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Leading the Unwilling: Unilateral Strategies to Prevent Arctic Oil Exploration

Abstract

Arctic oil extraction is inconsistent with the 2°C target. We study unilateral strategies by climate-concerned Arctic countries to deter extraction by others. Contradicting common theoretical assumptions about climate-change mitigation, our setting is one where countries may fundamentally disagree about whether mitigation by others is beneficial. Arctic extraction requires specific R&D, hence entry by one country expands the extraction-technology market, decreasing costs for others. Less environmentally-concerned countries (preferring maximum entry) have a first-mover advantage but, being reliant on entry by others, can be deterred if environmentally-concerned countries (preferring no entry) credibly coordinate on not following. Furthermore, using a pooling strategy, an environmentally-concerned country can deter entry by credibly "pretending" to be environmentally adamant, thus expected to not follow. A rough calibration, accounting for recent developments in U.S. politics, suggests a country like Norway, or prospects of a green future U.S. administration, could be pivotal in determining whether the Arctic will be explored.

JEL-Codes: D820, F500, O330, Q300, Q540.

Keywords: arctic region, oil exploration, climate change, geopolitics, unilateral action.

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1. Introduction

In recent years, the Arctic areas have received increased attention. One of the main reasons for this is the estimation that around a quarter of all undiscovered oil and gas reserves are located in the Arctic (Brownfield et al., 2012).[1] This has a number of implications of great global importance. Firstly, should these resources be used, the effect on climate change is expected to be severe and it has been recognized that, as part of meeting the two-degree goal of the UN, leaving the Arctic oil untapped is key (McGlade and Elkins, 2015). Secondly, the race for oil has made the Arctic hot from a geopolitical perspective, as is perhaps most clearly illustrated by Russia planting a flag under the North-Pole ice (see, for instance, reporting by The Guardian, 2011, and The Telegraph, 2009). Finally, the exploration and extraction of oil in the Arctic also implies substantial local environmental risks as the activity itself and, not least, an oil spill would have a devastating effect on the wildlife and fragile ecosystems in these areas (see also Cole et al. 2014 for other challenges in the Arctic). This risk is sufficiently great to even be emphasized by one of the oil companies (see statements by Total in the Financial Times, 2012) and is also illustrated by the U.S. recently choosing to protect some of Alaska's coast from drilling and exploration due to environmental concerns (The Guardian, 2014).

Hence, leaving these resources untouched is key both for the global environment and for global security. The purpose of this paper is to explore the possibility of unilateral action in doing so. In particular, we explore how the presence of technology spillovers may yield unilateral power to prevent Arctic oil extraction.

Extraction of oil in the Arctic requires tailored technologies due to the harsh weather and sea conditions (Wilson Center, 2014). These technologies do not exist today and developing them sufficiently to ensure that extraction costs are lower than the oil price requires large investments (Moe and Vigeland, 2015; Lindholdt and Glomsrud, 2011; Harsem et al., 2011). Thus, as for the development of any technology, market size is important in the Arctic.[2] More buyers of Arctic technologies implies that extraction per barrel will be cheaper (e.g., McDonald and Schrattenholzer, 2001) and the oil industry has expressed that bigger volumes of Arctic extraction will make extraction profitable under a lower oil price (see, e.g., Aftenposten, 2015). What makes this interesting from a perspective of unilateral action is the fact that there is a limited number of countries than can extract in the Arctic. Russia, the U.S., Canada, Greenland

[1] The Arctic is estimated to contain 16% of undiscovered oil, 30% of undiscovered gas and 26% of natural gas liquids (Brownfield et al, 2012).

[2] It is widely documented that technological costs fall with market size across a broad range of industries, including electrical vehicles (Klier et al., 2016), coal power plants (Joskow et al., 1985), wind turbines (Kouvaritakis et al., 2000), gas pipelines (Zhao, 2001) and, most relevant to our study, North Sea oil extraction (McDonald and Schrattenholzer, 2001, Table 1). See also EIA (2000).

and Norway each have jurisdiction over a certain area (see Figure 1).[3] Hence, if any one of these countries chooses to stay out of the Arctic, it will imply a smaller market for Arctic exploration and drilling technologies, and higher costs of extraction for the remaining four. These higher costs may then imply that another one of the countries prefers to stay out, thus increasing the costs for the remaining three.[4] This way, there is potential for a chain reaction whereby all countries end up staying out. This is particularly true under conditions – which preside today and are expected to remain for the next decade or two – where the oil price is low.[5]

Figure 1: Map of the Arctic region.

On the surface, this description resembles a classic coordination game whereby either all countries enter the Arctic or all countries stay out. The twist, however, is that in reality countries need not move simultaneously, which creates dynamic strategic interaction. This is particularly important since the countries in this game may perceive the environmental costs to be of varying importance. In particular, one country, say Russia, may prefer an equilibrium where all enter – to enjoy lower extraction costs – over one where all stay out. Another country, say Norway, may instead prefer the equilibrium where all

[3] The ownership of some areas in the Arctic are disputed. We abstract from that here and in the modeling but discuss its implication in the concluding section. Strictly speaking, also Iceland should be on the list of Arctic countries. However, their assessed reserves are unknown but expected to be very small (USGS, 2008). See Cole et al. (2014) for a game-theoretic approach to other challenges in the Arctic.

[4] Our calibration in Section 5 suggests that the fall in extraction costs following entry in the Arctic may be sizeable enough to warrant strategic considerations.

[5] While the oil price is notoriously difficult to predict and the market often has biases in the predictions (Hamilton, 2009; Hart and Spiro, 2011; Spiro, 2014) the appearance of shale oil on the market has depressed the price. This factor is likely to be important over the next decades. See Andrade de Sá and Daubanes (2016) for a discussion.

stay out, due to pro-environmental preferences. The problem for Russia is that it may not want to enter alone and, vice versa, the problem for Norway is that it may not be able to commit to be the only one staying out. That is, even for Norway, the profits of entering may be greater than the perceived environmental costs in a scenario where all others have entered. We analyze this strategic interaction and characterize under what conditions all countries stay out and under what conditions all enter. Since, in reality, underlying preferences are not directly observable, only actions are, we further extend the model to one where countries are uncertain of how the others perceive the environmental costs. Our main results and insights are as follows.

Our first result (Proposition 1) is that those countries that are moderately concerned with environmental damage – say, the U.S. or Canada – hold the most decisive strategic role. To see why, note on the one hand that the most environmentally-conscious country's only strategic influence is achieved by staying inactive. On the other hand, the country that cares the least about the environment has a strategic advantage: by taking action (entering) first, it can potentially set the wheels in motion for all others to enter as well. However, whether moving first is something that country wants to do depends on whether the moderately concerned countries will follow suit or not. Hence, a moderately concerned country can, by itself staying out, essentially determine that all other stay out as well.

The fact that the least environmentally-concerned country stays out if moderately concerned countries will not follow suit also motivates why uncertainty of other countries' preferences shifts the strategic advantage in favor of those who *do* care about the environment. Our second set of results pertains to how countries can use such uncertainty to their advantage. To help fix ideas, suppose there are two possible types of the most environmentally-conscious country (say, Norway) – a very green one, which stays out regardless of what the others do, and a moderately green one that would prefer if all stayed out but that enters if all others enter. The uncertainty that other countries may perceive about Norway's type gives it an advantage because by staying out it forces the other countries to enter possibly at a loss. If the other countries believe the very green Norway is sufficiently likely, then they will not enter. This way, by being inactive, the less green Norway acts, without detection, like the very green Norway (a pooling strategy, see Proposition 2). More broadly speaking, the policy implication is that environmentally-conscious countries – as well as those who are only moderately concerned with the environment – gain by convincing the other countries that they are very environmentally concerned (see Proposition 3). Finally, while there may exist preference uncertainty about all countries, it creates a strategic advantage only for environmentally-concerned countries and not for those who are not. The reason is that the uncertainty only exists as long as a country has not moved and therefore cannot be combined with the first-mover advantage of countries that do not care about the environment.

The model also reveals what forms of technological spillovers shift the strategic advantage in favor of environmentally-conscious countries. For instance, spillovers that are in the form of learning by doing

– whereby one has to encounter a large variety of situations before extraction is profitable – gives environmentally-conscious countries the ability to deter entry. Conversely, if spillovers are in the form of shared fixed costs of R&D investment then countries that would like to see exploration in the Arctic take place have a strategic advantage.

