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The Economics of Allowing More Domestic Oil Drilling

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Working Paper 08-21

August 2008
Revised: September 2008

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Executive Summary

The recent sharp increase in the price of oil has generated renewed interest in U.S. oil exploration and development. This paper examines the likely impact of developing new energy resources on oil and gasoline prices. In addition, we use a benefit-cost framework to analyze the impact of allowing oil drilling in the Arctic National Wildlife Refuge and the portions of the Outer Continental Shelf that are currently closed to development. We find that development of ANWR and off-limits OCS is likely to have only a modest impact on future world (and thus domestic) oil prices—on the order of one percent. Therefore, we believe that the impact of opening the new resource areas on current prices would be modest as well. Our benefit-cost analysis of developing off-limits OCS suggests that the benefits are very likely to exceed the costs. We are less confident in the case of ANWR, but still believe that the expected benefits of development are likely to exceed the costs. We suggest an alternative way of framing the issue of resource development that may give both policy makers and the public a better sense of the tradeoffs involved.

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1. Introduction

The near-doubling of crude oil prices in the past two years has sparked renewed interest in U.S. oil exploration and development.[1] Some politicians and commentators argue that increased domestic exploration could have a marked impact on prices. Others say the price impact would be small. In this paper, we begin by addressing that issue using a simple, transparent model of prices in the world oil market. Our principal finding is that crude oil price decreases associated with expected production increases from areas now closed to development are likely to be on the order of one percent, and would thus not have a significant impact on prices that consumers pay at the gasoline pump now or in the future.

We argue, however, that because the value of the oil available from restricted areas is large in absolute terms, the projected impact on consumer prices should not be the decisive factor driving decisions about development. Instead, it makes sense to recast the issue, comparing the likely benefits to the likely costs of increased development. And from this perspective, we think there is a very strong case to be made for opening new areas to drilling.

Indeed, we argue that the tangible benefits from development are so much greater than the tangible costs that the scales are only likely to tip toward the side of restricting exploration for unique locales on which society places very high "non-use values." We think those circumstances are rare, but acknowledge that this question could benefit from more research.

The policy debate currently centers on allowing drilling in a small part of Alaska's Arctic National Wildlife Refuge (hereafter referred to simply as ANWR) and the part of the Outer Continental Shelf where drilling is currently prohibited (hereafter

[1] In the beginning of July 2006, the price was $70 a barrel and in the beginning of June 2008, it was $129 (see Energy Information Agency (EIA) (2008a) for details). Unless otherwise noted, all dollar values are in constant 2007 dollars, adjusted using the Consumer Price Index.

referred to as off-limits OCS). Although there have been proposals to allow drilling in both these areas, no legislation has passed as of this writing.[2]

Section 2 of the paper uses a simple model of the world oil market to assess the likely price impact from allowing more domestic oil exploration. Section 3 presents a benefit-cost analysis for allowing drilling in Alaska's Arctic National Wildlife Refuge and more drilling in the offshore Outer Continental Shelf. Section 4 concludes and discusses policy options.

2. Estimating Price Impacts

There are three areas in the United States in which large oil reserves may be available, but exploration is not currently allowed. The first is a coastal plain in the Arctic National Wildlife Refuge (ANWR), often referred to as the "1002 area," which is jointly owned by the federal government, the State of Alaska and Native-American corporations (Energy Information Administration (EIA) 2008b).[3] This part of ANWR is thought to contain a relatively large amount of oil that is relatively cheap to develop.[4] Environmentalists and others have opposed drilling in ANWR because it is a pristine area that they believe is ecologically unique.[5] In particular, they are concerned that a spill or pipeline leak would endanger a key wildlife habitat. For example, development could affect the life cycle of the Porcupine caribou, a species that is of great cultural importance to local residents.[6]

The second area is the section of the Outer Continental Shelf (OCS) where drilling is currently not permitted, which we refer to as "off-limits OCS" (EIA 2007). The

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[2] In March 2003, the Senate voted to amend the Senate Budget Resolution to make passage of legislation to develop ANWR more difficult. In June 2004, a bill was proposed by Rep. Richard Pombo (Republican, 11th District California) to allow development of ANWR, but it received little attention (Corn and Gelb 2004). In July 2008, Rep. Nick Lampson (Democrat, 22nd District Texas) introduced a bill to terminate the moratoria on oil and gas leasing on the outer continental shelf and ANWR (CBO 2008).

[3] The 1002 area is 1.5 million acres and represents about 8% of total land in the 19 million acre ANWR. Of these 1.5 million acres, no more than 2,000 acres are currently allowed to be used for oil production (Department of Interior 2005). However, it is not clear that the environmental impacts would be contained within this region.

[4] The federally owned section of the 1002 section is thought to contain around 7.7 billion barrels out of an estimated 10.4 billion barrels of oil for the entire ANWR (EIA 2008b).

[5] The U.S. Fish and Wildlife Service (2006) describes the 1002 section as a habitat with a "greater degree of ecological diversity than any other similar sized area of Alaska's north slope."

[6] See the September 2, 2003 *New York Times* article by Nicholas D. Kristof. However, Cronin et al. (1998) conclude that oil development in northern Alaska fields is unlikely to have much impact on Porcupine caribou populations.

federally owned OCS is the land under relatively shallow waters circling the continental United States in a band approximately 200 nautical miles wide.[7] Around 15% of the OCS of the lower 48 states and 100% of the Alaskan OCS acreage is now open for drilling; the region currently provides 27% of the U.S.'s oil and 15% of its natural gas production (Mineral Management Service (MMS) 2007).[8] The remaining 85% of the OCS in the lower 48 is under drilling moratoria imposed by Congress.[9] Any drilling in the next several years would thus require the approval of Congress and the president. The existing moratorium on drilling will expire in 2012, but may be renewed (EIA 2007).

The third area includes other resources owned by the federal government and the states. We do not consider these here because good data on development costs are not available, though their potential is substantial.[10] The U.S. Geological Survey estimated in 1995 that there were about 110 billion barrels of undiscovered, technically recoverable crude oil in onshore areas and state waters.[11] In addition, the Department of the Interior estimated in 2008 that some 800 billion barrels of oil could be extracted from oil shale in the western part of the United States alone (Department of the Interior 2008). Unlike most of the 1002 area in ANWR and the off-limits OCS, which are under federal jurisdiction, developing these resources would require permission from the individual states.[12]

Past academic research, focused on ANWR development, suggests that the impact of development on crude oil prices would be modest.[13] Our paper goes a step further,

[7] The submerged land within three nautical miles is under control of the states. There are some exceptions to this general rule. See MMS (2008a).

[8] We do not explicitly consider natural gas resources in OCS in this analysis, though we recognize that these resources are likely to be important, especially in the case of off-limits OCS.

[9] The oil in the unrestricted area is mainly produced in the Gulf of Mexico (MMS 2008b). Oil resources in restricted areas are located in the Pacific region, the Atlantic region and the Gulf of Mexico (MMS 2005).

[10] Costs of oil production are generally lower for existing U.S. onshore production than for U.S. offshore production or foreign production. For a discussion of production costs, see EIA (2008c), http://www.eia.doe.gov/neic/infosheets/crudeproduction.html.

