

An Economic Assessment of Oil Development in the Alaskan Arctic

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**Abstract**

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The Arctic has become a subject of intense political and economic interest as the effects of climate change have led to rapid losses in sea ice and a subsequent expansion of economic opportunities. The circumpolar north is estimated to contain 13% of the world's undiscovered oil resources, with over 10 billion barrels (Bbbls) of oil estimated in the Chukchi Sea alone. This thesis presents an empirical model of a supply curve for oil development in the Chukchi Sea, suggesting that at prices of \$60/bbl, approximately 3.2 Bbbls of oil are recoverable from the region. With much higher prices, total production could reach upwards of 15 Bbbls. Revenues from the sale of these resources would ensure substantial economic benefits to the U.S.

However, oil development in the Arctic is not without risks – to the marine environment and to the Indigenous communities that subsist on Arctic marine resources. A major oil spill in the region would lead to economic losses in the form of reduced subsistence harvests and non-use

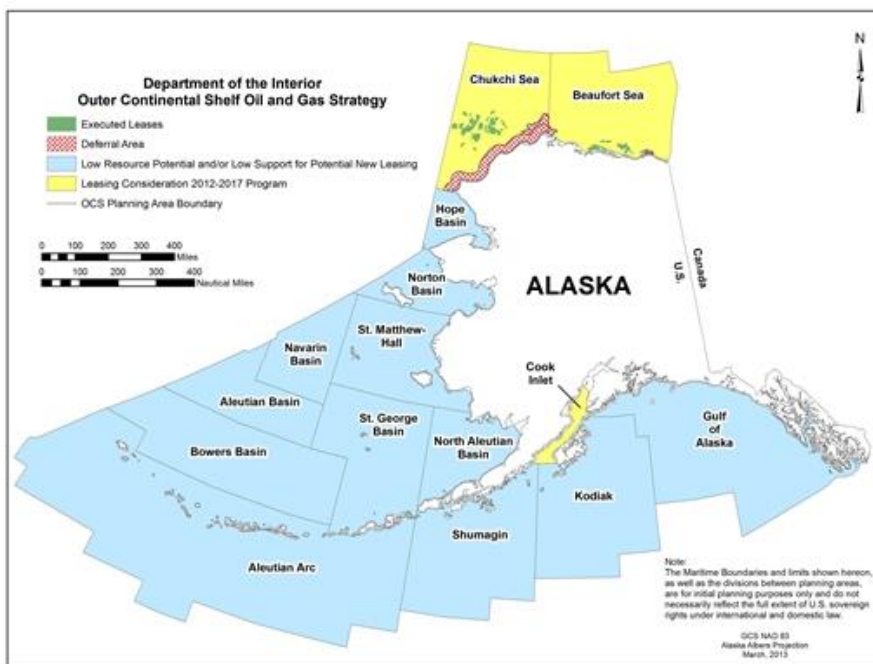
values for the region as a pristine wilderness. A benefit-cost analysis of oil development in this region shows that, because of these risks and the high costs of production for the region, net benefits are approximately \$6 billion when the market price of oil is \$60/bbl. Costs associated with the emission of greenhouse gases from the combustion of these resources are not directly considered in this thesis; however, if oil producers in the Chukchi Sea were made to internalize the costs of climate change in the form of a per-barrel tax equal to the social damages of carbon pollution, production costs increase such that no oil becomes profitable for development.

## **Introduction**

In the fifty-year period between 1960 and 2011, average ambient air temperatures in the Arctic region rose by more than 2 °C (3.6 °F); the corresponding loss of summer sea ice has been unprecedented in human history (NSIDC 2017). The warming climate has left northern passages and portions of the Arctic Ocean ice-free for longer periods of the year, and increased economic prospects in the form of shipping and hydrocarbon extraction have contributed to the emergence of the Arctic as an issue of intense geopolitical interest. An oft-cited 2008 USGS study estimated that the Arctic seabed contains 13% and 30% of the world's undiscovered oil and gas resources, respectively. These findings, combined with high oil prices and the conspicuous Russian flag-planting on the North Pole in 2007, have contributed to a sensation of an “Arctic gold rush” (e.g. Howard 2009, Unger 2014, Bourne 2016). While a global race for resources is likely overstated, interest in the region shows no sign of waning.

In the U.S. 2012-2017 5-year Oil and Gas Leasing Program, Shell bid a record \$2.1 billion for leases to explore and develop resources in the Chukchi Sea (Figure 1). After an unsuccessful exploration attempt, the company was forced to pull out of their lease agreement,

citing poor exploratory results, high costs, and regulatory barriers as responsible for their foiled efforts (Krauss and Reed 2015). Shell faced stringent limitations on exploratory drilling activities due to oil spill preparedness requirements and U.S. Fish and Wildlife marine mammal disturbance regulations (Dlouhy 2015, Shell Global 2015). Former President Obama later removed the Arctic from consideration entirely in the 2017–2022 5-year lease program, citing a need to protect the “sensitive and unique ecosystem that is unlike any other region on Earth” in a 2016 White House statement. However, the Trump administration has made it clear that energy exploration in the Arctic offshore is an important part of an “America first” economic policy that has been openly averse to the current regulatory environment for energy development (see Exec. Orders 13795 and 13783 allowing leasing in the Arctic and easing regulatory burdens, respectively).



**Figure 1.** The Chukchi Sea Planning Area, with leased areas, included in the 2012-2017 5-year Oil and Gas Leasing Program. Department of the Interior (DOI 2013)

A pro-oil political environment may result in leases available for bid in the Chukchi Sea in the 2022–2027 program, or in the 2017-2022 by Congressional approval. Furthermore, while costs to develop in the region are high, the specific economic constraints are relatively uncertain (Deloitte 2015). Average costs of oil production in the Arctic vary from \$35/bbl to \$100/bbl, depending upon the accessibility of the resource (Harsem et al. 2011, IEA 2008). For comparison, offshore U.S. oil resources in the Gulf of Mexico cost between \$35/bbl and \$65/bbl to produce, while unconventional U.S. shale oil resources cost between \$50/bbl to \$120/bbl (IEA 2008), though more recent reports indicate that advancements in technology and efficiency have lowered costs to as little as \$30/bbl for shale resources (Mlada 2017, Rapier 2016). This thesis presents an empirical model of a supply curve for oil development in the Chukchi Sea, based on data from the Bureau of Ocean Energy Management (BOEM), suggesting that prices of \$60/bbl will lead to the production of a little over 3.2 billion barrels of oil (hereafter Bbbl). With much higher prices, total production from the region could reach upwards of 15 Bbbls.

Such prospects would ensure significant economic benefits for the U.S. At \$60/bbl, total discounted revenues from the sale of 3.3 Bbbls of oil are estimated to be \$83 billion. However, the environmental and cultural costs associated with development may unfairly burden Indigenous communities of the North Slope Borough. Oil and gas activities have historically left these communities saddled with waste and pollution and have displaced traditional ways-of-life (Anders 1985, Williams 2011). Although no large oil spills have occurred in the Arctic near-shore, oil pollution has the potential to negatively impact important subsistence marine resources.