Broadly speaking, our analysis shows that a country that prefers the equilibrium where all stay out should certainly not be the first to enter. This poses critique over the implemented policy in, for instance, Norway. While Norway supposedly cares about the climate and hence should prefer all to refrain from Arctic oil extraction, in particular if considering the geopolitical heating, top politicians have resigned their own choices – the former Minister of Foreign Affairs has expressed that Arctic exploration is going to happen whether Norway wants it or not (Der Spiegel, 2012). While one can interpret this as Norway not truly caring for the climate, it may also be due to an underestimation of the technological spillovers. Indeed, if Norway stays out, others may do so as well; in particular because Norway, having the most accessible and least harsh Arctic areas, provides a testing ground for the technology.[6]

Section 5 offers an illustrative calibration of the model. Combining rough estimates of the environmental preferences of countries that have jurisdiction over the Arctic with estimates of technological spillovers (also taking into account that expected reserves differ between countries), we find it reasonable to believe that an allegedly environmentally-conscious country like Norway could induce others to leave the Arctic fields untouched at current oil prices. This conclusion hinges crucially on the price of oil not durably nearing the $90 mark, and on extraction costs in the Arctic not falling to $50/barrel (which, for instance, is slightly above current African offshore costs). We also discuss how recent developments in U.S. politics might affect this prediction. We find that Norway's role could become even more pivotal during a Trump administration: Norway's refusal to enter the Arctic would make extraction by a Trump-led U.S. and Russia only marginally profitable thus possibly deterring entry. Conversely, should Norway enter the Arctic, the profit margin increases, possibly leading to unrestrained exploitation from Arctic countries. Likewise, the prospects of a future green U.S. administration has an even more pivotal role as, absent U.S. entry, the costs for a single entrant would be very high which would greatly deter Russia.

Of course, the theoretical model abstracts from a number of real-world complications such as the fact that some regions are more natural to start exploration, that there are both gains and losses of moving first and that the property rights in some areas are not well defined. We discuss how such extensions would affect our results in the concluding section.

[6] See, for instance, reporting in Aftenposten (2013) and the discussion in the concluding Section 6.

Related literature

This paper relates to the very active literature on unilateral environmental policy. The starting point in this literature is that some countries *do* care about the environment and the analysis focuses on what tools they may use to reduce environmental harm globally. Most of this literature focuses on various forms of leakage where emission reductions in one country induces others to emit more as is nicely summarized by Meunier and Ponssard (2014) and Arroyo-Currás et al. (2015). Such leakage may be due to the pollution-haven effect – a displacement of activities to jurisdictions with lower environmental standards (Rock, 1996; Tobey, 1990; Markusen et al., 1993). It may also be due to the marginal damage of other countries' emissions falling when one country reduces its own emissions – the classic crowding-out effect (Varian, 1994). Alternatively, leakage may be the result of the policy affecting prices (Hoel, 1994; Markusen, 1975) through two possible channels: when demand for fossil fuels is reduced in one country this lowers the world price, which increases the consumption of fossil fuels in other countries (Copeland and Taylor, 1995; Stern et al., 1996; Arroyo-Currás, 2015; Tabaré et al., 2015); or, if a fossil-fuel exporter reduces its extraction, the world price increases, which raises extraction in other countries (Bohm, 1993; Harstad, 2012). These price channels have led to the focus on unilateral policies that do not create leakage, for instance the buying of high-cost reserves (Bohm, 1993; Harstad, 2012). While the price-leakage effect may exist in the Arctic as well – a lower extraction in the Arctic may increase the oil price in the long run – there also exist reversed externalities in the form of technological spillovers. These spillovers are the focus of this paper and imply that, not only may a policy of avoiding Arctic exploration cause no leakage, but it may in fact lead to a multiplier effect whereby the extraction is reduced in other countries. For this mechanism to be at work it is important that the technological leakage is stronger than the leakage through the price. Given how specific the technology for Arctic drilling is and given the many other factors that determine the price of oil (including shale oil reserves, alternative energy sources etc.), this seems plausible. Industry representatives have expressed this possibility by saying that "the full potential in the Arctic can only be tapped through innovation and technological improvements and by getting costs down".[7]

Our paper also relates to the literature on climate leadership (e.g., Varian, 1994, Hermelin 1998). Leadership (that is, moving first with ambitious abatement) may lead to crowding out of others' investments (Varian 1994) but it may also crowd *in* investments if the mitigation of one country reduces the cost of others (Hoel and Golombek, 2004) or if leadership conveys information on the low costs of abatement (see Hermelin, 1998, for an early treatment and Mideksa, 2016, for a recent treatment of the interaction between crowding out, spillovers and signaling). The core premise in these papers is that there is agreement between the players that abatement is desirable – all countries would like all others to abate more. In the Arctic, this may not be the case and hence our model contains heterogeneity –

[7] Expressed by Tom Dodson, director of exploration at Statoil (Aftenposten, 2012).

some countries want others to abate more (i.e., to not enter the Arctic) while some countries want the others to abate *less* (they prefer all to enter the Arctic). Hence, in our paper, there is a fundamental disagreement about which equilibrium is the most desirable; we study the dynamic interaction and the ability to induce others to behave according to one's own preferred equilibrium. A second important point of difference to existing papers on environmental leadership is that they study signaling about the costs of abatement, where leaders have an incentive to make followers believe the costs are low (Hermelin 1998, Mideksa 2016). Because in the Arctic there is disagreement about the best equilibrium, we study a fundamentally different form of uncertainty – about one's own environmental preferences. This difference is important since we, unlike the previously mentioned papers, are interested in a situation where countries cannot commit to future actions of abatement (there are no binding promises of not entering the Arctic for good). Hence, by being perceived as having strong environmental preferences, a country can make others believe it is more committed to not entering. Consequently, the policy implications are vastly different. When uncertainty is about costs (like in Hermelin, 1998, and Mideksa, 2016) leaders may want to seize the first-mover advantage to spur others to abate while in the Arctic those that care the least about the environment have a first-mover advantage.

The rest of the paper is structured as follows. In the next section, we illustrate the mechanism in a static game. Section 3 extends the model to be dynamic. Section 4 adds uncertainty of other countries' preferences. Section 5 performs a rough but illustrative calibration. Section 6 concludes by discussing effects that attenuate and strengthen the mechanism. All proofs are in the appendix.

2. Static model

We keep the modeling as simple as possible to highlight the main mechanism. The model consists of three countries. For each country $i \in \{A, B, C\}$ the monetary profits of exploring its own Arctic area ("entering") are:

$$\pi - c(n+1),$$

where π represents the oil revenues (assumed to be equal across countries), c is a function representing the cost of extraction, which depends on the number of *other* countries (n) that enter alongside itself.[8] To capture the technological spillovers we assume c to be a decreasing function and, to make the problem interesting, that

$$c(2) < \pi < c(1), \tag{1}$$

[8] We assume in the model that the countries are equally sized (affecting costs and damages equally). We discuss later the effect of relaxing this assumption.

so that no country wishes to enter the Arctic alone but entering with one other country is economically profitable. The total payoff of Country *i* is given by:

$$U_i(E_i,\, n) \;=\; [\pi \;-\; D_i \;-\; c(n+1)]E_i \;-\; nD_i, \tag{2}$$

where $E_i \in \{0,1\}$ is the binary choice variable of Country *i* of whether to enter ($E_i = 1$) or not ($E_i = 0$). The term $D_i \geq 0$ represents the marginal environmental damage of one country entering as perceived by Country i. Hence, D_i is country specific. Nevertheless, the perceived total damage depends both on what Country *i* does and on what the other countries do.

Countries are ordered by their environmental consciousness:

$$D_A \geq D_B \geq D_C = 0. \tag{3}$$

If all countries preferred the same outcome – all countries in, or all countries out – the game would be trivial. To make the problem interesting we will further assume that

$$\pi - c(3) > D_A \geq D_B > \frac{\pi - c(3)}{3}, \tag{4}$$

so that for $i \;=\; A, B$:

$$U_i(0{,}0) > U_i(1{,}2), \tag{5}$$

and

$$U_i(1{,}2) > U_i(0{,}2). \tag{6}$$

Condition (5) states that the two most environmentally-conscious countries would prefer that all stay out to all countries entering. Condition (6) implies that the most environmentally-conscious country—and, therefore, all countries—would prefer to enter if the other two did. It should be noted that, unlike countries A and B, Country C prefers an equilibrium where all enter over one where all stay out (this follows from (1) and (3)).

In the static version of the model, countries move simultaneously. In this case, it is simple to show that the model essentially becomes a three-player coordination game.

Lemma 1*: There exist two pure strategy Nash equilibria: one where all enter and one where all stay out.*

We omit the formal proof as this lemma is simple and intuitive. Technological spillovers imply that no country would want to stay out if the others entered (implied by the assumption in (6); even Country A wishes to enter if all others enter) and, likewise, no country would want to enter if the others stayed out since the costs of extraction would be prohibitive (due to the assumption in (1)).