[11] The precise U.S. Geological Survey estimate for the amount of technically recoverable crude oil onshore and in state waters is 112.6 billion barrels.

[12] Although the OCS is federally owned, the willingness of states to cooperate with offshore production projects is an important limiting factor. For example, in response to the request of the governor of Alaska in 2007, only one lease is being scheduled for sale in the North Aleutian basin even though the moratorium was lifted for the entire planning area (MMS 2007).

[13] See, for example, Kotchen and Burger (2007), Borenstein (2008), Coats and Pecquet (2008). See also the 2007 and 2008 Annual Energy Outlook (EIA, 2007 and 2008d).

using a more rigorous, transparent economic framework for analyzing the price impact for both ANWR and off-limits OCS.

We begin with the observation that the world oil market is global in nature (Schelling 1979). Oil is a fungible commodity that can (and is) moved vast distances from well to refinery to consumer in response to changing demand and supply. Thus we need to estimate the impact of increased domestic supply in the context of the global market.

We use two approaches. The first assumes that the existing supply of oil is not responsive to price changes (i.e., is perfectly inelastic); accordingly, the addition of new supplies leads to a movement along the demand curve. Other things equal, this approach leads to an overstatement of the impact on prices because it does not take into account the likelihood that a lower market price for oil would lead to lower levels of production from existing wells that were only marginally profitable.

Our second model, by contrast, assumes that the world supply curve for oil has an elasticity greater than zero. We do not attempt to model the possibility that OPEC (or some smaller group of producers) has market power – that is, it actually could raise the price of oil by reducing its collective production. We do, however, suggest a way of extending this model to account for suppliers' behavioral responses if they could, in fact, exercise market power. But we conclude that such an extension would not be likely to affect our key findings.

In the first model (zero supply elasticity), we simplify our analysis by assuming a constant elasticity of demand for crude oil (ε). We can then estimate the percentage change in prices based on the percentage change in quantities and the elasticity of demand.[14] We estimate the percentage change in quantity by first estimating the change in supply obtained from off-limits OCS, or ANWR, or both. We then divide by the projected world oil output in a future year.

In the second model, we derive an expression for the percentage change in prices ($\Delta p/p$), based on the elasticity of demand (ε); the elasticity of supply (η), the projected

[14] The formula for demand elasticity is $\varepsilon = (dq/q)/(dp/p)$. For small changes this can be approximated by the formula $(\Delta p/p) = (\Delta q/q)*\varepsilon$, where $(\Delta p/p)$ is equal to the percentage change in prices, $(\Delta q/q)$ is the percentage change in quantities and ε is assumed to be constant. For an arbitrary change in quantity, we can apply a version of Equation (1) discussed below. See the appendix for details.

world oil output (q), and the change in supply from increased drilling in ANWR or off-limits OCS (Δq). The formula for the percentage change in price is then:

$$\Delta p/p = [q/(q+\Delta q)]^{[1/(\eta-\varepsilon)]} - 1 \qquad (1)$$

where q and p are the original price and quantity, and Δp is the change in price.[15] In both models, we assume that elasticities are constant and do not change over time.

We are interested in estimating the percentage change in prices resulting from output changes in both models. In general, the percentage reduction in prices in the second model will be less than those in the first model. That is because the increased supply from off-limits OCS and ANWR is assumed not to affect world supply in the first model, whereas in the second model it does reduce supply.

Values assumed for key parameters for these models are shown in Table 1 below. We estimate the models for three different years—2020, 2025 and 2030—which takes into account the production lags associated with the development of new oil resources, assumed here to be about a decade for ANWR and 5 years for the off-limits OCS (EIA 2007 and 2008d).[16] Projections for production in the currently off-limits OCS and ANWR as well as for world oil production are taken from standard government sources.[17] We use supply and demand estimates for oil from the economics literature.[18] Our supply

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[15] See the appendix for details.

[16] It generally takes several years to sell leases, explore and drill before oil becomes available. In the case of the OCS, development normally occurs only if there is already sufficient existing offshore production infrastructure. For example, *Oil Daily* recently reported that it took 25 years after discovery for the Hebron oil field off Canada's Atlantic shore to begin production (Energy Intelligence Group 2008).

[17] We take the EIA total for international crude production and liquids and multiply by 0.87. That factor represents the average of the ratio of crude oil production to total liquids production, which includes oil, liquid natural gas and refinery gains, for the years 2000-2007 (EIA 2008d, 2008e).

[18] Gately and Huntington (2002) estimated that the long-run demand elasticity, ε, for OECD countries ranges from -0.59 to -0.71 and the range for non-OECD countries is -0.16 to -0.27. We note that the OECD accounted for approximately 60% of oil consumption in 2004 (EIA 2008h), and compute a weighted average to obtain $\varepsilon = 0.6*[-(0.59+0.71)/2] + 0.4*[-(0.16+0.27)/2] = -0.48$. We obtain the low end estimates for ε using the same weights. Gately (2004) estimated long-run supply elasticities for non-OPEC suppliers to be within the range of 0.15 to 0.58. We use the mean (0.36) for our initial analysis, and treat the response of OPEC separately. For a good overview of elasticities, see Greene and Ahmad (2005). For a discussion of OPEC supply responses, see Gately (2004) and Leiby (2007).

and demand elasticity estimates are for the “long-run” and are rough approximations.[19] We use long-run elasticities because they are more appropriate than short-run elasticities for an analysis with a 10-plus year time horizon.

The estimates for both future quantities and elasticities are based on historical data. They do not take into account the recent increases that have pushed prices above $100 per barrel.[20] Thus, the estimates below should be interpreted with care. We try to address this problem by doing sensitivity analysis (discussed below), but recognize that this may not be adequate.[21]

Table 2 presents results on the percentage change in prices for both models for the various years using best estimates of the parameters.[22] A few conclusions are worth noting. First, off-limits OCS development is less important than ANWR in terms of its price impact because oil production from the off-limits OCS is projected to be substantially less than from ANWR.[23] Second, Model 1, which ignores responses of supplies to price changes, leads to estimates in percentage price reductions that are considerably larger than those of Model 2. For example in 2025 the percentage decline in prices in Model 1 is projected to be about 3%, but it is only about 1% using Model 2.

We used sensitivity analysis to explore how the results would change with varying parameter assumptions. Table 3 reports on 10 sensitivity tests each for ANWR, OCS and a third case in which both areas are developed for the year 2025. For all four parameters, q, Δq, η and ε, we considered low and high values, while holding other

[19] We consider only non-OPEC supply elasticity estimates and apply them to world supply. See the appendix for a review of some elasticity estimates. Also see discussion below regarding OPEC and modeling.

[20] For example, EIA (2007) projected that allowing access to ANWR would produce 0.4 million barrels per day in 2020 at $55/barrel. EIA (2008b) projected that allowing access would produce 0.3 million barrels of oil per day in 2020 at $61/barrel. The EIA definition of world oil price is based on the market price of imported low sulfur light crude oil. The price assumptions used by EIA can be found in EIA (2007 and 2008d).

[21] Government agencies are currently in the process of revising their projections based on the recent large increase in oil prices. This revision could result in marked changes in price and quantity projections.

