2) calculated at the means is given as:

$$E = (\hat{\beta}_1 + \hat{\beta}_6) * \frac{\overline{MOVINGAVG\_PRICE}}{\overline{PRODOIL}} \tag{8}$$

For non-unitized wells,

$$E = (12{,}040.72 + (-9{,}797.05 * 0) * \frac{30.13}{30{,}116.56} = 12.05$$

And for unitized wells,

$$E = \left(12{,}040.72 + (-9{,}797.05 * 1)\right) * \frac{30.13}{30{,}116.56} = 2.24$$

Because β_6 is a large negative number, by inputting for UNITIZED first a value of 0 (non-unitized) and then comparing the result to when we instead input UNITIZED= 1 (unitized), we can clearly see that a unitized well's supply is far less elastic than that of a non-unitized well, with the policy in place. This lower elasticity represents a steeper supply curve: for every dollar increase in price, a non-unitized well will produce 5.38 times more barrels of oil signifying that it will take larger changes in price to affect a change in the quantity of output for unitized wells.

$\hat{\beta}_1$ and $\hat{\beta}_6$ directly determine the answer to my question. However, it is important to mention that the other variables influence production logically, as well. We expect the coefficient on YEAR, for instance, to be downward sloping because, as discussed previously, over time wells lose their ability to produce as much to do geologic factors and the characteristics of the oil and of the reserves. It is indeed negative, and significant in all specifications. The fact that the coefficient on YEARSQ is positive makes sense because the shape of the total supply curve is quadratic.

One interesting thing to note about these results is that the coefficient on MONTHS_OPER_PROD has the opposite sign from what is expected. Given that with a greater number of months in operation a well is expected to see diminishing output due to constantly dropping pressure, a negative coefficient is expected, and yet we see a positive sign. There are two important components that can help explain this discrepancy from our expectations. First, many wells may be subjected to "outside pressure support" (Lueck & Schenewerk, 1996). This technique, including injection gas and water into nearby wells to increase reservoir pressure and thus enhance recovery, is typically implemented late in a well's life – i.e. when MONTHS_OPER_PROD is high. This would make the wells affected then produce more than expected later in life.

Second, it is possible that MONTHS_OPER_PROD is only "picking up" some of the leftover variation that the wells experienced over time, since YEAR already picks up the majority of this. For each well, YEAR is larger the longer the well has been producing.

Conditional upon year, MONTHS_OPER_PROD is larger the earlier the well was initially drilled. Its coefficient being positive suggests more productive wells were drilled earlier. It makes sense then that YEAR picked up the trend in decreasing production across wells, leaving MONTHS_OPER_PROD to pick up remaining effects. The correlation coefficient of 0.4075 between the two supports this, as well, because it shows that they are in some way correlated, but not enough that we expect them to pick up identical effects.

The next key step in answering my question is to determine what role producers' decisions play in the way this policy impacted total production. Did unitization in fact cause producers to consciously slow production, looking toward the future and higher prices to come? Table 5, below, gives the results of regressions (3) and (4):

Table 5 Comparison of Fixed Effects Regression Results for Production Days

	(3) FE using PRODDAYS	(4) FE using PRODDAYS
MovingAvg_Price	0.0669***	0.1995***
	(0.0078)	(0.0269)
Months_Oper_Prod	0.0035	0.0033
	(0.0027)	(0.0027)
YearSimple	0.0829**	0.0617*
	(0.0334)	(0.0335)
YearSimpleSq	-0.0033***	-0.0030***
	(0.0001)	(0.0001)
Unitized		4.7987***
		(0.7465)
Un_MovingAvg_Int		-0.1407***
		(0.0270)
Constant	26.58***	22.40***
	(0.9418)	(1.16)
Observations	511,540	511,403
R-squared	0.0094	0.0095
F-Statistic for Reg.	1,197.97***	812.81***

Note: *** p<0.01, ** p<0.05, * p<0.1; standard errors in parentheses

First, note that producers do indeed increase the number of days wells are operated in months when the moving average price is higher. This signals that we are indeed recovering the supply relationship we seek. Next, note that PRODDAYS is affected very similarly by price and unitization, not in absolute value but in terms of positive versus negative impact, and the coefficients on MOVINGAVG_PRICE, UNITIZED, and UN_MOVINGAVG_INT are all significant with p-values of 0.000. Here, however, the implication is that this clarifies the role producers play in choosing to be price inelastic, exhibited by the relatively large negative value of $\hat{\beta}_6$ compared to $\hat{\beta}_1$.The elasticity of production effort calculated at the means is given as follows:

$$E = (\hat{\beta}_1 + \hat{\beta}_6 UNITIZED) * \frac{\overline{MOVINGGAVG\_PRICE}}{\overline{PRODDAYS}} \tag{9}$$