3. Dynamic model

We now extend the model to a dynamic setting. To convey the dynamics at play, it is sufficient to have three periods. We assume that a decision to enter is 'absorptive' in the sense that once a country enters, it cannot leave. This helps us abstract from various less interesting cases but is also realistic. In practice, there are large fixed costs associated with entry (exploration, setting up of rigs, etc.).

In period 1 all countries move simultaneously and decide individually whether to enter or not. These actions are observed before actions are taken in the second period. Here, those who did not enter previously may choose whether to enter or not. These actions are again observed before those who have not entered in previous periods decide, in period 3, whether to enter or not. Payoffs are given at the end of the game according to equation (2) based on the status of the countries in period 3.[9] We are interested in Subgame Perfect Nash Equilibria (SPNE) and there may exist multiple such equilibria. We proceed by analyzing the existence of an equilibrium where all stay out.

Proposition 1: *There exists an SPNE where all stay out iff (i)* $D_B \geq \pi - c(2)$ *and (ii)* $D_B \geq \frac{\pi - c(3)}{2}$.

Proof: In the appendix.

The proposition implies that it is the preferences of Country B that determine the existence of an equilibrium where all stay out. We only comment on condition (ii) because condition (i) is actually an artefact of the 3-period setup, as pointed out in the proof of Proposition 1 in the appendix.

[9] In the concluding section, we discuss the effect of having payoffs contingent on the date of entry.

Country A \ Country B	Enter	Do not enter
Enter	$\pi - c(3) - 3D_A, \pi - c(3) - 3D_B$	$\pi - c(2) - 2D_A, -2D_B$
Do not enter	$-2D_A, \pi - c(2) - 2D_B$	$-D_A, -D_B$

Figure 2: Normal form of 2-country subgame in period 3 after Country C has entered.

Condition (ii) says that the technological spillovers when there are many entrants have to be small ($c(3)$ has to be large) so that Country B prefers an outcome where only one other country enters over an outcome where all enter: $U_B(1,2) < U_B(0,1)$. To see the role of condition (ii) and the dynamics of the game, suppose condition (i) holds and consider a subgame starting in period 3 where Country C has entered but not the others. This situation – a simultaneous-move game between countries A and B – is depicted in Figure 2. This subgame is essentially a coordination game and it has two Nash equilibria: one where both enter and one where both stay out.[10] However, although the subgame of period 3 is a coordination game, the dynamic structure of the game implies that an outcome where countries A and B stay out may be unattainable under subgame perfection when instead starting in period 2. This is the case precisely when condition (ii) is violated. To see why, note that if countries B and C have entered before period 3, then Country A will enter as well in period 3. Hence, if Country B observes that Country C has entered in period 1, it essentially has the choice of either entering in period 2, thereby spurring a chain reaction where Country A enters as well, or staying out and stopping the chain reaction. Hence, and because the game is dynamic, Country B can ensure that both entering is achieved if it wants to; in a sense it can choose its preferred equilibrium from the normal form coordination game in Figure 2. Country C is aware of this chain reaction. Hence, if $U_B(0,1) < U_B(1,2)$ then Country C, by entering, can ensure its preferred outcome where all enter while the subgame where it does not enter in the first or second period may end up with all staying out. Recall that Country B really would prefer all to stay

[10] This is ensured by condition (i) in the proposition holding and by the assumption in (6).

out. Thus, a low $c(3)$ can be viewed as a form of temptation for Country B to enter after Country C, which prevents Country B from attaining its preferred outcome.

This means that strong technological spillovers (in the form of a low $c(3)$) give countries that do *not* care about the environment a strategic advantage.

A related statement about the *environmental preferences* of Country B can be made since they have an interesting multiplier effect. If D_B is so large that Country B prefers to stay out after only Country C has entered (condition (ii) holds) then Country B gets its preferred outcome since the equilibrium will then be that all, including Country C, stay out as staying out is a credible threat for Country B even after Country C has entered. Thus, having strong environmental preferences is a strategic advantage as it is easier to commit to staying out.

4. Preference uncertainty

We now extend the dynamic model to include uncertainty of the environmental preferences of other countries. To highlight the strategic impact of this uncertainty we consider uncertainty only about one country at a time. That is, one country has private knowledge of her own type while the preferences of the two remaining countries are common knowledge.

We start by analyzing uncertainty about Country A. Suppose there are two possible types of Country A: one *green* type, denoted by subscript g, which has preferences according to (5) and (6) and such that $D_g \geq \pi - c(2)$; and one *very green* type, denoted by subscript gg, for which assumption (6) is violated and instead:

$$D_{gg} > \pi - c(3) \leftrightarrow U_{gg}(0,2) > U_{gg}(1,2). \tag{7}$$

That is, the very green type prefers to stay out regardless of whether the others enter. Furthermore, we denote by q the exogenous probability of Country A being of gg-type. This probability is common knowledge. To stack the cards against an all-out equilibrium we will assume that Country B is not particularly environmentally conscious so that it prefers that all enter over one other country entering alone ($U_B(1,2) > U_B(0,1)$); in other words, condition (ii) in Proposition 1 is violated.[11] We are looking for a Perfect Bayesian Equilibrium (PBE), meaning that beliefs have to be consistent with the history of play.

[11] It follows then from Proposition 2 that a full-information game played between countries B, C, and the g-type of Country A admits no all-out SPNEs. This is due to the fact that Country C can start a chain reaction by entering, thereby inducing Country B to enter as well ($U_B(1,2) > U_B(0,1)$), which in turn induces the g-type to enter.

Proposition 2: *All staying out is the unique PBE outcome iff q is sufficiently large* $\left(q > \frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B}\right)$.

Proof: In the appendix.

Country A can use the uncertainty others perceive about its preferences to its advantage. To see this, recall that the gg-type will always stay out, independently of what the others do. This means that if Country B dislikes entering with only one other country ($U_B(1,1) < U_B(0,1)$, which holds whenever $\frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B} < 1$ and is therefore implied by the condition in the proposition), a known realization of the gg-type would induce Country B to stay out, which in turn would induce Country C to stay out as well. Now, suppose the realization is that Country A is of the g-type. Had Country C known that Country A was of the g-type then it could have entered expecting Country B and then Country A to follow. However, by staying out, the g-type can mimic the behavior of the gg-type which leaves countries B and C with uncertainty of what the type realization is. Whether the others enter then depends, again, on the preferences of Country B. Not knowing the type of Country A, Country B has to attach a sufficiently high probability to Country A being of type gg in order to stay out, so that the risk of possibly entering with only Country C outweighs the possible gains from entering, even knowing that it would lead the g-type to follow suit. It may be interesting to note that the preferences of Country C do not play a role here. This is because Country C relies on the reaction of Country B: if Country B follows then Country C will enter and if Country B does not, then Country C will stay out.

A strategic interpretation of this result is that staying out is a way for Country A of hiding her type, which constitutes a strategic advantage. This strategic advantage of preference uncertainty is sufficiently potent to imply that "all out" is the unique equilibrium outcome unlike in the full-information game where, even if an all-out equilibrium exists, there will always exist an all-in equilibrium too. More loosely interpreted, the policy implication is that an environmentally-conscious country has a reason to try to influence the beliefs of the others (q). That is, it should try to get others to believe it is environmentally adamant and will never enter the Arctic—expressing environmental concerns is a form of cheap talk that is effective in this case.

The extent of this strategic advantage is measured by the difference $c(2) - c(3)$, because the larger this difference, the lower q can be. Proposition 2 can thus be interpreted through the lens of the properties of technological spillovers. To make things simple, fix the value of $c(3)$ high enough that condition (ii) in Proposition 1 does not hold.[12] Recall also that it is not economically profitable to enter alone ($c(1) > \pi$). Then, Proposition 2 states that the likelihood of an all-out equilibrium outcome will depend on the

[12] Otherwise, a SPNE outcome where all stay out exists, as per Proposition 1, and the introduction of uncertainty is moot. Also, we make no assumptions about $c(2)$; recall that condition (i) in Proposition 1 is an artefact of the 3-period structure of our model, but has no real economic meaning for the purpose of this discussion.

magnitude of the difference $c(2)-c(3)$. More precisely, if $c(2)-c(3)$ is large, corresponding to a situation where the bulk of the spillovers kick in only after most countries enter, an all-out equilibrium outcome is more likely. For example, this could correspond to the case where spillovers are in the form of expertise acquired through 'learning-by-doing': one must have been confronted with various adverse situations to be confident that the most significant setbacks can be avoided. In such a case, c will be a concavely falling function. Conversely, the smaller $c(2)-c(3)$, so that most of the spillovers are already exhausted with few entrants, the less likely an all-out equilibrium. This is the case if, for instance, drilling in the Arctic incurs a fixed cost of developing a new design of drilling equipment to withstand the harsh sea and weather conditions whereas the marginal improvement, after this equipment has been developed, is small (zero). In this case we would get a convexly falling cost function.