[22] We do not consider the impact of increased natural gas production from ANWR and OCS on oil prices. The MMS includes the relationship between oil and gas prices in their analysis, but this relationship has become less predictable after recent events in the oil market. We note that the increased natural gas production would likely increase the downward pressure on oil prices, to the extent that natural gas can substitute for oil.

[23] Figure 1 (below) suggests that more oil can be extracted from the off-limits OCS than ANWR at a given price based on our best estimates. This apparent inconsistency is partly caused by the fact that there is little information about oil prospects in off-limits OCS. As drilling begins and infrastructure is built, developers may produce more oil over time.

parameter values at the best estimate reported in Table 1. For the “extreme values” case, we selected those values of key parameters that would lead to the lowest and highest percentage change in prices.[24]

The first row of the table confirms that, as world production increases (excluding ANWR and off-limits OCS), the percentage reduction in prices from adding a given amount of resources from ANWR is smaller. The next row shows that, depending on the amount produced in ANWR, prices will decline by approximately 1% to 2%—with a higher production level, of course, leading to a higher price decline. Row three shows that as the supply of oil from ANWR becomes more elastic, the percentage change in prices is smaller because total production is decreased by a smaller amount, attenuating the impact of increased domestic exploration. Row four shows that as demand becomes more elastic, the price impact is smaller because it takes a greater change in production to generate the same fall in price.

Finally, the extreme case shows that the percentage reduction in prices could be close to zero or as high as 3 percent, depending on parameter assumptions. The results are most sensitive to parameter choices for the change in production resulting from ANWR and elasticities.

One weakness of this analysis is that the supply elasticity projections were based on prices that now appear unrealistically low. For example, the Department of Energy projected prices are \$61/barrel in 2020 and \$77/barrel in 2030 (EIA 2008d). We do not know how supplies from ANWR, off-limits OCS and world production would change with higher prices in these years. As a bounding exercise, suppose the supplies in ANWR and off-limits OCS doubled because higher prices increased the amount of oil that could be profitably recovered, but world production did not change. Then the opening of ANWR and off-limits OCS reserves would lead to a 4.4% price reduction in 2025.[25]

We have thus far ignored the important question of how OPEC would respond to a marked supply increase from the United States. OPEC might attempt to retain market share, or it might reduce output by an amount that fully offset new U.S. production. Yet

[24] So, for example, choosing high world production, low ANWR production, high demand elasticity (in absolute value) and high supply elasticity leads to the lowest percentage change in prices.

[25] This result is obtained using Model 1, which overstates the likely price reduction, with the other parameter values based on Table 1.

another possibility is that OPEC would attempt to maximize discounted profits based on residual demand for oil.[26]

Because we do not have a good sense of OPEC's strategic behavior — or even its capacity to act strategically — we do not model it here. Our strong intuition is that OPEC (or at least Gulf producers running substantial current account surpluses) would adjust output downward in order to increase the world price of oil. Thus, the results in Table 2 are probably best viewed as upper bounds on the percentage reduction in prices that would follow from increased U.S. production.[27]

One can argue about whether a 1% reduction in prices is a big number or a small number. If the price of oil were $100/barrel and decreased by 1%, this would translate into a decrease in the cost of gasoline of about 2.4 cents per gallon – a figure too small to be noticed by consumers routinely experiencing price changes this large on a weekly basis.[28] On the other hand, a $1 decrease in the price of crude would decrease the amount paid for oil imports by an amount equal to about $10 million a day (EIA 2008g) – a seemingly significant sum.

There is a separate, ongoing political discussion about the extent to which increased domestic exploration starting now would affect today's prices – much depends on the ability (and willingness) of producers to increase current production in the expectation of lower prices years in the future.[29] Note, however, that any short-term change in prices is likely to be modest (i.e., less than 1 percent) if only because the long-term price change would be modest.[30] Our modeling approach does not explicitly consider this connection. If the model were extended this way, however, it would likely reduce projected future price reductions because some of the additional output would be shifted toward the current period.

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[26] See, for example, Leiby (2007).

[27] Another factor that needs to be considered is how other consuming countries, such as China, might respond to a supply decrease.

[28] We obtain 2.4 cents by dividing $1 by 42 gallons in each barrel of crude oil (EIA 2008f). This is an approximation because refined gasoline is only part of a barrel of crude oil.

[29] See, e.g., Feldstein (2008) and Coats and Pecquet (2008).

[30] For a theoretical treatment, see Tietenberg (1999) and Hotelling (1931). For an analysis in the context of the ANWR, see Coats and Pecquet (2008).

3. Benefits and Costs of Drilling

The current political debate over domestic oil drilling has been framed in a way that misses what we believe is the central economic issue: whether the likely benefits of development would exceed the likely costs. We believe that opening off-limits OCS for drilling is very likely to pass a benefit-cost test.[31] The answer for ANWR is less clear, but there are good reasons to believe that drilling would pass muster. We explain our reasoning below.

The literature on benefits and costs of developing off-limits OCS and ANWR is small but growing. For OCS, we build on work by Farrow (1990) and the Department of the Interior's Minerals Management Service. In its 5-year Oil and Gas Leasing Program for 2007 to 2012, the MMS did a benefit-cost analysis of leasing selected areas that are not currently producing fuels, even though they are not covered by the drilling moratorium.[32] The analysis estimates revenues, direct costs and environmental costs, as well as the benefits from the increased consumer surplus generated by the increase in world supply. MMS estimates that net benefits from developing 10 billion barrels of oil from these unrestricted areas would be around $165 billion. In contrast, we will be considering the costs and benefits of allowing drilling in restricted areas.

Kotchen and Burger (2007) relatively recently estimated benefits and costs for ANWR development. We use this analysis as a starting point for our own. Our basic model of benefits and costs is stylized: it assumes that all production occurs in one period. Kotchen and Burger note that such an assumption does not affect the benefit-cost outcome very much if one assumes that the path of oil prices is in equilibrium over time. The one-period model thus allows us to develop the basic qualitative insight with a minimum of complexity.[33]

[31] In this paper, we do not consider the benefits of natural gas development, which would almost certainly accompany oil drilling once the ban on development is lifted. Natural gas is abundant in both ANWR and off-limits OCS. A larger supply of natural gas, a relatively clean fuel, could reduce U.S. oil consumption and imports as well as leading to environmental benefits.

[32] The MMS also suggests leasing off the coast of Virginia, which is currently off-limits. See National Ocean Industries Association (2008) for a discussion of the MMS 5-year plan and its approach towards drilling limitations.

[33] For the model to be equivalent to a multi-period analysis, we would need to make assumptions not only about private benefits and costs satisfying an equilibrium condition in line with Hotelling (1931), but also on externalities.

We consider three categories of benefits: the revenues that go to producers, the domestic benefits to consumers associated with lower world oil prices, and the reduction in economic costs of disruption associated with adjusting to rapid price fluctuations (Leiby 2007).[34] Kotchen and Burger, for their part, take only the revenues into account.[35] We believe that considering these other benefits offers insights, but acknowledge that the benefits are difficult to pin down.