Conservationists argue that the ecological risks are simply too high to permit oil development in a region already stressed by the effects of climate change (Shestakov 2013, Schmidt 2011). Oil spill response strategies are untested in the Arctic, and the *Deepwater Horizon* oil spill disaster of 2010 looms large in the public consciousness. Despite reassurances of safety, accidents do happen, and Shell's grounding of a drill ship during their exploratory activity, combined with the failure of a key oil-spill containment dome in test trials, confirms that the Arctic is a challenging, risky environment for oil development (Funk 2014).

Importantly, oil development also carries with it a virtual guarantee that the sum of hydrocarbons extracted from the seafloor will reach the atmosphere in the form of many gigatons of carbon dioxide, advancing anthropogenic climate change. But damages associated with climate change are not typically estimated in benefit-cost analyses of oil and gas activities when the resource is small relative to the global supply, and the displacement of emissions through the combustion of other oil resources would be expected (e.g. Kotchen and Burger 2007, BOEM 2015b). This thesis aims to address these concerns by presenting an analysis of the benefits and costs of oil development in the Chukchi Sea both with and without a hypothetically-imposed carbon tax. I find that if oil producers were made to internalize the costs of climate change in the form of a tax equal to the social damages of carbon pollution, production costs increase by approximately \$15.5/bbl and no oil becomes profitable for development.

This thesis considers costs associated with losses in both use and non-use values for the Chukchi Sea in the event of a significant oil spill. To my knowledge, this is the first benefit-cost analysis of oil development in this region of the Arctic, and the first to specifically consider the economic costs associated with losses in subsistence harvests for Arctic Indigenous communities

of the North Slope, and the first to consider the net benefits of offshore oil production in the presence of a hypothetically-imposed carbon tax on oil producers.

## **Methods**

Benefit-cost analysis is a useful analytical tool for evaluating the net effects of projects that will have impacts on societal welfare. A quantitative assessment of benefits and costs can allow for an objective appraisal of contentious policies or projects, such as oil development in otherwise pristine wildernesses or natural resources. In this analysis, I conform to the method of benefit-cost analysis from a national accounting perspective, in line with Hahn and Passell's (2010) and Kotchen and Burger's (2007) economic assessments of oil resources in ANWR and on the U.S. Outer Continental Shelf (OCS), respectively.

The Outer Continental Shelf (OCS) of the Chukchi Sea is estimated to contain a mean sum of 15.38 billion barrels of technically recoverable oil and gas resources (BOEM 2016a). Undiscovered, technically recoverable resources (UTRR) are defined as resources that can feasibly be recovered with current technologies. Undiscovered, economically recoverable resources (UEER) are resources that can be extracted under imposed economic constraints, where the supply is tied to the market price of oil. In this thesis, I examine the benefits and costs associated with the cumulative development of the UEER of the Chukchi Sea OCS over the course of 70 years, including: revenues from the sale of extracted resources, production costs, and costs associated with lost use and non-use values from potential oil spills.

### *1. Benefits*

Benefits from development include revenues from the sale of all economically recoverable oil resources. Gas resources will provide additional revenues; however, gas is a significantly less

valuable product of oil development and, therefore, not considered here. Gas sales are also not considered in cost-benefit analyses of oil development conducted by Hahn and Passell (2010) and Kotchen and Burger (2007). Because the volume of the UERR depends upon the market price, it is necessary that I choose a hypothetical price for the analysis. There is little correlation between oil price and inflation, and large fluctuations and price shocks make it extremely difficult to forecast the price of oil many years into the future. Since 2005, the price of Alaska North Slope crude has fluctuated between \$26/bbl and \$129/bbl, with a peak in 2008 and a relatively gradual decline to the current (2017) value of \$49/bbl (U.S. EIA 2017a). The central results of this analysis consider a price of \$60/bbl, which is between the average of the last two years (\$42) and the last ten (\$75), but net benefits are also assessed at a low of \$40/bbl and a high of \$100/bbl to address uncertainty in price.

The volume of oil produced at each market price is determined by estimating an empirical model of a supply curve with a regression of price on exponential, logarithmic, and level terms of quantity. The function is graphed in Figure 2 and is expressed as follows:

$$\text{Eqn. 1: } y = 51.628e^{(0.03177x)} + 2.216\ln(x) + 0.001x^{4.464}, R^2 = 0.99$$

where  $x$  is the volume of economically recoverable oil (Bbbls) and  $y$  is the per-barrel market price of oil. Solving for the quantity of recoverable oil at a price of \$60/bbl yields 3.23 Bbbls. At \$40/bbl and \$100/bbl, approximately 0.46 and 11.4 Bbbls are produced, respectively. Revenues are calculated for each price and associated volume of oil, and real prices are assumed constant for a 70-year lifetime of development, which is consistent with the projected life of all oil

exploration, development, and decommissioning activities for a cumulative OCS program (Ji et al. 2017).<sup>1</sup>

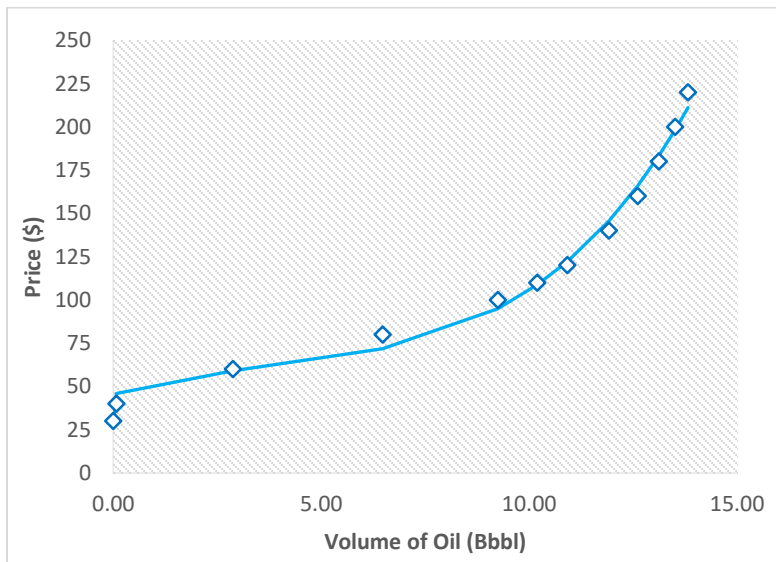
The supply of 3.2 Bbbls is equal to that supplied by total U.S. oil production in 2016 alone (U.S. EIA 2017b). Distributed over 70 years, the annual production from this project is approximately 46 million bbls (Mbbls), which is less than 2% of the annual domestic supply, and is therefore unlikely to have any effect on global price. Hahn and Passell (2010) conducted a cost-benefit analysis for the full development of the UERR of the Alaska National Wildlife Refuge (ANWR) and the Outer Continental Shelf (OCS) of the lower 48 states. In their analysis, the authors considered benefits from an increase in consumer surplus associated with decreased oil prices, and from a reduction in the economic costs of disruption that result from rapid fluctuations in the global oil market (also considered more broadly as “energy security”). However, their analysis examines the benefits accruing from a much larger development scenario: the total production of 16.7 Bbbls at \$50/bbl or 18.6 Bbbls at \$100/bbl. Because the supply considered is so large, changes in consumer surplus due to changes in global supply must be considered. However, even with these large supplies, the authors found price effects of only 1%. The supply of 3.2 Bbbls considered in this analysis is much smaller, and so I consider consumer surplus effects due to changes in global prices and energy dynamics to be negligible.