We move now to look at the case where there is uncertainty about the preferences of Country B. It is commonly known that Country B is less environmentally conscious than Country A, and more environmentally conscious than Country C, but uncertainty remains about its exact preferences. Formally, we have:

$$D_A \geq D_g > D_{br} \geq D_C = 0, \tag{8}$$

where Country B can either be of *green* or *brown* type. The *green* type, with some abuse of notation we denote it by subscript g, whose preferences satisfy the conditions in Proposition 1. That is, it would only want to enter if the other two countries did. The other type is *brown*, denoted by subscript br, with preferences:

$$U_{br}(0,0) > U_{br}(1,2) > U_{br}(1,1) > U_{br}(0,1). \tag{9}$$

This type prefers that all enter to entering with one other country, which it prefers over staying out when one other country enters (that is, neither condition in Proposition 1 holds). The only element that makes it slightly environmentally conscious is that it prefers that all stay out to any other outcome.[13]

Denote by p the exogenous probability that Country B is of the green type. p is common knowledge.

Proposition 3: *All staying out is a PBE outcome iff p is sufficiently large: (i)* $p \geq \frac{\pi - c(3)}{c(1)-c(3)} \in]0,1[$ *and (ii)* $p \geq \frac{\pi - c(3) - D_A}{c(2)-c(3)} \in]0,1[$.

[13] To see that this preference set is non-empty note that the inequalities in (9) imply $D_{br} > \frac{\pi - c(3)}{3}$, $D_{br} < c(2) - c(3)$ and $D_{br} < \pi - c(2)$. That is, two upper bounds on D_{br} and one lower bound. The first upper bound is compatible with the lower bound iff $3c(2) - 2c(3) > \pi$ and the second upper bound is compatible with the lower bound iff $3c(2) - c(3) < 2\pi$. These two constraints are compatible as long as $c(2) > c(3)$, which holds by assumption.

Proof: In the appendix.

The strategic intuition behind this proposition is similar but more straightforward than the intuition for the previous result. We will focus on condition (i).[14] Country A and the g-type of Country B, both being environmentally conscious, prefer to coordinate on staying out even if Country C entered in some earlier period. The br-type of Country B, would follow an entry of Country C but, by staying out, the br-type can mimic the behavior of the g-type and thus force Country C to consider the risk that, if it enters, it might be entering alone. Hence, for Country C to stay out, p has to be sufficiently large so that the risk of $U_C(1,0)$ is greater than the positive prospect of $U_C(1,2)$. The comparison for Country C is between entering alone and entering with two others because, if countries B and C enter, Country A will enter as well. The interpretation of this result is that a less green country (the brown type of Country B) that still prefers that the Arctic be left untouched has reason to pretend to be more environmentally conscious than it actually is.

The nature of the technological spillovers also plays a key role in Proposition 3, although this time it is the overall technological spillovers $(c(1) - c(3))$ that determine the likelihood of existence of an all-out equilibrium outcome, rather than the tail end of the cost function $(c(2) - c(3))$ as was the case in Proposition 2. This is because in Proposition 3 it is Country C that needs to be deterred from entry for there to exist an all-out equilibrium. This country compares the risk of entering alone with the prospect of getting the others to join. The magnitude of the spillovers, $c(1) - c(3)$, capture how reliant Country C is on others entering: a large difference implicitly means that entering alone is costly, which deters entry.

As a final step, we move now to discuss the case where Country C can be of two types. The first is very brown, denoted by *vbr*, and has preferences according to (3). This type prefers entering as long as at least one other country does. The second is extremely brown, denoted by *vvbr*, and would enter even on its own: D_{vvbr} is sufficiently negative so that it is worthwhile for it to enter despite making an economic loss.[15]

The most interesting aspect of this case is that Country C *cannot* use uncertainty about its preferences in any strategic way. Since both types of Country C have greater incentives to enter than countries A and B, these latter countries have the option to wait and then enter only after Country C has. Country C

[14] Condition (ii) is spelled out for completeness, but it is essentially an artefact of our limitation of the game to be over three, and not more, periods. Hence, it is of less economic interest. The condition says that, should Country C enter in period 2, then Country A needs to prefer the risk of being the only one staying out (should the br-type of Country B be the state of nature) over the risk of entering alone with Country C (should the g-type of Country B be the state of nature).

[15] Hence, we have $D_A \geq D_B \geq D_{vbr} = 0 > D_{vvbr}$. While difficult to frame in terms of environmental preference, a negative value of D_{vvbr} can for instance be interpreted as Country C enjoying additional country-specific spillovers, for example, to increase employment or the population density in remote regions.

of the *vvbr*-type will enter independently of what the others do and the *vbr*-type will enter if and only if Country B is expected to follow suit. So the uncertainty of Country C's preferences does not play a role. An interpretation of this is that uncertainty of environmental preferences among those who do care about the environment is more important than of those that do not care about the environment. The strategic advantage of a country that does not care about the environment is that it can move first and thereby possibly initiate a process where more countries enter. However, the strategic advantage of an environmentally-conscious country is a result of the uncertainty about its preferences, which it can exploit by staying out. This cannot be used by the country that does not care about the environment since it can only get the market rolling by moving first.

5. Illustrative calibration

We now propose a rough calibration to illustrate the model results and to get an idea about whether countries that do care about the environment can credibly commit to not entering. Naturally, being a highly stylized model, the results should be interpreted with caution. Our model requires information about oil production costs and technological spillovers, about the price of oil, and about the environmental harm as perceived by the players. To illustrate our results, we will simplify the Arctic map and consider the three-player game consisting of only Russia, the U.S. and Norway.

In this calibration we depart from the setup of the theoretical model in two ways. Firstly, to make the calibrated numbers more realistic, we will take into account that the prospective reserves differ between countries, hence have heterogeneous effects on both damages and spillovers. This is without consequence for the qualitative results but implies (to assess the possibility of different equilibria quantitatively) that we need to keep track of who it is that enters in various scenarios since not only the number of entrants but also their size plays a role. Had we included the possibility of heterogeneous reserves in the theoretical section, then we would have needed to deal with a number of subcases that are devoid of economic insights. To avoid dealing with these uninteresting subcases here, our second departure from the theoretical setup is that we fix the order of actions so that the least environmentally-conscious country moves first and the most environmentally-conscious country moves last. This is without quantitative consequences as compared to our basic theoretical setup since it only presupposes that the least environmentally-conscious country enjoys a first-mover advantage, which is what arose endogenously in the theory section.

Oil price

For the oil price, we shall take $\pi = 70$ \$/bbl, the marginal cost of shale as a base scenario. This is motivated by the cost of shale extraction largely setting a maximum price for oil today.[16] This factor is likely to be important over the next decades. It is of course straightforward to adjust the results to other price scenarios.

Production costs and spillovers

Calibrating the production costs and spillovers involves a great degree of uncertainty. For the purpose of this illustration, we will use the best available estimates of this but it is important to note that the estimates and results need to be interpreted with caution.

McDonald and Schrattenholzer (2001) estimate the learning spillovers in terms of reducing production costs in the energy sector. For North-Sea oil (the closest equivalent to Arctic off-shore oil) a doubling of the number of rigs lowers the average cost per rig by 25%. That is, for a current cost of production k_0, average production costs will be $k(s) = k_0 0.75^s$ where $s = \ln(m)/\ln(2)$ and m is the number of multiplications of current market size.

To get a rough idea of the effect that entry of Russia, U.S. and Norway will have on the costs, we also need estimates of their expected Arctic reserves. Naturally, a large degree of uncertainty surrounds such estimates but, following USGS (2008), Russia and the U.S. have roughly equal-sized reserves and Norway's reserves are at around a quarter of each of them.[17]

Existing estimates of today's production costs of Arctic oil in Russia are around 120 \$/bbl which gives an estimate for k_0.[18]

The most difficult value to estimate is the existing stock of knowledge of Arctic production. This determines how many doublings of market size, for instance, an entry of Russia to the Arctic would induce. This is determined partly by the current amount of offshore oil extraction in general, by the current amount of near-Arctic (e.g., Norwegian and Russian) oil extraction in particular but, importantly, by how much such extraction has in common with the more extreme Arctic extraction we are interested in here. Unfortunately, there are no reliable estimates for this implying that we have to make a guess

[16] This assumption is motivated by OPEC's well-established strategy of limiting output so as to keep the oil price below the break-even point of competing fuels. We refer the reader to Andrade de Sá and Daubanes (2016) for a discussion.
[17] We focus here on off-shore oil technology hence exclude the predominantly on-shore regions WSB, YK, TPB, LA, LV and ZB (see USGS, 2008).
[18] https://knoema.com/vyronoe/cost-of-oil-production-by-country#, accessed Dec. 9th 2016

about it.[19] We will assume Russia alone would double the current market size so that $m = 2$ if Russia enters alone and (based on the relative reserve estimates) $m = 4$ if Russia and the U.S. enter and $m = 4.5$ if also Norway enters.