A complete model would include still other potential benefits. For example, some scholars have suggested that reduced expenditures on oil imports (and thus reduced revenues from oil exports) would reduce terrorist activities and/or destabilizing military expenditures in the Middle East.[36] While this is possible, we have not seen any persuasive research on the subject that would enable us to quantify the marginal benefits. Delucchi and Murphy (2008) estimate the costs of maintaining a foreign military presence in the Middle East to secure oil resources, but do not argue that a reduction in imports would lead to savings that could be quantified at the margin.

Another potential source of benefits consists of tax revenues as well as revenues from auctioning leases. To the extent that these revenue streams substitute for other revenue streams and have no impact on efficiency, they are already taken into account in a benefit-cost analysis. However, this need not be the case. For example, if revenues from auctions were substituted for payroll taxes, the substitution would generate a net social gain. We do not consider these sources of revenue here because we do not have good data on the size of different revenue sources, how they compare in efficiency to other sources, and whether the new sources of revenue would actually substitute for existing sources. In principle, such an analysis could be done. We do not believe, however, that it would change our basic conclusions.[37]

We also consider three categories of costs. First, there are the direct costs that producers incur in extracting the oil and bringing it to market. The second is “use value.”

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[34] Leiby (2007) discusses two main effects of a sudden increase in oil prices. First, higher prices reduce U.S. output. Second, as the economy adjusts, some resources, such as labor, are temporarily not used.

[35] They also focus on the transfers to the state and federal government. We do not focus on these transfers because they are not a part of this benefit-cost analysis.

[36] See, e.g., Leiby (2007); Parry and Darmstadter (2003).

[37] In part, this is because the economic evidence in favor of drilling is so persuasive. See discussion below. Also, see Goulder (1993) and Parry (1995) for a discussion of the possible substitution of pollution and energy for other taxes.

This is the cost of not being able to use the affected resource for other purposes if drilling occurred. The category might include, for example, the cost associated with a reduction in opportunities for hunting, fishing and bird-watching.

Finally, there is a category called "non-use value," which is the intangible adjunct to use value.[38] For example, people may value a resource such as ANWR in its current relatively pristine state, even though they never intend to visit it.[39] The value derives in part from the perceived uniqueness of the resource. If the resource is one-of-a-kind, like the Grand Canyon, people may assign it a very high non-use value.

Before turning to the main results of the benefit-cost analysis, we review some of the key assumptions. The revenues are based on a price of $100 per barrel oil, which is a rough estimate based on current prices.

The per-barrel price reduction generated by reduced U.S. demand for imported oil is based on Leiby (2007). This price-reduction benefit (or monopsony benefit) is derived from the United States' status as a major buyer of oil. Other things equal, when the U.S. buys less oil, the world price falls. This decreases the total import bill for all barrels consumed, not just for the barrels at the margin.[40] While we think Leiby's estimate of about $10/barrel is high because it may not adequately take into account the response of OPEC as well as that of other large buyers of oil such as China, it can be defended quantitatively. In any case, the choice of this number does not have much impact on our analysis. The reduced-economic-disruption cost of $5 per barrel associated with reducing imports is also taken from Leiby, and here, too, we believe the benefit is probably overstated.[41]

Some more detail on the cost numbers is worth noting. First, estimated supply curves for production from off-limits OCS are not publicly available for oil above

[38] Non-use value is sometimes referred to as existence value or lost passive use values.
[39] See, e.g., Krutilla (1967) and Kotchen and Burger (2007).
[40] See, e.g., Bohi and Montgomery (1982); Broadman and Hogan (1988); Hamilton (1983).
[41] See, e.g., Nordhaus (2007). Parry and Darmstadter suggest a value of $5 per barrel (2003 dollars) for the total "quantifiable" benefits of reducing imports. Even after updating this value to 2007 dollars the Parry and Darmstadter figure is 38% of the combined "energy security" benefits resulting from the price reduction and reduced costs of disruption that we use in our analysis.

$82/barrel (MMS 2006).[42] For ANWR, they do not exceed $62 per barrel (Attanasi 2005).

Figure 1 shows the supply curves.[43] Note here that off-limits OCS may actually yield more oil than ANWR at a given price.[44] Total production costs, which are the areas under the curves, include taxes that oil companies have to pay that are not costs to society. Therefore, the total costs are overestimated. We adjust for taxes by using an approximation contained in Kotchen and Burger (2007), which results in a marginal tax rate of about 31.5%.[45]

We assume for simplicity that production does not exceed the point of maximum production on the government's estimated supply curve (the rightward-most point), even if price exceeds that value. Our analysis for the case of $100 per barrel oil is thus likely to understate the net profits (and thus net benefits) unless the curves become perfectly inelastic beyond the highest prices used in the cost-curve estimates.

The losses associated with use value are likely to be understated for ANWR. Kotchen and Burger (2007), for example, review the effect that roads and pipelines may have on animal populations and habitat degradation due to oil spills. They do not, however, monetize these values in terms of damages that affect the economic welfare of human beings. Nor do we.

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[42] MMS 2006 does not provide cost curves for off-limits OCS only. We obtain our cost curves by taking a fraction of each OCS region's supply curve equal to the ratio of unrestricted oil resources to total oil resources, and summing these curves. This method may understate true costs, as there is little infrastructure to support drilling activities in off-limits OCS.

[43] MMS provides "price-supply" curves for OCS that show the relationship of economically recoverable resources to prices. They calculate producers' net incomes after accounting for taxes and costs, and thereby determine the level of production that would occur at each price.

[44] These estimates are highly uncertain, and were done at different points in time. Therefore, they may not be directly comparable, but they do give a sense of the likely supplies. More up-to-date analysis would need to reflect increases in production costs, which we discuss in our sensitivity analyses below. Another point about the supply curves is that they are rough approximations. In the analysis presented on price changes in the preceding section, note that the off-limits OCS quantities are lower than ANWR quantities. This could reflect a number of factors, including the geographical distribution of sites, differences in field size, and economies of scale in getting oil to market. The point is that choices for the time path of development are likely to reflect a number of factors not considered in the estimation of the cost curves in Figure 1. We are grateful to Philip Budzik for explaining aspects of the model used by the Department of Energy.

[45] This can be derived from Kotchen and Burger's expression for total state and federal taxes, which include royalty and other payments. Tax per barrel is obtained through the formula $0.000355 - 0.21953z + 0.53467p$, where z is the marginal cost and p is price. At the margin, $z = p$, so tax per barrel is equal to $0.000355 - 0.31514z$, so that the tax rate is approximately 31.5%. We apply this same formula to off-limits OCS, though we are aware that state taxes may differ there. As discussed below, the choice of a particular marginal tax rate is unlikely to affect our qualitative findings.

Another environmental impact affecting use value is the impact of increased oil supply on air pollution. Kotchen and Burger do not consider these to be significant because they believe the oil would simply be replaced with oil from other sources. Using our analysis, however, total production would likely increase with the opening of restricted areas. And, other things equal, this could lead to an increase in emissions.

Complicating the picture, the increased supply of oil could also change the mix of fuels used by consumers, and thus the overall environmental consequences of fuel use. For example, developing off-limits OCS could reduce greenhouse gas emissions if it led to a substitution of natural gas and oil for coal. In our sensitivity analysis, discussed below, we consider the possible effects of including increases in carbon dioxide emissions.