For non-unitized wells then,

$$E = \big(0.1995 + (-0.1407 * 0)\big) * \frac{30.13}{27.11} = 0.2217$$

And for unitized wells,

$$E = \big(0.1995 + (-0.1407 * 1)\big) * \frac{30.13}{27.11} = 0.0654$$

We can see from this that producer behavior is not very elastic at all, but the behavior of producers of unitized wells it is even less elastic than that of producers of non-unitized wells. The far lower willingness to change behavior in supplying oil based on shifts in price is important because it shows that policy, not just geologic functions, does in fact have the potential to have a significant impact, as we have been assuming.

Finally I examine the results of forecasting future oil production based on my model. First I present a graph of projections by the EIA, and directly below that, the figure of my projections, for comparison:

Fig. 6 EIA Production Projection for Alaska in avg bbls/mo (2010 – 2025)

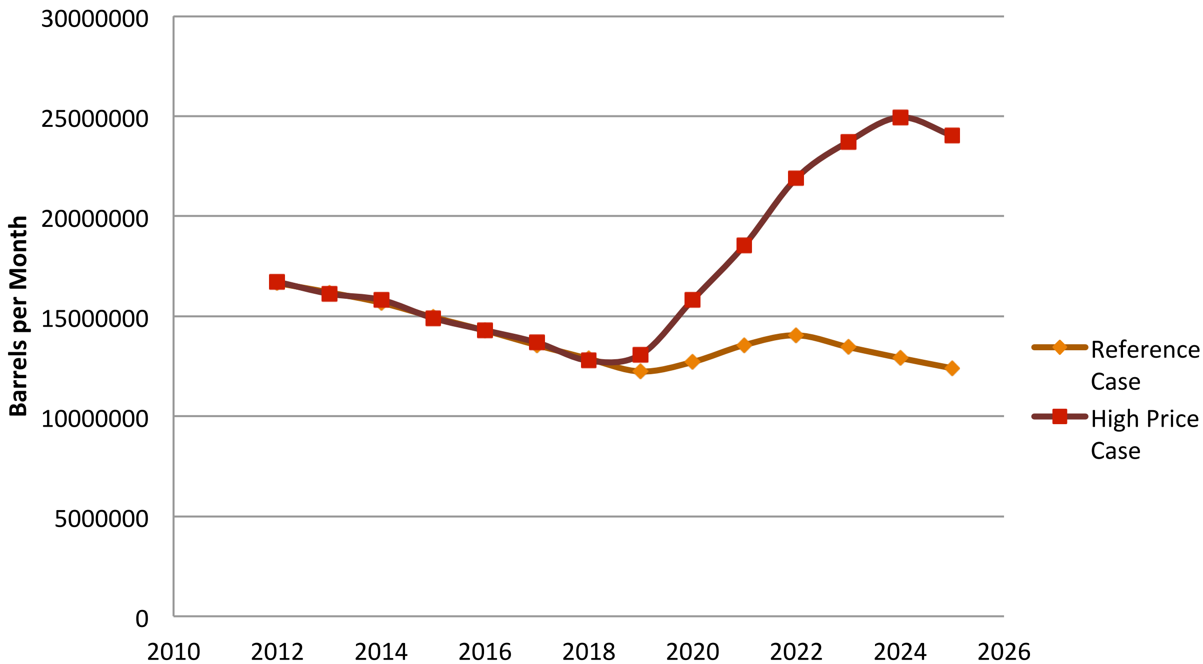
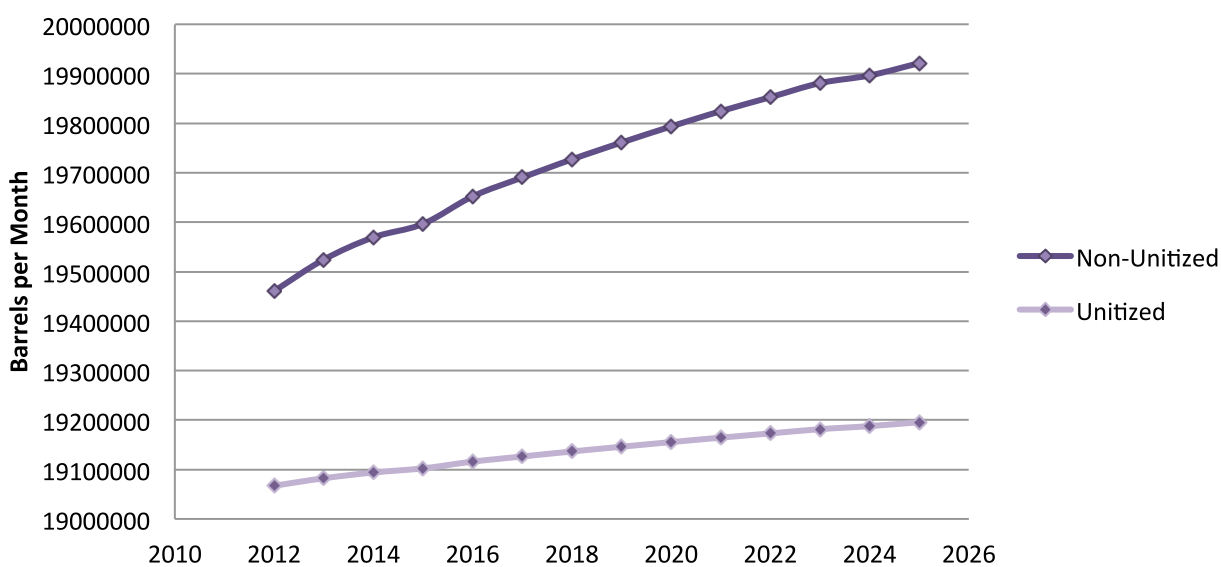