Put together this gives us $c(1) = 120 * 0.75^2 \approx 90$, $c(2) = 120 * 0.75^4 \approx 68$, $c(3) = 120 * 0.75^{4.5} \approx 64$.[20]

Perceived climate damage

We now calibrate the values that each country attaches to climate harm. We use each country's social cost of carbon (SCC) as an approximation. The SCC theoretically corresponds to the damage incurred worldwide as the result of GHG emissions, which is not the same thing as damage suffered in a given country. That being said, it is also apparent that the values declared – or revealed – by countries are in the lower range of estimates of the SCC (for example, Moore and Diaz, 2015, obtain a value of $220/tCO2). Our view is that the stances taken by countries with regard to the SCC convey information about their concern for climate change nonetheless. While not perfect, we take these values to constitute reasonable approximations.

The US has officially adopted an SCC for 2016 of 37 $/tCO2 though we relax this later.[21] For comparison with the price and costs of oil extraction, we convert this based on the carbon content in a barrel of oil. Following the EPA, we use the conversion ratio 0.43 tCO2/bbl.[22] This means the adopted SCC in the US is about 16$/bbl of oil. For Norway, there is no official SCC to our knowledge, so we use a cost as implied by the CO2-tax it imposes on gasoline of 0.88 NOK/liter ≈ 0.1 $/liter,[23] which translates into $0.1\ x\ 425 = 42.5\$/tCO2 \approx$ 18 $/bbl of oil.[24] We take Russia's SCC to be 0 $/tCO2 since it has shown no signs of putting a monetary value on CO2 emissions (neither by defining a SCC nor through taxation). Mapping these values to our model yields: $D_A = 18$, $D_B = 16$, and $D_C = 0$.

These damage values are measured in $ per barrel of oil, hence are comparable to the extraction cost and price of oil. Note, however, that since countries differ in the size of their Arctic oil reserves, the

[19] One very basic reason for the lack of estimates is that there is uncertainty even around the current activity in the Russian Arctic (Oil and Gas Eurasia, 2007). A second reason is that it is hard to know how applicable the current technologies are to more remote Arctic areas.
[20] That is, as mentioned, here we assume that the entry order is always Russia first, then possibly US and then possibly Norway.
[21] https://www.epa.gov/climatechange/social-cost-carbon, accessed Dec. 9th 2016.
[22] Source: https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references, accessed Dec. 9th 2016.

[23] http://www.statsbudsjettet.no/Statsbudsjettet-2011/English/?pid=48921#hopp. For the conversion, we use 1 NOK = 0.11764 USD, according to http://www.xe.com/currencyconverter/convert/?Amount=0.88&From=NOK&To=USD, accessed Dec. 9th 2016.
[24] 1 ton of CO2 is equivalent to 425 liters of gasoline. See https://www.eia.gov/environment/emissions/co2_vol_mass.cfm, accessed Dec. 9th 2016.

damage as perceived by country *i* when country *j* enters may not be the same as that perceived by *i* when *i* itself enters. Because the effective order of entry, if at all, is Russia, then the U.S., the Norway, the only time this will play a role is for the damage perceived by the U.S. when Norway enters which, by Norway's reserves relative to the U.S., we consequently set to $\frac{1}{4}D_B = 4$.

Predictions of the dynamic model

For Norway and the U.S. to prefer the all-out outcome over the all-in outcome, it must be that $D_A, D_B > (\pi - c(3))/3 = (70 - 64)/3 = 2$ \$/bbl. The empirical values of D_A and D_B identified above clear this threshold by a wide margin.

Condition i) in Proposition 1 requires: $D_B > \pi - c(2)$. This means $D_B > 2$ \$/bbl which is satisfied.

Condition ii) in Proposition 1 ($2D_B > \pi - c(3)$) needs to be reformulated taking into account that the damages as perceived by the U.S. when Norway enters are only $D_B/4$. Hence this condition reads $1.25 * D_B > \pi - c(3)$. This condition is fulfilled if $D_B > (\pi - c(3))/1.25 = 4.8$ \$/bbl, which corresponds to the threshold value for the U.S. to credibly not enter after Russia. This is also clearly satisfied.

For Norway and the U.S. to enter after enough other countries enter, we need $D_A, D_B < \pi - c(3) =$ \$6/bbl. This condition is not satisfied by any country but Russia. Hence, Norway and the U.S. would not enter following Russia.

The conclusion of this numerical illustration is that an all-out outcome seems credible should the U.S. and Norway really want to.[25] Enough countries are sufficiently climate conscious to prevent a chain reaction of entry from unraveling and, by doing so, to discourage Russia from initiating it in the first place. Russia is also reliant on the entry of others given that its cost when entering alone far exceeds the price of oil.

Given that the values adopted in our base scenario are broad approximations, we now perform a sensitivity analysis of sorts. Namely, we investigate how robust our prediction is to these values differing from the base scenario. We perform this analysis along three dimensions: the approximated perceived damages by the U.S. and Norway, the price of oil, π and the magnitude of technological spillovers.

In the previous calibration there are two obstacles for "all-in" outcome. Firstly, D_B is so high that the U.S. would not follow Russia even if it knew that Norway would join. The estimate of damage for the

[25] Strictly speaking, the results of Proposition 1 do not directly apply since this proposition was proven for the more involved case under the restrictions in expression (6) which does not hold with these calibrated values. However, it is easy to show that, under the calibrated values, "all out" is an equilibrium. To see this note that Russia does not make economic profits unless at least the U.S. enters. Then note that Norway's and the U.S.'s damage estimates are such that none of them would want to enter even if the other two did which means none of them would follow Russia.

U.S. is $D_B = \$16$/bbl. For the U.S. to join after Russia (given that Norway will not follow) it is necessary that $D_B < \pi - c(2) = 2$. Hence, the U.S.'s perceived SCC has to be reduced to nearly zero. Is this a likely scenario? Had this paper been finalized a few months ago, our answer would have been no. It was likely that Hillary Clinton would have upheld Obama's strict policies about Arctic drilling. However, with the new elected administration it could be that the U.S. shifts its policy substantially as could suggest, for instance, Donald Trump's denying of climate change and nomination of Exxon Mobil CEO and 'Friend' of the Putin administration, Rex Tillerson (NY Times, 2016). If the Trump administration is representative of the long-term climate policy in the U.S. it is likely that their SCC will go to near zero.

As for Norway's perceived climate damage, it is not necessarily written in stone either. For Norway to enter after the U.S. it is necessary that its SCC be $D_A < \pi - c(3) = 6$. If this were the case, then Proposition 1 would apply and the U.S. would enter (knowing Norway will follow) iff $D_B < (\pi - c(3))/1.25 = 4.8$ \$/bbl. Hence, if both Norway and the U.S. lower their perceived climate costs to be below 6 and 4.8 \$/bbl respectively, then all-enter is the equilibrium.

Holding the D's fixed as in the base scenario, we can investigate what oil price would be needed to get an equilibrium where some or all countries enter. Firstly, and quite directly, if the price exceeds \$90/bbl for a durable period of time, Russia would enter independently of the other countries' strategies since $c(1) = 90 < \pi$. Next, for Norway to enter after the U.S., it is necessary that $D_A < \pi - c(3)$ hence that the oil price exceeds \$82/bbl. If this is the case then using Proposition 1, for the U.S. to enter the oil price would have to durably exceed either $\pi \geq D_B + c(2) =$ \$84/bbl (constraint i) or $\pi > 1.25D_B + c(3) =$ \$84/bbl (constraint ii). Hence, in total, an oil price above \$84/bbl would lead to entry of all.

Finally, supposing the price of oil hovers around π = \$70/bbl, technological spillovers will have to be so large as to reduce $c(3)$ down to costs of \$52/bbl for Norway to follow the U.S. and to reduce either $c(2) < \pi - D_B = \$54/\text{bbl}$ (constraint i) or $c(3) < \pi - 1.25D_B =$ \$50/bbl (constraint ii). Alternatively, if $c(1) < 70$ then Russia would enter also alone.

Given the uncertainty surrounding these values, and that the model is not a full account of the forces shaping Arctic extraction, the ambition of the calibration is of course not to provide a forecast of what will actually happen. Rather, and as the calibration values seem to indicate, it shows that the costs of extraction and the oil price are at such levels as to make the forces of our model relevant and that profitable entry by one player is contingent on the actions of other players and furthermore, that it is possible that countries such as Norway would be able to commit to not enter, should they want to. This illustration was of course done under the assumption that the preferences (SCC) of all countries are known. As illustrated by the case of the U.S. where the current and previous administration differ greatly in the views on climate change, we turn now to illustrate the results on preference uncertainty quantitatively.