Oil development in the Chukchi Sea poses technical and financial challenges that are specific to the Arctic, including a harsh, freezing environment; limited infrastructure; long

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<sup>1</sup> Hahn and Passell (2010) and Kotchen and Burger (2007) simplify the quantitative analysis by assuming the price of oil is in equilibrium over time (as in, prices rise at the rate of interest) (Hotelling 1931), which allows for the use of a one-period model of oil development. There is little evidence of this in historical oil price data (Mason 2014), and for ease of calculation I instead assume that prices remain constant over the lifetime of a 70-year model. This may also be unrealistic, so net benefits are calculated at three prices in an attempt to address this uncertainty.

development times; and a requirement for high initial capital outlays, complex project management, and advanced engineering (Pugliaresi 2013). Hence, offshore oil development is more expensive here than in the Beaufort Sea, ANWR, or on the OCS of the lower 48 (Pugliaresi 2013, McGlade and Ekins 2015, Bourne 2016). I rely on data provided in a governmental assessment of undiscovered oil and gas resources of the OCS (BOEM 2016a) to arrive at a supply curve specific to oil development in the Chukchi Sea (Figure 2). The supply of economically recoverable resources as a function of market price is shown in Figure 2, and at high market prices the UERR converges to the mean value of the UTRR (15.38 Bbbls). Revenues are calculated by multiplying the price per barrel (\$60) by the sum of oil produced in each year of development, and the present value of revenues is calculated using a 3% social discount rate. Annual oil production is assumed constant over the lifetime of development.<sup>2</sup>



**Figure 2.** Price-supply data for oil development in the Chukchi Sea region, generated from BOEM (2016a) data on the volume of undiscovered resources that are economically recoverable at twelve independent prices (blue diamonds). The supply curve is modeled using a multivariate non-linear regression (Equation 1). All prices are in 2016 USD.

<sup>2</sup> Bartlett (2000) uses Hubbert-style (Guassian) curves to estimate the path of world oil development. However, limitations on data preclude a more detailed projection of annual oil development in the Chukchi Sea.

## 2. Costs

Three categories of costs are examined for the full-development scenario in the Chukchi Sea: production costs, subsistence harvest losses associated with an oil spill, and non-use losses associated with an oil spill.

### 2.1 Production Costs

Production costs are determined using Equation 1, which represents the supply curve and thus the marginal cost of production. Let  $x_t$  denote cumulative production through year  $t$ , etc.

Integrating the supply function from  $x_{t-1}$  to  $x_t$  yields annual production costs in year  $t$ . Total, discounted costs are given in Table 1, in the results section.

### 2.2 Environmental Damages

The primary causes of significant environmental damages from offshore oil development are oil spills. In welfare economics, environmental damages create costs in the form of losses in use values (including hunting, fishing, recreation, and tourism) and non-use values (also called existence values, which encapsulate the non-consumptive enjoyment of a pure public good, such as a pristine wilderness, without interacting directly with the resource (Krutilla 1967, Kopp 1992)). I am not aware of any commercial fishing or tourism industries in the Chukchi Sea. However, I do consider subsistence use by the North Slope Indigenous communities as a category of use-values that may become compromised due to an oil spill. Non-use values are also considered in this analysis.

*Oil Spills.* Anderson, Mayes, and Labelle (2012) present an analysis of historical oil spill rates for offshore oil drilling in the U.S. OCS between the years of 1964 and 2010. Their report, published by BOEM, models oil spill occurrence as a function of the volume of oil handled (i.e.

extracted and transported) from OCS platforms, pipelines, and tankers. Because spills from tankers transporting Arctic oil may not necessarily occur in the Chukchi Sea, I ignore this spill source. Overall, the report suggests that the rate of oil spills has decreased significantly since 1964, though the total volume of oil handled has increased. Therefore, the estimates of oil spill occurrence from the most recent period (1990 to 2009) are the most applicable to future development. Note that this timeline excludes the largest spills in recent history: the *Exxon Valdez* oil spill (hereafter, EVOS) (1989) and the *Deepwater Horizon* oil spill (2010). During this period, the average oil spill occurrence from platforms and pipelines was 6,400 barrels for every Bbbl handled. Therefore, for 3.2 Bbbls extracted, roughly 20,000 barrels could be expected to be spilled in the Chukchi Sea over the lifetime of development.

In an environmental cost model for the proposed exploration of the Chukchi Sea area leased during Lease Sale 193, BOEM (2015b) assesses potential impacts associated with a hypothetical development scenario that results in the production of 4.3 Bbbls of oil. This scenario excludes future lease sales and encompasses only a portion of the UERR and the development of two fields. BOEM conducts an oil spill analysis and expects that two large (>1,000 bbls) spills will occur with 75% cumulative probability over a 78-year lifetime (see BOEM 2015c, for more detail). The total volume of oil spilled is specifically modeled for the Arctic, and amounts to approximately 6,800 bbls, which is substantially less than the 20,000 bbl estimate that is based upon historical spills for the whole of the U.S. OCS. (Anderson et al. 2012). However, the Arctic offshore is also untested territory, with heightened risks to oil and gas activities and infrastructure due to severe weather, limited daylight, ice floes, freezing temperatures, and other Arctic-specific hazards (Shestakov 2013). A less conservative estimate that is consistent with historical observations may provide a more reasonable expectation of spill

size; however, this thesis does not make any specific assumption about the volume of oil spilled for purposes of analysis. Rather, I examine the effects of a class of spills that are considered “major.”

In order to isolate the effects of major oil spills, I use BOEMRE (2011) estimates of oil spill risk occurrence that are specific to the Chukchi Sea. I consider impacts associated with the category of largest spills analyzed in the report (spills greater than 10,000 bbls, hereafter referred to as “major”). Major oil spills are likely to result in acute biological effects from high concentrations of petroleum, and exposure may be short-term or long-term, depending upon the degradability of the oil, either through physical (e.g. evaporation) or biological (e.g. microbial oxidation) processes (National Research Council 2003).