For OCS, we take the losses of use value from MMS (2007). The environmental costs for OCS considered by MMS were assessed for the portions of OCS where leasing is currently allowed. We assume that the environmental costs would be similar in the off-limits OCS – a reasonable assumption since the moratorium was not specifically targeted at ecologically sensitive territory.

MMS calculated that developing unrestricted areas in the OCS would produce 10 billion barrels of oil and 45 trillion cubic feet of natural gas, and cost $0.7 billion in environmental damage. (This implies an average environmental cost of $0.07 per barrel). MMS considered the loss of use value from adverse impacts on air and water quality on marine and land habitats and animal populations, as well as on tourism onsite and in the nearby coastal areas. In addition, they considered the impact on direct use value, including land use, income, employment and archeological resources.[46]

In the case of off-limits OCS, we assume that non-use value is likely to be very small because most of these offshore waters are not likely to be perceived as unique, and thus ignore it entirely. But some areas nearest the coast may generate significant non-use values as well as use values. It is also the case that the larger the area, the more likely that

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[46] If we assign user costs to ANWR similar to those in off-limits OCS ($0.07/bbl), the difference to the net benefits is trivial. Because some oil resources are developed closer to shore in the Pacific region compared to the Gulf of Mexico region, the use values may be higher there – though hardly by enough to tip the balance in a calculation of net benefits.

non-use values are at risk. Thus, the non-use issues that have added to the controversy over drilling in the ANWR could also come into play for OCS.

Kotchen and Burger note that non-use value has never been formally estimated for ANWR. They only consider revenues less tangible costs in their benefit-cost analysis, and then note that non-use value would have to exceed their calculated net benefits if ANWR development is to fail a more inclusive the benefit-cost test. This is a reasonable approach to the problem. However, we offer a modification in perspective that may further clarify the issue.

We suggest a plausible estimate for non-use value for ANWR based on Carson et al. (2003), who ground their figures on non-use values estimated for the litigation over damages in the Exxon Valdez oil spill. This estimate may serve as a lower bound on non-use value for ANWR; however, several caveats are in order.

First, the two resources are not identical, and therefore would not be expected to have the same non-use value.[47] Second, Carson et al. estimate non-use value from the public's willingness to pay (WTP) for avoiding another Exxon Valdez-type oil spill. Kotchen and Burger argue that the conceptually different "willingness to accept" (in this case, to accept oil drilling) framework is appropriate in the case of ANWR because citizens already have the implicit property right. Assuming this perspective is correct, the Carson et al. estimate would be biased downward. However, we acknowledge that reasonable analysts may disagree over the assignment of the implicit property right. Below, we consider both a willingness-to-pay and a willingness-to-accept (WTA) perspective. In the conclusion, we consider an alternative approach in which neither producers nor consumers are assumed to have the property right.

Third, the Carson et al. estimate is not based on willingness to pay for maintaining a pristine area, but rather for avoiding an additional Exxon Valdez-type oil spill. While some areas of the affected Prince William Sound were still "pristine" after the first oil

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[47] There are three types of impacts that may be of concern in ANWR: 1. the possibility of substantial degradation of a small part of ANWR where resource extraction takes place; 2. the less likely risk of substantial impacts to a larger area; and 3. the loss of the pristine status of ANWR. Carson et al. (2003) directly address the first two in a different context (the oil spill). They address the third indirectly because substantial parts of Prince William Sound were not affected by the oil spill and those parts were shown to respondents on a map in the process of gathering data on individuals' willingness to pay to avoid spills. We are grateful to Richard Carson for educating us on the nature of the Carson et al. contingent valuation study.

spill, the entire area was not pristine after the spill.[48] People may place a higher non-use value on a pristine area like ANWR. We think that, if the Carson et al. numbers do represent an unbiased estimate, they may provide a reasonable lower bound for non-use values.[49]

Carson et al. estimated that aggregate non-use value for ANWR is about $7.19 billion (1990 dollars).[50] We update this number to 2007 dollars and employ it as our estimate of non-use value.

The results of the benefit-cost analysis are shown in Table 4. It appears that off-limits OCS is likely to pass a benefit-cost test under almost any plausible scenario: Estimates of net benefits are on the order of $1 trillion. Thus, even if the area has a very large non-use value, developing off-limits OCS is likely to pass a benefit-cost test. It follows that, in cases where the cost of lifting access restrictions is low –– which is likely to be true for most of the off-limits OCS -- access restrictions should be lifted even if the expected benefits were modest.

The picture is a bit less clear for ANWR because the non-use value could be large. But, on balance, we think that the benefits of development are very likely to exceed the costs. Suppose, for the sake of argument, that willingness-to-accept were deemed the appropriate measure of non-use value for ANWR. Assume, too, that willingness-to-pay was only one-tenth as large as willingness-to-accept, which is probably conservative.[51] That implies we would need to multiply the WTP non-use values used by Carson et al by a factor of 10. Even then, ANWR development would still generate net benefits of $550 billion.[52]

We admit there is reason to be skeptical about our choice of non-use value for ANWR, given the absence of data and the intrinsic difficulty of reliably measuring this intangible (Diamond and Hausman 1994). Thus, while it is not critical for the results, we

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[48] Pristine is likely to be a relative concept. Here, we mean that there are no obvious signs of anthropomorphic impacts.
[49] For a critique of this analysis and approach, see Hausman (1993). For a more positive assessment, see Hanemann (1994) and Portney (1994).
[50] The authors provided a $2.8 billion estimate as a lower bound; and a conservative estimate of $4.87 billion. The $7.19 billion estimate is based on a mean WTP estimate. All estimates in 1990 dollars.
[51] Horowitz and McConnell (2000) find that the mean WTA/WTP ratio is around 7.
[52] Multiplying ANWR non-use value as provided in Table 4 by a factor of 10 would yield $114 billion. That would cut the net benefits by $108 billion, from $668 billion to $554 billion.

offer a thought experiment that we think illuminates the tradeoffs involved in deciding whether to develop the restricted oil resources. Kotchen and Burger find net benefits are about $250 billion (in 2007 dollars) for ANWR excluding (relatively modest) losses in use value.[53] We estimate net benefits for ANWR to be about $650 billion, excluding non-use values.

Are non-use values, in fact, larger or smaller than $650 billion? The traditional willingness-to-pay question is, "would the citizens of the United States be willing to accept expenditures of this order of this magnitude in order to preserve the pristine state of ANWR?" But now imagine that the net benefits could instead be spent on preserving other land resources with non-use values that might be viewed as comparable.

Table 5 provides some idea of what could be purchased with as little as $100 billion. The table shows some recent investments by the U.S. government, the states and the Nature Conservancy, which is a leading non-governmental organization that has protected more than 117 million acres of land and 5,000 miles of rivers around the world since 1951.[54] The Nature Conservancy currently has about $5 billion in assets, which means that $100 billion could fund about 20 such organizations.[55] Alternatively, one could fund roughly three large-scale restoration projects like the Chesapeake Bay cleanup or about nine on the scale of the ongoing Everglades restoration.

Of course, the money could be spent in other ways as well. For example, if one wanted to reduce local air pollution or greenhouse gas emissions, one could intervene directly in markets where such property rights are traded.[56] The point here is not to identify particular projects, but to suggest that there may be any number of attractive investments that have the potential to make most U.S. citizens—even those who place high non-use values on ANWR and the off-limits OCS—better off with drilling.