Predictions of the dynamic model with preference uncertainty

Of course, in reality the indicated SCC for Norway and the U.S. may not be entirely representative of long-run preferences as they can be changed by future governments and, in particular, they may not represent how these countries view climate damage arising from their own selling of oil.[26] For instance, there is a heated discussion in Norway over whether exploration should be allowed in its Northern territories. Several political parties are in favor of essentially stopping new exploration while others are in favor of continued exploration. As an illustration of the uncertainty of preferences in our model, suppose these pro-environment parties indeed have an SCC of \$18/bbl, making these parties of the gg-type. Suppose further that the recent election in the U.S. will have long-term consequences, lowering the SCC of the U.S.. If the U.S. uses a value between \$2 and \$4.8/bbl in the future, then it fulfills the assumptions of Country B in Proposition 2.[27] Hence, as a first example, suppose $D_B = \$4$/bbl. Then, according to the requirement of Proposition 2, the U.S. would not follow Russia (and hence Russia would not enter) if $q > \frac{\pi - c(3) - 1.25D_B}{c(2) - c(3) - 0.25D_B} = \frac{70-64-5}{68-64-0.25} \approx 27\%$.[28] That is, if a green coalition is more likely than this to set the long-run policy of Norway then that discourages entry by others.

Turning now to the uncertainty of the preferences of the U.S., we can first note that if the Trump administration values the SCC at zero then, under the assumed oil price and spillovers they would simply enter since they would then face an oil price above their costs of extraction ($\pi - c(2) = 70 - 68 > 0$) as Russia would then enter as well. Under a slightly lower price scenario or slightly higher cost scenario the U.S. under Trump would be more reliant on Norway's entry.

However, it is not certain that the Trump administration will be able to alter the Arctic policy of the U.S. and, given that Trump's re-election is highly uncertain, there is uncertainty about the long-run preferences of the U.S.. Suppose that with probability p a relatively environmentally friendly U.S. administration will determine the long-run preferences of the US, with an SCC at $D_B = 16$ as per the

[26] That is, Norway may treat emissions arising when others burn fossil fuels Norway has extracted differently than emissions Norway causes when burning fossil fuels itself. Such a distinction was actually present in the drafting of the Kyoto Protocol.

[27] The condition $D_B > \$2$ is for $U_B(0,1) > U_B(1,1)$ to hold and the condition $D_B < \$4.8$ is for $U_B(1,2) > U_B(0,1)$. In our context, where the perceived damages by the U.S. when Norway enters are $0.25D_B$, the latter translates to $D_B < (\pi - c(3))/1.25 = 4.8$.

[28] From the proof of Proposition 2 the condition in Proposition 2 stems from the requirement $U_B(0,1) > qU_B(1,1) + (1-q)U_B(1,2)$. When the damages perceived damages of the US when Norway enters are $0.25D_B$ this requirement translates to $q > \frac{\pi - c(3) - 1.25D_B}{c(2) - c(3) - 0.25D_B}$.

Obama administration.[29] With probability *1-p* the Trump (or similar) administration will set the long-run policy of the U.S. at $D_B = 0$. Clearly, with $D_A = 18$ Norway would not enter under any circumstances since $D_A > \pi - c(3)$ and similarly the green U.S. administration would not enter under any circumstances. Likewise, as concluded above, a U.S. administration with $D_B = 0$ would enter provided that Russia does. Hence, Russia, if it wants to enter today, faces with probability p costs at $c(1) = 0$ with profits at -20 and with probability *1-p* faces costs at $c(2) = 68$ with profits at *2*. For Russia to enter today under such a scenario, expected profits have to be positive ($p(-15) + (1-p)2 > 0$) implying the probability of $p < 0.09$. That is, Trump has to be re-elected with a probability greater than 91 for Russia to enter today. Hence, the environmental preferences of Norway or a green U.S. administration could play a pivotal role in deterring entry by Russia.

6. Conclusions and discussion

We have shown in this paper that market size for arctic technology creates strategic interaction between countries that may want to induce others to enter the Arctic or may want to induce others not to do so. A rough calibration suggests that, indeed, the cost of extraction and price of oil are such that countries that do not care about the environment are reliant on environmentally-conscious countries joining also. In turn, this gives a country like Norway a pivotal role in letting the Arctic fields remain untouched, if it wishes. This pivotal role seems to be particularly central in light of the new uncertainty surrounding the upcoming Trump administration.

We have kept the modeling as simple and sparse as possible to highlight this strategic interaction and the main results. A few factors attenuating or strengthening the results are, however, worth mentioning. The first is that size is unevenly distributed among the five countries with jurisdiction over the Arctic. Russia has by far the largest piece of the pie. This was abstracted from in the theoretical analysis but was incorporated in the numerical illustration. To the extent that Russia has the weakest environmental preferences, this size gives them an advantage to be partly able to push the technology by themselves. However, as the numerical illustration suggests, they are reliant on a less environmentally-friendly US administration setting the long-run policy.

On the other hand, Russia partly has the least accessible areas while Norway is sometimes called the gateway to the Arctic since it can start extraction in rather mild Arctic areas thus providing a testing ground for the technology. Hence, to the extent that Norway has a strong environmental consciousness, they may largely halt the development of the necessary technology, as a stepwise testing of this technology is hard to perform if firms only have access to Russia's Arctic region. Russia may also face

[29] A survey of attitudes towards climate change in the U.S. population shows that a majority thinks that the US government should do “A great deal” or “A lot” to fight climate change and a vast majority are in favor of unilateral action (Resources for the Future, 2015).

problems with the willingness to invest by firms possessing these technologies (Harsem et al., 2011). In terms of our model, this would mean Norway has the first-mover advantage.

We have assumed in the model that the payoffs arrive at the end of the game and only depend on the final status of the countries – the sequence of decisions to enter has no effect. In practice there are probably both gains of waiting and benefits of being first to enter. If one enters early, one may sink large costs if the oil price drops and the others decide to stay out. In addition, one may need to cover the costs of various failed technological attempts. The benefit of being first is that one gives a testing ground for domestic firms that may be able to patent and then sell this technology to other countries.

A final factor is the partial uncertainty of property rights in the Arctic. There is, for instance, a dispute over which country owns the North Pole and, by international law, the one whose continental shelf goes under it is the rightful owner (UNCLOS, 1982). This means that keeping one's own territory free of oil drilling may imply that a country with stronger military muscles may partially explore that area instead. Now, this uncertainty over the rights does not cover the entire Arctic region – no one would argue that the US does not have sole jurisdiction of the waters of the Alaskan coast or that Norway does not have jurisdiction over the Lofoten Islands. Therefore, the model results apply to such areas where there is less of a dispute. Furthermore, the fact that there is a dispute is a reason by itself to avoid making such areas more economically appealing which can be achieved by not drilling in the undisputed areas hence cooling down the geostrategic tensions in the Arctic.

Finally, while this paper has been applied to oil extraction in the Arctic, the analysis and insights may be applicable also to other domains. For instance, within environmental economics, similar interaction may exist when it comes to fisheries in remote or deep locations or other oil resources that require specific technologies. Outside of environmental economics, it may have bearing on investments in weapon systems or surveillance technologies.

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7. Appendix

Proof of Proposition 1

Before beginning the formal proof, we make the following observation. The normal-form game described by Figure 2 pertains to a subgame starting in period 3 after Country C, but no other country, has entered. This subgame admits (Do not enter, Do not enter) as an NE if and only if condition (i) holds. There also exists another NE of this subgame, which is that both countries enter. The latter equilibrium follows from (6) and is independent of condition (i) or (ii) holding.

<u>If.</u>

Suppose condition (ii) holds so that $D_B \geq \frac{\pi - c(3)}{2}$ or, equivalently, $U_B(1,2) \leq U_B(0,1)$.[30] Suppose further that condition (i) holds so that $D_B \geq \pi - c(2)$ or, equivalently, $U_B(1,1) \leq U_B(0,1)$. We claim that the following profile of strategies constitutes an SPNE:

- Country A: "Do not enter in period 1, and enter in subsequent periods if and only if B has entered already."
- Country B: "Do not enter in period 1, and enter in subsequent periods if and only if A has entered already."
- Country C: "Do not enter in Period 1, and enter in subsequent periods if and only if at least one other country has already entered."