In this analysis, the agency estimates that the expected rate of occurrence of major oil spills (>10,000 bbls) in the Chukchi Sea is 0.203 spills per Bbbl produced. Therefore, the annual probability of a major oil spill for any development scenario is simply written as:  $0.203 \times \text{annual production (Bbbls)}$ . This probability encapsulates the risk of spills from pipelines, platforms, and wells (BOEMRE 2011). Both use- and non-use losses are risked using this probability.<sup>3</sup>

### *2.3 Use values*

One category of use values is considered in this analysis: subsistence harvest of marine mammals by Native Alaskans. Oil pollution poses a significant threat to subsistence-harvest patterns among Indigenous Inupiat communities of the North Slope area. Specifically, the Bowhead whale and Pacific walrus are vital to the subsistence and culture of Inupiat peoples

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<sup>3</sup> A major oil spill is generally defined by BOEM (2011) as >10,000 bbls. A sum of 20,000 bbls spilled would be in line with historical observations for the U.S. OCS (Anderson et al. 2012); however, no upper bound is specified for a major oil spill, so this probability includes spills that exceed 20,000 bbls.

(BOEM 2015b). A large oil spill may diminish resource abundance, especially if its occurrence overlapped both spatially and temporally with the fall bowhead whale migration (Huntington et al. 2009, BOEM 2015b). If oil were to become trapped in ice, it may lead to contamination of the resource in subsequent warm seasons. Contamination, whether actual or perceived, could persist for many years (BOEM 2015a). These concerns were voiced by Indigenous communities in response to offshore oil exploration and development proposals first put forward by BP in the 2007–2012 Oil and Gas Leasing Program (MMS 2005). Negotiations were made between the BP and the North Slope Bureau (NSB), the Alaska Eskimo Whaling Commission (AEWC), and Native tribal governments on the appropriate form and amount of compensation for any disturbances to subsistence-harvest patterns because of oil and gas activities (MMS 2005). The NSB and AEWC estimated the monetary impact of a major oil spill, considering direct (nutritional replacement) and indirect (cultural) values, the costs associated with temporary food supplies, the relocation of hunting crews and equipment, hauling of harvested meat, and socio-cultural counseling. These agreements were called the Good Neighbor Policy, and are cited by BOEM (2015a) as a social externality associated with the full-development scenario of Lease Sale 193. Based on this information, BOEM estimates that the value of the subsistence harvest is approximately \$120/kg. This is significantly higher than the \$8.80/kg - \$17.6/kg that is reported by the Alaska Division of Fish and Game (ADFG 2014) for simple nutritional replacement costs. This suggests that the cultural and economic value attached to subsistence, along with the preference for this food source and the difficulty of relocating hunting areas, can be significantly higher than nutritional replacement costs alone would suggest.

BOEM (2015a) uses these values for subsistence to estimate the subsistence harvest loss associated with a continuous discharge event (CDE). A CDE is typically associated with

catastrophic well blow-outs or tanker spills that result in high-volume, extended duration oil spills of “national significance” (BOEM 2017); however, due to limitations in data availability, I am not able to separate the effects on subsistence for major, rather than catastrophic, oil spills. To avoid under-estimating the impacts on subsistence-users of a major oil spill by limiting subsistence losses strictly to these low-probability, catastrophic events, I assume that the more probable major oil spill will elicit the same effects predicted by BOEM for a CDE: specifically, a suspension of the harvest for three seasons (in the fall following the drilling season and the spring and fall hunting seasons in the year after).<sup>4</sup> The associated loss in subsistence harvest for a three-season suspension is estimated to be 1.6 million kg for all marine mammals. This amounts to use losses of approximately \$197 million (BOEM 2015b, p. 93). Expected costs are estimated using the annual probability of a major oil spill. These costs are not the result of an economic study, but rather of pre-spill negotiations between members of the Indigenous community and the oil industry, and come closest to estimating the willingness-to-accept for damages associated with subsistence harvest losses due to an oil spill without employing a contingent valuation study.

I am not aware of any contingent valuation studies that place a value on subsistence harvest in the Arctic. However, Wolfe and Walker’s (1987) economic study conducted prior to the EVOS provided an estimate of the value of subsistence harvests across Alaska using a revealed preference method. The study indicated that individuals were willing to accept lower average incomes in the market economy if subsistence harvest opportunities existed, which

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<sup>4</sup> A major oil spill may or may not be a continuous discharge event (CDE), so there is considerable uncertainty in the extent of damages possible from a major oil spill. Further rationale for use of the high-end of damages is given in the discussion, but I attempt to address this uncertainty in a Monte Carlo sensitivity analysis.

demonstrated that subsistence livelihoods had greater value to the individuals than the foregone wage earnings (Wolfe and Walker 1987, cited in Duffield 1997). The per capita value of the subsistence harvest was estimated at \$118/lb (1982 dollars) for any subsistence product (marine mammal, fish, caribou, etc.). Updating this to 2017 gives a value of the Alaskan subsistence harvest of about \$300/lb, or \$660/kg. This may provide a reasonable upper-bound for the value of the Arctic subsistence harvest.<sup>5</sup>

#### *2.4 Non-use Values*

The last category of costs treated in this analysis is non-use (also called passive use) value of the Chukchi Sea natural resource. Hahn and Passell (2007) estimate non-use values for both ANWR and the Atlantic OCS using estimates drawn from a contingent valuation study conducted in the wake of the EVOS. The survey, outlined by Carson et al. (2003), estimated the nation-wide willingness-to-pay (WTP) to avoid another *Exxon Valdez*-like oil spill. Because the resource studied is also offshore of Alaska, I, too, employ this value as an estimate for non-use losses. Hahn and Passell (2007) count these passive use values as a guaranteed cost of development in ANWR; however, I do not make this assumption about the Chukchi Sea, as oil development has been ongoing in the near-shore Arctic (Beaufort Sea) for several decades, and the resource is therefore not pristine in the sense that it is entirely unindustrialized. Furthermore, it is likely that the WTP to avoid another EVOS is not equal to the WTP to avoid oil development all-together. That being said, offshore natural resources are held in the public trust,

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<sup>5</sup> Wolfe and Walker's (1987) study results were used to estimate the value of the lost subsistence harvest over a 10-year period post-EVOS. In the *Exxon Valdez* litigation, the Defendant's expert, Haufman, reported a much lower value for subsistence: approximately \$34/lb (1987), arguing that the Wolfe-Walker model could lead to an overestimation due to selection bias, and valued more than just subsistence harvest (Duffield 1997). Wolfe and Walker's (1987) estimate is thus treated as an upper-bound, and Haufman's estimate as a lower-bound, in the Monte Carlo sensitivity analysis.

and thus to not include passive use values is “to effectively say that resources that the public had chosen to set aside and not develop could be harmed at little or no cost to the responsible party” (Carson et al. 2003, p. 279). For these reasons, I consider non-use values as a cost associated with harm to the natural resource, harm which I assume will occur in the event of a major oil spill. Non-use values are estimated using the updated mean WTP for avoiding an EVOS and multiplying this value by the annual probability of the expected oil spill.<sup>6</sup>

### 3. *Carbon Tax*

McGlade and Ekins (2015) confirmed the incompatibility of Arctic oil development with climate constraints in a study that assessed the global carbon budget for 2011-2050. The authors determined that of 11,000 gigatons C available to the global society in the form of undeveloped hydrocarbon resources, only 1,100 gigatons C can be emitted over this period to have a better-than-even chance of not surpassing a 2 degrees C global temperature change threshold. Due to the high production costs associated with Arctic oil development, Arctic resources are not part of the economically-optimal solution to stay within this carbon budget. Similarly, this thesis applies a climate constraint to oil development, in the form of a hypothetical carbon tax levied on producers, and determines the new volume of recoverable oil from the Chukchi Sea.