We performed a variety of sensitivity analyses on the benefit-cost calculation. These included varying the per-barrel value of externalities, the price of oil, the parameters of the oil supply curve, the quantity of oil produced worldwide, the non-use

[53] Their estimate was $267 billion in 2007 dollars.

[54] See the Nature Conservancy website, http://www.nature.org/aboutus/?src=t5.

[55] See the Nature Conservancy, Inc. (2007). IRS Form 990. Conservation International has assets of about $200 million, so one could fund about 500 such organizations. See Conservation International, Inc. (2007). IRS Form 990.

[56] The entire market capitalization for the so-called Clean Development Mechanism aimed at limiting greenhouse gas emissions is on the order of $100 billion (Boer 2008).

value, and the tax rate. The key *qualitative* results are not very sensitive to changes in assumptions because the net benefits from both ANWR and off-limits OCS are so large. For example, a one-dollar increase in the market price of oil, a $1 increase in the price-reduction benefit per barrel, and a $1 increase in the disruption cost all yield roughly $7 billion in benefits for ANWR and $11 billion in benefits for off-limits OCS.[57]

As noted above, we did not attempt a comprehensive analysis of costs associated with added air pollution damages. However, we did do a bounding analysis on possible impacts of increased carbon emissions. To identify an upper bound on these costs, we multiplied the entire additional production from ANWR and/or off-limits OCS by the carbon contained in a barrel of oil and then by a "shadow price" for carbon emissions. The result: the costs for ANWR increased by $35 billion and costs for off-limits OCS increased by $60 billion, or about $5 per additional barrel of oil consumed.[58]

This approach assumes that none of the new oil produced is offset by supply reductions elsewhere, and thus every barrel burned adds proportionately to carbon emissions. If, on the other hand, we assume the supply response in Model 2, the costs from carbon emissions would be 43 percent lower.[59] And, of course, if we assumed a greater supply response—say, through strategic cuts in OPEC output—the numbers

[57] We obtained these values by multiplying the increased per barrel benefits by the quantity of oil from ANWR and OCS. There are 7.14 billion barrels of oil in ANWR and 11.48 billion barrels in OCS. A $1 increase in per barrel benefits would therefore yield an extra $11.48 billion in benefits for the OCS and an additional $7.14 billion for ANWR. The unit benefits in the text are appropriate for small changes. If, for example, prices are reduced by 50 percent, the quantity supplied changes—and that would need to be factored into the analysis.

[58] Additional production for ANWR is 7.14 billion barrels and additional production for off-limits OCS is 11.48 billion barrels at a price of $100 per barrel. There are 0.85 metric tons of carbon or 3.12 metric tons of CO_2 in 1 ton of crude oil (Blasing et al. 2004; Oak Ridge National Laboratory 2008). In other words, 1 ton, or 7.33 barrels, of crude oil contain 3.12 tons of CO_2 (EIA 2008f). Therefore, the carbon dioxide resulting from burning a barrel of oil is 0.43 metric tons / barrel. The shadow price of carbon dioxide is assumed to be $12.07/metric ton based on IPCC (2007) estimates. Multiplying $12.07 x 0.43 x 7.14 billion barrels for ANWR yields $36.63 billion in additional costs. For off-limits OCS, multiplying $12.07 x 0.43 x 11.48 billion barrels yields $33.45 billion. The additional cost of carbon dioxide emissions from a barrel of oil consumed is computed by multiplying 0.43, the tons of carbon dioxide/barrel of oil times $12.07, the cost per metric ton of CO2, which yields $5.13.

[59] This number is computed with the following information using the equations in the appendix. We assume that price is $100/barrel, world production is 93 million barrels (EIA (2008d)'s best estimate for 2025), supply elasticity = 0.36 and demand elasticity is -0.48 (see footnote 21 for a discussion of choice of elasticities). We calculate the price change from an increase in supply of 1 barrel from ANWR and/or OCS. The estimated price change then allows us to predict the change in world production at the equilibrium, which is a fraction of the original increase of 1 barrel. We calculate that the fraction is 0.57.

would be reduced further. In any case, including greenhouse gas impacts on the cost side of the calculation would not affect our qualitative conclusions.[60]

Perhaps the most critical assumption in our analysis is the change in production costs that accompanies a change in prices. As oil prices go up and drilling increases, so do production costs. For example, rental costs for offshore rigs have increased by 225% in recent years in response to the big run-up in oil and gas prices (EIA 2007).[61] To capture the potential impact on our benefit-cost analysis, we consider a case in which costs increase by 200% (i.e., tripled).[62] The results, not surprisingly, are rather dramatic: net benefits fall from $668 billion to $386 billion in the case of ANWR and from $1073 billion to $630 billion in the case of off-limits OCS. Thus, while the qualitative conclusion that development passes any plausible benefit-cost test still hold, the net benefits are cut by roughly half.[63] Note, however, that much of the run-up in drilling costs may be rent accruing to the owners of scarce equipment and thus could overstate long-term supply costs.

4. Conclusion

This paper assesses the economic consequences of relaxing constraints on U.S. oil drilling. We find that such an initiative would likely have only a modest impact on future world oil prices—on the order of one percent. Therefore, we believe that the impact on current prices would be modest as well.

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[60] Including other air pollution impacts in the U.S. is unlikely to have a substantial impact, either. First, the impact on incremental oil consumption in the U.S. is likely to be relatively small; second, pollution from the burning of fossil fuels is already regulated.

[61] "Though graphs may show additions to reserves for the higher prices, *if prices rise substantially and rapidly, it is unrealistic to assume that constant real costs would hold.* Historical experience has shown that oil and gas price increases lead to escalation in industry capital and operating costs" (Kuuskraa et al. 1987 as cited in Attanasi 2005).

[62] We do not have precise data here. We chose 200% based on the EIA (2007) estimate for cost increases in offshore rigs. We do not know how other costs, such as transportation costs are affected. Fortunately, the government is in the process of updating the cost numbers.

[63] Net benefits are reduced by 57.8 percent in the case of ANWR and 58.7 percent in the case of off-limits OCS. We also did a breakeven analysis for the price of oil. That is, we sought to determine whether there was a price for crude oil at which the social benefits of drilling fall short of the social costs. For the case of off-limits OCS, given our assumptions in Table 1, net benefits are positive at any price that exceeds $8 per barrel. In the case of ANWR, the issue is complicated by the non-use value, which we assume disappears after any exploration for oil. We find that ANWR drilling would not pass the benefit-cost analysis at a zero price, but the benefits exceed the costs at all prices above $20 per barrel. The results are sensitive to assumptions on the size of externalities.

We argue that the central question for developing currently restricted resources, such as ANWR and off-limits OCS, should be whether the benefits are likely to exceed the costs. In the case of off-limits OCS, we are very confident that they would. In the case of ANWR, we are less confident, but still believe that the expected net benefits are positive and large.

The key economic issue in analyzing the consequences of exploiting resources such as ANWR is how to estimate non-use value. Some economists focus on whether the concept of willingness-to-pay or willingness-to-accept is the better measure. They argue (correctly) that it depends on who owns the property rights. In our view, it is not clear who has the property rights in many cases where the government owns the resource.