The outcome of these strategies is that all stay out and each obtains a payoff of zero. We check that the strategies indeed constitute an SPNE. Given the strategies of countries A and B, Country C cannot gain by entering alone (due to (1) and (3)) but it is optimal for it to enter (off the equilibrium path) if someone else did. Likewise, Country B cannot gain by entering alone in period 1: this will spark a chain reaction in which Country C, then Country A, end up entering. Country B loses by such a move because $D_B \geq \frac{\pi - c(3)}{2}$, implying $U_B(1,2) \leq U_B(0,1) \leq U_B(0,0)$, so that Country B prefers an all-out outcome to an all-in outcome, hence gets lower payoff by entering in period 1. Similarly, Country B cannot gain by entering alone in period 2: this will entice Country C to enter, but not Country A, who will not have

[30] Note that it follows from $D_A > D_B$ that we also have $U_A(1,2) \leq U_A(0,1)$.

time to enter after Country C.[31] Here, because $D_B \geq \pi - c(2)$, we have $U_B(1,1) \leq U_B(0,1) \leq U_B(0,0)$, so that Country B prefers an all-out outcome to an outcome where only two countries have entered. Country B's best response is to not enter after only Country C has entered (off the equilibrium path) since $U_B(0,1) > U_B(1,2)$ and $U_B(0,1) > U_B(1,1)$, which are the only payoffs it could get by entering after Country C given the strategy of Country A. Finally (off the equilibrium path), upon observing an entry by Country A, Country B does best by entering since by the strategy of Country C, Country B would otherwise end up staying out alone. A similar argument holds for Country A.

Only if.

Suppose $D_B < \pi - c(2)$, so that $U_B(1,1) > U_B(0,1)$. Then, as mentioned in the introduction to the proof, the subgame where Country C is the only one to have entered by period 3 has only one NE and in this NE countries A and B enter (see Figure 2). Hence, by entering no later than in period 2, Country C can ensure all will enter, which is her preferred outcome. It follows that any SPNE of the game must have all enter as the outcome as otherwise Country C would profitably deviate to entering before period 3. Hence, condition (i) is necessary for the existence of an SPNE outcome where all stay out.

Alternatively, suppose $D_B < \frac{\pi - c(3)}{2}$, so that $U_B(1,2) > U_B(0,1)$. Suppose also that condition (i) holds (if not, we are back to the previous case). Consider now a strategy where Country C enters in the first period. Then, in the subgame played between countries A and B in periods 2 and 3, Country B can ensure getting $U_B(1,2) > U_B(0,1)$ by entering in period 2, so that Country A may observe that it is the only one out and enter in period 3 (because $U_A(1,2) > U_A(0,2)$ by Expression (6)). Hence, the outcome of this subgame must be that all enter. Because Country C anticipates this strategy, it follows that any SPNE of the game must have all enter as the outcome as otherwise Country C could avoid that subgame by entering in the first period. The SPNE outcome is that all countries have entered by the end of the game. Hence, condition (ii) is necessary.

END OF PROOF

Proof of Proposition 2

In the proof we simply write A when referring to Country A, same for B and C. Likewise, g and gg will stand for the green and very green type of Country A, respectively.

[31] This suggests that condition (i) is actually an artefact of our 3-period setup. Indeed, in an infinite-horizon setting, we would never expect countries B and C to remain alone: Country A would always have "time" to enter afterward.

First, note that the condition $q > \frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B} = \frac{U_B(1,2) - U_B(0,1)}{U_B(1,2) - U_B(1,1)}$ is equivalent to $U_B(0,1) > qU_B(1,1) + (1-q)U_B(1,2)$. The numerator of $\frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B}$ is strictly positive because we assumed $U_B(1,2) > U_B(0,1)$; i.e., $D_B < \frac{\pi - c(3)}{2}$. The denominator is strictly positive if and only if $D_B < c(2) - c(3)$, which may or may not hold, but this is of little consequence.[32]

<u>If.</u>

Suppose $q > \frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B} = \frac{U_B(1,2) - U_B(0,1)}{U_B(1,2) - U_B(1,1)}$. Note that this implies that:

$$\frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B} < 1 \leftrightarrow D_B > \pi - c(2). \tag{10}$$

<u>Existence</u>

Denote $\mu_j(h(T))$ Country *j*'s belief in period *T* along history *h* that A is of type *gg* (*j* = B,C, *T* = 2,3). Consider the following belief system:

- $\mu_B(h(2))=\mu_C(h(2))=q$ if A did not enter in period 1.
- $\mu_B(h(3))=\mu_C(h(3))=q$ if A has entered in neither periods 1 nor 2 and B had not entered in period 1.
- $\mu_B(h(3))=\mu_C(h(3))=0$ if A has entered in period 2 after B has entered in period 1 (with or without C).
- $\mu_B(h(3))=\mu_C(h(3))=1$ if A has not entered in period 2 after B has entered in period 1 (with or without C).
- $\mu_B(h(2))=\mu_C(h(2))=q'$ for any $q' \in [0,1]$, if A entered in period 1.
- $\mu_B(h(3))=\mu_C(h(3))=q''$ for any $q'' \in [0,1]$, if A entered in period 2 and no one had entered in period 1.
- $\mu_B(h(3))=\mu_C(h(3))=q'''$ for any $q''' \in [0,1]$, if A entered in period 2 after C (but not B) entered in period 1.

Now consider the same strategy profile as in the 'If' part of the proof of Proposition 1, adapting it as follows: type-g plays the strategy of Country A; type-gg never enters. The reader can check that the belief system and strategy profile just described constitute a PBE. In particular, one can verify that,

[32] Because the numerator is positive, a negative denominator simply means that the equilibrium condition is satisfied for all values of *q*. This corresponds to the setting of Proposition 1, where an all-out equilibrium outcome exists and uncertainty about A's preferences plays no role.

given the condition on q, B would not follow an entry by C in period 1 and hence C will not enter in period 1.

Uniqueness

To contradict uniqueness it is necessary to show that there exists a PBE with an outcome where at least one country has entered. We list and contradict all such possible outcomes:

A number of outcomes involving entry by only B and C can easily be refuted: C enters alone → C deviates. Only B and C enter → B deviates by Expression (10). B enters alone → B deviates.

Now note that no PBE exists in which gg enters. Hence, all outcomes involving entry by gg can be refuted.

We will now show that no PBE exists with an outcome involving entry by g.

Note that C will enter if it expects or observes B's entry, so no PBE exists where the outcome is that only g and B enter.

Consider player strategies that involve g entering in period 3 but not before (and gg not entering, naturally). Then B and C need to decide whether to enter without having learnt anything about A's type; hence, going into period 3 their beliefs must be q. The condition on q implies that B will not enter even if it observed or expected C to enter (since it is unsure of A's type, and hence of whether A will enter, and since $q > \frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B}$). Therefore, B will not enter. Given this, there exist two possible subcases depending on C's preferences that have not been eliminated. 1) Under the condition that C has sufficient expected profits of entering only with g, C will enter: g gets payoff $U_g(1,1) < U_g(0,1)$, hence g will deviate to not entering in period 3. 2) Alternatively, if C does not have sufficient expected profits to enter with g alone, C will stay out and g will enter alone and get payoff $U_g(1,0) < U_g(0,0)$, hence g will deviate to not entering in period 3.

Consider all player strategies involving a strategy of g saying "enter iff B has been observed to previously enter". The best response for B is to not enter before it has observed entry by A by the same argument as under the case just described where g supposedly enters in period 3. The best response of C is thus not to enter since it will get $U_C(0,1) < U_C(0,0)$. Hence, under this strategy g gets $U_g(0,0)$.

Compare this to all player strategies which involve a strategy of g of entering (in period 1 or period 2) without having observed a previous entry of B. C's best response is to enter after g and so it is the best response of B to enter as well. This yields g a payoff of $U_g(1,2)$, which is less than what it obtains by using "enter iff B has been observed to previously enter" (in which case it obtains $U_g(0,0) > U_g(1,2)$, as we just saw). Hence, "enter iff B has been observed to previously enter" is strictly better strategy for g and hence B and C will not enter either on the equilibrium path.

Only if.

Suppose $q \leq \frac{\pi - c(3) - 2D_B}{c(2) - c(3) - D_B} = \frac{U_B(1,2) - U_B(0,1)}{U_B(1,2) - U_B(1,1)}$. Note that this means that B wishes to enter after C if it expects g to enter and gg not to. Then, the following strategy profiles and beliefs are part of a PBE:

- gg: "Never enter."
- g: "Enter in period 3 (but not earlier)."
- B: "Do not enter in period 1. In period 2, enter if and only if at least one country has entered. In period 3, enter if not yet in."
- C: "Enter in period 1 (and, off the equilibrium path, enter if not already entered)."
- $\mu_B(h(T))=\mu_C(h(T))=q$ for $T=2,3$, if A has not entered in a previous period.
- $\mu_B(h(3))=\mu_C(h(3))=q'$ for any $q' \in [0,1]$ and $T=2,3$ if A has entered in period 1 or 2.