In line with Kotchen and Burger (2005) and BOEM (2015a), I do not consider greenhouse gas damages as a cost of oil development because the supply is very small compared to the global market for oil. Annual production from the Chukchi Sea is estimated to be 45

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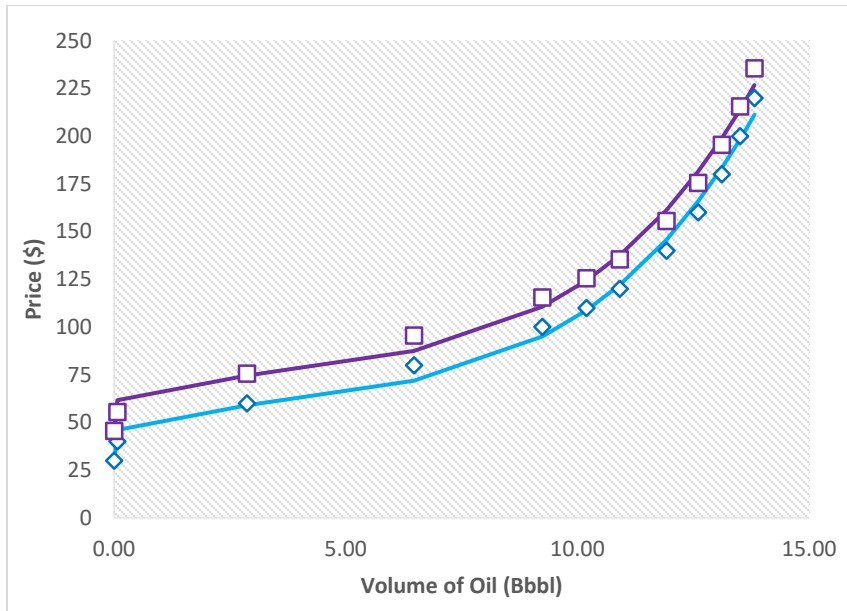
<sup>6</sup> The original contingent valuation survey (Carson et al. 1998) estimates that the mean willingness-to-pay (WTP) to prevent another EVOS was \$7.2 billion, with lower and upper bounds of \$3 and \$15 billion, respectively (1990 dollars). Adjusted for inflation, the mean 2017 value of non-use losses is \$13.8 billion, with lower and upper bounds of \$5.2 and \$28 billion, respectively. I address the uncertainty in this value in the Monte Carlo sensitivity analysis.

Mbbls, which is less than 1% of annual world oil consumption (approximately 35 Bbbls, U.S. EIA 2017c), so the cumulative impact of the development of these specific resources on global oil demand is negligible. Thus, one can expect that if demand were not met with Chukchi Sea oil resources, they would be met somewhere else. This effectively means that the supply and its associated greenhouse gas emissions would be fully displaced, and that no net positive greenhouse gas emissions would arise from the scenario, an assumption that is also made in economic analyses by Kotchen and Burger (2007) and BOEM (2015b).

The costs of greenhouse gas emissions from the use of oil and gas resources are real and non-negligible. The EPA (2015) has calculated the global social cost of carbon, which in 2015 was \$36/ton of CO<sub>2</sub> and is expected to rise at 3% per year. I ask: How would the NPV of development change if a greenhouse gas tax were levied on producers in the Chukchi Sea? Assuming no price increase, one would expect production costs to rise by an amount equal to the 2015 per-barrel social cost of carbon, which is calculated to be approximately \$15.5/barrel.<sup>7</sup> The adjusted supply curve is shown in Figure 3.

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<sup>7</sup> The per-barrel social cost of carbon is calculated by estimating the mass of CO<sub>2</sub> that would be emitted through the combustion of a barrel of typical North Slope crude, which is considered “light,” meaning that it is rich in gasoline-forming hydrocarbons and low in asphaltenes (tars) (Fingas 2010). Estimates of the carbon content of crude oil are determined using an average density of North Slope crude oil (0.86 g/mL, Fingas 2010), multiplied by the relative carbon content of light crude (approximately 85%), and converted to a mass of CO<sub>2</sub> using stoichiometry.



**Figure 3.** Price-supply data for the Chukchi Sea region. Blue curve represents the original modeled supply curve; purple curve represents the modeled supply curve with an added carbon tax, using data drawn from EPA (2016) on the social cost of carbon. New prices are calculated by converting the cost per ton of carbon emissions to a cost per barrel of oil, and adding this to the original (blue) supply curve. The purple supply curve is generated using a regression as before. All prices are in 2016 USD.

The carbon-tax supply curve is modeled by adding \$15.5 to Equation 1. Given this new supply curve and a constant market price of oil of \$60/barrel, the new volume of economically recoverable resources from the Chukchi Sea effectively becomes 0. At a price of \$100/bbl, 8.3 Bbbls of oil are recoverable. Production is again assumed constant in each year and benefits and costs are calculated in the same manner as without the tax. Revenues are calculated as the production in each year of development multiplied by the price of oil. Production costs are determined for each year of development using the area under the new supply curve.

Subsistence harvest losses and non-use losses associated with oil spills in the carbon-tax scenario are risked using the same frequency rate for major oil spills, but expected damages are lower due to decreased annual production.

## Results

Net benefits for the full development scenario of the Chukchi Sea UERR are calculated according to the volume of recoverable oil at prices of \$40/bbl, \$60/bbl and \$100/bbl. Annual losses in use and non-use values for the Chukchi Sea are dependent upon the annual production of oil: more oil production leads to an increased probability of an oil spill and thus increased expected damages. Central results indicate that net benefits are \$6.2 billion at a constant price of \$60/bbl and a social discount rate of 3% (Table 1). Overall, the economic value of oil development in this region is highly price-dependent. Net benefits increase dramatically at \$100/bbl, and are negative at \$40/bbl. With a carbon tax, production falls significantly, and no oil is developed with prices at or below \$60/bbl. These results indicate that internalizing climate externalities due to carbon pollution from the combustion of the Chukchi Sea resources renders Arctic oil development uneconomical except at \$100/bbl. Environmental damages increase with production; however, damages do not tip the outcome in any scenario.

**Table 1.** Summary of costs and benefits for the full-development of the Chukchi Sea UERR at three different prices. All values are in \$ billions (2017).

	\$40/bbl	\$60/bbl	\$100/bbl
Volume oil	<b>0.46</b>	<b>3.2</b>	<b>11.4</b>
<b>Benefits</b>			
Revenues	7.9	83	489
<b>Costs</b>			
Production costs	9.2	72.9	316
Use value	0.01	0.06	0.195
Non-use value	0.5	3.9	13.4
<i>Total costs</i>	9.8	76.8	330
<i>Net Benefits</i>	<b>-1.9</b>	<b>6.2</b>	<b>159</b>

**Table 2.** Summary of costs and benefits for the development of the Chukchi Sea UERR given a carbon tax levied on producers. All values are in \$ billions (2017).