Decision makers could address the issue of resource valuation more creatively. For example, if property rights do not belong to any particular group, the government could auction them to the highest bidder.[64] If, say, developers were willing to pay more than non-developers, then perhaps the resource should be developed. We say "perhaps" because problems with free-riding would need to be addressed: citizens who value the status quo would not generally have sufficient incentives to bid in such an auction. In addition, externalities would need to be included, such as those related to energy security.

As an alternative way of thinking about the development of resources such as ANWR, we presented an example where some or all of the rents from development were allocated to the preservation of other resources. We think such thought experiments could help decision makers and consumers recognize potential tradeoffs in the development of resources owned by the government.

Even if benefits far exceed costs for expanded drilling, one must assume that some people would nonetheless be made worse off. There are several mechanisms that could be used to improve the economic welfare of the potential losers. These include earmarking rents for the preservation of other valued resources or, more broadly, improving air, land and water quality; or even assigning the property rights to a non-

[64] See, e.g., Farrow (1987); Farrow and Morel (2001).

governmental organization such as the Nature Conservancy and letting the NGO decide how to use the resource.[65]

The narrow lesson of this paper is that economics can help push political discussions related to the development of domestic oil resources beyond rhetoric. The broader lesson, we hope, is that economics can serve as a useful reality check, focusing policy makers on the issues most relevant to improving economic welfare.

[65] Revenue collected from drilling activity in the OCS is an important source of conservation funding. The Land and Water Conservation Fund receives almost $900 million annually for protecting habitats, biodiversity and developing resources for recreational use. The National Historic Preservation Fund receives $150 million annually for the preservation of cultural and historic sites and traditions (MMS 2007).

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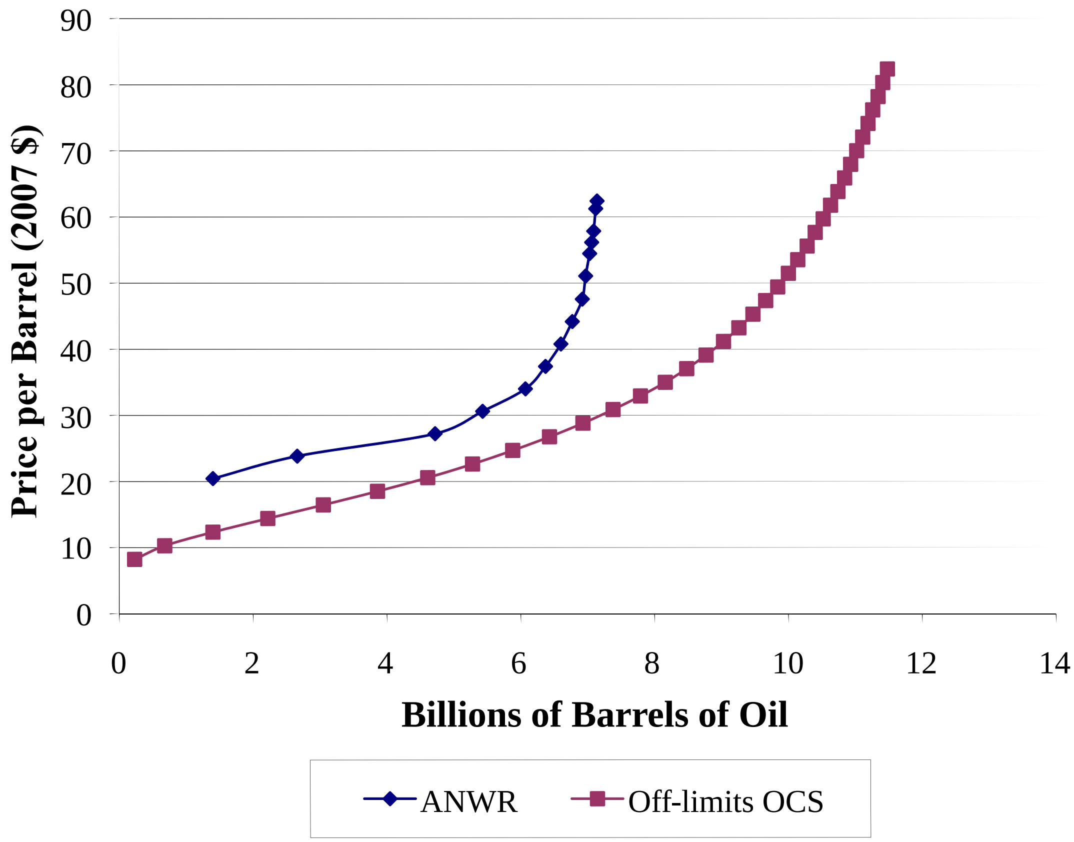
Figures and Tables
(in order that they appear in the text)

Figure 1: ANWR and Off-limits OCS Supply Curves



Sources: For ANWR supply curve data, see Attanasi (2005). Supply curve data for OCS are calculated by authors with data from MMS (2006) by taking a fraction of each OCS region's supply curve equal to the ratio of unrestricted oil resources to total oil resources, and summing these curves.

Notes: All values are in 2007 dollars. Quantities for off-limits OCS refer to the mean estimates of projected production from areas that do not currently allow exploration. Federal taxes, state taxes and other payments, such as depreciation, are included in this figure. See text for details.

Table 1: Key Assumptions Used in Modeling

	Best estimate 2020	Low estimate 2025	Best estimate 2025	High estimate 2025	Best estimate 2030
World production	88	83	93	101	98
Oil supplied from ANWR	0.3	0.5	0.8	1.3	0.7
Oil supplied from off-limits OCS	0.1	NA	0.2	NA	0.2
Supply elasticity	0.4	0.2	0.4	0.6	0.4
Demand elasticity	-0.5	-0.4	-0.5	-0.5	-0.5

Sources: For quantities, see EIA (2007, 2008b, 2008e). For estimates of supply and demand elasticity, see Gately and Huntington (2002) and Gately (2004).

Notes: Quantities are in millions of barrels per day. We obtained estimates of projected world crude oil production by multiplying projected world total liquids production by 0.87.

Table 2: Best Estimates of Percentage Change in World Price of Oil Resulting from Increased U.S. Domestic Production

	2020		2025		2030	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Source of Supply						
ANWR	-0.7	-0.4	-1.8	-1.0	-1.5	-0.8
Off-limits OCS	-0.3	-0.2	-0.5	-0.3	-0.3	-0.2
Both ANWR and off-limits OCS	-1.0	-0.6	-2.3	-1.3	-1.8	-1.0

Sources: Calculations by authors. See sources for Table 1.

Notes: We round estimates to one decimal place.

Table 3: Sensitivity Analysis for the Percentage Change in Prices for 2025 from Increases in Production from ANWR and Off-limits OCS

Variable tested	Low Value	Best estimate	High Value
		ANWR	
World production	-1.1	-1.0	-0.9
Supply from ANWR	-0.6	-1.0	-1.6
Supply elasticity	-1.4	-1.0	-0.8
Demand elasticity	-1.1	-1.0	-0.9
Extreme values	-0.4	NA	-2.7
		Off-limits OCS	
World production	-0.3	-0.3	-0.2
Supply from off-limits OCS	-0.3	-0.3	-0.3
Supply elasticity	-0.3	-0.3	-0.2
Demand elasticity	-0.3	-0.3	-0.2
Extreme values	-0.2	NA	-0.4
		Both ANWR and off-limits OCS	
World production	-1.4	-1.3	-1.2
Supply from ANWR and off-limits OCS	-0.9	-1.3	-1.9
Supply elasticity	-1.7	-1.3	-1.0
Demand elasticity	-1.4	-1.3	-1.2
Extreme values	-0.6	NA	-3.1

Sources: Calculations by authors. See sources for Table 1.