Fig. 7 Model-Based Production Projection for Alaska in avg bbls/mo – High Price Case (2010 – 2025)



While the two portray values in a similar range, the values given by my projection are far more concentrated than are those forecast by the EIA. This is likely because the EIA is also taking into account a great deal more institutional and general economic factors that have the potential to affect oil price and supply. The most important aspect of the model-based projection, however, is the difference between yearly production in the state of Alaska if all wells are unitized and the level of production if no wells are unitized. While at its maximum this value is only 726,066.89 bbls/mo, or 8,712,802.68 bbls/yr, this still represents a savings of 3,746,505.15 metric tons of carbon (from equation (7)). Because more than 90% of Alaskan wells are already unitized (see Figure 1), we are close already to achieving this, a statistic of which oil producers elsewhere should take note.

VII. Conclusion

Unitizing oil reserves decreases the elasticity of supply for the wells on the unit. This in turn prevents over-exploitation by steepens the supply curve, which minimizes economic rent dissipation and localized environmental impact. However, there is potentially a greater impact than just on the producers in question. Depending how widely this policy is enacted, it could have a massive negative effect on carbon dioxide emissions, both directly and indirectly, and thus be a positive influence on global climate change.

Likely of greater importance to climate change initiatives than the direct savings of carbon emissions is the indirect effect of unitization on investment in alternative energy technology. Because of the much smaller elasticity of supply exhibited by unitized wells, a much higher price is required to incentivize these producers to supply the same amount of oil. At some point, if all producers worldwide unitized production, price would become high enough that demand for oil would drop, incentivizing investment in the alternative energy market and eventually resulting in a shift to use of a backstop technology cheaper than the inelastic oil supply. The substitution of these technologies for oil could significantly affect the rate of global climate change. With oil production at 94.6 million bbls/yr in 2010 in Alaska, completely cutting production would equate to nearly 50 million tons of CO2 emissions avoiding per year just from this region. Globally ceasing to use crude oil would decrease CO2 emissions by more than 13.4 billion tons per year.

Of course, this is not a likely scenario. Our world has grown up with petroleum playing an integral role in our lives. This resource does more than generate energy, and it will not disappear entirely so soon. If even just the energy generation component of petroleum use were to drop somewhat due to unitization, however, the impact would still be felt. Because greenhouse gases are "stock gases," once added to the atmosphere they are present and acting upon it for decades, even centuries. Any reduction that unitization causes today will therefore be felt for many years down the road. Additionally, even if viable alternative energy technologies are not rapidly on their way, slowing the rate at which we burn fossil fuels at least allows us more time to develop them before releasing the full stock of carbon into the atmosphere right away. It also allows us more time – and thus a lower cost – for sequestering carbon and mitigating the impacts of global climate change. Pacing the release of carbon also slows the pace of global warming because it means that the gas is less concentrated in the air and thus not acting as extremely on the atmosphere. Future research done to further analyze any of the ideas proposed above would likely yield interesting insights into this timely and relevant field of economics.