	\$40/bbl	\$60/bbl	\$100/bbl
Volume oil	<b>0</b>	<b>0</b>	<b>8.3</b>
<b>Benefits</b>			
Revenues	0	0	355
<b>Costs</b>			
Production costs	0	0	264
Use value	0	0	0.142
Non-use value	0	0	4.9
<i>Total costs</i>	0	0	269
<i>Net Benefits</i>	<b>0</b>	<b>0</b>	<b>86</b>

**Notes.** Net benefits are total benefits (revenues) less total costs. Revenues are calculated at a constant price of North Slope Alaska crude oil. Net present values are calculated for expected environmental and social damages, which vary with the probability of an oil spill, which is in turn dependent upon the volume of oil produced in each year. Non-use losses are drawn from Carson et al. (2003), and are assumed lost with a major oil spill. Carbon-tax scenario represents diminished production due to increased production costs for the industry.

## Discussion

Two significant drivers of uncertainty in this analysis are those associated with oil price and with expected losses of non-use values for the Chukchi Sea as an unpolluted wilderness resource.

Current oil prices are around \$44/bbl for Alaska North Slope crude, and have stayed relatively stable at this price since 2015 (EIA 2017). Assuming a constant real price for 70 years is a strong assumption; however, advancements in hydraulic fracturing technology and efficiency have allowed the U.S. to double domestic oil production in recent years, and U.S. shale resources promise abundant supply even at low prices (DiChristopher 2017). Advancements in renewable technologies and energy efficiency may lead to decreased demand for oil and thus lower prices, though there is little doubt that fossil fuels will remain a dominant energy source for the next few

decades (Kotchen and Burger 2007). For these reasons, \$60/bbl appears to be a realistic, if even high, estimate for oil prices in the years to come.

The other important source of uncertainty addressed in this analysis is that of non-use losses. Non-uses losses are expected to occur in the event of a major oil spill. Due to the lack of contingent valuation data in existence for the Arctic natural resource, the best estimate for non-use losses are taken from Carson et al. (1992, 2003), which measured losses due to the EVOS.

The EVOS was a very large tanker spill of at least 260,000 barrels of crude oil in the Prince William Sound of Alaska. The spill resulted in mass mortality of animals, benthic invertebrates, and microalgae. Losses of approximately 250,000 seabirds, 2,000 sea lions, and 300 harbor seals were documented during the days after the spill (Peterson et al. 2003). Carson et al. (1992) conducted a nation-wide contingent valuation study that estimated that the mean willingness-to-pay to avoid another such spill was approximately \$7.2 billion (1990 dollars). Updated to 2017 dollars, this is \$13.8 billion. This study assumes that these costs would be incurred from a spill greater than 10,000 bbls. Because of the significant difference in spill size between the EVOS and the lower-bound examined in this thesis, this value may be an overestimate of expected non-use losses for oil development in the Chukchi Sea. However, many reasons support the use of an upward bias, each of which are explained in the following paragraphs.

First, any spills greater than 10,000 bbls are considered “major,” and can be expected to have negative effects on the ecosystem that may create losses in non-use that are comparable to those of the EVOS. A 2015 biological study by the National Ocean and Atmospheric Administration’s National Marine Fisheries Service (NMFS) determined that a spill of this size could have adverse effects on the fitness and population of cetaceans (whales), pinnipeds (seals),

walruses, and seabirds due to increased morbidity and mortality from exposure to toxic fumes and/or the ingestion of oil, with major effects likely for multiple large oil spills or catastrophic spills (p. 264). Peterson et al. (2003) note that mortality is highest for animals that require routine contact with the sea surface, and that the oiling of fur or feathers from floating oil slicks can lead to death from “hypothermia, smothering, drowning, and ingestion of toxic hydrocarbons” (p. 2082).

Second, A NMFS (Whitehouse 2012) report on the Chukchi Sea ecosystem found that the Chukchi Sea is a benthic-driven environment, with lower levels of primary productivity (i.e. phytoplankton) compared to sub-Arctic systems. The strong benthos supports benthic-foraging marine mammals; however, due to the low ratio of primary production to marine biomass, the Chukchi Sea ecosystem is not expected to be resilient to high-mortality events following an oil spill (Whitehouse 2012). Furthermore, BOEM (2015b) modeling studies of ecological impacts of identical spill sizes in the Arctic and Cook Inlet estimate an increased sensitivity of the Arctic environment compared to the Cook Inlet of approximately 130% (p. 73). This suggests that an oil spill in the Arctic may elicit more profound ecological effects than those observed in the sub-Arctic of Alaska.

Third, certain areas of the Chukchi Sea provide critical habitat for marine mammals, and oil pollution in these areas could lead to adverse effects on species’ populations. The Hanna Shoal, for example, is an extremely important breeding and foraging area for the Pacific Walrus (Jay et al. 2012), and was withdrawn in 2015 from oil and gas leasing by the Obama Administration (Pew Charitable Trusts 2015). However, a major oil spill could extend into this region even if no drilling activity were to take place directly in the region.

Fourth, the timing of an oil spill is key to the potential magnitude of impacts. In their analysis of walrus areas of use in the Chukchi Sea, Jay et al. (2012) note that the leased blocks within LS 193 overlap with walrus foraging areas, with the highest overlap occurring with high walrus foraging concentrations during July and August. Walrus have also been found to alter their foraging activities in response to the last 5-yr minimum in summer sea ice extent in the Chukchi Sea. Summer habitat changes may incur increased pressures on the species, which may be exacerbated by heightened exposure to oil and gas activities on the OCS during the summer (Jay et al. 2012). The bowhead whale also visits Barrow in great numbers during the fall and spring migration (Quakenbush 2010). The National Marine Fisheries Service (NMFS 2015) notes that: “if a very large oil spill were to occur during a time when many bowhead whale calves were present, calves could die and recovery from the loss of a substantial portion of an age class cohort and its contribution to recruitment and species population growth could take decades” (p. 263).

Fifth, the effects of a major oil spill may be much more significant in the Arctic due to the enhanced difficulties in cleaning up the oil. Response windows are small, technology is limited, nearby infrastructure to facilitate safety responses is virtually non-existent, and oil companies are generally considered ill-prepared to meet these challenges (Shestakov 2013). Furthermore, if oil were to become trapped in ice over the winter, it would not be recoverable, and could elicit negative impacts on an entire stock of migratory mammals as the ice melts and mammals begin foraging and breeding in the area during the summer and fall seasons (Huntington et al. 2009).

Sixth, a recent ecological study suggests that the EVOS has had much more significant, lasting impacts than were predicted at the time of the Carson et al. (1992) study. Scientists have

found that oil has persisted in both volume and toxicity, leading to persistent biological exposure and population-level effects on animal and fish species not felt until several years after the spill (Peterson et al. 2003). These effects were not known at the time of the study, and could not have been included in the measure of non-use losses. As a result, non-use losses estimated in 1992 may have underestimated actual losses resulting from the spill.