The outcome of this PBE is that all enter. Hence, condition (ii) is necessary.

END OF PROOF

Proof of Proposition 3

As in the proof of Proposition 2, we write A when referring to Country A, same for B and C. Here, g and br will stand for the green and brown types of Country B, respectively.

Note first that (i) $p \geq \frac{\pi - c(3)}{c(1) - c(3)}$ is equivalent to $U_C(0,0) = 0 \geq pU_C(1,0) + (1-p)U_C(1,2)$; and (ii) $p \geq \frac{\pi - c(3) - D_A}{c(2) - c(3)}$ is equivalent to $pU_A(0,1) + (1-p)U_A(0,2) \geq pU_A(1,1) + (1-p)U_A(1,2)$.

Note also that it follows from (8) and the assumptions on D_g (see conditions (i) and (ii) in Proposition 1) that

$$\pi - c(2) < D_A. \quad (11)$$

Finally, $\frac{\pi - c(3)}{c(1) - c(3)} \in]0,1[$ since by assumption $c(3) < \pi < c(1)$. Finally, $\frac{\pi - c(3) - D_A}{c(2) - c(3)} \in]0,1[$ since the numerator is positive (by assumption (5)), the denominator is positive ($c(2) - c(3) > 0$) and the numerator is smaller than the denominator since $\pi - c(2) < D_A$ by the condition in (11).

If.

Suppose the conditions hold. Denote $\mu_j(h(T))$ Country j's belief in period T along history h that B is of type g (j = A,C, T = 2,3). Consider the following belief system:

- $\mu_A(h(T))=\mu_C(h(T))=p$, $T=2,3$, if no country has yet entered.
- $\mu_A(h(3))=\mu_C(h(3))=p$ if B entered in period 2 after A (or A and C) had entered in period 1.
- $\mu_A(h(3))=\mu_C(h(3))=0$ if B entered in period 2 after C had entered alone in period 1.
- $\mu_A(h(3))=\mu_C(h(3))=1$ if B did not enter in period 2 after C had entered alone in period 1.
- $\mu_A(h(T))=\mu_C(h(T))=p'$, $T=2,3$, for any $p' \in [0,1]$, if B entered in period 1.
- $\mu_A(h(3))=\mu_C(h(3)=p''$, for any $p'' \in [0,1]$ if B entered in period 2 after no one had entered in period 1.
- $\mu_A(h(3))=\mu_C(h(3))=p'''$, for any $p''' \in [0,1]$, if B did not enter in period 2 after A had entered alone in period 1.
- $\mu_A(h(3))=\mu_C(h(3))=p''''$, for any $p'''' \in [0,1]$, if B did not enter in period 2 after A and C entered together in period 1.

We will show that these beliefs are part of a PBE with the following strategies:

- A begins by staying out and later stays out unless B has entered in an earlier period, in which case it enters immediately;
- B of both types begin by staying out, g stays out unless A (or A and C) has entered in an earlier period and br stays out unless either A or C have entered in an earlier period, in which case br enters immediately;
- C begins by staying out and later stays out unless at least one of the other countries has entered in an earlier period, in which case it enters immediately. Note that the above belief system is consistent with these strategies.

<u>Proof that Country B is playing a best-response strategy</u>

Possible subgames for B depending on the behaviors of A and C:

- Period-1 subgame: Given the others' strategies, B's best response is not to enter.
- Period-2 subgame where A has entered alone in period 1. C will enter in period 2 by its postulated strategy. Both types of B do best by entering in period 2. This is because $U_i(1,2) > U_i(0,2)$ for $i=g,br$.
    - Period-3 subgame where A has entered in period 2 (and C has not entered in period 1 or 2). Similar argument as previous point.
- Period-2 subgame where C enters alone in period 1. By its postulated strategy, A does not enter in period 2. If br enters in period 2, A will enter in period 3 given its postulated strategy. Then br's payoff is better than that of not entering ($U_{br}(1,2) > U_{br}(0,1)$) or than that of entering in period 3 ($U_{br}(1,2) > U_{br}(1,1)$). If g does not enter in period 2, A will not enter in period 3,

yielding a payoff of $U_g(0,1)$ to g. If g does enter in period 2, A will enter in period 3, yielding a payoff of $U_g(1,2)$ to g. Since $U_g(1,2) < U_g(0,1)$, g's best response is to not enter.

  - Period-3 subgame where C enters in period 2 (and A has not entered in period 1 or 2). Similar argument as previous point.

- Period-2 subgame where A and C have entered in period 1. Both types of B have best response of entering in period 2.
- Period-2 subgame where no one has entered in period 1 (equilibrium path). By their postulated strategies, neither A and C enter in period 2. Both types have a preference for an all-out outcome—$U_i(0,0) > U_i(1,2)$ and $U_i(0,0) > U_i(1,1)$ for i=*g*,*br*—so neither type will choose to enter *before* the others. Furthermore, neither type wishes to enter alone in period 3.
  - Period-3 subgame where no one has entered in period 1 or 2. Similar argument as previous point.
- Period-3 subgame where A and C have both entered (in some order) before period 3. The best response for both g and br is to enter in period 3.

Proof that Country C is playing a best-response strategy

If A or B or both have entered in period 1 or 2, C will prefer to enter immediately. The remaining cases are the ones where C compares the equilibrium path with entering first (no one else has previously entered) in period 1, in period 2, or in period 3.

Suppose C enters in period 1. Then, if the br-type is realized, B enters, which will induce A to enter in period 3. Hence, if C enters in period 1 and the br-type is realized, it gets payoff $U_C(1,2)$. Otherwise, if the g-type is realized, B does not enter in period 2, neither does A by its postulated strategy. In addition, neither country enters in period 3 by their postulated strategies. Hence, if C enters in period 1 and the g-type is realized, it gets payoff $U_C(1,0)$. Given condition i), C's expected payoff of entering in period 1 is less than that of not entering in period 1.

Now suppose C enters in period 2. Then, if the br-type is realized, it enters and does so in period 3. However, by its postulated strategy, A does not enter in period 3. Hence, if C enters in period 2 and the br-type is realized, C gets payoff $U_C(1,1)$. Otherwise, if the g-type is realized, B does not enter in period 2, nor does it enter in period 3. Hence, if C enters in period 2 and the g-type is realized, C gets payoff $U_C(1,0)$. Because $U_C(1,1) < U_C(1,2)$, condition i) implies that C's expected payoff of entering in period 2 would be less than that of not entering in period 2.

Finally, given the strategies of the other countries, C would never enter in period 3 if no other country has entered since $U_C(1,0) < U_C(0,0)$.

Proof that Country A is using a best-response strategy

On the equilibrium path, A will not enter because "all out" is her preferred outcome.

After a history of B (with or without C) entering in period 1 or period 2 it is a best response for A to enter immediately since C will eventually enter by its postulated strategy and $U_A(1,2) > U_A(0,2)$.

After a history of only C having entered by the end of period 2, A is better off not entering if and only if $pU_A(0,1) + (1-p)U_A(0,2) \geq pU_A(1,1) + (1-p)U_A(1,2)$, which is true by condition (ii).

Suppose only C entered in period 1. Then, A is better off not entering in period 2. To see why, note that the strategy being played by B is a separating one in this subgame: the br-type enters in period 2 whereas the g-type does not. By entering in period 2, A induces also the g-type to enter in period 3 thus earning the certain payoff $U_A(1,2)$. By staying out in period 2, A gets expected payoff $pU_A(0,1) + (1-p)U_A(1,2) \geq U_A(1,2)$; hence, staying out in period 2 is a best response.

Only if.

Suppose condition (i) does not hold. Then C is strictly better off entering in period 1 compared to any strategy, which implies all staying out at the end. To see this, note that C knows that at least the br-type will follow in period 2 or 3. Hence, by entering in period 1, C ensures a payoff of at least $pU_C(1,0) + (1-p)U_C(1,2)$ (and possibly more if the g-type follows also), which we know to be greater than $U_C(0,0) = 0$ whenever condition (i) is violated. Hence, condition (i) is necessary.

Suppose condition (ii) does not hold. Then C is strictly better off entering in period 2 compared to any strategy, which implies staying out at the end. To see this, note that the br-type will follow in period 3. Furthermore, A, having preferences (by the violated condition (ii)) where $pU_A(0,1) + (1-p)U_A(0,2) < pU_A(1,1) + (1-p)U_A(1,2)$ will prefer to enter in period 3 as well even if the g-type would stay out in period 3. Hence, C, by entering in period 2, can ensure at least one other country entering in period 3 which we know it prefers over all staying out. Hence, condition (ii) is necessary.

END OF PROOF