Alternative Specifications

Alternative Definitions of Price

	(i)	(ii)	(iii)	(iv)
Price	2,127.73***	11,279.13***		
	(34.71)	(131.30)		
Lag1_Price			2,127.73***	11,2787.73***
			(34.47)	(131.50)
Months_Oper_Prod	342.94***	317.85***	276.37***	264.89***
	(13.57)	(13.48)	(13.42)	(13.33)
YearSimple	-13,569.79**	-14,594.77***	-12,754.9***	-13,936.67***
	(169.25)	(168.44)	(167.42)	(166.78)
YearSimpleSq	75.90***	93.69***	75.53***	93.22***
	(0.6413)	(0.6719)	(0.6418)	(0.6724)
Unitized		293,045.1***		291,634.2***
		(3,654.85)		(3,657.78)
Un_Price_Int		-9,602.46***		
		(131.98)		
Un_Lag1_Int				-9,562.10***
				(132.23)
Constant	336,264.4***	71,088.31***	311,914.8***	52,686.65***
	(4,754.87)	(5,789.75)	(4,767.97)	(5,767.87)
Observations	511,540	511,403	511,540	511,403
R-squared	0.2519	0.2629	0.2521	0.2630
F-Statistic for Reg.	42,688.52	30,141.26	42,747.97	30,165.86

Note: *** p<0.01, ** p<0.05, * p<0.1; standard errors in parentheses

Alternative Specifications: Production Days

	(ix)	(x)
ProdDays	1,551.02***	1,543.74***
	(6.74)	(6.69)
MovingAvg_Price	2,650.73***	11,732.71***
	(37.57)	(128.02)
Months_Oper_Prod	338.16***	315.07***
	(12.85)	(12.76)
YearSimple	-13,702.74***	-14,732.65***
	(160.29)	(159.52)
YearSimpleSq	78.04***	95.97***
	(0.6152)	(0.6469)
Unitized		290,564.1***
		(3,558.36)
Un_MovingAvg_Int		-9,579.91***
		(128.66)
Constant	279,820.1***	19,526.91***
	(4,526.45)	(5,532.65)
Observations	511,540	511,403
R-squared	0.3242	0.3344
F-Statistic for Reg.	48,656.59***	36,389.55***

Note: *** p<0.01, ** p<0.05, * p<0.1; standard errors in parentheses

Supply Curve Without Fixed Effects

	(xi)	(xii)	(xiii)	(xiv)
MovingAvg_Price	2,443.59***	11,950.55***	2,346.36***	11,662.73***
	(238.54)	(2,060.36)	(237.83)	(2,052.82)
Months_Oper_Prod	13.89***	13.68***	12.75***	12.52***
	(3.79)	(3.79)	(3.79)	(3.78)
YearSimple	-29,375.78***	-29,435.95***	-29,279.29***	-29,322.11
	(354.85)	(354.89)	(358.73)	(358.76)
YearSimpleSq	302.31***	303.29***	301.68***	302.44***
	(4.42)	(4.42)	(4.49)	(4.47)
Elev_Gr	-70.16***	-67.47***	-44.77***	-43.52***
	(11.38)	(11.38)	(12.70)	(12.69)
MethodOper	-4,336.23***	-4,377.03***	-4,226.74***	-4,251.40***
	(262.40)	(262.32)	(265.72)	(265.46)
DTD	2.72***	2.73***	2.60***	2.63***
	(0.1043)	(0.1043)	(0.1070)	(0.1070)
Wh_GeoArea	166.89***	166.96***	176.40***	177.18***
	(40.94)	(40.89)	(41.00)	(40.94)
Wh_Lat	15,102.31***	15,167.35***	14,905.21***	14,968.42***
	(542.13)	(541.61)	(543.22)	(542.62)
Wh_Long	-7,446.75***	-7,466.23***	-7,526.44***	-7,554.19***
	(416.20)	(415.88)	(419.43)	(419.07)
Wh_OnOffShore	-2,599.86	-2,649.06	275.55	240.08
	(2,116.66)	(2,114.21)	(2,130.91)	(2,128.21)
Wh_NS			6,022.98***	6,077.80***
			(588.59)	(588.05)
Wh_EW			1,0002.06*	1,129.36**
			(567.16)	(567.30)
Wh_FTNS			1.25***	1.15***
			(0.3203)	(0.3206)
Wh_FTEW			-0.3589	-0.2788
			(0.2993)	(0.2993)
Unitized		285,968.3***		282,080.4***
		(58,283.57)		(58,066.06)
Un_MovingAvg_Int		-9,628.18***		-9,442.40***
		(2,062.26)		(2,054.60)
Constant	-1,697,482***	-1,986,570***	-1,710,172***	-1,997,339***
	(74,133.3)	(93,677.63)	(74,473.56)	(93,852.96)
Observations	15,705	15,702	15,705	15,702
R-squared	0.5088	0.5101	0.5125	0.5139
F-Statistic for Reg.	1,477.72***	1,256.51***	1,099.77***	975.5***

Note: *** p<0.01, ** p<0.05, * p<0.1; standard errors in parentheses

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