Notes: Cells show percentage change in prices. We round numbers to one decimal place. Estimates are obtained using equation 1 and values from Table 1. NA is not applicable. Extreme values are obtained by selecting parameter values that maximize or minimize the percentage change in price.

Table 4: Benefit-Cost Calculations for ANWR and Off-limits OCS

	ANWR		Off-limits OCS	
	Total (billion $)	$ per barrel	Total (billion $)	$ per barrel
Benefits				
Revenue	714	100	1148	100
Price reduction	70	10	112	10
Reduced disruption cost	37	5	59	5
Total benefits	821	115	1319	115
Costs (if drilling were allowed)				
Direct costs	141	20	246	21
Use value	0	0	1	0
Non-use value	11	NA	0	NA
Total costs	153	20	247	21
Net Benefits	**668**	**95**	**1073**	**94**

Sources: Quantities and direct costs for ANWR estimates obtained from Attanasi (2005). Quantities and direct costs for OCS were derived from data from MMS (2006) and transportation costs from Attanasi (2005). Disruption and price reduction benefit estimates obtained from Leiby (2007). Use value for OCS obtained from MMS (2007). Non-use value for ANWR obtained from Carson et al. (2003). Inflation data were obtained from Bureau of Labor Statistics, available at http://data.bls.gov/cgi-bin/cpicalc.pl.

Notes: Total benefits is the sum of benefits and total costs is the sum of costs. Net benefit is total benefits minus total costs. We round all numbers to the nearest whole numbers. All values are in 2007 dollars. Numbers may not add due to rounding. NA is not applicable. That is, there is no loss in non-use value associated with oil production after the first barrel. We assume price to be $100 per barrel. We obtain per barrel estimates by dividing total benefits and costs by the mean estimates of quantity of oil extracted. The per barrel use value for OCS is $0.072/barrel. We obtain direct costs for ANWR and off-limits OCS by using the approach in Kotchen and Burger (2007).

Table 5: Examples of Investments in Preservation and Restoration

Recent Programs	Location	Cost	Acres
Comprehensive Everglades Restoration Plan	Florida	$12 billion	11,520,000
Chesapeake Bay Program (Bay clean-up and watershed restoration)	Mid-Atlantic Region	$32 billion	Bay: 2,866,560 Watershed: 40,960,000
Coastal Wetlands Planning, Protection and Restoration Act	Louisiana	$18 billion	200,000-plus
Nature Conservancy preservation	Montana forest	$480 million	320,000
Nature Conservancy preservation	New York Adirondack forest	$110 million	161,000
Nature Conservancy preservation	Wisconsin forest	$86 million	64,633
Nature Conservancy preservation	Valdivian rainforest (Chile)	$8 million	147,000

Source: Everglades restoration costs are obtained from National Academy of Sciences (2006). Chesapeake Bay clean-up costs are obtained from Chesapeake Bay Watershed Blue Ribbon Finance Panel (2003). Gulf coast restoration costs are obtained from Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (1998). Information about Nature Conservancy land deals is available at http://www.nature.org/pressroom/EPR/zc_search_results

Notes: All values are in 2007 dollars, adjusted using the Consumer Price Index. We round all numbers to the nearest million or billion.

Appendix

Derivation of Percentage Change in Prices

We note that the constant elasticity functional form is

$$Q = AP^{\varepsilon}, \quad (1a)$$

where Q is quantity, P is price, A is a constant, ε is the elasticity.[66]

Suppose the point (q,p) satisfies (1a). Then

$q = Ap^{\varepsilon}$, and
$A = q/p^{\varepsilon}$

Substituting into equation (1a) yields:

$$Q = AP^{\varepsilon} = q(P^{\varepsilon}/p^{\varepsilon}) = q(P/p)^{\varepsilon},$$

Assuming constant elasticity, the equations for supply and demand are as follows:

Supply: $Q_S = q_S(P/p_S)^{\eta}$
Demand: $Q_D = q_D(P/p_D)^{\varepsilon}$,

where Q_S, Q_D are the quantities supplied and demanded at price P, it is assumed that the point (q_S,p_S) lies on the supply curve and (q_D,p_D) lies on the demand curve, and ε, η are the constant supply and demand elasticities.

At equilibrium, supply equals demand, so $Q_S = Q_D$. Suppose further that the initial equilibrium is (q,p).

Suppose that there is increased production, Δq, from ANWR or OCS. Then, let $q_S = q + \Delta q$, where (q + Δq,p) is a point on the new supply curve, and (q,p) is a point on the old demand curve. To focus on the change in price, we redefine P as P = p + Δp. We will be interested in obtaining an expression for the percentage change in prices (Δp/p) that results from the change in supply.

At the new equilibrium, supply equals demand ($Q_S = Q_D$), so $q_S(P/p_S)^{\eta} = q_D(P/p_D)^{\varepsilon}$.

Noting that (q + Δq,p) is a point on the new supply curve, and (q,p) is a point on the old demand curve, Further substitution for q_S, q_D, p_S, p_D and P yields:

$$(\Delta q + q)[(p + \Delta p)/p]^{\eta} = q[(p + \Delta p)/p)]^{\varepsilon}$$

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[66] See Perloff (2003) at
http://wpscms.pearsoncmg.com/aw_perloff_microecon_3/9/2365/605606.cw/index.html.

Then, using algebra we have:

$$[(p + \Delta p)/p]^{\eta}/[(p + \Delta p)/p)]^{\varepsilon} = q/(\Delta q + q)$$
$$[(p + \Delta p)/p]^{(\eta\text{-}\varepsilon)} = q/(\Delta q + q)$$
$$\ln[(p + \Delta p)/p]^{(\eta\text{-}\varepsilon)} = \ln[q/(\Delta q + q)]$$
$$(\eta - \varepsilon)\ln[(p + \Delta p)/p] = \ln[q/(\Delta q + q)]$$
$$\ln[(p + \Delta p)/p] = \ln[q/(\Delta q + q)]/(\eta - \varepsilon)$$
$$(p + \Delta p)/p = e^{\ln[q/(q+\Delta q)]/(\eta\text{-}\varepsilon)}$$
$$1 + \Delta p/p = e^{\ln[q/(q+\Delta q)]/(\eta\text{-}\varepsilon)}$$
$$\Delta p/p = e^{\ln[q/(q+\Delta dq)]/(\eta\text{-}\varepsilon)} - 1$$
$$\Delta p/p = [q/(q+\Delta q)]^{[1/(\eta\text{-}\varepsilon)]} - 1 \qquad \text{(2a)}$$

Equation (2a) is the formula used to implement Model 2. Model 1, which considers a movement along the demand curve, can be implemented by setting η equal to 0 in equation (2a).