Finally, in their analysis of oil development in ANWR, Kotchen and Burger (2007) put forward the reasoning that non-use values that people hold for wilderness areas have more to do with avoiding industrialization than with any specific environmental damages: “To many people, regardless of whether or not they belong to an environmental organization, the notion of any development in one of the great remaining wilderness areas is the real cost of drilling in ANWR. From an economic perspective, the challenge is to put a value on such nonmarket costs” (p. 4726). This suggests that non-use losses may be incurred in a wilderness regardless of oil spill occurrence. Although the Chukchi Sea is not a wilderness preserve like ANWR, the effects of climate change have arguably rarified features of the Arctic as a whole, such as ice-obligate marine mammals and icy habitats. Diminishing sea ice brings with it the sad possibility of losing some of the most charismatic and unique marine species on Earth, including polar bears, grey whales, humpback whales, walruses, and seabirds, along with one of the worlds’ greatest reserves of snow and ice. For many, this concern is enough to make the idea of exposing this vulnerable area to further impacts downright disturbing.

*Routine Effects.* Use losses associated with routine effects are not considered in the net benefit calculations in this study, but are nonetheless deserving of discussion. Huntington et al. (2009) suggest that oil and gas activities may alter habitats and disturb marine mammal behavior through routine effects, including: “noise from seismic surveys, shipping, and drilling; increased

chronic pollution and the risk of an accidental oil spill from platforms and tankers; and...cumulative impacts as activities encompass increasing areas of arctic continental shelves...” (p. 79). The effects of underwater noise (especially those associated with seismic surveying during the exploration phase of oil development) are an important subject for evaluating environmental impacts. Marine mammals have been found to shift migratory routes to avoid industrialized areas or sound in the Beaufort Sea, including those associated with drilling sites (Huntington et al. 2009, Sheard 2007). Moore et al. (2012) give several ways in which noise can negatively affect marine mammals, including: disrupting important behaviors, such as breeding, resting, and feeding; injury or stress; masking of important sounds; hearing loss; and decreased prey availability due to changes in the ecosystem. Masking is defined as chronic increases in low-frequency sound that impede sonar communication between mammals. Both shipping and seismic surveying have been found to be sources of masking (Hildebrand 2009, cited in Moore et al. 2012).

Moore et al. (2012) also note that the current strategies to mitigate acoustic harassment involve creating a radius around sensitive zones, the size of which is “derived solely on the basis of an anticipated received level from a given source, an approach that is inconsistent with current scientific understanding of how noise affects marine mammal behavior” (p. 290). This suggests that simply removing certain areas from oil and gas exploration may not effectively limit the adverse effects of sound on marine mammals. While a precise quantification of the effects of sound on marine mammals is beyond the scope of this study, estimates of impacts of other coastal industrial activities on subsistence users may provide a rough idea of the losses in use-value due to routine oil and gas activities.

A 2014 economic study on subsistence used a travel-cost method, *ex ante*, to estimate the losses in welfare associated with a decrease in subsistence harvest availability due to a proposed large port development project near the Arctic village of Kivalina, Alaska (Raheem 2014). The dredging and pollution associated with this project was expected to interrupt the feeding and migration of marine mammal species, displacing hunting activities from the most desirable areas to less desirable ones. The costs to the Kivalina village of this displacement were estimated to be about \$189,000/yr (2014 USD) or \$472/person given the approximate population of 400. These costs are unique to the distances required by Kivalina residents to utilize alternative hunting areas. However, they may be useful to inform this analysis for the North Slope, at least for routine oil and gas operations that lead to similar disruptions, such as those associated with drilling and noise, sediment excavation, and pipeline construction and dredging (AMAP 1997). Scaling this value up to the population of the North Slope Borough (9,703) yields annual costs of approximately \$4.6 million. If disruptions are expected to be greatest with seismic surveying and construction of platforms, pipelines and commercial infrastructure during the exploration phase (roughly the first 10 years) of development, then total costs are approximately \$46 million. These costs don't consider the adverse effects of a large oil spill, nor do they account for the damages that may accrue if alternative hunting areas do not provide the same level of subsistence as the previous ones. Although this thesis does not include losses in use-value due to routine oil and gas operations in the analysis, this is an important area for future research.

*Distribution of benefits and costs.* A benefit-cost analysis of a large oil development project would do well to analyze the distribution of revenues and costs. A full distributional analysis requires determining weights by which benefits and costs are multiplied depending upon how strongly society favors benefitting those individuals or preventing burdensome costs upon

them (ex. those who are impoverished, disabled, or marginalized). Such an analysis is beyond the scope of this study; however, it is worth considering the extent to which costs and benefits will fall upon Indigenous communities who inhabit the Arctic.

The Inupiat Indigenous communities of the North Slope rely on subsistence harvests of marine mammals to provide valuable nutrition and preserve cultural and traditional practices that are central to the Inupiat identity. The North Slope is composed of eight traditional villages: Atkasuk, Anaktuvuk Pass, Point Hope, Point Lay, Wainwright, Kaktovik, Nuiqsut and Barrow. These villages engage in a mixed subsistence/cash economy that is in part supported by revenues from oil development. Subsistence foods include the bowhead whale, the Pacific walrus, bearded seals, fish and caribou. Of these, the bowhead whale and the Pacific walrus are most at risk from the proposed development of the Chukchi Sea OCS (BOEM 2015b). Interruptions to subsistence harvests have significant negative effects that are not limited to decreased nutrition, including impacts on “subsistence culture and ideas about the environment...economic and social organization, religious beliefs, political institutions, law and order and health services” (Ganapathy 1995, p. 16). Inupiat peoples have complained that oil development has led to disruptions in harvests since development began in the 1930s (Ganapathy 1995). Very few studies have translated these losses to decreased social welfare; arguably, values such as cultural and spiritual identity, sharing, and environmental stewardship, cannot, and indeed should not, be expressed in monetary form.

However, not all Inupiat peoples oppose oil development given that revenues from this industry support social welfare (including improved infrastructure, schools, health services, and housing) (Ganapathy 1995). Thus, removing oil development opportunities due to environmental risks demands a real trade-off in economic welfare for North Slope communities.

Ganapathy (1995) found that annual revenues to the North Slope Borough from oil and gas activities in 1988 amounted to approximately \$222 million, or \$453 million in 2017 dollars. For a population of approximately 9,000, this amounted to per capita annual revenues of about \$50,000. However, because oil in the Chukchi Sea is in federal, as opposed to State, waters, the production of these resources would not direct revenues to the North Slope Borough beyond what is received by the State in the form of taxes on the use of on-shore oil infrastructure (use of the trans-Alaska pipeline at full capacity, for example, is estimated to raise tax revenues of only \$250 per capita to the State (DeMarban 2016)).

In a larger sense, expanding oil development into the Chukchi Sea threatens to contribute to the culturally-destabilizing effects of what Williams (2011) calls “neocolonialism”. The industrialization of Indigenous lands essentially demands a painful transition from a subsistence-based economy to a capitalistic, cash economy, with internal conflicts among communities about whether to advance mineral development for the sake of income or to fight such projects for the sake of preserving subsistence, the environment, and Indigenous traditions. Williams (2011), a Native Alaskan herself, puts it poignantly when she writes:

Because of oil, Alaska’s politics have a tendency to be skewed. As the politicians support more oil development, resulting in lawsuits to protect Alaska’s lands, a David and Goliath battle has emerged. A prime example is the two-decade battle to open up the Alaska National Wildlife Refuge, which has pitted anti-oil Native people against pro-oil Native people and created a schizophrenic economic scenario in which they have been presented with one option –oil development for economic gain at the sacrifice of their subsistence-based cultures. The end game is to erase the Native; to engage them into a capitalistic model and become resource exploiters rather than living in concert with their environment as

hunter/fishers which they have done admirably since the Pleistocene age (p. 193).

This is the ultimate cost to Indigenous communities of expanding oil development in the Arctic. While negotiations between the MMS and the North Slope Borough may shed light on a reasonable compensation for the impact of oil pollution on subsistence, such a sum does not capture the environmental and social injustice associated with degrading the integrity of a thousand-year-old culture, nor with the symptoms of colonialism that are manifested in the high rates of suicide, alcoholism, and drug abuse that are prevalent among communities of the North Slope (Williams 2011).

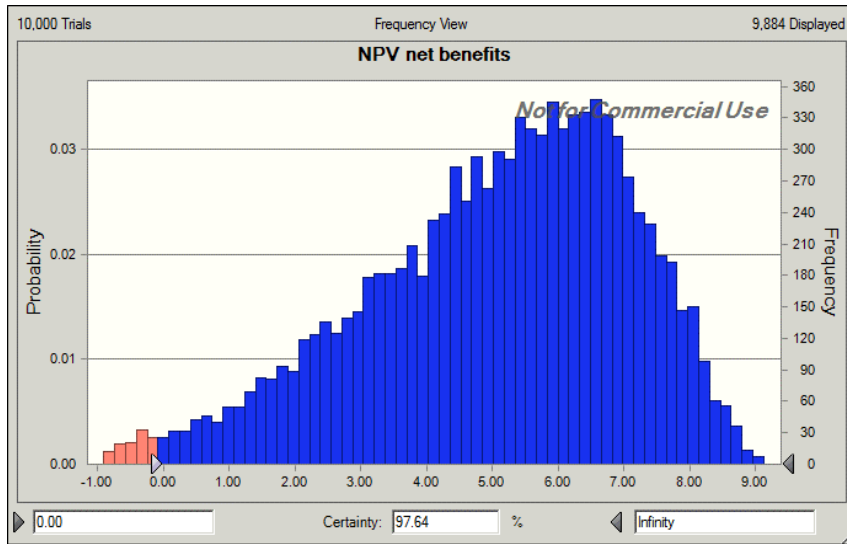
*Sensitivity Analysis.* Uncertainties in the value of Arctic subsistence uses, non-uses, and the probability of an oil spill are addressed in a Monte Carlo sensitivity analysis at \$60/bbl for the full development scenario. Results indicate that positive net benefits at this price are robust to uncertainties in oil-spill related impacts within ranges considered in the analysis, with the project exceeding zero net benefits with over 97% confidence. Key parameters are shown in Table 3, and results of the analysis shown in Figure 4.

**Table 3.** Key parameters used in Monte Carlo sensitivity analysis

Parameter	Unit	Min	Mean	Max	Distribution
Probability of major spill (>10,000 bbls)	Spills per Bbbl produced	0.10	0.20	0.30	Triangular
Non-use values	USD (billions)	5.2	13.8	28.0	Triangular
Use values	USD (billions)	0.10	0.20	1.08	Triangular

**Notes.** I assume a constant mean price of Alaska North Slope crude oil of \$60. Minimum and maximum oil prices approximate the lowest and highest average annual price of oil in the last 5 years. I obtain the mean probability of a major spill from statistical analyses conducted by BOEMRE (2011). Minimum and maximum probabilities are assumed to be 50% and 150% of the mean, respectively. The range of non-use values are obtained from Carson et al. (2003). Mean use-values are obtained from BOEM (2015b) for a 3-season hunting suspension.

Maximum use-values are also estimated for a 3-season suspension, but at a subsistence value of \$118/lb (\$300/kg, 1987 dollars) or \$660/kg (2017), in accordance with Wolfe and Walker's (1987) hedonic price estimate for Alaskan subsistence, conducted in the wake of the EVOS. Minimum use-values are estimated at 50% of the mean, approximating a 1.5-season hunting suspension.



**Figure 4.** Distribution of net benefits for the full development scenario at \$60/bbl using parameters described in Table 3. The simulation is run for 10,000 iterations, and benefits are found to exceed costs in greater than 97% of trials.

## Conclusion

This thesis has attempted to encapsulate the biggest economic and policy-related concerns regarding oil development in the Arctic: namely, the environmental and social risks that are unique to the Arctic environment and its Indigenous communities, as well as the high costs of production and the value of the recoverable resources. Due to the high costs and, to a lesser extent, the environmental risks of operating in the Arctic, net benefits are slim at \$6 billion. To put this figure in perspective, Kotchen and Burger (2007) estimated net revenues of drilling in ANWR to be \$251 billion (not considering non-use losses, which may be very significant for the region). From a social justice perspective, a big concern that this issue raises is the effect of oil development on Indigenous communities, who appear to bear a disproportionate burden of the

risks with little direct benefit. Expected losses for the North Slope communities are \$60 million, or \$6,700 per capita. Additionally, Indigenous communities are facing costs associated with climate change. Currently, erosion due to thawing perma-frosts and melting coastal ice is an imminent threat to at least five Arctic villages in Alaska, including, especially, Kivalina, Shishmaref, and Newtok, the latter of which is estimated to be losing 70 feet of land per year and recently sought federal disaster relief to relocate (Waldholz 2017).

The threat that climate change poses in the Arctic is both imminent and long-term: climate studies show that “business-as-usual” emissions scenarios will lead to substantial reductions in summer sea-ice extent by mid-century, with near complete loss by the end of the century (Overland and Wang 2007, Arzel et al. 2006). Short of halting greenhouse gas emissions all together, it is unlikely that a carbon taxation scheme will be successful in preventing or alleviating the short-term ills of climate change in the Arctic. Therefore, it may be that the best solution to redressing these immediate issues is through establishing special funds for those who need them most. Imagine, for example, that the \$6 billion net benefits of oil development were earmarked for use by Indigenous communities of the Arctic to address climate-related relocation needs. With relocation costs estimated to be between \$100 million and \$400 million per village, the diversion of \$6 billion could be used to facilitate the relocation of an average 24 of 43 Arctic and Western Alaska villages, if necessary (U.S. GAO 2003, Hamilton et al. 2016).

The social costs of climate change, however, will only increase with emissions, and it is imperative that these costs do not rest entirely external to the polluter. Applying a carbon tax that places these costs upon the producers of oil sends a clear message: today’s society cannot afford to develop Arctic resources.

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